



Long Term Resource Monitoring Program
An element of the U.S. Army Corps of Engineers'
Upper Mississippi River Restoration-Environmental Management Program

Program Report

2014-P001a

Monitoring Rationale, Strategy, Issues, and Methods

UMRR-EMP LTRMP Fish Component



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Cover photo. Staff from the Missouri Department of Conservation Big Rivers and Wetlands Field Station setting a fyke net. Photo by Dave Ostendorf, Missouri Department of Conservation.

Monitoring Rationale, Strategy, Issues, and Methods

UMRR-EMP LTRMP Fish Component

By Brian S. Ickes, Jennifer S. Sauer, and James T. Rogala

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Preface

The U.S. Army Corps of Engineers' (USACE) Upper Mississippi River Restoration-Environmental Management Program (UMRR-EMP), including its Long Term Resource Monitoring Program element (LTRMP), was authorized under the Water Resources Development Act of 1986 (Public Law 99-662). The UMRR-EMP is a multi-federal and state agency partnership among the USACE, the U.S. Geological Survey's (USGS) Upper Midwest Environmental Sciences Center (UMESC), the U.S. Fish and Wildlife Service (USFWS), and the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The USACE provides guidance and has overall Program responsibility. UMESC provides science coordination and leadership for the LTRMP element.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP element is to support decision makers with the information and understanding needed to manage the UMRS as a sustainable, large river ecosystem, given its multiple use character. The long-term goals of the LTRMP are to better understand the UMRS ecosystem and its resource problems, monitor and determine resource status and trends, develop management alternatives, and proper management and delivery of information.

This report supports Outcome 1: Enhanced knowledge about system status and trends in the Strategic and Operational Plan for the Long Term Resource Monitoring Program on the Upper Mississippi River System, Fiscal Years 2010-2014 (2009) and supplements milestone #2013B5 from the FY13 LTRMP scope of work. This report was developed with funding provided by the USACE through the UMRR-EMP.

Executive Summary

- The Upper Mississippi River System (UMRS) provides habitat to a wide array of fish and wildlife species distributed among a complex assortment of flowing channels, floodplain lakes, backwaters, wetlands, and floodplain forests. In ecosystems as diverse and complex as the UMRS, many processes and their interrelationships are not well known. Long-term monitoring is perhaps most effective means—and in some cases, the only means—by which large, complex ecosystems such as the UMRS can be studied and managed.
- The Long Term Resource Monitoring Program (LTRMP), an element of the multiagency partnership Upper Mississippi River Restoration-Environmental Management Program (UMRR-EMP), has been monitoring fishes in the Upper Mississippi River System for over two decades, using scientific and highly standardized methods. Today, the LTRMP's data assets represent one of the world's largest and most extensive datasets on a great river.
- Methods and procedures used over the past two decades have been documented (Gutreuter et al. 1995, and subsequent revisions in Ratcliff et al. 2014) and have proven a key tool towards gaining data that are (a) scientifically valid, (b) comparable over time, and (c) comparable over space. These procedures manuals coordinate and standardize methods, procedures, and field behaviors in the execution of long-term monitoring, permitting the informed management and control of important sources of error actually under program control.
- As LTRMP databases have matured in scope and accumulated more years' worth of data, their utility in research and management in the UMRS basin has increased notably. To maximize their utility, data users need not only be aware of "how the data were collected," as portrayed in the procedures manuals, but also "why the data were collected in the way they were, at the scales they were, and in the manner that they were." Whereas the procedures manuals contribute information as to the "how" the data were gained, this document seeks to contribute information as to the "why." As such, this document is intended to be a companion document to the procedures manuals.
- Herein, we present information on the rationale for monitoring nearly one-fifth of the entire North American freshwater fish fauna (representing the greatest freshwater fish diversity on the planet at temperate latitudes); strategies employed and their reasoning; and discussions on issues associated with the sampling design itself, data arising therefrom, and uses of those data in different contexts.
- It is our sincerest hope that this document aids prospective investigators and natural resource managers in navigating and understanding these globally-unique empirical assets.

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Monitoring Rationale, Strategy, Issues, and Methods UMRR-EMP LTRMP Fish Component

By Brian S. Ickes, Jennifer S. Sauer, and James T. Rogala

A General Case for Monitoring in the Upper Mississippi River System

The Upper Mississippi River System (UMRS) provides habitat to a wide array of fish and wildlife species distributed among a complex assortment of flowing channels, floodplain lakes, backwaters, wetlands, and floodplain forests. In ecosystems as diverse and complex as the UMRS, many processes and their interrelationships are not well known. Long-term monitoring is perhaps the most effective means—and in some cases, the only means—by which large, complex ecosystems such as the UMRS can be studied and managed. This is because large, complex systems such as the UMRS do not have comparable ecological analogues and, thus, do not easily lend themselves to reductive scientific methods (e.g., test and control subjects). Moreover, most large ecosystems have been modified to such an extent by human activity that no effective control systems exist. Consequently, changes in the state of the ecosystem, due to human activities or otherwise, can only be identified and investigated in the context of past observations on the same system, as opposed to differences in an experimental control.

To be optimally effective and efficient, a monitoring program should operate under strict protocols that use standardized sampling methods and target informative characteristics of the ecosystem under study (Beard et al. 1999). To ensure comparability of the data and appropriate inference, the sampling design should be statistically rigorous, data collection should be continuous through time, and sampling should be scaled spatially and temporally to the system under study. When designed properly, a long-term monitoring program can be a powerful method for quantifying the status and trends of key resources in the ecosystem under study, understanding system dynamics in response to new stresses (e.g., invasive species introductions, commercial uses, changes in regional land use patterns, etc.), and for investigating the effects and efficacy of alternative management actions designed to rehabilitate the ecosystem.

A Case for Monitoring Fishes in the UMRS

The UMRS is probably the most biologically productive and economically important large floodplain river system in the United States (Patrick 1998; U.S. Geological Survey 1999). Fish are among the most important goods and services that the UMRS provides to humans, and commercial and recreational fisheries both contribute substantially to local economies (Carlander 1954, Fremling et al. 1989). For example, recreation on the Upper Mississippi River was estimated to provide 18,000 jobs and \$1.2 billion annually to the economy, and fishing is a key component of recreation on the river (Carlson et al. 1995; Sparks et al. 1998).

The UMRS is also a nexus of freshwater fish diversity in North America. Approximately one-fifth of the entire North American freshwater fish fauna is native to the UMRS basin. Numerous species are recognized as endangered, threatened, or of particular conservation concern (see Ickes et al. 2005, Chapter 5 therein). Notable examples include

paddlefish (Polyodontidae - *Polyodon spathula*), one of only two extant species of paddlefishes in the world, and three species of sturgeons (Acipenseridae), perhaps the most threatened family of freshwater fishes in the world. The UMRS and its principal tributaries provide a highway for nonnative species to travel from areas as geographically disparate as the Atlantic Gulf Coast and the Laurentian Great Lakes deep into the interior of the North American continent (Ickes 2008).

Scientists and fishery managers also recognize fish communities as an integrative index for a complex set of physical and biological conditions on the UMRS. Thus, fish communities, because of their diversity and response to environmental variation at multiple scales, are frequently used as indicators of ecological integrity for large-river ecosystems (Gammon and Simon 2000; Schiemer 2000; Schmutz et al. 2000; Dukerschein et al. 2011). Moreover, the general public often perceives environmental impacts in the UMRS in terms of changes in the fish community or its habitat.

Because of their economic importance, conservation potential, and utility for assessing the ecological integrity of the UMRS aquatic ecosystem, fishes were chosen as a key ecological component to be monitored by the Long Term Resource Monitoring Program (LTRMP; Jackson et al. 1981; U.S. Fish and Wildlife Service 1993). Fisheries data, thus collected, are used to quantify the status and trends of fish populations and communities (U.S. Geological Survey 1999; Johnson and Hagerty 2008), identify relations with various other ecological attributes (Barko and Herzog 2003; Koel 2004; Barko et al. 2004; Ickes et al. 2005; Chick et al. 2005; Barko et al. 2005; Kirby and Ickes 2006; Barko et al. 2006; Irons et al. 2007; Knights et al. 2007; Irons et al. 2009; Garvey et al. 2010; Dukerschein et al. 2011; McCain et al. 2011), assess efficiencies and redundancies in the monitoring methods used (Ickes and Burkhardt 2002), and address fisheries management concerns in a multiuse, large-river resource (Gutreuter and Theiling 1999; Ickes et al. 2014).

A Focus on the Wider Fish Community and Tradeoffs

At its core, the LTRMP fisheries component monitors fish community dynamics in the UMRS basin. It uses multiple standardized methods and a well-described scientific sampling approach (Gutreuter et al. 1995; Ratcliff et al. 2014) to gain indexed abundance and size structure data on the preponderance of species composing the fish community in each study reach it observes. These data are used to describe the status of the fish community (species lists, frequency of occurrence, rank abundance, community composition, community structure, species richness, diversity, evenness, etc.), as well as changes in the community over time and differences in the community across space. This is not, however, to say that an annual effort represents a complete ichthyofaunal assessment. The methods and design of LTRMP, described more fully below, seek to characterize the preponderance of species present through use of a randomized sampling design. Nontrivial effort ensures that the preponderance of the community is observed, but there is no guaranteed expectation that all species present will be observed in an annual effort for any given location. However, over periods of years or decades, it is reasonable to assume that species lists will approach “complete” for a given study reach, except perhaps for species that may specialize in occupying unique or limited habitats (e.g., main-channel thalwegs and bedforms).

Because of the LTRMP fish component’s community focus and large annual sample sizes, the program has the ability to inform a wider set of management and scientific perspectives within the UMRS basin as well. For example, the program provides considerable information regarding status of individual species and trends in their abundance and size structure, which also permits investigations into environmental determinants for trends, distribution, and habitat suitability (e.g., Ickes et al. 2005; Ickes et al. 2014; Kirby and Ickes 2006). However, the program cannot

provide robust information for every species in the system, because many species are less common and their abundance dynamics are consequently less well determined. Additionally, many natural resource groups are presently concerned about invasive species within the basin. The community focus of the LTRMP fish component and the methods used may be adequate for detecting new instances of invasive species within the system in monitored areas but inadequate for accurately estimating abundance, determining population size structure, and delineating species distribution across the entire UMRS (Ickes et al. 2005). Such situations should not be perceived as program deficiencies but rather as benefits derived from a community-focused program. At a minimum, the program provides baseline information for a host of perspectives that can be exploited to develop studies specific to these important issues. Several important fisheries issues have benefitted greatly from LTRMP observational data sources (for example, Ickes et al. 2005; Ickes et al. 2014; Irons et al. 2007; Irons et al. 2009; Ickes and Kirby 2005; Phelps et al. 2014).

A Fishery-Independent Source of Information

A key concept for the LTRMP fish component is that its data resources represent a fishery-independent source of information. A fishery-dependent source of information is one in which observations are made upon the catch from a commercial or recreational fishery. Fishery-dependent sources of information are prone to the following inadequacies, which make stock assessments and status and trend determinations problematic:

1. Effort can vary over space and time, owing to changes in the fishery, markets and regulations.
2. The efficiency of the fishing fleet can also differ over space and change over time, owing to changes in methods technology (nets, electronics, processing and production efficiencies, ship/boat designs, etc.).

The LTRMP fish component is a fishery-independent source of information because it does not directly sample the recreational and commercial fisheries but instead conducts its own assessments independent of these fisheries. Moreover, it controls for all of the factors that complicate fishery-dependent observation. For example, the LTRMP fish component strictly standardizes its sampling methods—and the effort it uses—in highly prescribed ways. Occasionally, when one of the methods is potentially compromised (for example, when a sampling device or some aspect of its use and deployment needs replaced and the device may no longer be available), planned studies are conducted to demonstrate any changes in the method have no measurable effect relative to past observations (see Ickes et al. 2013; Ickes et al. 2014). Details on these minor and studied changes can be found in the Supplemental Historical Documents repository on the LTRMP fish component home page (http://www.umesc.usgs.gov/data_library/fisheries/fish_page.html; accessed 28 December 2013).

General Sampling Approach

The LTRMP monitors only selected aspects of fishes in the UMRS. Fisheries monitoring in the LTRMP emphasizes basic fish population and community characteristics that pertain to the indexed abundance, size structure, and community characterization of fishes (Gutreuter et al. 1995; Ratcliff et al. 2014). Because of logistic and fiscal limitations, fish monitoring in the LTRMP includes only a small subset of important fisheries variables. For example, whereas LTRMP indexes abundance and gains information on size structure, it does not have the capacity to gain direct data on important dynamic rate functions such as mortality, age-structure, recruitment, fecundity, and

age-at-maturity, though some of these can be inferred indirectly from index data collected by LTRMP, with limitations. Standard methods are used in all data collection efforts, and because the LTRMP strives to document long-term trends, long-term consistency in field practices and methods is essential. The LTRMP fish component Procedures Manual (Gutreuter et al. 1995; Ratcliff et al. 2014) serves this program goal and purpose.

General Sampling Design

The LTRMP monitoring network for fishes has a mixed sampling design. Within each LTRMP study reach, and annually, a relatively small number of nonrandom (“fixed”) sites are monitored every year, another small number of unique features are sampled randomly, and a larger number of randomly selected locations are sampled at seasonal and annual intervals from a spatially stratified sampling design.

Before 1993, all fisheries monitoring took place at nonrandom (“fixed”) sampling locations. In this pre-1993 design, statistical inferences were possible only for the specific locations selected for sampling. Randomization of sampling sites was absent (constraining inferences to single sampling sites only), there was no statistical capability to extrapolate to larger areas or to site types, and points of unique or special significance (i.e., tributary mouths, tailwaters, and wing dams) were not adequately represented. Consequently, the LTRMP scientific staff revised the design in 1992–93. This new design combined nonrandom site sampling for special site types (i.e., tributary mouths and tailwaters), with simple random sampling from populations of unique features within study reaches (i.e., wing dams), with spatially stratified random sampling (SRS) to allow valid statistical inferences upon sampled strata and across entire study reaches over time. Further details of these designs, implemented in 1993, are contained in the following sections.

The LTRMP fish component takes an ecological community based approach to monitoring. Fish community monitoring is conducted by the state-employed staffs of six field stations that collect samples and information from the Mississippi River and Illinois River. Each field station conducts monitoring operations on reaches within an 80-km (50-mi) radius of its base station, and field teams are familiar with the sampled areas. The reaches covered by each field station are as follows (Figure 1):

1. Minnesota Department of Natural Resources, Lake City (field station 1, Lake City, Minnesota), Pool 4, excluding Lake Pepin.
2. Wisconsin Department of Natural Resources, La Crosse (field station 2, La Crosse, Wisconsin), Pool 8.
3. Iowa Department of Natural Resources, Mississippi River Monitoring Station (field station 3, Bellevue, Iowa), Pool 13.
4. Illinois Natural History Survey, National Great Rivers Research and Education Center (field station 4, East Alton, Illinois), Pool 26.
5. Missouri Department of Conservation, Big Rivers and Wetlands Field Station (field station 5, Jackson, Missouri), from the Ohio River to about 100 mi upstream of the confluence.
6. Illinois Natural History Survey, Illinois River Biological Station (field station 6, Havana, Illinois), La Grange Pool of the Illinois River.

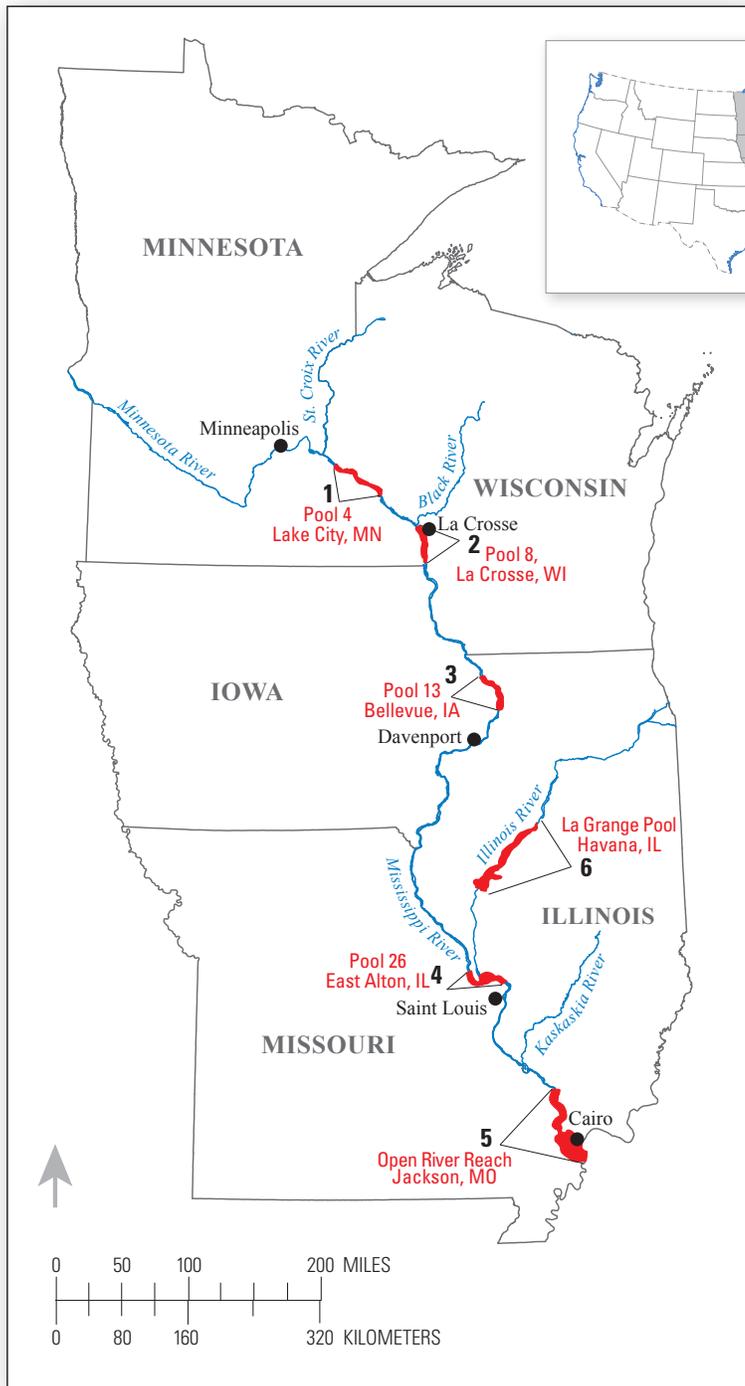
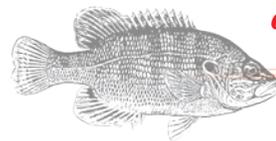


Figure 1. Map of the Upper Mississippi River System and the localities of the six state-operated field stations for the Long Term Resource Monitoring Program, an element of the Upper Mississippi River Restoration-Environmental Management Program.

...the routine fish monitoring of LTRMP is designed to detect patterns at spatial scales on the order of tens of kilometers and temporal scales of seasons and years.



The timing and location of fish community monitoring is guided, in part, by the spatial and temporal patterns of variance in the parameters being measured and by the information desired. Data are collected during an 18-week growing season, annually, partitioned among three equal, discrete, yet contiguous time periods (Period 1=June 15–July 31; Period 2=August 1–September 15; Period 3=September 16–October 31). Routine annual fish community monitoring in the LTRMP is performed in three concurrent phases: (1) nonrandom (“fixed”) site sampling of important river features within study reaches, (2) simple random sampling of a discrete population of unique river features within study reaches, and (3) spatially stratified random sampling (SRS) of entire study reaches. SRS sampling represents the preponderance of effort in LTRMP, and the former two phases represent minor elements in the annual effort.

The limited resources of the LTRMP and the large spatial expanse of the study area prohibit routine measurements at high frequencies (i.e., daily or hourly) or close spatial intervals (i.e., <50 m between sampling points). However, measurements are achieved at intervals of time and space that allow the detection of large-scale changes in biotic responses among adjacent years and over multiple years. Consequently, the routine fish monitoring of LTRMP is designed to detect patterns at spatial scales on the order of tens of kilometers and temporal scales of seasons and years.

Because the LTRMP is attempting to detect resource differences and similarities among the study reaches, as well as changes over time, the sampling regime in all reaches must be consistent and adhere closely to established protocols. Without this consistency, apparent differences in observations can result from differences in methodology rather than actual temporal or geographic variation.

Sampling Design Specifics

Nonrandom ("Fixed Site") Sampling

Historical basis

Prior to 1993, all LTRMP fish component sampling locations were selected nonrandomly within designated study reaches. Correspondingly, all pre-1993 LTRMP fish data derive from a nonrandom sample site selection process and thus represent judgment samples. Details on pre-1993 judgment sampling can be found in Gutreuter (1993). Because of issues associated with nonrandom sampling (bias, inability to extend inferences beyond the sampling site, etc.), pre-1993 data are typically not used concomitantly with contemporary stratified random sample data for trend-analysis purposes. However, pre-1993 data remain useful for characterizing size structure within populations and developing length \times weight relationships, for example, and continue to be served on LTRMP fish component raw data portals (http://www.umesc.usgs.gov/data_library/fisheries/fish1_query.shtml). Pre-1993 data are easily separable from SRS-era data in that each pre-1993 barcode, which is a data field that uniquely identifies a sample within the database, is served as a negative numeric value, whereas SRS-era barcodes are positive values.

Specific aspects

Nonrandom site selection remains a minor portion of annual LTRMP fish component sampling. Nonrandom sampling continues uninterrupted in two unique river environments (tailwater and tributary mouth) that cannot otherwise be effectively sampled by using random sampling procedures. Tail water zones are sampled in Pools 4, 8, 13, and 26 in the Upper Mississippi River, and the La Grange Pool of the Illinois River with tributary mouths sampled in the Open River Reach of the Mississippi River. For the purpose of LTRMP fish sampling, a tailwater area is defined as the area immediately downstream from a lock and dam and includes the plunge-pool (scour hole) created by the dam, and a tailwater zone (TWZ) is defined as the first 500 m of shoreline below a lock and dam (Figure 2). A tributary mouth (TRI) is the portion of a tributary stream that is within the floodplain of a large river (Figure 3).



Figure 2. Aerial view of a typical lock and dam tailwater zone in the Upper Mississippi River System.



Figure 3. A typical example of a tributary mouth zone. These features are monitored only in the Open River Reach of the Upper Mississippi River System.

Additionally, a limited number of nonrandom sites are also sampled annually at sites of exceptional interest to the program and its partnering agencies (e.g., sites with historical occurrences of endangered species; sites associated with habitat rehabilitation projects). These collections remain in place because of a site-specific need to document trends, requiring repeated visits to those specific sites over time, that otherwise would not be gained in a randomized sampling effort.

Simple Random Sampling of Unique River Features

Wing Dams

A main (navigation) channel border-wing dam area (MCB-W) is a localized portion of main navigation channel border area in which a wing dam is the predominant physical feature. Wing dams are artificial structures that act to divert flow to the navigation channel and are usually constructed of rock (see also Wilcox 1993). Wing dams protrude from the shoreline, typically perpendicular to flow, and may be totally submerged or emergent, depending on water elevation and construction height.

Wing dam sites are uniquely handled in the LTRMP fish component sampling protocol. Data deriving from wing dam sampling represent a simple random sample of these important river features within each study reach. Wing dams are distinct and discrete features within the UMRS and have no area-based weight upon which to characterize them in the larger stratified random sampling design. Correspondingly, annual estimates of MCB-W metrics (e.g., catch-per-unit-effort, or CPUE) are the simple mean, variance, and standard error, with derived estimates applying only to the population of wing dams composing the sampling list rather than all wing dams in the entire study reach. Each wing dam is treated as a finite element and independent sample, and no sample weighting is applied on the basis of wing dam position or size in the calculation of the estimators.

Fish sampling by the LTRMP is restricted procedurally to those wing dams that (1) are at least 50 m long (from shore to tip) and (2) have an exploitable hydraulic effect. Therefore, wing dams submerged under more than 2 m of water are not sampled. This procedural constraint was derived from pre-1993 experiences in deploying various LTRMP sampling gears in proximity to wing dams. In 1993, wing dams that fit these criteria were surveyed within each LTRMP study reach, and a list of compliant wing dams was generated for each LTRMP study reach. This list represents a population (census) of all wing dams in each study reach that could be sampled by using LTRMP Fish Component methods. Annually, the LTRMP Database Administrator selects a sampling allocation (varies by study reach) for wing dam sites from these study-reach-specific lists. Selection is achieved by using randomization protocols (simple random sample with replacement) from the population list for each study reach, until a full annual allocation is achieved.



Figure 4. Wing dam in the Upper Mississippi River System (credit: <http://www.idylltime.com/?p=713>, accessed 28 December 2013).

Other Features

Since 1993, several new engineering features have become increasingly common in portions of the UMRS. Most of them are associated with U.S. Army Corps of Engineers (USACE) channel management activities to ensure commercial navigation. Two particular examples are (1) chevron dikes and (2) bendway weirs. At the time of this writing, and as far as we are aware, each feature only occurs in river miles under the management authority of the St. Louis District of the USACE. Because these features are regional, the LTRMP fish component, as a more systemic assessment program, does not presently have any procedures or protocols for sampling these new and unique river features, though some localized assessments take place as part of project emplacement process outside of LTRMP. Should such features become more prominent throughout the UMRS, LTRMP should consider whether or not these features should be monitored over time in standardized ways and by use of common protocols. If the decision is made to do so, it is recommended these features be treated similarly to wing dam sampling within the LTRMP fish component protocols (simple random sample of these unique features). An alternative would be a nonrandom and repeated measures assessment of a select few.

Stratified Random Sampling Within LTRMP Study Reaches

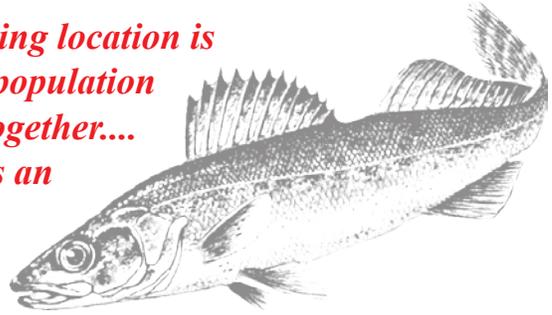
A stratified random sampling (SRS) design has been used in the LTRMP for fish, water quality, and macroinvertebrates since 1993 and for aquatic vegetation monitoring since 1998. This approach is designed to give unbiased estimates that can be extrapolated to entire strata and study reaches and for making comparisons among strata, among study reaches, and over time. Random selection of sites eliminates most potential sources of sampling bias and produces results that can be extrapolated with known confidence. The principal benefits of an SRS design relate primarily to the statistical estimators deriving from the design:

1. they are free of bias because they arise from randomization procedures in the sample selection process;
2. they follow directly from well-determined sampling theory, and they are unimpeachable at design-based scales of time and space; and
3. they possess well-understood variance and error components in their determination.

The use of defined statistical strata allows the sampling effort to be adjusted to variability within, or to the perceived ecological importance of, targeted areas. The SRS tracks conditions at spatial scales corresponding to the statistical sampling strata or larger (i.e., whole study reach) and seasonal-annual time scales or longer. Seasonal SRS episodes are intended to encompass major seasonal events (i.e., recruitment, growth), but their scheduling is not changed from year to year or in accordance with river conditions (e.g., hydrology, water temperature). The allocation of sampling locations among the statistical strata is not proportional to stratum surface area, so a weighting method (e.g., area based) must be used to extrapolate SRS estimators to an entire study reach (see Table 1). Additional details on weighting design-based estimates can be gained from online resources available through the LTRMP fish component home page (http://www.umesc.usgs.gov/data_library/fisheries/fish_page.html).

The sample collection methods used in SRS sampling (e.g., gear types and configurations, site quantification and characterization) are identical to those used for nonrandom sampling and unique feature sampling (Gutreuter et al. 1995; Ratcliff et al. 2014). However, there are important design differences among these sampling designs. For SRS, (1) the sampling locations are selected with statistical randomization to represent specific strata (enduring geomorphic classes; see Wilcox 1993), (2) the suitability of the site and its precise location must be determined

...the measurement at an individual sampling location is considered a random observation from a population during a sampling period. When pooled together... this set of random measurements provides an accurate indexed estimate of conditions within the entire stratum...



in the field at the time of sampling; and (3) a specific sampling site is unlikely to be sampled repeatedly over time except in reaches where certain strata are rare. An important concept of the SRS design in LTRMP fish monitoring is that the measurement at an individual sampling location is considered a random observation from a population (stratum of sampling points) during a sampling period. When pooled together and properly treated analytically, this set of random measurements provides an accurate indexed estimate of conditions within the entire stratum, even though any individual site measurement may not be a good representation of typical (i.e., average) conditions at the specific point of sampling or across the whole stratum during a sampling period (season, year).

Specific Aspects and Statistical Methods for SRS

The principal attribute of interest within the SRS design for the LTRMP fish component is mean catch-per-unit-effort (CPUE). Design-based estimates of CPUE are used as an index of population density (Ney 1999) within LTRMP. Units of effort are specific to particular gears and are described in detail in Gutreuter et al. (1995) and Ratcliff et al. (2014). Catch and effort are recorded for each species from individual samples, selected from a spatially stratified sampling frame composed of 50- × 50-m cells (0.25 ha; see Table 1). Sites are selected at the intersections of the sampling grid, as opposed to the center of the cells. Whenever a species is not caught in a sample, the catch for that species in the sample is imputed as a zero. The estimates of annual study reach-wide mean CPUE (so called “poolwide” estimates) can be obtained from the conventional design-based estimator for stratified random samples (Cochran 1977). The mean CPUE of stratified samples, \bar{y}_{st} , is given by

$$\bar{y}_{st} = \frac{1}{N} \sum_{h=1}^L N_h \bar{y}_h \quad (1)$$

where N_h is the number of sampling units within stratum h , L is total number of strata, $N = \sum_{h=1}^L N_h$, and \bar{y}_h denotes the estimator of the simple mean of y for stratum h . The estimator of the variance of \bar{y}_{st} is

$$s^2(\bar{y}_{st}) = \frac{1}{N^2} \sum_{h=1}^L N_h (N_h - n_h) \left(\frac{s_h^2}{n_h} \right) \quad (2)$$

where

$$s_h^2 = \frac{\sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2}{n_h - 1} \quad (3)$$

is the usual estimator of the variance of y_h , and n_h is the number of samples taken in stratum h (Cochran 1977). The standard error of \bar{y}_{st} is therefore $s(\bar{y}_{st})$.

The sample weights applicable to each stratum, required to attain design-based estimates at the study reach scale, are provided in Table 1 for each study reach for reference.

Table 1. Strata population sizes by study reach and stratum for the fish component of the Long Term Resource Monitoring Program on the Upper Mississippi River System. Nh denotes the number of sampling frame elements composing each stratum in each study reach (Reach) and is suitable for finite population corrections. Each sampling frame element is 50 × 50 m, or 0.25 ha.

Reach	Stratum	Stratum code	Years	Nh	Cell area (ha)
Pool 4	MCB-O	1502	All	2252	0.25
	MCB-S	1503	All	766	0.25
	SC-O	1504	All	2887	0.25
	SC-S	1504	All	1717	0.25
	BWC-O	1510	All	5073	0.25
	BWC-S	1511	All	3860	0.25
	TOTAL			All	16555
Pool 8	MCB-O	1502	All	2376	0.25
	MCB-S	1503	All	756	0.25
	SC-O	1504	All	4148	0.25
	SC-S	1504	All	3026	0.25
	BWC-O	1510	All	1978	0.25
	BWC-S	1511	All	3434	0.25
	IMP-O	1520	All	13204	0.25
	IMP-S	1521	All	494	0.25
TOTAL			All	29416	0.25
Pool 13	MCB-O	1502	All	4437	0.25
	MCB-S	1503	All	910	0.25
	SC-O	1504	All	2758	0.25
	SC-S	1504	All	2010	0.25
	BWC-O	1510	All	5871	0.25
	BWC-S	1511	All	3626	0.25
	IMP-O	1520	All	10002	0.25
	IMP-S	1521	All	438	0.25
TOTAL			All	30052	0.25
Pool 26	MCB-O	1502	All	13231	0.25
	MCB-S	1503	All	3199	0.25
	SC-O	1504	All	5671	0.25
	SC-S	1504	All	2503	0.25
	BWC-O	1510	All	358	0.25
	BWC-S	1511	All	764	0.25
	IMP-O	1520	All	588	0.25
	IMP-S	1521	All	172	0.25
TOTAL			All	26486	0.25
Open river	MCB-O	1502	All	12593	0.25
	MCB-S	1503	All	2592	0.25
	SC-O	1504	All	1872	0.25
	SC-S	1504	All	1077	0.25
TOTAL			All	18134	0.25

Table 1. Strata population sizes by study reach and stratum for the fish component of the Long Term Resource Monitoring Program on the Upper Mississippi River System. Nh denotes the number of sampling frame elements composing each stratum in each study reach (Reach) and is suitable for finite population corrections. Each sampling frame element is 50 × 50 m, or 0.25 ha.—Continued

Reach	Stratum	Stratum code	Years	Nh	Cell area (ha)
La Grange Pool	MCB-O	1502	All	9764	0.25
	MCB-S	1503	All	4935	0.25
	SC-O	1504	All	653	0.25
	SC-S	1504	All	565	0.25
	BWC-O	1510	All	6946	0.25
	BWC-S	1511	All	3616	0.25

Considerations and Issues

What Sampling Strata Represent

The primary function of the sampling strata is statistical, and they are based on the “enduring geomorphic classes” of Wilcox (1993) as implemented by Gutreuter et al. (1995) and reinforced by Ratcliff et al. (2014). Beyond this function, the individual strata have innate value, and differences among them in their environmental and biological attributes are expected. With the use of strata, one can gain not only design-based estimates at the “study reach” (or “poolwide”) scale, but also at individual “stratum scales.” Resource managers and scientists are typically interested in (a) differences among strata, within and among study reaches, for a given time, (b) differences within a stratum, within and among study reaches and over time, and (c) unbiased weighted “poolwide” estimators over time and among study reaches. As such, these are the design-based scales at (1) which the LTRMP is designed, (2) estimates are calculated, and (3) estimators are served (e.g., http://www.umesc.usgs.gov/data_library/fisheries/graphical/fish_front.html, accessed 28 December 2013).

Although the LTRMP sampling strata reflect—indeed, contain—differing habitat types, they are not habitat classes, and a precise correspondence between strata and habitat is not intended in the design. The statistical validity and utility of the strata does not require a perfect match between mapped strata and habitat or aquatic areas. However, it is essential that the strata be defined and mapped quantitatively. In the LTRMP, this means the sampling

strata are areas on a map defined by major, enduring geomorphic and physical features as described by Wilcox (1993) and quantified from 1989 aerial photography by using a geographic information system (GIS) (Appendix A). These maps are the LTRMP sampling universe, and all design-based inferences and estimates pertain to that universe solely. Extrapolation beyond that universe requires model-based approaches and inherent model-specific assumptions. Further guidance

...a precise correspondence between strata and habitat is not intended in the design



on design-based versus model-based inference is provided in sections below and can also be gained from online resources detailing select statistical issues available through the LTRMP fish component home page (http://www.umesc.usgs.gov/data_library/fisheries/fish_page.html, accessed 28 December 2013). Ickes et al. (2014) also speaks to some of these issues in a model-based context.

Changing Stratum Boundaries

To facilitate analysis of the LTRMP data, and to meaningfully represent annual measurements over periods of years or decades, the boundaries of the sampling strata are intended to be static over time. These boundaries are clearly defined and reproducible within a GIS framework and are immutable once established. Often, over the past 20 years, practitioners and others have argued that the strata should be redefined because they have observed changes in various environmental features within various strata over time (e.g., more shallow shore slopes, changes in vegetation density, changes in flow, etc.). However, doing so would change site selection probabilities upon which the weighted estimators are exercised, in nonreproducible ways. Field personnel can report apparent changes in strata boundaries as part of a site observation in the “comments” field of provided data entry utilities, and they are encouraged to do so (Ratcliff et al. 2014), but redefining the sampling strata requires more extensive information and should never be attempted on the basis of observed site characteristics at any point in time, or over a period of observation. Subjective interpretations, or reinterpretations, of strata boundaries are not consistent or reproducible over time, and inconsistent changes in the strata boundaries would make long-term data interpretation difficult or impossible. Subjective interpretations differ among individuals, and modifications based on transient properties (e.g., river stage or flow velocities) are not appropriate. Again, field investigators are encouraged to make such observations in the provided “comments” field of the data entry applications they use during a site visit. Such notes can prove useful when LTRMP data are used in analytical or model based work.

...the boundaries of the sampling strata are intended to be static over time



Encountering Atypical Conditions Within Strata

Sampling strata are not expected to be uniform, and each individual site is not expected to be typical of the average physical, chemical, or biological conditions within the stratum. Each stratum is expected to contain a broad mosaic of habitat types, with the distribution of habitats differing among the strata. Unlike habitats, strata do not have a set of physical, chemical, or biotic attributes (i.e., depth, velocity, substrate type, vegetation) that uniquely define them. Habitat conditions and classifications can change on a scale of minutes to hours in response to discharge, for example. In contrast, LTRMP sampling strata are intended to reflect relatively permanent geomorphic conditions and characteristics (Wilcox 1993), reflecting important and reasonably enduring river and floodplain morphometry.

...sampling strata are intended to reflect relatively permanent geomorphic conditions...



Changes in the River Over Time

Two fundamentally different approaches can be taken to assess changes within a stratified sampling framework. One method is to frequently remap the strata on the basis of field observations and then attempt to track or quantify the mapped changes. This approach is impractical because of the enormous difficulties inherent in remapping at frequent intervals in a defined, quantitative, and consistent manner. Further, the routine field sampling in the LTRMP does not generally provide the level of spatial information needed to perform this remapping.

An alternative is to have the sampling strata permanently fixed in space, and then quantify changes in conditions within the permanently fixed strata based on the sampling data over time. This approach is workable and consistent with the LTRMP design.

The premiere purpose and utility of stratification in the LTRMP SRS design is to appropriate sampling effort randomly across a well-defined sampling frame but not necessarily to track changes in aquatic area composition. Thus, to date, the LTRMP fish component has implemented a highly conservative approach to this issue. Strata are regarded as statistical design elements, as opposed to aquatic area types or habitats. Moreover, strata are regarded as permanent and immutable.

Importantly, thus defined, changes in conditions within the strata (and at the pool or reach level), rather than changes in the strata boundaries, are used to indicate short-term changes in the system. In other words, changes within the ecosystem over time are inferred within and among the strata, rather than by changes to the extent of the strata over time via successive remappings.

Intended Spatial-Temporal Scaling in LTRMP SRS Monitoring Data

The explicit focus of SRS within the LTRMP is the study reach and annual scale, and the sampling strata are statistical tools that allow valid, unbiased estimates at this scale of time and space. Secondly, the strata allow inferences about the strata themselves and, to a lesser degree, about habitats or aquatic areas within each stratum.

Patterns at the sub-annual scale can sometimes be addressed with the SRS data, and interpretations of SRS data at smaller spatial scales and in terms of specific habitats are sometimes possible, but not always (e.g., Knights et al. 2008; Barko and Herzog 2003; Ickes et al. 2014). Approaches to achieving such can vary from poststratifying a singular stratum (e.g., Barko and Herzog 2003) or set of strata, which requires design-based methods known as Domain Analysis, to other methods that require developing and applying models (typically statistical models) at either finer or coarser scales (e.g., Ickes et al. 2014). Issues with doing so depend on the selected model, the nature of the question and the goals of the analysis, the inherent assumptions of the chosen model, and the adequacy of LTRMP data to contribute to any given model-based approach at nondesigned scales. Regardless, investigating either finer scales (e.g., habitats within strata) or coarser scales (e.g., dynamics at UMRS systemic or regional scales) that are outside of the design-based scales LTRMP was created to address must be done with care and a mature understanding of many design-based and model-based issues. Consultancy with the designated LTRMP component Principal Investigators and/or a statistician is strongly encouraged. Accordingly, the LTRMP fisheries component makes no claims as to the veracity of any such utility or adequacy of model-based uses of its design-based data sources.

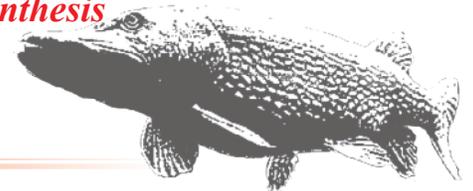
Using LTRMP SRS Data in Cross Component Analysis and Research

Because the primary target of SRS is the study reach and annual scale, this is also the intended spatial-temporal scale for cross-component synthesis or integration using the SRS data. For example, the fisheries data from SRS are not intended to explain why a certain sample produced a certain result (synoptic environmental data collected while sampling a site might partially serve this purpose) but rather why catches or year classes of some species may be declining in a study reach or a stratum over several years. Sometimes, data from the other LTRMP components (i.e., water quality and aquatic vegetation) can be useful and informative in helping to explain observed patterns in fisheries responses. However, the design-based strata used for each component need not be identical across components because the wider program design is not intended for cross-component inferences at the stratum scale. Further, to make valid cross-component inferences at the study reach and annual scale, the strata must differ among

components. If, for example, the water quality sampling was limited to the times and locations (e.g., strata) used for fish sampling, conditions at times and places unsuited for fishing (e.g., ice cover in shallow backwaters), but critical to fish survival, would not be sampled. The same holds for vegetation and macroinvertebrates. Cross-com-

ponent analysis or synthesis at time scales shorter than years and space scales less than a whole study reach are not prohibited by the SRS design but often require a customized approach to the data, and some analyses at the stratum or substratum level may not be fully supported. Appropriate ancillary information must be collected if small-scale, short-term processes are of interest and, in the LTRMP design, this finer scale of time and space is considered the realm of focused specialized studies rather than routine, long-term monitoring.

Because the primary target of SRS is the study reach and annual scale, this is also the intended scale for cross-component synthesis or integration using the SRS data



Inferences Using LTRMP Data

Available inferences on observed phenomenon gained by LTRMP within the UMRS vary by scale (e.g., system, study reach, individual sampling strata, substrata) and type (design-based versus model-based approaches to inference).

At the “systemic” UMRS scale, representing the LTRMP’s legislative domain (all navigable reaches of the UMRS), LTRMP samples the UMRS by using a judgment (nonrandom) sampling scheme. Five study reaches (navigational pools or “zones”) of the Upper Mississippi River (UMR) and one reach of the Illinois River (Figure 1; average length of each study area is approximately 80 km) were selected to represent the 1,930-km UMRS. Although not positioned within the UMRS at equidistance, these six study reaches traverse many important environmental and human use gradients inherent to the UMRS and seek to observe the full range of variation in measured attributes across these gradients. As such, these six study reaches can be argued to represent a nonrandom gradient sampling scheme across the 1,930 km of river the program samples. At this scale, there is no design-based theoretic basis by which to gain design-based inferences on system status, trends, or state (e.g., study reaches are not randomized but rather are “fixed” as nonrandom elements at the system scale and sampled repeatedly over time). All such inferential intentions at the system scale (and arguably at any scale larger than an individual study reach observed by LTRMP) must therefore be gained by using model-based approaches exercised upon the design-based estimates achieved within each study reach or upon individual sample-site-scale data gained as part of the study reach SRS design.

A key concept/assumption in the design at this “systemic” scale is that each of the six study reaches is representative of proximate navigation pools.



reaches coincided very closely with index scores derived for a spatially more expansive U.S. Environmental Protection Agency monitoring effort known as EMAP (Angradi et al. 2009).

A key concept/assumption in the design at this “systemic” scale is that each of the six study reaches is representative of proximate navigation pools. The LTRMP has studied this issue previously for fishes and has found that this assumption is acceptable for the primary responses LTRMP was designed to detect. For example, Chick and Pegg (2004) found that both community composition and community structure indices were highly similar among pools adjacent to LTRMP study areas in a spatially expanded monitoring effort in 2000 conducted to address this exact issue by LTRMP. Similarly, Duker-schein et al. (2011, Figure 3 therein) found that patterns in a widely used index of biological integrity derived from the six LTRMP study

Within each LTRMP study reach (N=6), sampling is achieved annually using probabilistic methods (Ratcliff et al. 2014). This represents LTRMP's spatially Stratified Random Sampling design for fish community monitoring. Thus, at the individual study reach scale, LTRMP produces unbiased design-based estimates that follow from well-established sampling theory (Cochran 1977). As such, design-based estimators gained via the SRS design of LTRMP are probability based, unbiased, and unimpeachable at the study reach scale. All inferences and estimators gained via the SRS design applied at the study reach scale represent, unequivocally, the sampling frame developed for each study reach. For example, annual mean catch-per-unit-effort estimates for bluegill in Pool 4 apply strictly to the sampling frame, which excludes Lake Pepin (see Appendix A), rather than to the "Pool as a whole." Often, in reports, "Pool 4" or otherwise the study reach name, is associated with the reported statistics and/or inferences. This is purely heuristic. Design-based inference is solely to the sampling frame within each study reach.

Within each LTRMP study reach, and within individual statistical strata comprising the SRS sampling frame, sampling effort represents a simple random sample at the stratum scale. As such, sampling at the individual stratum scale is similarly probabilistic, unbiased, and unimpeachable. This approach permits accurate and unbiased estimation of observed phenomenon; however, precision will be to a large degree a function of applied random effort, in terms of sample size within each stratum (N samples). Estimators for observed phenomena at the stratum scale are the simple statistical first and second moments (mean and variance measures).

Occasionally, and depending upon sample sizes and investigator intentions, individual strata can be "poststratified" to achieve either design-based or model-based inferences at spatial scales smaller than an individual stratum. The idea behind poststratification is to take all random observations made in one (or more) individual stratum and further parse them post de facto into two or more different substratum classes. For example, side-channel observations, consisting of a simple random sample at the stratum scale, can be parsed into two or more groups based on perceived or demonstrated functional differences among all side channels in a given study area (e.g., "open" and "closed", relating hydrologic connection conditions over some stated period of time). Such sub-strata are not part of LTRMP's innate design but can occasionally be accommodated given nontrivial sampling effort applied at the individual sampling stratum scale. Accordingly, effort may be parsed, after the fact, among two or more investigator-defined classes. Inferences, thus pursued, can be gained via design-based methods (because the individual samples remain random elements in a simple random sample within a stratum) using methods known as Domain Analysis, or via investigator-chosen model-based approaches. There are many nuanced issues inherent to both methods, and investigators interested in such inferences are strongly encouraged to consult with a trained statistician.

NEVER should field investigators redefine LTRMP sampling strata a priori or at the time of collection. These are postsampling period methods conceived to explore investigator-driven questions at scales beyond the innate LTRMP SRS design.



Potential Sources of Error in LTRMP Fish Monitoring Data

There are several potential sources of error in monitoring observations. Not all can be controlled, but well-designed and well-implemented monitoring programs can control many/most sources of potential error.

Error sources in observational studies derive from three principal sources: (1) sampling error, (2) nonsampling error, and (3) environmental error/variation. The LTRMP fish component, under its SRS mode of observation, seeks to strictly control those sources of error actually under its control (sampling and nonsampling error) in order to infer sources of environmental error (a.k.a., variation). Indeed, tracking the dynamics and responses of the UMRS fish community and its compositional species to changes in the environment is the entire point of LTRMP. By controlling and limiting the first two sources of error by using standardized methods and a scientifically defensible sampling design, changes in measured features will, to the greatest degree possible, track and respond to changes in the natural environment.

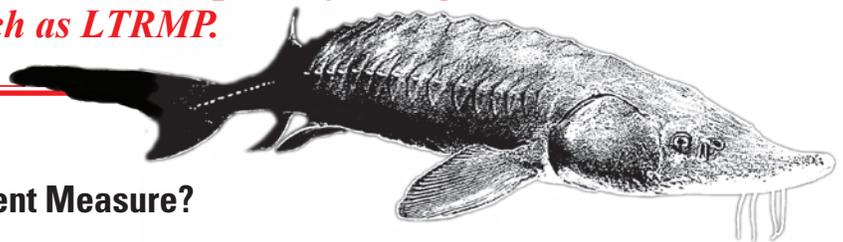
Sampling error is error arising from the sampling process itself. Strictly defined, it is the difference between an estimate based on a sample and the corresponding value that would be obtained if the estimate were based on the entire population (as from a census). Note that sample-based estimates will vary depending on the particular sample selected from the population. Measures of the magnitude of sampling error in direct survey tabular estimates (variances, standard deviations, or coefficients of variation) reflect the variation in the estimates over all possible samples that could have been selected from the population using the same sampling methodology. LTRMP seeks to control, and to understand, sampling error in its data by (1) establishing a scientifically valid sampling design and frame across which probabilistic (randomized) sampling is implemented; (2) treating the design as an immutable framework for sampling so that data and inferences derived therefrom are comparable over long periods of time and space; (3) estimating design-based parameters in documented, reproducible, and statistically coherent ways; (4) expressing uncertainty in sample-derived estimates from the statistical populations it samples; and (5) documenting the established design and the methods by which data are surveyed and handled and the methods by which estimators are gained relative to the design. The LTRMP fish component Procedures Manual conveys this information (Gutreuter et al. 1995; Ratcliff et al. 2014), and additional details can be found on the LTRMP fish component homepage: http://www.umesc.usgs.gov/data_library/fisheries/fish_page.html (accessed 28 December 2013).

Nonsampling error is error arising from factors associated with observer fallibility, such as may occur during the development or execution of a survey. These errors are all associated with human error in the implementation, collection, and reporting of survey information. There are several sources of nonsampling error (e.g., measurement error, coverage error, nonresponse error, and processing error). The LTRMP fish component exerts numerous standardized field and reporting procedures to minimize and eliminate these sources of error, and the methods for doing so are expressed throughout the component's procedures manual (Gutreuter et al. 1995; Ratcliff et al. 2014). For example, measurement errors arise when nonstandardized effort is applied to sampling methods, and signals in the resulting data are at least in part due to such changes in effort over time and/or space. In the LTRMP fish component, sampling error applies to the sampling methods it uses to index UMRS fish community and population attributes (e.g., sampling gears). LTRMP controls this source of potential error by entirely and strictly standardizing the sampling gears it uses over space and time and by applying standardized effort within each sampling method. Similarly, observer error is controlled to the extent humanly possible through a series of quality assurance audits, executed in real time at the point of data capture and during annual processing of the entire annual record. Coverage errors are controlled by using geographic information system technologies linked with global

positioning system components to aid field staff in accurately navigating to randomly chosen sampling locations, and also via a set of explicit procedural instructions for locating and sampling selected sites. Additional details concerning these error sources and the procedures the LTRMP fish component uses to minimize and control them can be found in Gutreuter et al. (1995), in Ratcliff et al. (2014), and on the LTRMP fish component homepage: http://www.umesc.usgs.gov/data_library/fisheries/fish_page.html (accessed 28 December 2013).

Environmental error/variation is a source of error usually outside of the control of a monitoring program. For the LTRMP, changes in river conditions over time and space result in variability in measured attributes. However, by adequately controlling and minimizing sampling and nonsampling error sources, the variation in the measured attributes will reflect changes in the environment to the fullest extent possible. Indeed, this is the entire point of a long-term monitoring program, such as LTRMP. This can only be assured to the extent that sources of sampling and nonsampling errors can be adequately controlled, thus justifying the existence of a detailed LTRMP fisheries procedures manual. Environmental conditions can also affect sampling error (see above) as well as environmental error. For example, a large flood could lower catch by reducing catchability.

...by controlling and minimizing sampling and nonsampling error sources, the variation in the measured attributes will reflect changes in the environment—this is the entire point of a long-term monitoring program, such as LTRMP.



What Does the LTRMP Fish Component Measure?

Details on the attributes measured by the LTRMP fish component are contained in its procedures manual (Gutreuter et al. 1995; Ratcliff et al. 2014). The point of this section is to convey what these attributes represent.

Ascertaining the true abundance of living animals (absolute population size, density, or biomass) is incredibly difficult and rarely, if ever, achieved. Doing so requires perfect sampling, with perfect methods, performed in specific ways (area or volumetric based enumeration). Correspondingly, it is almost always necessary to create a population index which is assumed to be related to true abundance or density. Creating an index of abundance requires controlling important sources of error in the survey design and the intersection of that design with field observers and observations. Therefore, index estimators are a reflection of both the actual numbers of biological organisms truly present and the ability of the index-based monitoring program to detect and enumerate them.

The LTRMP fish component is an index-based monitoring program, which standardizes its methods and procedures in a design-based context (Gutreuter et al. 1995; Ratcliff et al. 2014) to achieve statistically unbiased and accurate index data. The estimators (mean and variance) generated by the observations are assumed to be an index of the attributes LTRMP samples (e.g., abundance estimates within species and specific sampling methods [gears]), but in no way are direct measures of true abundance or density (though they are presumed to be associated with and related to them). Three important points follow from this:

1. Annual indices of abundance (say catch-per-unit-effort) are not a direct measure of actual abundance or density and should never be represented as such from LTRMP fish component data sources. They are indexed estimates of abundance, observed in highly standardized ways over space and time.
2. The point of indexing annual abundance within LTRMP is not to provide annual point estimates of true abundance but to monitor the indexed quantity in highly standardized ways to understand and infer dynamics over time, and differences and similarities in comparably measured indices across space, and perhaps their environmental associations in response to natural variability or management interventions.
3. Gaining true abundance or density from LTRMP index statistics requires knowledge upon how the sampling method(s) intersect with actual true population abundance (i.e., understanding the selectivity or catchability of the sampling method(s) relative to the population(s) of interest).

Point number 3 above deserves greater exploration. The catchability of any given method is a function of several things. First, the organism must encounter the sampling method. Secondly, the organism must be entrapped by the sampling method. Third, the organism must be retained by the sampling method until identified and enumerated. Each of these circumstances has a unique probability specific to both the method of sampling and the species/population being quantified. These probabilities may also vary over time as a function of any of a number of environmental circumstances (e.g., weather patterns, river flows, water transparency, vegetation density, etc.) and perhaps even by species life stage. This represents a lot of required knowledge to gain information to evaluate the catchability of a given sampling method, even for just a single species, in order to estimate true abundance.

It is important to note that as of 2014, the LTRMP fish component has been sampling for 20 years and samples with six standardized gear types over 1,930 km of river and within a diverse array of river conditions, habitat types, and geomorphic settings. Moreover, to date, the LTRMP has observed 144 fish species and many additional hybrids. Gaining the requisite information to achieve absolute abundance or density estimates across all design elements, time, sampling methods, and species is beyond prohibitive.

Thus, the LTRMP fisheries component must make the necessary simplifying assumption that indexed abundance reflects changes in true abundance over time. Because LTRMP is designed to detect large changes in ecosystem state over long periods of time, this assumption is not as invalid as it otherwise would be in short-term directed studies practiced upon the same system, or as it would be for studies seeking small, yet discernible, changes in resource state. Over long periods of time, the catchability of the methods, which likely vary as a function of myriad environmental covariates, is assumed a random factor, and as a minor component of observation error.

Finally, it is also important to note that given its index-based design in the attributes it measures, the LTRMP fish component is not able to model the generating processes by which it observes its data. This of course follows directly from the explanation provided immediately above. Modeling or otherwise estimating the processes by which the observed indexed quantities derive depends on knowledge not provided by the LTRMP fish component sampling design. This does not preclude independent study of these issues outside of the monitoring context, and indeed, such studies have recently been completed for limited sampling methods and species (Dr. John Chick, National Great Rivers Research and Education Center, East Alton, Illinois; personal communication).

Summary

A long-term monitoring program on the UMRS with standardized and detailed protocols is necessary to ensure that changes detected by monitoring actually are occurring in nature and not simply a result of measurement error (Oakley et al. 2003). The LTRMP fisheries component has developed one of the most extensive and comprehensive datasets on any large river fisheries in the world. The continuing role of the LTRMP component will be to provide the data needed to assess changes in river conditions and to determine how those changes relate to management actions, natural variation, and the overall ecological integrity of the UMRS riverine ecosystem.

Literature Cited

- Angradi T.R., Bolgrien, D.W., Jicha, T.M., Pearson, M.S. Hill, B.H., Taylor, D.L., Schweiger E.W., Shepard, L., Batterman, A.R., Moffett, M.F., Elonen, C.M., and L.E. Anderson. 2009. A bioassessment approach for mid-continent great rivers: the Upper Mississippi, Missouri, and Ohio (USA). *Environmental Monitoring and Assessment* 152(1–4): 425–442.
- Barko, V. A., and D. P. Herzog. 2003. Relationships among side channels, fish assemblages, and environmental gradients in the unimpounded Upper Mississippi River. *Journal of Freshwater Ecology* 18(3):377–382.
- Barko, V. A., D. P. Herzog, R. A. Hrabik, and J. Scheiber. 2004. Relationship among fish assemblages and main channel border physical habitats in the unimpounded Upper Mississippi River. *Transactions of the American Fisheries Society* 133(2):370–383.
- Barko, V. A., B. S. Ickes, D. P. Herzog, R. A. Hrabik, J. H. Chick, and M. A. Pegg. 2005. Spatial, temporal, and environmental trends of fish assemblages within six reaches of the Upper Mississippi River System. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, February 2005. LTRMP Technical Report 2005-T002. 27 pp. (DTIC ADA-431398)
- Barko, V. A., D. P. Herzog, and M. T. O’Connell. 2006. Response of fishes to floodplain connectivity during and following a 500-year flood event in the unimpounded upper Mississippi River. *Wetlands* 26(1): 244–257.
- Beard, G. R., W. A. Scott, and J. K. Adamson. 1999. The value of consistent methodology in long-term environmental monitoring. *Environmental Monitoring and Assessment* 54:239–258.
- Carlander, H. B. 1954. A history of fish and fishing in the Upper Mississippi River. Upper Mississippi River Conservation Committee Special Publication. Upper Mississippi River Conservation Committee, Rock Island, Illinois.
- Carlson, B. D., D. B. Propst, D. J. Synes, and R. S. Jackson. 1995. Economic impact of recreation on the Upper Mississippi River System. Prepared for U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. Technical Report EL-95-16.
- Chick, J. H., B. S. Ickes, M. A. Pegg, V. A. Barko, R. A. Hrabik, and D. P. Herzog. 2005. Spatial structure and temporal variation of fish communities in the Upper Mississippi River System. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, May 2005. LTRMP Technical Report 2005-T004. 15 pp. (NTIS PB2005-106535)
- Chick, J. H., and M. A. Pegg. 2004. Long Term Resource Monitoring Program outpool fisheries analysis: Final report. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, March 2004. LTRMP Technical Report 2004-T001. 21 pp. (NTIS PB2004-105365)

- Cochran, W. G. 1977. Sampling techniques, 3rd edition. John Wiley and Sons, New York. 428 pp.
- Dukerschein, J. T., A. D. Bartels, B. S. Ickes, and M. S. Pearson. 2011. Are two systemic fish assemblage sampling-programmes on the Upper Mississippi River telling us the same thing? *River Research and Applications* 29(1):79–89. DOI: 10.1002/rra.1575.
- Fremling, C. R., J. L. Rasmussen, R. E. Sparks, S. P. Cobb, C. F. Bryan, and T. O. Claflin. 1989. Mississippi River fisheries: A case history. Pages 309–351 in D. P. Dodge, editor. *Proceedings of the International Large River Symposium*. Canadian Special Publication of Fisheries and Aquatic Sciences 106. Department of Fisheries and Oceans, Ottawa, Ontario.
- Gammon, J. R., and T. P. Simon. 2000. Variation in a great river index of biotic integrity over a 20-year period. *Hydrobiologia* 422/423:291–304.
- Garvey, J., B. Ickes, and S. Zigler. 2010. Challenges in merging fisheries research and management: The Upper Mississippi River experience. *Hydrobiologia* 640:125–144. DOI: 10.1007/s10750-009-0061-x.
- Gutreuter, S. 1993. A statistical review of sampling of fishes in the Long Term Resource Monitoring Program. National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, December 1993. EMTC 93-T004. 15 pp. (NTIS PB94-150828)
- Gutreuter, S., R. Burkhardt, and K. Lubinski. 1995. Long Term Resource Monitoring Program procedures: Fish monitoring. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, July 1995. LTRMP 95-P002-1. 42 pp. + Appendixes A–J.
- Gutreuter, S., and C. H. Theiling, 1999. Fishes. Chapter 12 in *Ecological status and trends of the Upper Mississippi River System 1998: A report of the Long Term Resource Monitoring Program*. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, April 1999. LTRMP 99-T001. 236 pp.
- Ickes, B. S., and R. W. Burkhardt. 2002. Evaluation and proposed refinement of the sampling design for the Long Term Resource Monitoring Program's fish component. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, October 2002. LTRMP Technical Report 2002-T001. 17 pp. + Appendixes A–E. CD-ROM included. (NTIS PB2003-500042)
- Ickes, B. S., M. C. Bowler, A. D. Bartels, D. J. Kirby, S. DeLain, J. H. Chick, V. A. Barko, K. S. Irons, and M. A. Pegg. 2005. Multiyear synthesis of the fish component from 1993 to 2002 for the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP Technical Report 2005-T005. 60 pp. + Appendixes A–E.
- Ickes, B.S., and D. Kirby. 2005. Mississippi River data on American eel: 50 CFR Part 17 90-day finding for American eel listing under the Endangered Species Act of 1973. Submitted to the National offices of the U.S. Fish and Wildlife Service 30 August, 2005. Microsoft PowerPoint file (15 slides). Available from the U.S. Geological Survey, Upper Midwest Environmental Sciences Center archives (B.S. Ickes, contact).
- Ickes, B.S. 2008. Fisheries indicators: Nonnative fishes. In Johnson, B.L. and K.H. Hagerty, editors. *Status and Trends of Selected Resources of the Upper Mississippi River System*. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, LTRMP Technical Report 2008-T002. pp. 73–74.
- Ickes, B.S., A. Bartels, J. Ridings (and 9 others). 2013. UMRR-EMP LTRMP Fish component hoop net study: Results from comparative in situ trials of substitute bait for standardized UMRR-EMP LTRMP hoop net sampling. Summary letter UMRR-EMP LTRMP 2013B14 submitted to the U.S. Geological Survey's Upper Midwest Environmental Sciences Center, March 8, 2013, for remittance to the U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. 19 pp.

- Ickes, B.S. 2013. Mapping of the electrical fields on the new fleet of electrofishing boats. Summary letter UMRR-EMP LTRMP 2013B13 submitted to the U.S. Geological Survey's Upper Midwest Environmental Sciences Center June 15, 2013, for remittance to the U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. 18 pp.
- Ickes, B. S., J. S. Sauer, N. Richards, M. Bowler, and B. Schlifer. 2014. Spatially-explicit habitat models for 28 fishes from the Upper Mississippi River System (AHAG 2.0). A Program Report submitted to the U.S. Army Corps of Engineers' Upper Mississippi River Restoration-Environmental Management Program from the U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. January 2014. LTRMP Program Report 2014-P001. 26 pp. + Appendixes A–B.
- Irons, K.S., S. A. DeLain, E. Gittinger, B. S. Ickes, C. S. Kolar, D. Ostendorf, E. N. Ratcliff, and A. J. Benson. 2009. Nonnative fishes in the Upper Mississippi River System. U.S. Geological Survey Scientific Investigations Report 2009–5176. 68 pp.
- Irons, K. S., G. G. Sass, M. A. McClelland, J. D. and Stafford. 2007. Reduced condition factor of two native fish species coincident with invasion of non-native Asian carps in the Illinois River, U.S.A.: Is this evidence for competition and reduced fitness? *Journal of Fish Biology* 71: 258–273.
- Jackson, G. A., C. E. Korschgen, P. A. Thiel, J. M. Besser, D. W. Steffek, and M. H. Bockenhauer. 1981. A long-term resource monitoring plan for the Upper Mississippi River System. Volume 1. Contract Report Number 14-16-009-81-903 for the Upper Mississippi River Basin Commission, Bloomington, Minnesota.
- Johnson, B. L., and K. H. Hagerty, editors. 2008. Status and trends of selected resources of the Upper Mississippi River System. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, December 2008. LTRMP Technical Report 2008-T002. 102 pp. + Appendixes A–B.
- Kirby, D. J., and B. S. Ickes. 2006. Temporal and spatial trends in the frequency of occurrence, length-frequency distributions, length-weight relationships, and relative abundance of Upper Mississippi River fish. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, July 2006. LTRMP Technical Report 2006-T002. 68 pp. (NTIS PB2006-114569)
- Knights, B. C., B. S. Ickes, and J. N. Houser. 2008. Fish assemblages in off-channel areas of the Upper Mississippi and Illinois Rivers: Implications for habitat restoration at management-relevant scales. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, September 2008. Long Term Resource Monitoring Program Completion Report 2007APE07 submitted to the US Army Corps of Engineers, Rock Island, Illinois. 53 pp.
- Koel, T. M. 2004. Spatial variation in fish species richness of the upper Mississippi River system. *Transactions of the American Fisheries Society* 133(4): 984–1003.
- McCain, K. N. S., J. W. Ridings, Q. Phelps, and R. A. Hrabik. 2011. Population trends of flathead catfish, channel catfish, and blue catfish in impounded and unimpounded reaches of the Upper Mississippi River (1993–2007). Pages 141-153 in P. H. Michaletz and V. H. Travnicek, editors. *Conservation, Ecology, and Management of Catfish: The Second International Symposium*. American Fisheries Society, Symposium 77, Bethesda, Maryland.
- Ney, J. J. 1999. Practical uses of biological statistics. Pages 167–191 in C. C. Kohler and W. A. Hubert, editors. *Inland fisheries management in North America*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin* 31:1000–1003.
- Patrick, R. 1998. *Rivers of the United States. The Mississippi River and Tributaries*. Volume 4, Parts A & B. John Wiley and Sons, New York.

- Phelps, Q. E., J. W. Ridings, and D. P. Herzog. 2014. American eel population characteristics in the Upper Mississippi River. *American Midland Naturalist* 171:165–171.
- Ratcliff, E. N., E. J. Gittinger, T. M. O'Hara, and B. S. Ickes. 2014. Long Term Resource Monitoring Program procedures: Fish monitoring, 2nd edition. A Program Report submitted to the U.S. Army Corps of Engineers' Upper Mississippi River Restoration-Environmental Management Program from the U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. February 2014. LTRMP Program Report 2013-P001 91 pp. including Appendixes A–G.
- Schiemer, F. 2000. Fish as indicators for the assessment of ecological integrity of large rivers. *Hydrobiologia* 422/423: 271–278.
- Schmutz, S., M. Kaufmann, B. Vogel, M. Jungwirth, and S. Muhar. 2000. A multi-level concept for fish-based, river-type-specific assessment of ecological integrity. *Hydrobiologia* 422/423: 279–289.
- Sparks, R. E., J. C. Nelson, and Y. Yin. 1998. Naturalization of the flood regime in regulated rivers: The case of the upper Mississippi River. *Bioscience* 48:706–720.
- U.S. Fish and Wildlife Service. 1993. Operating plan for the Upper Mississippi River System Long Term Resource Monitoring Program. Environmental Management Technical Center, Onalaska, Wisconsin, Revised September 1993. EMTC 91-P002R. 179 pp. (NTIS #PB94-160199)
- U.S. Geological Survey (USGS). 1999. Ecological status and trends of the Upper Mississippi River system 1998. A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP 99-T001. 236 pp.
- Wilcox, D. B. 1993. An aquatic habitat classification system for the Upper Mississippi River System. U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, May 1993. EMTC 93-T003.9 pp. + Appendix A. (NTIS PB93-208981)

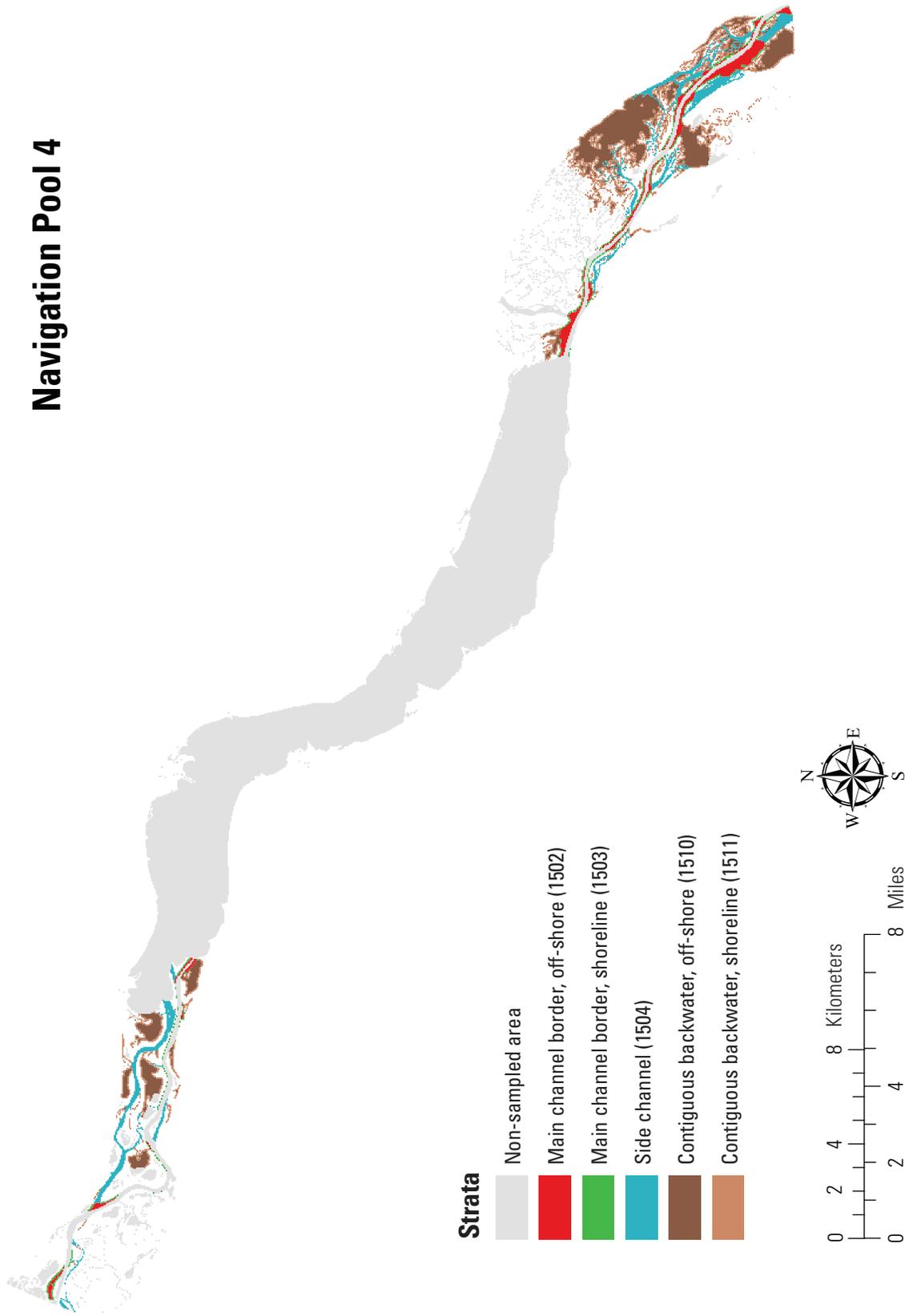
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Appendix A

Study Reach sampling strata based on mapped 1989 coverages.

Navigation Pool 4



Navigation Pool 8

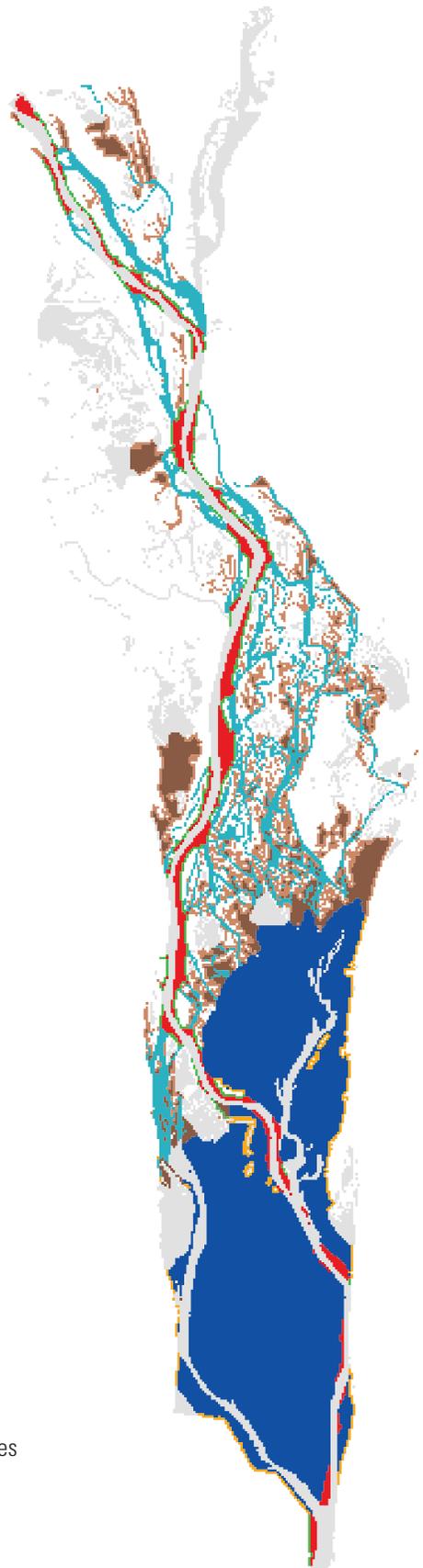
Strata

-  Non-sampled area
-  Main channel border, off-shore (1502)
-  Main channel border, shoreline (1503)
-  Side channel (1504)
-  Contiguous backwater, off-shore (1510)
-  Contiguous backwater, shoreline (1511)
-  Impounded, off-shore (1520)
-  Impounded, shoreline (1521)



0 2 4 8 Kilometers

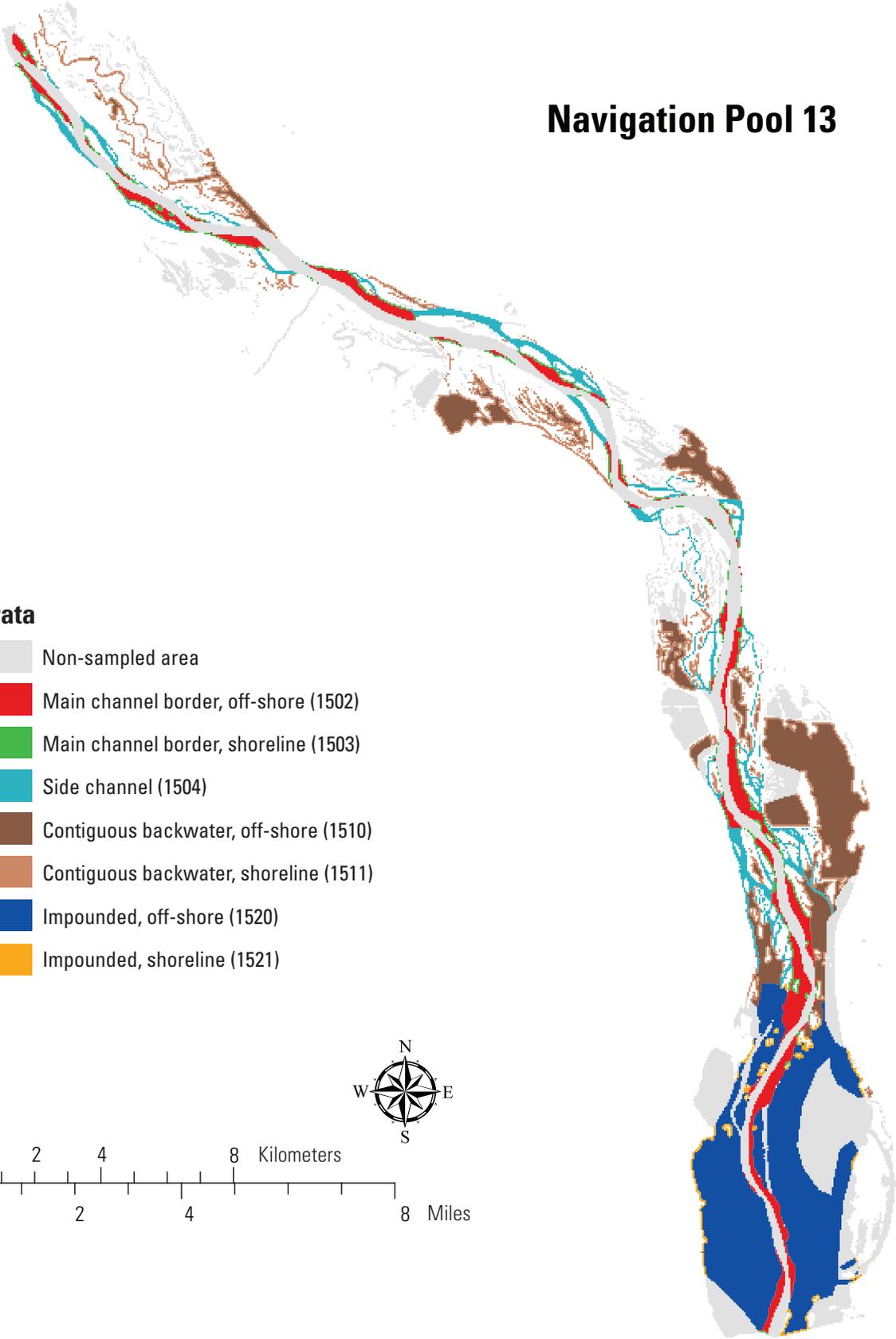
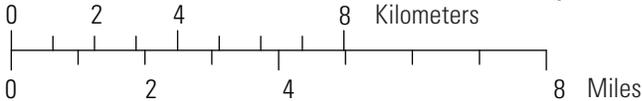
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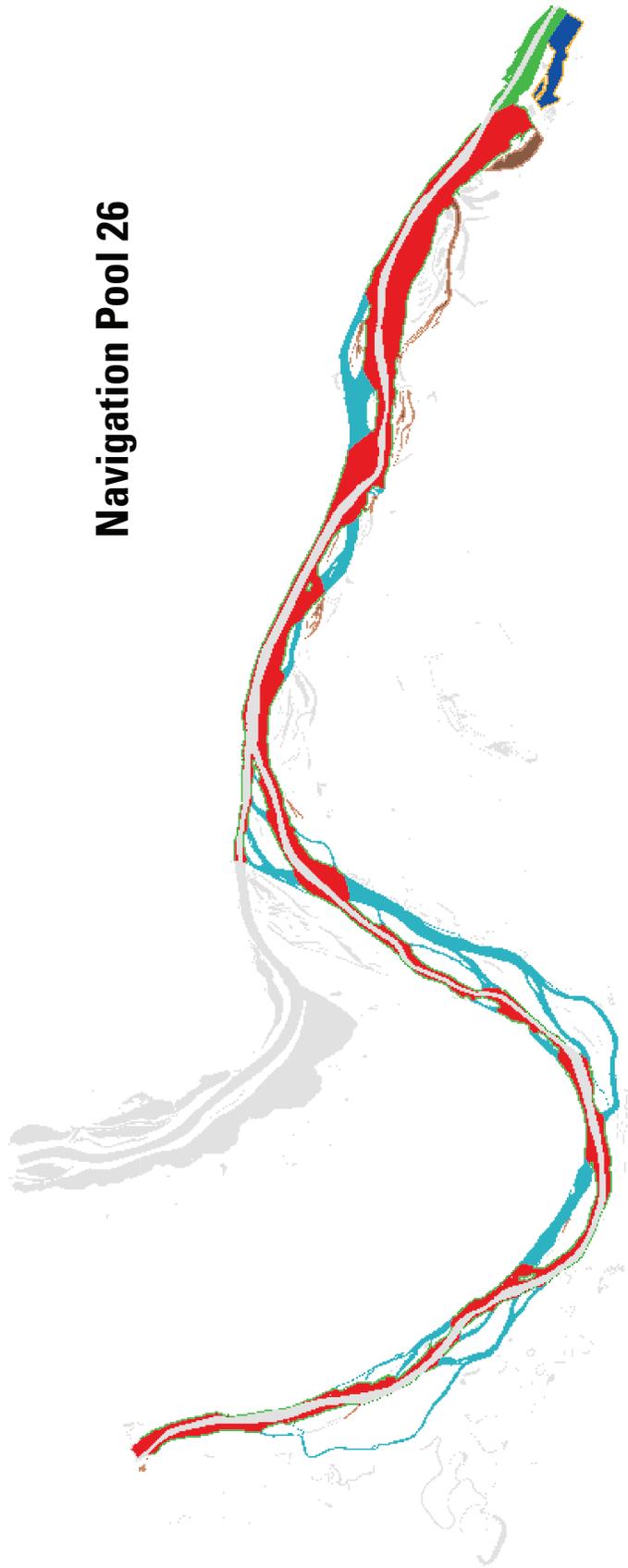
Navigation Pool 13

Strata

- Non-sampled area
- Main channel border, off-shore (1502)
- Main channel border, shoreline (1503)
- Side channel (1504)
- Contiguous backwater, off-shore (1510)
- Contiguous backwater, shoreline (1511)
- Impounded, off-shore (1520)
- Impounded, shoreline (1521)

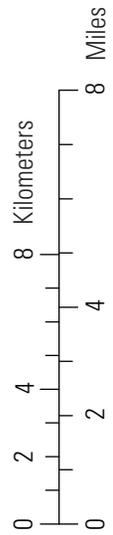


Navigation Pool 26



Strata

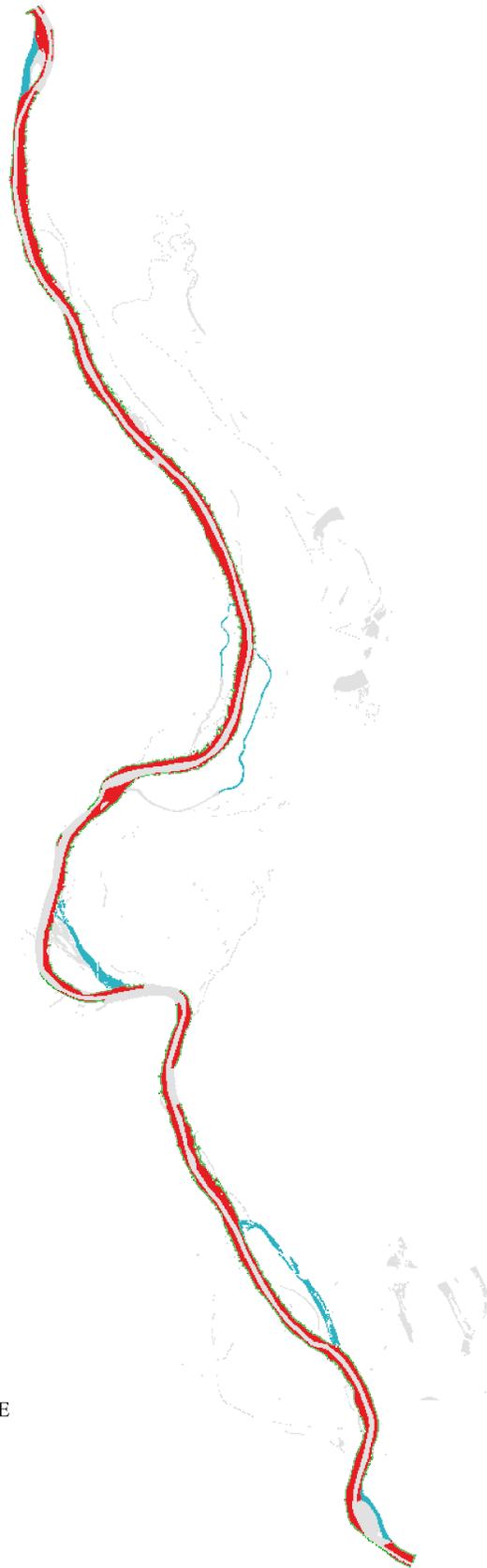
- Non-sampled area
- Main channel border, off-shore (1502)
- Main channel border, shoreline (1503)
- Side channel (1504)
- Contiguous backwater, off-shore (1510)
- Contiguous backwater, shoreline (1511)
- Impounded, off-shore (1520)
- Impounded, shoreline (1521)



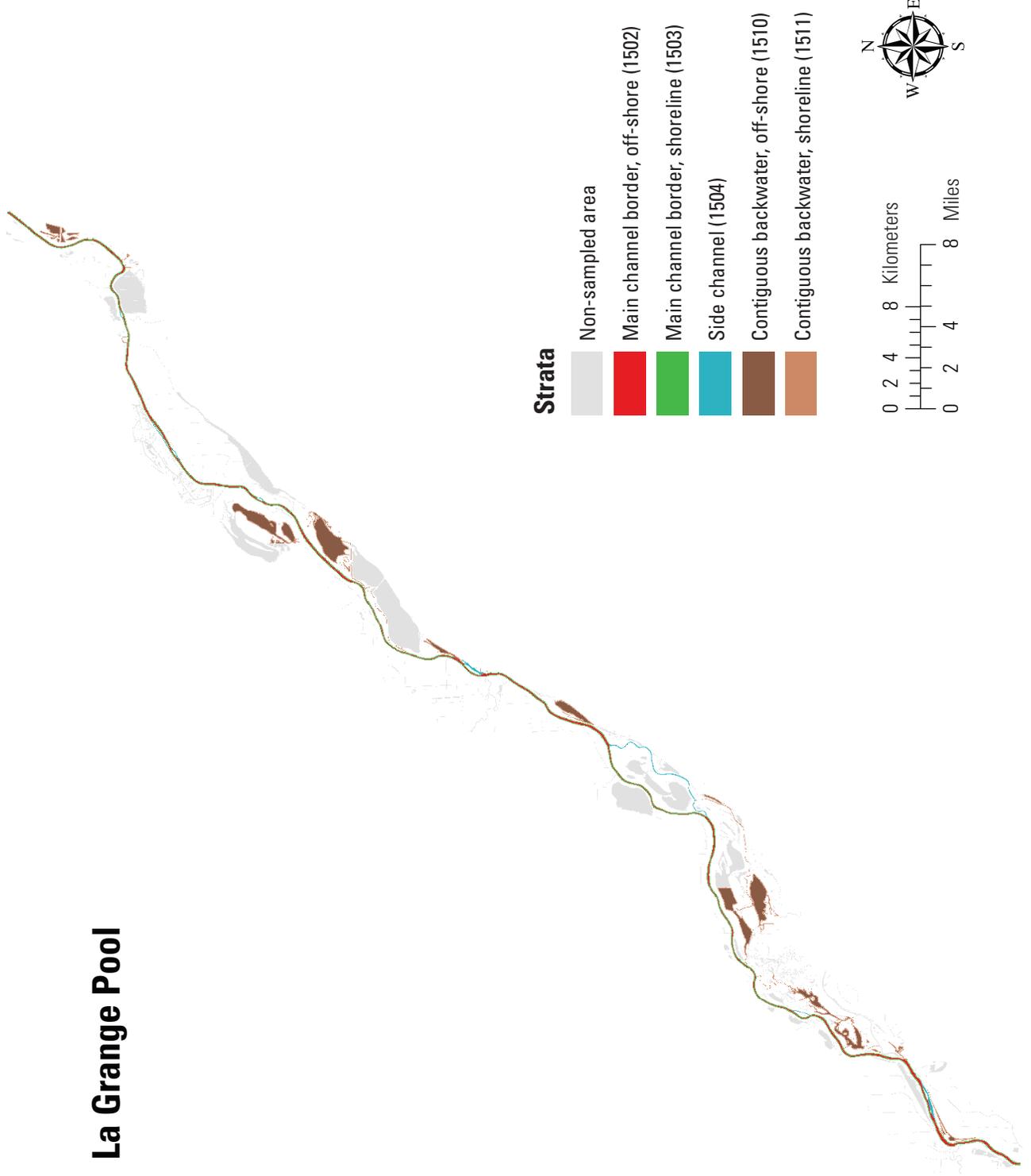
Open River Reach

Strata

-  Non-sampled area
-  Main channel border, off-shore (1502)
-  Main channel border, shoreline (1503)
-  Side channel (1504)



La Grange Pool



The Upper Mississippi River Restoration-Environmental Management Program (UMRR-EMP), including its Long Term Resource Monitoring Program (LTRMP) element, was authorized by the Water Resources Development Act (WRDA) of 1986. The mission of the LTRMP element is to provide river managers with information for maintaining the Upper Mississippi River System as a sustainable large river ecosystem given its multiple use character. The LTRMP element is implemented by the U.S. Geological Survey, Upper Midwest Environment Sciences Center, in cooperation with the five Upper Mississippi River System states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin; overall management responsibility of the UMRR-EMP is vested with the U.S. Army Corps of Engineers.

