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Distribution of Potential Spawning Habitat for Sturgeon in the Lower Missouri River, 2003–06

By Mark S. Laustrup, Robert B. Jacobson, and Darin G. Simpkins

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Cover: Photograph of gravel-cobble substrate in the Missouri River just downstream from Yankton, South Dakota.

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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		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Area		
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
Flow rate		
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

By custom, distances along the Missouri River are given in river miles upstream of St. Louis, Mo.
Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88
Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83
Altitude, as used in this report, refers to distance above the vertical datum.

Distribution of Potential Spawning Habitat for Sturgeon in the Lower Missouri River, 2003–06

By Mark S. Laustrup, Robert B. Jacobson, and Darin G. Simpkins

Abstract

We surveyed the Lower Missouri River downstream from Gavins Point Dam near Yankton, South Dakota, to St. Louis, Missouri, during low water conditions in 2003–06 to identify and map coarse substrate deposits and bedrock exposures that might serve as spawning areas for sturgeon and other fishes. More than 330 deposits were identified, including tributary fans, bars, and habitat-enhancement projects. The location and extent of riverside bedrock exposures immediately adjacent to the channel also were mapped. Field surveys identified 48 bedrock exposures whereas the analysis of aerial orthophotographs identified an additional 65 exposures for a total of 113. Maps illustrating the distribution of deposits and their density were developed to aid researchers studying reproductive ecology of sturgeon and other lithophilic fishes.

Introduction

The U.S. Fish and Wildlife Service (USFWS) listed pallid sturgeon (*Scaphirhynchus albus*) as endangered in 1990 and identified in a Biological Opinion to the U.S. Army Corps of Engineers (USACE) that river engineering and flow management practices on the Missouri River have affected spawning, growth, recruitment, and survival (Dryer and Sandvol, 1993; U.S. Fish and Wildlife Service, 2000; 2003). In response, the USACE has been modifying river control structures to create shallow water habitat, exploring flow modifications to naturalize the hydrograph, and pursuing a research program to improve understanding of the life history requirements of native sturgeon. This study was conducted as a task within a larger research endeavor carried out by the U.S. Geological Survey (USGS) Columbia Environmental Research Center to aid the USACE in understanding the factors affecting the reproduction and survival of pallid sturgeon in the Missouri River.

Little is known about the spawning habitat needs for pallid sturgeon, although the importance of spawning habitat to the persistence of other sturgeon populations has been well documented (Auer, 1996; Buckley and Kynard, 1981; Fox and others, 2002; Krykhtin and Svirskii, 1997; Paragamian and Kruse, 2001; Paragamian and others, 2001; Parsley and others, 1993; Williot and others, 1997; Zhuang and others, 1997). The lack of understanding of spawning habitat use and availability has been identified as a key information gap in pallid sturgeon recovery. The Middle (Missouri River) Basin Pallid Sturgeon Recovery Work Group prioritized recovery needs at a workgroup meeting in November 2001 (Middle Basin Pallid Sturgeon Recovery Work Group, 2005). Thirty-one participants ranked the need to locate, quantify, and characterize spawning habitat and behavior of pallid sturgeon as the highest priority out of 50 identified recovery needs. In addition, sturgeon experts at a national meeting in 2004 reaffirmed the need to determine specific locations and ecological conditions associated with spawning and to identify the use and availability of spawning habitat in the Missouri River for recovery of pallid sturgeon (Quist and others, 2004).

Spawning habitat for pallid sturgeon and shovelnose sturgeon (*Scaphirhynchus platorynchus*) has not been described, but is thought to have physical characteristics similar to that used by various sturgeon species for spawning in other systems (Quist and others, 2004). Sturgeon generally aggregate and spawn over coarse gravel, cobble, or boulder substrates where water velocities are swift. Shovelnose sturgeon (June, 1977), white sturgeon (*Acipenser transmontanus*) (Paragamian and others, 2001; Parsley and others, 1993), gulf sturgeon (*Acipenser oxyrinchus desotoi*) (Fox and others, 2000), lake sturgeon (*Acipenser fulvescens*) (Manny and Kennedy, 2002), shortnose sturgeon (*Acipenser brevirostrum*) (Kynard, 1997), Atlantic sturgeon (*Acipenser oxyrinchus*) (Hatin and others, 2002), and common sturgeon (*Acipenser sturio*) (Kolman and Aarkua, 2002) all have been known to spawn on coarse substrates or riverside bedrock exposures.

Purpose and Scope

The purpose of this report is to provide fisheries biologists with the locations of coarse substrate deposits and bedrock exposures in the Lower Missouri River (fig. 1) that may be used by fishes, including pallid sturgeon, for spawning. Information on the locations and distribution of deposits and exposures is intended to be used to guide efforts in designing reproductive studies and identifying spawning sites of sturgeon in the Lower Missouri River. This report provides a regional reconnaissance of the distribution of potential spawning sites covering more than 811 miles (1,300 kilometers, km) of the Lower Missouri River. Our intention is not to provide precise, sie-specific measurements of the size and character of each patch.

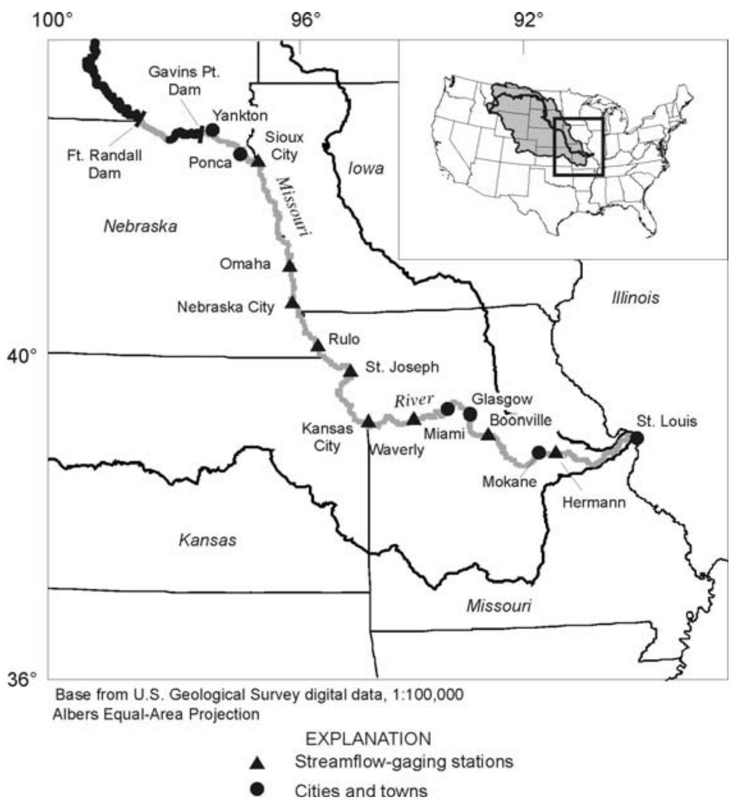


Figure 1. Location of spawning substrate survey, Lower Missouri River.

The objectives of this study were to survey the Lower Missouri River downstream from Gavins Point Dam near Yankton, South Dakota to St. Louis, Missouri (fig. 1) for locations of coarse substrates and riverside bedrock and to analyze the distribution of these patches to identify areas that may be important spawning habitats for sturgeon. An additional objective was to document the location, relative size, and composition of coarse substrate patches in a digital Geographic Information System (GIS) for application in habitat-use and associated reproductive studies on the Missouri River.

Acknowledgments

Brian Corollo, Carl Korschgen , Anne Donahue, Robin Lipkin, Chad Vishy, Carrie Elliott, and Gary D'Urso of the U.S. Geological Survey provided critical field assistance by gathering quality data under demanding conditions.

Methods

Substrate surveys were conducted under low-water conditions, as determined from discharge estimates from streamflow-gaging stations and flow-duration analyses (Gordon and others, 1992) of post-impoundment data from 1967 to 2004. National Water Information System for the Sioux City, Iowa; Omaha, Nebraska; Nebraska City, Nebraska; Rulo, Nebraska; St. Joseph, Missouri; Kansas City, Missouri; Waverly, Missouri; Boonville, Missouri; and Hermann, Missouri streamflow-gaging stations (U.S. Geological Survey, 2001). Discharge for each reach was evaluated before conducting surveys to assure that flows were at or below 90-percent exceedance (that is, flow that is equaled or exceeded 90 percent of the time) to maximize the potential for locating substrate deposits and bedrock exposures (fig. 2). River surveys were conducted longitudinally from a boat and substrate patches were identified by sight using binoculars.

The term patch is used to denote a mappable area of riverbed substrate, generally greater than 100 square meters (m^2) in area. We divided substrate patches into two dominant classes: bedrock expostures and particulate deposits. Bedrock was defined as an in-place riverside rock exposure with small quantities of locally derived rock and colluvium. Particulate deposits included transported particles of any origin.

Once a patch was located, the site was examined to determine substrate-size classes or to classify as bedrock exposure. We used the standard sedimentological classification system described by (Pettijohn, 1975) to describe dominant substrate particle size for each patch. Classes included granule [2–4 millimeter (mm)], pebble (4–64 mm), cobble (65–255 mm), boulders (256–4096 mm), and bedrock. The sizes of non-bedrock patches were estimated by pacing each patch. The center of each patch was recorded as its location in the universal transverse Mercator (UTM) coordinate system (Zone 14 or 15, with units of meters, and NAD83) using a wide-area augmentation system (WAAS) -enabled, 12 parallel channel handheld global positioning system (GPS) (Garmin 76C ™) that had an accuracy of approximately 3 m.

The lengths of riverside bedrock exposures were mapped from the boat with beginning and end points recorded from GPS. Because many of the outcrops were blanketed with rock debris associated with railroad bed construction or bank revetment, bedrock effects also were inferred from maps of the valley wall and present-day channel location to identify where bedrock was likely to be exposed on the riverbed. The valley wall was digitized from topographic maps and orthophotography. We used a side-scan sonar (Humminbird 987c SI ™) in 2005 and 2006 to verify

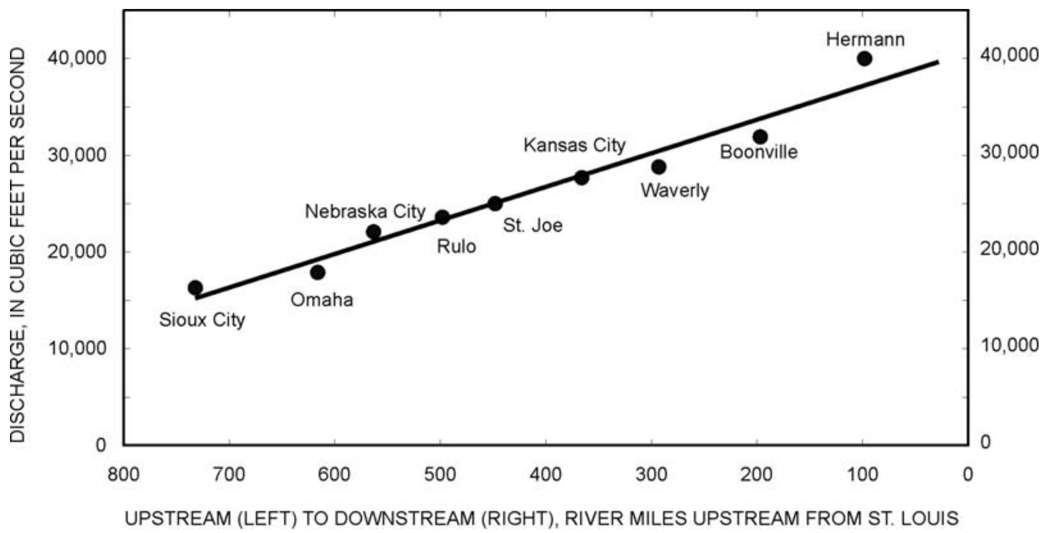


Figure 2. Missouri River 90-percent exceedance discharge, Sioux City, Iowa, to Hermann, Missouri.

the locations of underwater bedrock exposures and other substrate deposits that were identified visually subaerially. Side-scan images and digital photos were acquired for many substrate deposits and riverside bedrock exposures encountered. Site locations and attributes were transferred from the GPS units to a GIS application upon returning from the field.

Results

The following sections describe results of the substrate survey, including general sedimentary characteristics of deposits and bedrock exposures, and their spatial distributions.

Types of Potential Spawning Patches

A total of 449 bedrock (113) and coarse particulate substrate (336) patches were identified on the Lower Missouri River (fig. 1). Local bedrock patches exist where the river has impinged on a bedrock exposure (fig. 3). Particulate-substrate patches are derived primarily from local hillslopes (colluvial deposits), tributary inputs (alluvial fan deposits), glacial drift/till deposits adjacent to the channel, bars formed from redeposited coarse sediment, and USACE habitat-enhancement projects, including dike modifications, mitigation sites, and shallow-water habitat projects. Colluvial wedges and alluvial fans occur where local bedrock has supplied fragments that have been redeposited at the base of slopes or at tributary junctions (figs. 4, 5). Local bedrock fragments also may be present on bars downstream from tributary junctions (fig. 6).

Glacial drift is a general term used to describe all varieties of rock debris deposited in close association with glaciers. Stratified glacial drift refers to glacial sediments transported dominantly by water; glacial till, in contrast, refers specifically to sediments deposited directly from ice without water transport (Strahler, 1975). Because glacial environments have large capacities to transport coarse sediment, the distribution and abundance of coarse substrate deposits may be related to glacial history of the Missouri River valley; however, assignment of coarse substrate patches to specific glacial origin is speculative because of lack of historical data on erosion and redeposition processes. Nevertheless, glacial drift deposits adjacent to the modern river channel in South

Dakota and Nebraska (Martin and others, 2004) can be directly associated with in-channel coarse substrate patches in that area (fig. 7).

Figure 3. In-place dolomite bedrock patch located on the left descending bank about 10 km downstream from Glasgow, Missouri. Photograph by Aaron Delonay, U.S. Geological Survey.

Figure 4. An alluvial fan located at the mouth of a small, low-gradient tributary in central Missouri.

Figure 5. Alluvial fans at the mouths of high-gradient tributaries are composed primarily of boulder-cobble sized material.

Figure 6. A right descending bank sandbar with a cobble-pebble veneer located upstream from the Interstate Highway 70 bridge, and downstream of a small tributary, west of Columbia, Missouri.

The mainstem and many tributaries of the Lower Missouri River have been affected to varying degrees by glaciation and may contain deposits of glacial drift or redeposited glacial drift. Presence of non-local igneous or metamorphic rocks supports the interpretation of a glacial origin. Some of the coarse substrate deposits within the lower 200 river miles of the river are suspected to have formed from erosion of glacially derived sediments in the bed of the mainstem channel. Some of these deposits occur in bars immediately downstream from wing dikes with associated deep scours, indicating that such deposits may have been redistributed during high-energy floods that occurred in the 1990s (fig. 8).

Figure 7. In-place glacial drift located on the right descending bank downstream from the Highway 81 bridge, near Yankton, South Dakota

Base aerial photograph, U.S. Army Corps of Engineers, 2000

Figure 8. A gravel-cobble deposit with non-local igneous and metamorphic rocks, near Stanley Bend, river mile 151, central Missouri.

In addition to naturally occurring patches, other coarse substrate deposits exist in USACE habitat-enhancement projects including dike modifications, sills at the entrances and exits of chutes, and shallow-water habitat rock-bar islands. Enhancement projects were not designed specifically to provide spawning habitat for sturgeon; rather, they were designed primarily to create shallow, low-velocity patches believed to be important for young life stages of sturgeon and other fishes that may be food resources for sturgeon (U.S. Fish and Wildlife Service, 2003). It is important to note that this project was initiated in June 2003 and completed in March of 2006, spanning a time of extensive channel re-engineering. Hence, our identification and mapping of patches associated with engineering projects should be considered a snapshot of a rapidly changing system.

In addition to engineered deposits, the Lower Missouri River is characterized by ubiquitous deposits of angular, cobble-boulder-sized, limestone/dolomite/quartzite rocks associated with wing dikes and bank revetments. Helms (Helms, 1974) speculated that river-control structures (dikes and revetments) may function as spawning habitat for shovelnose sturgeon on the Mississippi River. To gain insight into the potential contribution of river-control structures to sturgeon spawning habitat on the Missouri River, we mapped wing dikes between Ponca, Nebraska, and St. Louis, Missouri, using USACE low-altitude, color, aerial orthophotography collected in 2000. Wing dikes were measured along their centerlines to the water's edge at the tip. Where subsurface structure was visible riverward of the water’s edge, an additional line was added to characterize its length and location. With the exception of a segment of river between Rulo and Omaha, Nebraska, the orthophotography was collected during low-water conditions characterized by low turbidity. This conservative method estimated the total length of wing dikes on the Lower Missouri River as 575 km.

Bank revetments were not mapped directly, but we conservatively estimated their length by measuring river length downstream from Ponca, Nebraska (river mile 746) under the assumption that at least one river bank was always revetted downstream to St. Louis. Upstream from Ponca, almost one-third of the river bank has been armored by bank stabilization structures (Elliott and Jacobson, 2006). Consequently, dikes and revetments may contribute as much as 1,800 linear km of potential spawning substrate in the Missouri River. Using the conservative approximation that dikes and revetments average 20 m wide, they could provide as much as 36 square kilometers (km^2) of spawning substrate, compared to approximately 1 km^2 of natural and engineered deposits identified and mapped between 2003 and 2006 (table 1). Although river-control structures potentially provide a large area of spawning substrate, they are substantially steeper than natural or engineered deposits [20–40 degree ($^{\circ}$), compared to less than 10°], which may affect local hydraulics and their value as spawning habitat.

Table 1. Numbers and characteristics of coarse particulate substrate deposits on the Lower Missouri River, Gavins Point dam, South Dakota to the mouth.at St. Louis, Missouri.

[m^2, square meters; USACE, U.S. Army Corps of Engineers.]

		Dominant particle-size class, numbers of deposits mapped[1]					Location in channel					
Sedimentological class	Total count	Bedrock	Boulder	Cobble	Pebble	Granule	Left Bank	Right bank	Mid-channel bar	Mean size, (m^2)	Total size, (m^2)	Number of glacial deposits
Bar deposit	115	1	24	71	91	72	33	33	49	308	1,010,825	48
Tributary fan	47	4	30	46	45	23	12	33	2	217	56,408	0
USACE chute project	5	0	5	1	0	0	1	4	0	629	1,766	0
USACE dike modification	146	0	132	143	27	0	49	94	3	581	31,452	0
USACE shallow water habitat	23	0	20	23	19	6	2	3	18	319	11,599	0
Sums	336	5	211	284	182	101	97	167	72		1,112,050	48

[1]Particle size classes are from Pettihohn (1975).

Distribution of Substrate Patches

To illustrate distributions of bedrock and particulate deposits at a scale inclusive of the Lower Missouri River, we developed two different cartographic representations. The actual locations and size of bedrock and particulate deposits are shown using discrete (point) and continuous surface (density) representations. The points representing locations of exposures or deposits are scaled by the length or area, using graduated circles and a five-class equal interval classification. Points representing the centroids of bedrock exposures are scaled by exposure length. We developed density maps by creating continuous surfaces from point observations to identify concentrations of bedrock exposures and particulate deposits. We hypothesize that the greater the density of coarse substrate and bedrock deposits for a given area, the greater the opportunity to identify additional patches that were not identified in our survey, and to verify spawning activity. Density analysis uses known quantities — in this case, bedrock exposure length or particulate deposit area — and interpolates across the valley bottom based on the spatial relations of point locations and their weights, creating a raster or cell data layer. We calculated kernel density using a search radius of 10,000 m, and an output cell size of 100 m.

Bedrock

In field surveys, 48 bedrock patches were identified. Analysis of aerial photographs identified an additional 65 bedrock exposures (table 2). Field surveys located 42 percent of the bedrock patches identified from aerial orthophotography, but only 14 percent of the total length of bedrock exposures (fig. 9). Data from field surveys underestimated the average length of bedrock patches by 66 percent, compared to estimates from aerial photography (table 2). Bedrock patches identified from aerial photography often were covered by revetment or railroad ballast near the water surface, but presumably are exposed on the riverbed. Many potential bedrock exposures also were isolated from the river by L-head dikes.

Table 2. Comparison of numbers and longitudinal lengths of bedrock exposures mapped on the water to those mapped through photo interpretation.

	Count	Minimum, in meters	Maximum, in meters	Mean, in meters	Sum, in meters	Standard deviation, in meters
On-water identification	48	8.7	4,165.1	558.7	26,817.8	742.5
Mapped from aerial photography	113	151.2	8,369.1	1,643.8	185,749.8	1,471.2

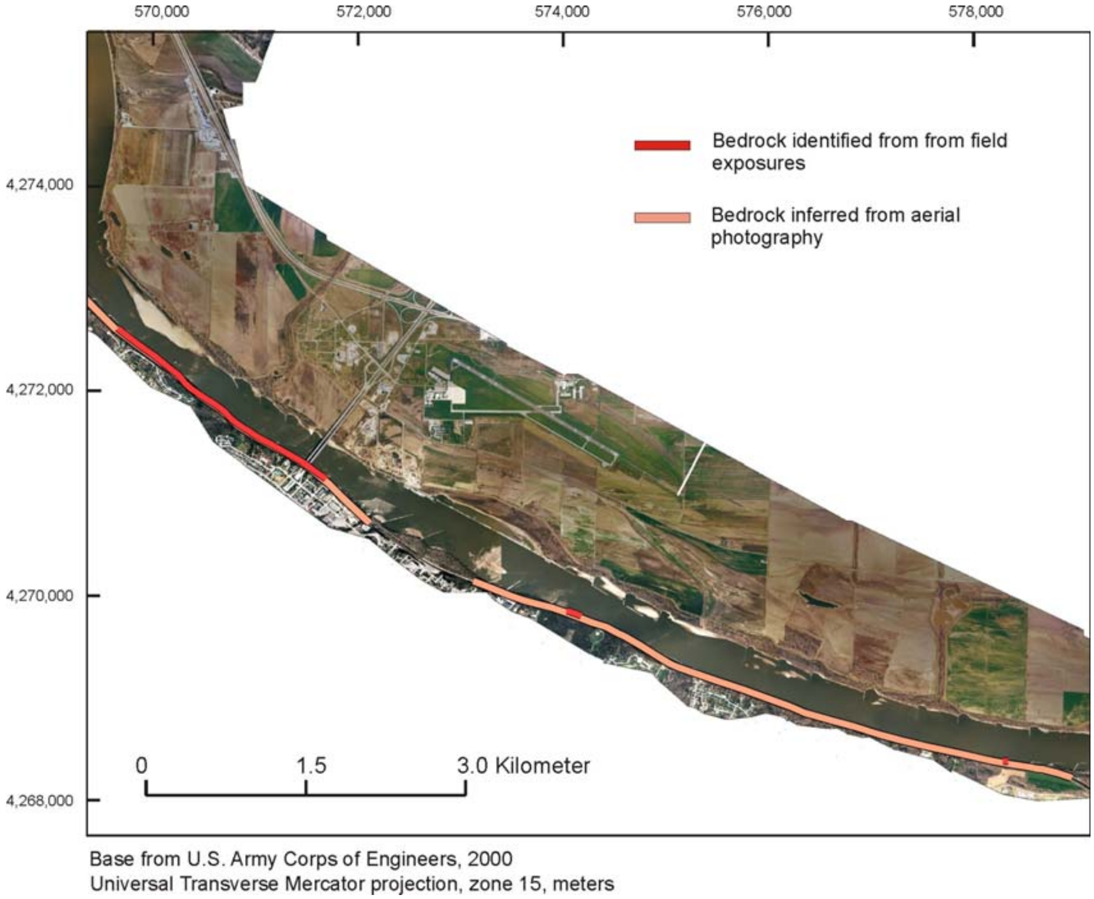


Figure 9. Comparison of field-determined and aerial-photograph inference of bedrock exposure extent at Jefferson City, Missouri.

The densities (meters per square kilometer, m/km^2) of bedrock patches that were identified from aerial orthophotographs were computed by determining the centroid of each exposure, and weighting the points based on exposure length. The highest concentration of bedrock was located within the lower 200 river miles of the Missouri River where the river valley narrows and abuts the Ozark Plateau Physiographic Province (figs. 10a, 11, 12). Additional concentrations were located along the Kansas-Missouri border and near Ponca State Park in Nebraska.

Beginning in 2005, we used side-scan sonar to validate coarse substrate and bedrock patches identified during low-water surveys. The areas surveyed with side-scan sonar included 113 km (70 miles) of river immediately downstream from Gavins Point Dam, 126 km (78 miles) of river between just east of Kansas City (Cooley Lake) and Miami, Missouri, and 201 km (125 miles) of river downstream from Mokane, Missouri (fig. 1). We captured a total of 264 side-scan sonar images. Multiple images were collected at each exposure to define the extent of subsurface bedrock. Of the 35 bedrock exposures identified on side-scan sonar images, 30 (86 percent) were located within 100 m of the valley wall. Proximity of the modern channel to the valley wall, therefore, seems to be a robust predictor of bedrock exposures in the riverbed. The relations among bedrock exposures mapped from observations on the water, those mapped from side-scan imagery, and those identified through aerial photo interpretation are shown in figure 13.

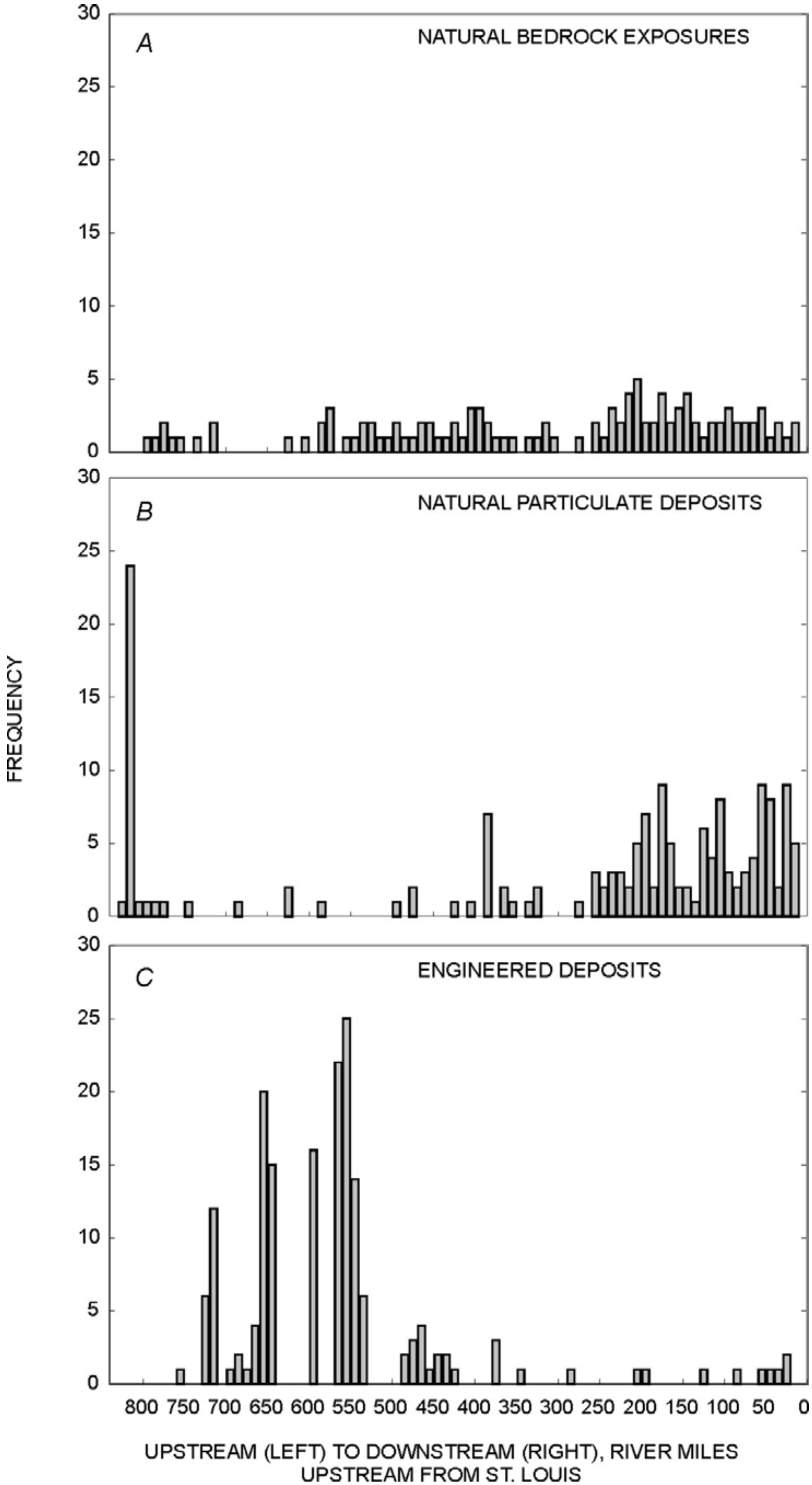
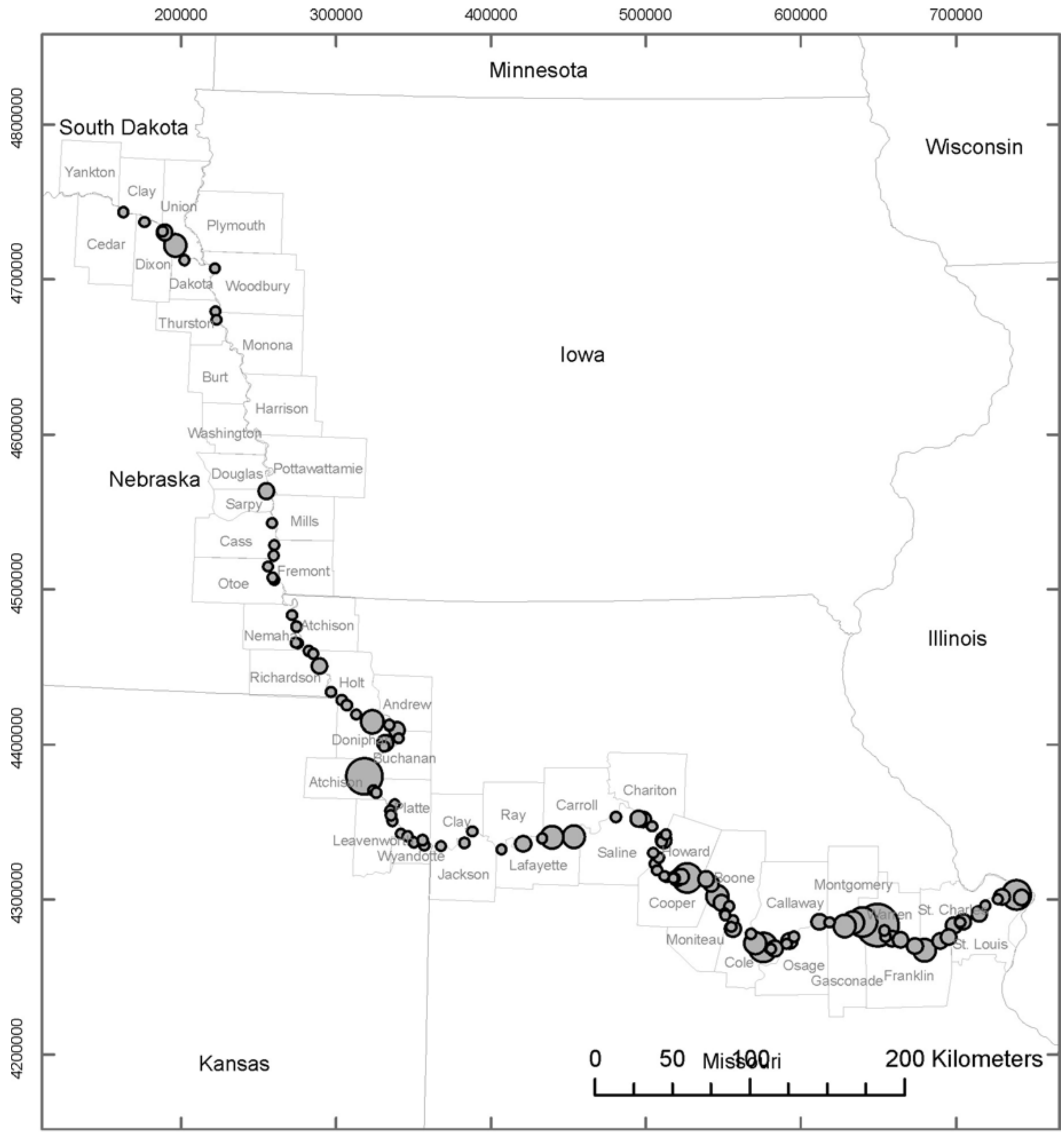


Figure 10. Distribution of hard substrate types by river mile.



Base from U.S. Geological Survey digital data
Universal Transverse Mercator projection, zone 15, meters

EXPLANATION
Bedrock exposure length, in meters

- 1 to 1,500
- 1,501 to 3,000
- 3,001 to 4,500
- 4,501 to 6,000
- 6,001 to 7,500
- 7,501 to 9,000

Figure 11. Distribution of bedrock exposures, Lower Missouri River. Length of exposure along the river is indicated by the radius of the circle.

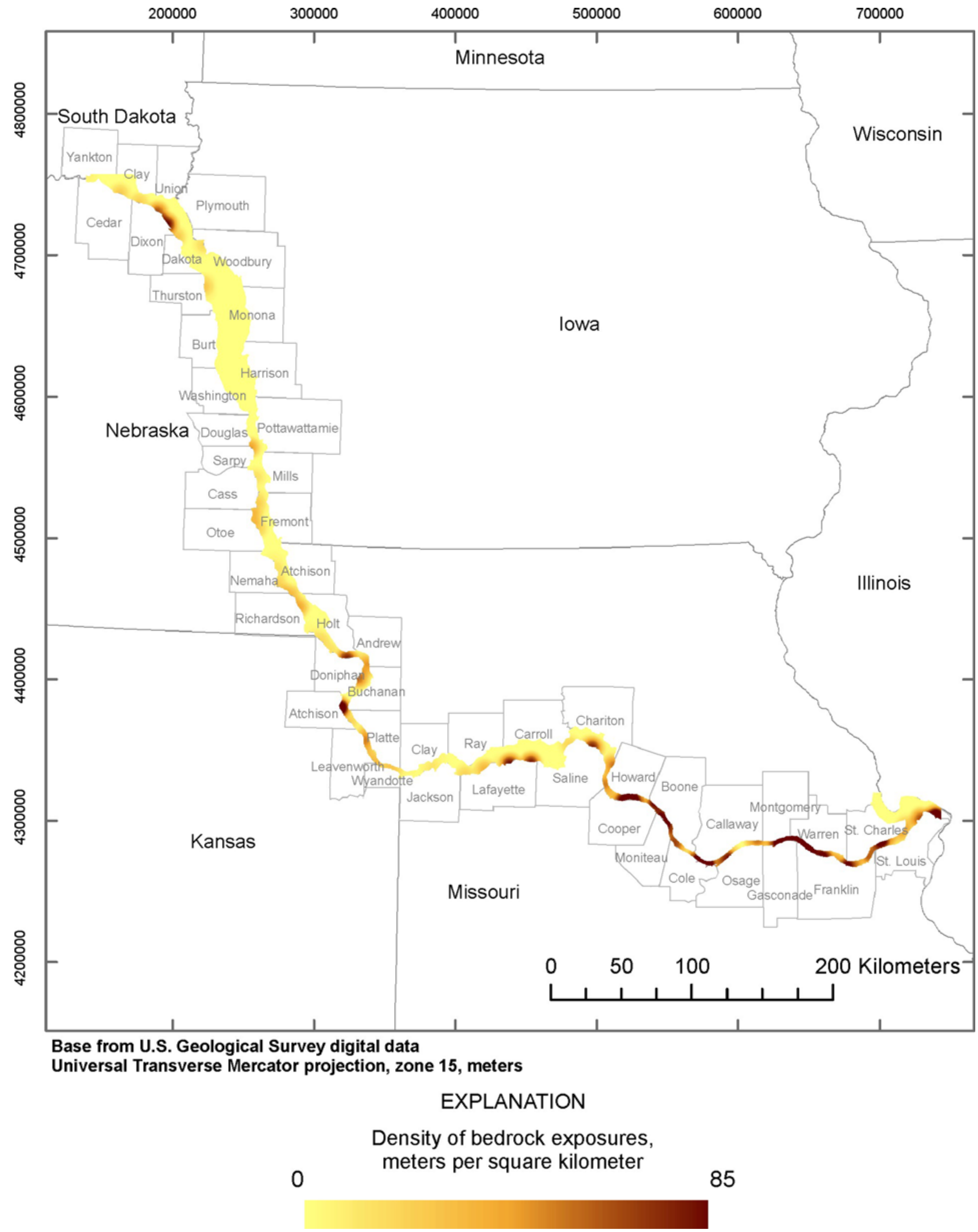


Figure 12. Density map of bedrock exposures, Lower Missouri River.

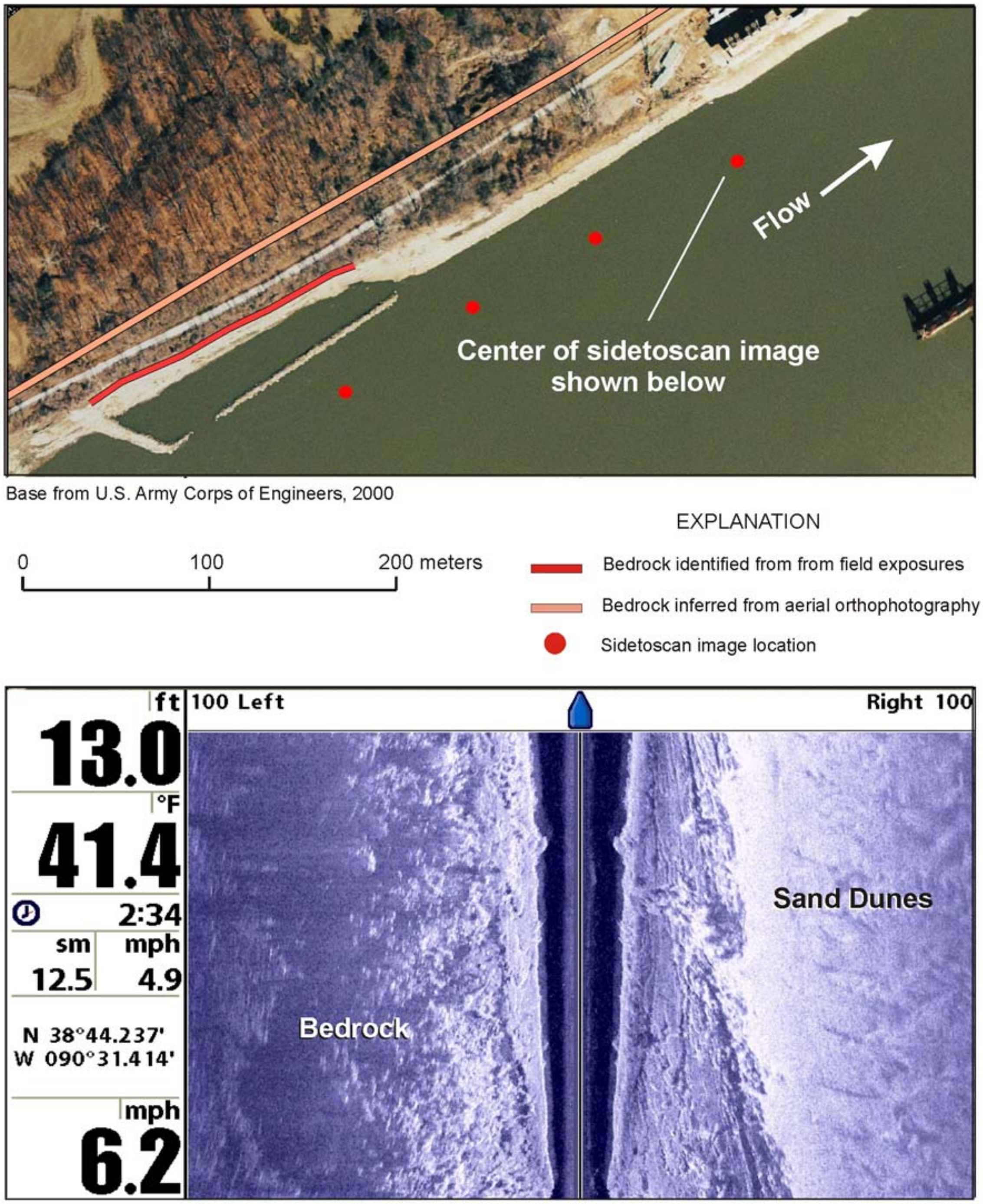


Figure 13. Relations among submerged bedrock exposures confirmed by side-scan imagery, bedrock exposures observed in the field, and sub-surface bedrock extent inferred from aerial orthophotography. The boat was traveling downstream; the left side of the side-scan image shows the area closest to the river bank. This side-scan image was recorded at river mile 32.6.

Particulate Deposits

The number and extent of natural particulate deposits were greatest immediately downstream from Gavins Point Dam (fig. 14), but they also were increased within the lowermost 200 river miles of the Missouri River (figs. 10b, 15, 16). Few natural deposits occur between river miles 370 and 730. Natural particulate deposits included tributary fans and bar deposits. Tributary fans were classified as either low or high gradient based on the dominant particle size that characterized the deposits. Low-gradient fans generally contained granule- to cobble-sized particles (fig. 4) located some distance from the valley wall, whereas high-gradient fans (including colluvial deposits) tended to have larger, more angular particles than low-gradient fans (fig. 5) in close proximity to the valley wall. Bar deposits were characterized as either mid-channel or lateral. Mid-channel bars were identified as areas having a secondary channel that separated deposits from the river bank. Lateral bars were identified as areas where deposits were attached to the river bank. Bar deposits often were single layers of granule- to cobble-sized substrates that were deposited over sand (fig. 6). However, bars in the vicinity of Yankton, South Dakota, were dominated by cobble and boulder substrates and seem to be of substantial thickness (fig. 14).

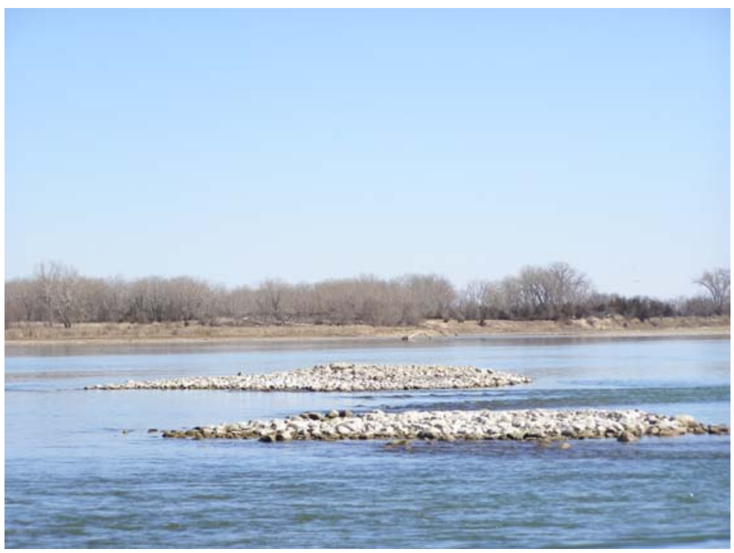


Figure 14. Till-derived boulder/cobble deposits located downstream from the Highway 81 bridge at Yankton, South Dakota. The photo was acquired March 13, 2006 at a low discharge from Gavins Point Dam of 9,000 cubic feet per second.

Engineered deposits tend to be concentrated where natural deposits are least prevalent. The number and extent of engineered deposits were largest between river mile 370 and 730 (figs. 10c, 17 and 18). Engineered deposits included structures associated with habitat-enhancement projects developed by the USACE and do not include river training structures (dikes, revetments) discussed earlier. Although these projects were not designed to provide spawning habitat, coarse substrates that may be used by sturgeon and other fishes for spawning were introduced in low-angle deposits in the river channel. For example, sills or flat-lying rock structures at the entrance and exits of engineered side-channel chutes could provide suitable spawning habitat. Additionally, wing-dike modifications that include knocking down and spreading out rock into channel margins or constructing low-angle rock sills could serve as spawning habitat for sturgeon and other fishes.

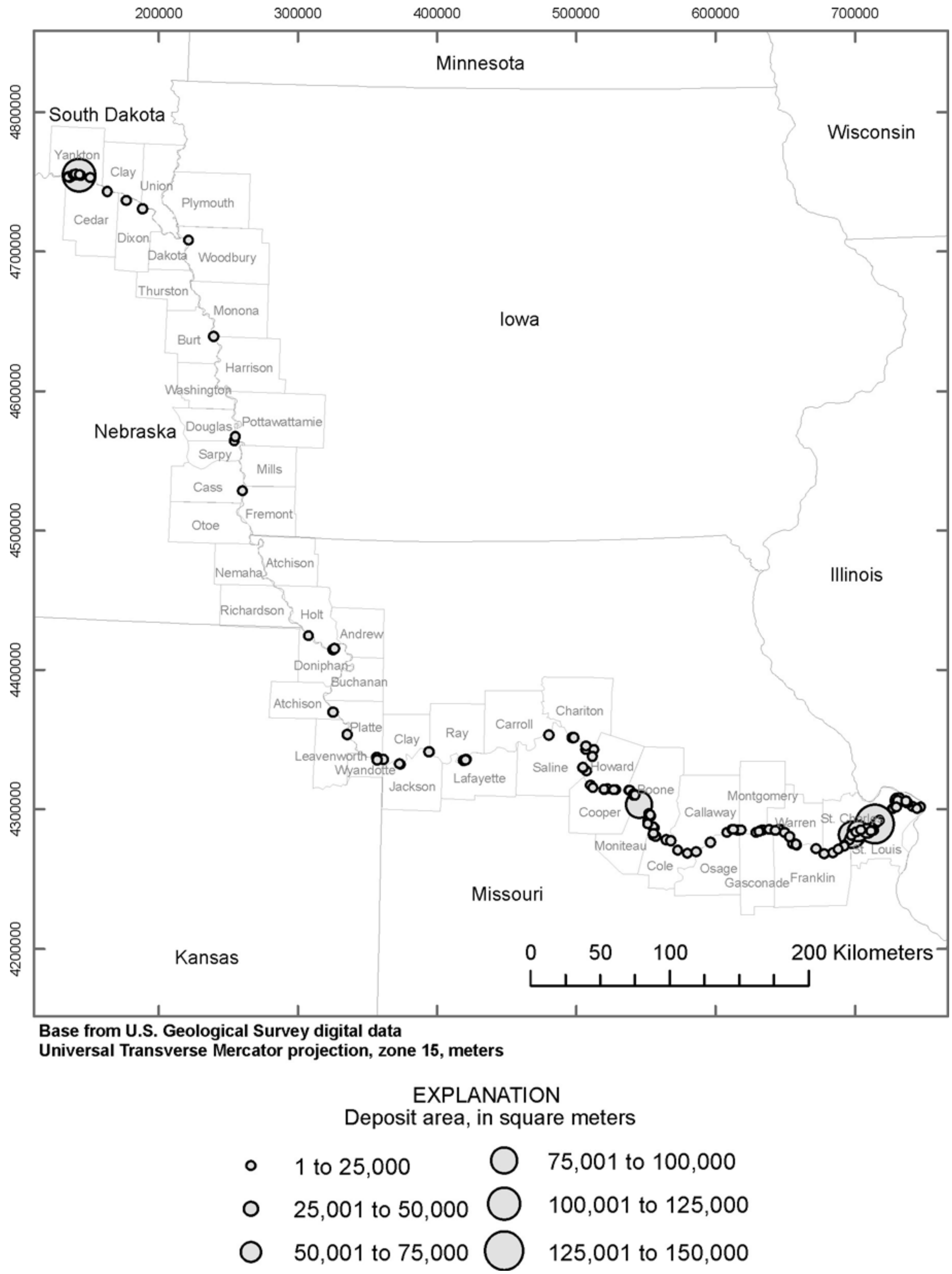
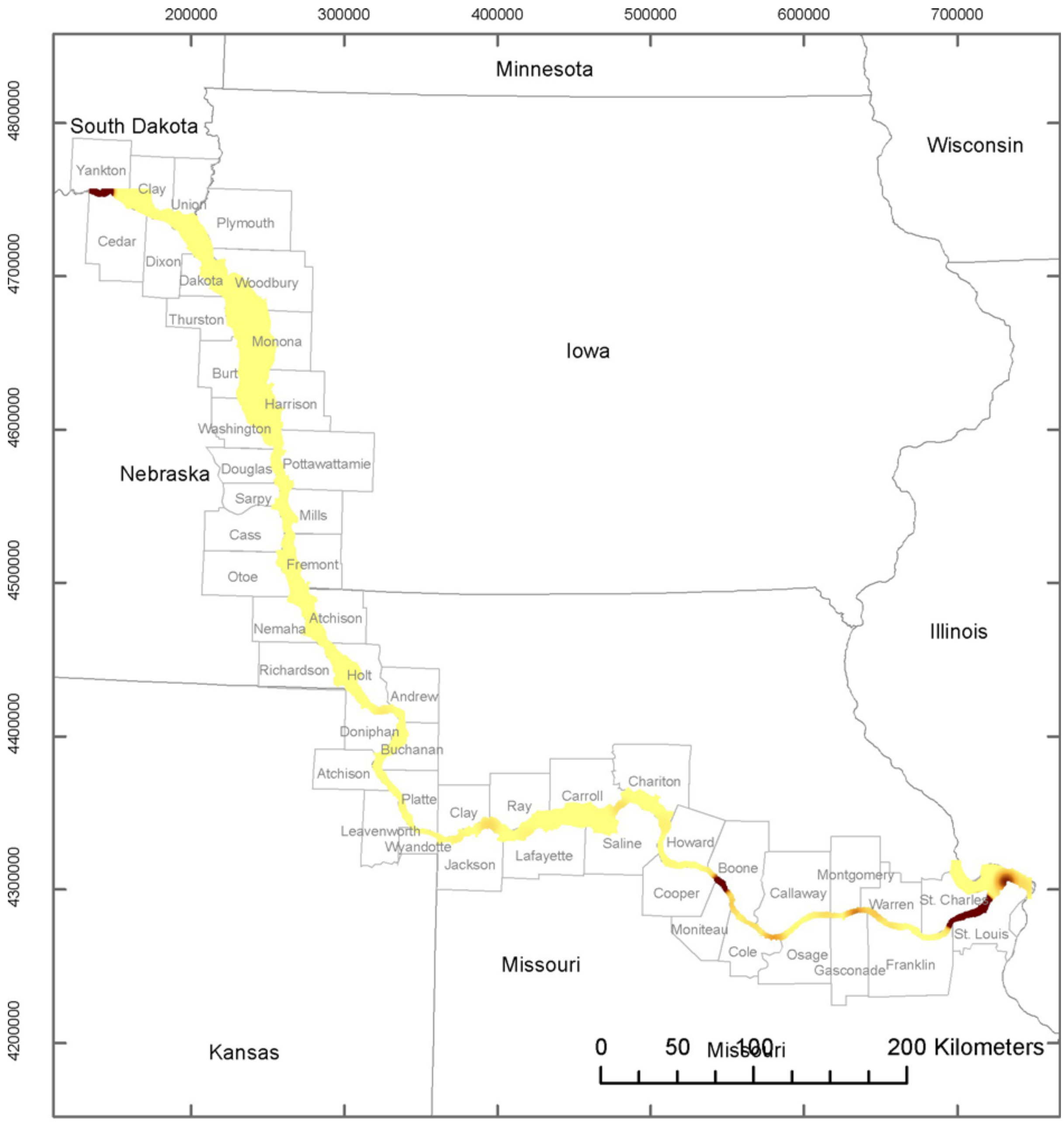


Figure 15. Distribution of natural particulate deposits by patch area class, Lower Missouri River. Area of patch is indicated by the radius of the circle.



Base from U.S. Geological Survey digital data
Universal Transverse Mercator projection, zone 15, meters

EXPLANATION

Density of natural particulate deposits, square meters per square kilometer

0 3,300

Figure 16. Density map of natural particulate deposits, Lower Missouri River.

Natural particulate deposits (bars and tributary fans) were the most prevalent deposit type downstream from Kansas City, Missouri, and upstream from Sioux City, Iowa (fig. 19). Engineered deposits were the most prevalent deposit type between Kansas City, Missouri and Sioux City, Iowa. Among natural deposits, boulder deposits decrease in density from Gavins Point Dam to Kansas City, Missouri, until the river meets the Ozark physiographic province, at which point they are again encountered (fig. 20).

Density maps for natural and engineered deposits were generated separately because of differences in scale. The average size of natural (tributary fans, bars) deposits was 6,590 square meters (m^2) (N=162) whereas the average size of engineered deposits to develop habitat was 338 m^2 (N=174).

Natural particulate deposits were concentrated in St. Charles and St. Louis counties, Missouri at rive river miles 12–19.5 and 27.5–53 (fig. 16). A small concentration was located in Gasconade County, Missouri, at river mile 99.7. Another concentration of deposits is located upstream, between river miles 173.5 and 182.5, a 9-mile section bordering Boone, Moniteau, and Cooper counties, Missouri. Six-hundred miles separate these deposits from the next upstream concentration of natural particulate deposits, located in a 19-km segment between Gavins Point Dam and the James River in Yankton County, South Dakota, and Cedar County, Nebraska.

The largest densities of engineered deposits were located upstream of Kansas City, Missouri, where the USACE unrooted (breaking the connection between the shoreline and the dike) and knocked down dikes along inside bends of the channel (fig. 18). These semicircular deposits often were larger than the original dike footprint because they had been flattened and spread out (fig. 19). The largest concentration of engineered deposits was located at Winnebago Bend (river mile 708.8–709.9) in Woodbury County, Iowa. Additional concentrations were located adjacent to DeSoto National Wildlife Refuge lands between river miles 634 and 643 in Harrison and Pottawattamie Counties, Iowa, and Washington County, Nebraska.

Downstream from Omaha, Nebraska, 40 dikes had been unrooted or flattened between river miles 555 and 545 on Upper and Lower Hamburg Bends, Lower Barney Bend, and Upper Kansas Bend in Otoe and Nemaha counties, Nebraska, Fremont County, Iowa, and Atchison County, Missouri. An additional 20 dikes had been modified on Langdon Bend between river miles 531.6 and 529.2 in Nemaha County, Nebraska. Dikes along the inside bend at Mill Creek Bend (river mile 459–461) in Doniphan County, Kansas also were modified.

Other USACE habitat-rehabilitation projects, including the construction of flat-topped, circular rock bars to induce sedimentation and create shallow water, were located throughout the system from Sioux City, Iowa, to the Missouri River's confluence with the Mississippi River. Chute projects that included rock sills, however, were located dominantly upstream from Kansas City, Missouri.

From a total of 336 particulate deposits identified in this study (table 2), 132 deposits were located downstream from Kansas City, Missouri, and 88 percent of these were of natural origin (either bar deposits or tributary fans). Of the 204 deposits identified upstream from Kansas City, 77 percent were engineered and 23 percent were natural.

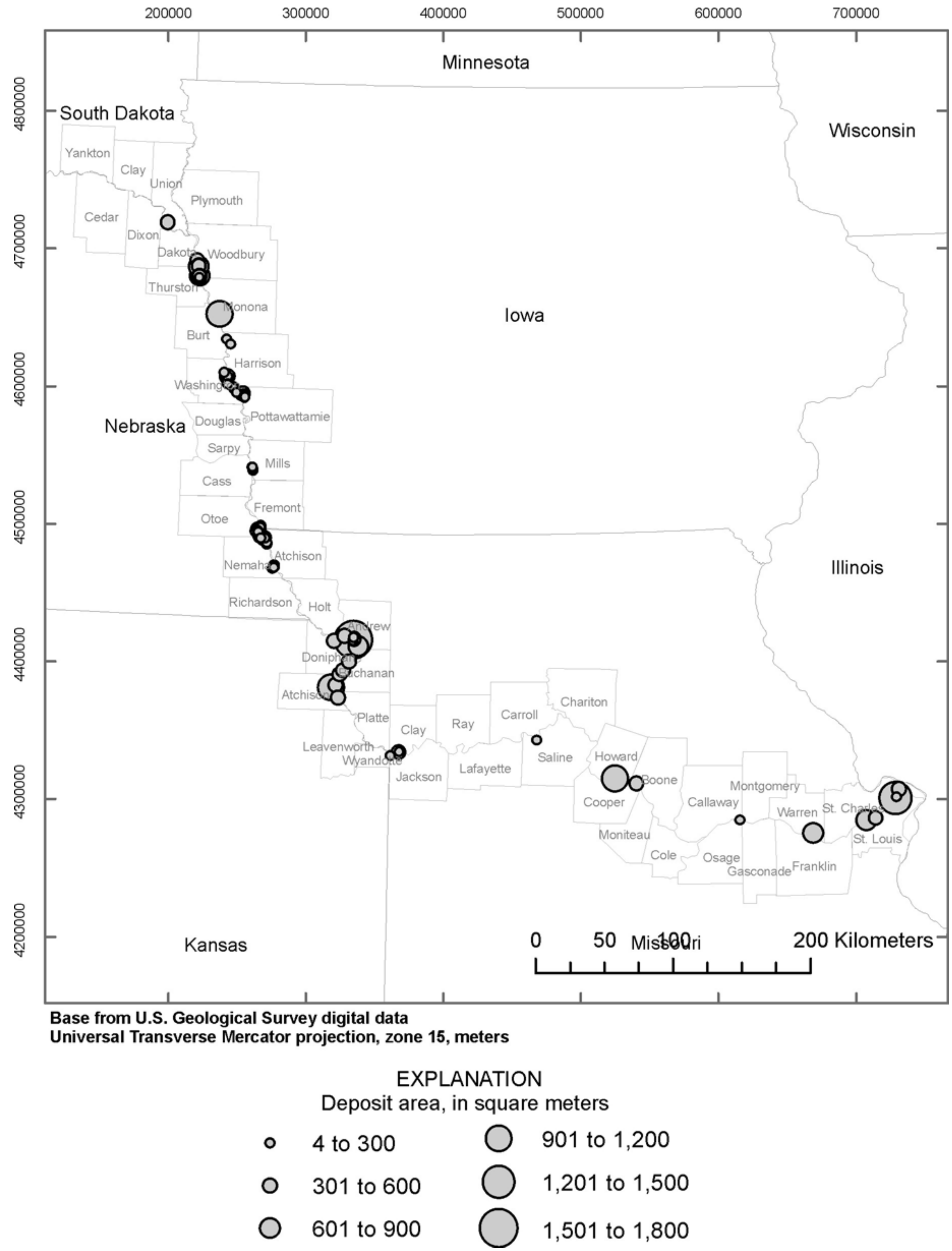


Figure 17. Distribution of engineered deposits by patch area class, Lower Missouri River. Area of patch is indicated by the radius of the circle.

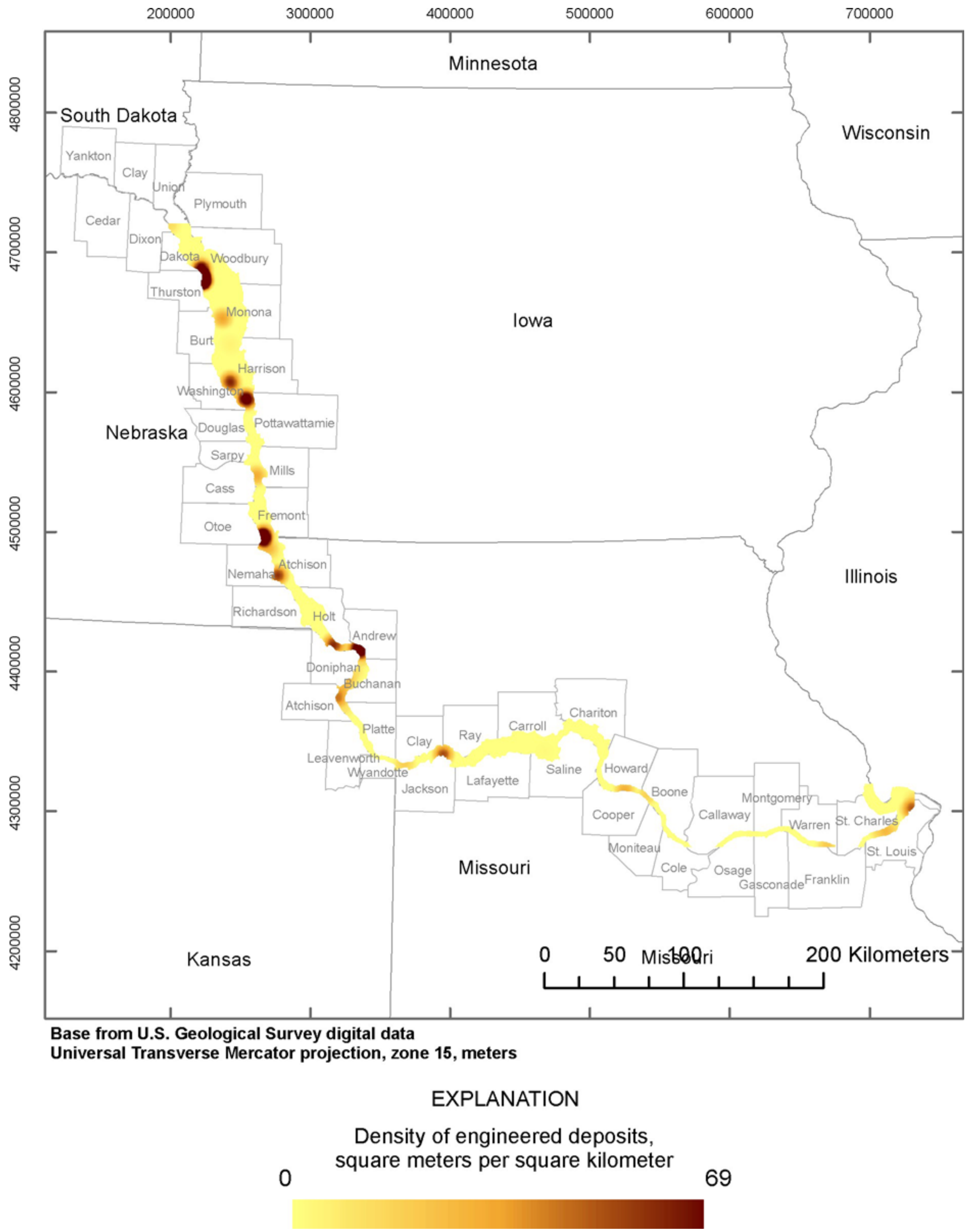


Figure 18. Density map of engineered deposits, Lower Missouri River.

Figure 19. Example of unrooted dike that has been knocked down and flattened to create habitat. These low-angle engineered deposits may mimic naturally occurring particulate spawning substrate.

Discussion

Conducting biological studies on fishes in large rivers is a daunting task because of challenges in characterizing relevant behaviors and habitats over large spatial and temporal scales and at a wide range of flows, depths, and velocities. Consequently, little is known about spawning behavior and habitat use of sturgeon and other fishes in the Missouri River. Based on other sturgeon species in other river systems, sturgeon in the Missouri River are believed to aggregate and spawn over coarse gravel, cobble, or boulder substrates where water velocities are swift (Quist and others, 2004). Knowledge about the origin and distribution of such deposits in relation to fish behavior will aid researchers in designing focused research activities to determine when, where, and under what environmental conditions sturgeon and other fishes spawn.

The present-day distribution of natural, coarse substrate deposits in the Missouri River seems to be broadly controlled by the Pleistocene history of glacial advances and retreats. Before Pleistocene glaciation about 1.8 million years ago, the ancestral Missouri River drained north to Hudson Bay (Wayne and others, 1991). As the glaciers advanced, the river channel was forced generally southward, along the ice margin (Trimble, 1980). Glacial lakes formed along this ice margin and remained until water levels overtopped a drainage divide, when the river would create a new course. In South Dakota, four to five glacial advances are suspected to have occurred during the Pleistocene (Johnson and McCormick, 2005), each reworking the landscape of the previous advance.

The most extensive deposits of naturally occurring cobble-boulder substrate in the Lower Missouri River were identified in Yankton County, South Dakota, directly downstream from Gavins Point Dam. End moraine, ground moraine, and outwash terrace deposits (Martin and others, 2004) occur in close proximity to and in the modern river channel at Yankton (fig. 14). These deposits are less than 13,000 years old, based on carbon-14 dates (Johnson and McCormick, 2005). The Yankton County deposits were the only Late Wisconsinan glacial deposits present downstream from Gavins Point Dam that were directly adjacent to the modern river. Downstream from Yankton, the valley bottom progressively widens, isolating the river from access to naturally occurring coarse substrate materials on the valley margins. Dominance of cobble-boulder substrate near Yankton, South Dakota, may also be attributed in part to channel degradation downstream of Gavins Point dam (U.S. Army Corps of Engineers, 2004) that may have preferentially left coarse sediment as a lag deposit.

We did not survey the river for potential spawning areas upstream from Gavins Point Dam for this study. According to research on the Quaternary history of South Dakota, however, Late Pleistocene glacial deposits increase in frequency and adjacency to the Missouri River upstream from Gavins Point Dam (Martin and others, 2004; Petsch, 1946). Construction of dams on the Missouri River has permanently separated downstream fish populations from these potential spawning deposits.

The Missouri River served as the conduit for outwash from the Wisconsinan glacial border. Drill logs of Missouri River alluvial sediments document that most of the 30–45 m thickness in central Missouri is composed of sand, although gravel has been detected at the base and in thin layers (Emmett and Jefferey, 1969). Hence, coarse, hard substrate deposits could be potentially exhumed or remobilized from alluvial sediments throughout the Lower Missouri River Valley. Because most of the coarse sediment seems to be concentrated at depth with the alluvial strata, deep erosion would be required to emplace coarse substrate within the modern channel.

Downstream from Yankton County, South Dakota, glacial drift is not adjacent to the Missouri River mainstem. Although this part of the Lower Missouri River Valley was affected by multiple glacial advances, deposits of pre-Wisconsinan glaciations have had much more time to be eroded and redistributed. For example, in the vicinity of St. Joseph, Missouri, pre-Illinoian glacial till, estimated to be approximately 540,000 years old (Langer and others, 2002), blankets the uplands. Presumably, these deposits initially were also present adjacent to the modern Missouri River channel, but because of erosion operating over the last one-half million years, they are now no closer than 3 km. Pre-Wisconsinan glaciations may, therefore, have an indirect affect on the distributions of modern spawning substrate in the Lower Missouri River Valley. Because of their age, however, it is much more difficult to establish the linkage compared to those of the Late Wisconsinan glaciation.

Summary

We identified and mapped more than 330 coarse substrate deposits and bedrock exposures in the Lower Missouri River downstream from Gavins Point Dam, from Yankton, South Dakota, to St. Louis, Missouri, during low water conditions 2003–06 to document where sturgeon and other lithophilic fishes may spawn. Riverside bedrock exposures were mapped throughout the Lower Missouri River. Deposits included tributary fans, bars, and USACE habitat-enhancement projects. Distributions of coarse substrate were affected by geologic history and river engineering. The largest concentrations of naturally occurring coarse-substrate deposits were glacial in origin, and were mapped immediately downstream from Gavins Point dam, but densities were also large within 200 river miles of the confluence with the Mississippi River because of tributary inputs from the Ozark Plateaus. In contrast, structures engineered by the USACE that contained low-angle, submerged coarse substrates, were most common in areas where naturally occurring coarse substrate deposits were rare. Knowing the distribution and origin of coarse substrate deposits and bedrock exposures will aid researchers studying reproductive ecology of sturgeon and other lithophilic fishes.

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