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Multiyear Synthesis of the Fish Component from 1993 to 2002 for the Long Term Resource Monitoring Program

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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers Environmental Management Program. The LTRMP is being implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) states of Illinois, Iowa, Minnesota, Missouri and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

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 is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiuse character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

This multiyear report supports Task 2.2.8 as specified in Goal 2, Monitor and Evaluate Fish Communities, Guilds, and Populations of the Operating Plan (U.S. Fish and Wildlife Service 1993). This report was developed with funding provided by the LTRMP.

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Abstract: Fisheries data are collected in the Upper Mississippi River System (UMRS) under the Long Term Resource Monitoring Program (LTRMP). From 1993 to 2002, monitoring activities were conducted at six primary study areas in the UMRS, Navigation Pools 4, 8, 13, 26, and the Open River reach in the Mississippi River and the La Grange Pool in the Illinois. The monitoring began with LTRMP in 1989 for all study areas except the Open River reach, which began in 1991. Since 1993, LTRMP staff have completed 24,791 samplings in the 6 study areas and collected more than 3 million fish of 134 species. From 1993 to 2002, the most fish species (98) were collected in the Open River reach and the fewest species (83) collected in Pool 13.

Key words: Fish community structure, habitat, Illinois River, Long Term Resource Monitoring Program, Mississippi River, native species, nonnative species, stratified random sampling.

Chapter 1: Introduction

Purpose and Scope

The Environmental Management Program (EMP) consists of two principal entities managed by the U.S. Army Corps of Engineers and implemented in cooperation with the five Midwestern states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, as well as several additional federal resource agencies. The first of these is the Habitat Rehabilitation and Enhancement Program (HREP), which is charged with physically rehabilitating aquatic habitats degraded by navigation development. The second is the Long Term Resources Monitoring Program (LTRMP), which is charged with monitoring key ecological components within the UMRS in support of natural resource management and science. The LTRMP is conducted by the U.S. Geological Survey, Upper Midwest Environmental Sciences Center (UMESC), through field stations operated by the five UMRS states. This report is a product of the LTRMP.

Key ecological components monitored by the LTRMP include fisheries, water quality, aquatic vegetation, and aquatic macroinvertebrates. Four long-term goals have been established for the LTRMP: (1) increase understanding of how the river ecosystem operates, (2) monitor the status and trends of UMRS natural resources, (3) assist in the development and evaluation of management alternatives, and (4) manage and provide access to resulting data, information, and products. The LTRMP is the nation's largest river monitoring program and, since its inception in 1989, has amassed databases on large river ecology unrivaled in North America and perhaps the world.

The purpose of this report is to synthesize and present information from the fisheries component of the LTRMP for the period 1993–2002. This is one of four such reports being developed for each of the four LTRMP ecological components. The primary audience for the report is natural resource managers and scientists within the UMRS basin. However, other audiences such as the general public, nongovernmental organizations, and academia will likely find much of this information useful and relevant.

The scope of this report is broad, yet necessarily synthetic. At its core, the LTRMP fisheries component monitors fish community dynamics in the UMRS basin. Reasons for this are presented in the following section titled "Monitoring Rationale", and in greater detail in Chapter 2. Because of the LTRMP fish component's community focus and large annual sample sizes (see "Summary of Collections" section in this chapter), however, the program has the ability to inform a wider set of management and scientific perspectives within the UMRS basin. For example, the program provides considerable information regarding status of individual species and trends in their abundance. 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. In addition, many natural resource groups are presently concerned about invasive species within the basin. The community focus of the program 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 relative abundance, determining population size structure, and delineating species distribution across the entire UMRS. 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.

In the following chapters, we highlight several perspectives important to resource management and scientific interests within the basin. We provide data summaries as baseline information for a variety of topics, and when possible, we present results of in-depth analytical work. For several topics in this report, much greater detail can be found in additional reports developed in parallel with this report (Barko et al. 2005; Chick et al. 2005; Irons et al. In press; Kirby and Ickes In press).

Finally, it is important to realize the LTRMP is still relatively young and is in a transition period from critical evaluation and refinement of monitoring strategies to enhanced scientific understanding through focused analyses of the monitoring data. This report presents results from both program evaluations and focused research. Consequently, results presented from focused research represent the beginning of a new stage in the history of the program. We hope the material presented in this report, as well as in several accompanying reports, will provide baseline information for research planning and prioritization among LTRMP agency partners.

Monitoring Rationale

A general argument for monitoring

In a general sense, 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 traditional 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 can only be identified and investigated in the context of past observations on the same system, as opposed to differences in an experimental control.

An argument for monitoring fishes within the Upper Mississippi River System

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), and fish are one of the most important goods and services the UMRS provides to humans (Carlander 1954). Fishes within the UMRS are the subject of commercial and recreational fisheries, both of which contribute substantially to local economies (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 a nexus of freshwater fish diversity in North America. Approximately one fourth of the entire North American freshwater fish fauna is endemic to the UMRS basin. Numerous species are recognized as endangered, threatened or of particular conservation concern. 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.

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). Moreover, the general public often perceives environmental impacts in the UMRS in terms of changes in the fish community or 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 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, identify relations with various other ecological attributes, and address fisheries management concerns in a multiuse, large-river resource (Gutreuter and Theiling 1999).

Study Area

The UMRS was defined in the Water Resources Development Act as the Mississippi River between Minneapolis, Minnesota, and the mouth of the Ohio River at Cairo, Illinois (approximately 850 miles), and all commercially navigable tributaries, including all of the Illinois River. This definition excludes the Missouri River. The UMRS is one of most important natural resources in the United States, draining one-third of the landmass of the conterminous United States (approximately 713,500 mi^2), and encompassing over 400,000 acres of water (Pitlo et al. 1995). To ensure dependable navigation, Congress authorized the 9-Foot Channel Project on the Upper Mississippi River in 1920. The project included 29 lock-and-dam structures between Minneapolis, Minnesota, and St. Louis, Missouri, with a total fall of approximately 400 feet.

The LTRMP conducts standardized monitoring activities at six primary study areas within the UMRS (Gutreuter et al. 1995). Five are located on the Mississippi River and one on the Illinois River (Figure 1.1). Study areas are referred to by the U.S. Army Corps of Engineers navigation pool designations wherein a pool name corresponds to the number of the dam impounding that pool. River miles on the UMR begin at the confluence with the Ohio River and on the Illinois River begin at the confluence with the Mississippi River. Mississippi River navigation pools monitored by the LTRMP fisheries component include Pool 4 (river miles 752–797), Pool 8 (679–703), Pool 13 (523–557), Pool 26 (202–242), and an unimpounded, Open River reach (29–80, Figure 1.1). The remaining study area is La Grange Pool of the Illinois River (river miles 80–158; Figure 1.1). The LTRMP study areas were chosen, in part, to encompass important gradients in geomorphology, floodplain features, and navigation management strategies existing within the UMRS.

Pools 4, 8, and 13 are located in an upper impounded reach characterized by high percentages of open water and aquatic vegetation and low agricultural use (Table 1.1). Relatively high percentages of the total aquatic area in these study areas are contiguous backwaters (i.e., connected to the main channel at base flow) with relatively low percentages of main channel habitat. Pools 4, 8, and 13 are geomorphically complex and contain braided side channels and backwaters.

Figure 1.1. Location of the six Long Term Resource Monitoring Program field stations on the Upper Mississippi River System.

Pool 26, in a lower impounded reach, and the Open River study area are characterized by relatively low percentages of open water and aquatic vegetation and a high percentage of agriculture in the floodplain (Table 1.1). La Grange Pool is similar to Pool 26 in floodplain composition, but is similar to Pools 8 and 13 in composition of the aquatic area and has the greatest percentage (52%) of contiguous backwaters among the six LTRMP study areas (Table 1.1).

Within the LTRMP fisheries component, only contiguous bodies of water were sampled; there was no sampling in isolated water bodies. However, not all contiguous aquatic areas are sampled in a given pool (e.g., Black River mouth in Pool 8, Swan Lake in Pool 26) for various reasons decided early in the history of the program. The spatial sampling frame has remained

Table 1.1. Key features of the floodplain and aquatic area compositions of the Long Term Resource Monitoring Program Mississippi and Illinois River study reaches.

		Floodplain composition[a] (%)			Aquatic area composition[b] (%)	
Study reach	**Floodplain area (ha)**	**Open water**	**Aquatic vegetation**	**Agriculture**	**Contiguous backwater**	**Main channel[c]**
Pool 4	28,358	51	10	12	21	11
Pool 8	19,068	40	14	1	31	14
Pool 13	34,528	30	9	28	29	25
Pool 26	51,688	13	1	65	17	54
Open River	105,244	10	1	72	2	79
La Grange Pool, Illinois River	89,554	16	2	60	52	21

[a] Data on floodplain composition are from Laustrup and Lowenberg (1994).

[b] Aquatic area is that portion of the floodplain that is inundated at normal summer water elevations. Data on the composition of aquatic areas are from the Long Term Resource Monitoring Program aquatic areas spatial database.

[c] Main channel includes area in the navigation channel and main channel border areas.

static since established, however, and proper inferences are to the sampling frame rather than all aquatic areas present in a given study area.

Sampling Methods and Databases

History of Methodological Changes

To be effective and efficient, a monitoring program should use scientifically-defensible standardized sampling methods and target informative characteristics of the ecosystem. When designed properly, a long-term monitoring program can be a powerful method for quantifying the status and trends of key resources and for investigating the effects and efficacy of management actions. In addition, these data can be used to assess the monitoring design itself. Such assessments have occurred twice in the history of the LTRMP fisheries component resulting in the following changes to the monitoring protocol.

The first major programmatic change was in 1993. The LTRMP fish component began fisheries monitoring in 1989 for all study reaches except the Open River reach, which began in 1991. From 1989 until 1993, monitoring was conducted under a fixed-site design with sites revisited on an annual rotation. Consequently, inferences were site-specific and lack of randomization in the site selection process injected potential sampling bias into monitoring observations. These early years in the program were used to test sampling methods and refine sampling protocols. In 1993, the LTRMP fisheries component adopted a probabilistic statistical design for annual site selection known as stratified random sampling (SRS). Inferential scales shifted from sampling sites to an entire study reach, making pre-1993 and post-1993 data largely incompatible (Figure 1.2). However, randomization in the new design ensured that any potential bias in sample site selection was removed from observed outcomes. This change, coupled with refined standardized protocols and sampling methods, significantly improved the scientific merit of the program (Gutreuter 1993).

The second major programmatic change was in 2002. After eight years of sampling under the significantly improved stratified random sampling design, data were sufficient to explore potential sampling redundancies. Ickes and Burkhardt (2002) concluded that 4 of 10 sampling methods employed could be removed from the sampling protocols with minor effects on the quantity and quality of information provided by the fish component. These changes, implemented in 2002, represented about a 33% reduction in sampling effort across the program. By redirecting that effort into scientific investigations on the monitoring data themselves, these changes have enhanced the fiscal and scientific efficiency of the program. We discuss this change in detail in Chapter 8.

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 to the system under study. Breaks in data continuity can affect assessments of status and trends, hamper efforts to model ecological responses observed by the monitoring network, and reduce the ability to assess the efficacy of management alternatives. These were serious considerations in each of the above assessments. In the 1993 switch from fixed sites to SRS, data continuity was almost entirely severed (a few fixed sites carried through into the SRS era and remain today). Increased scientific rigor in the sampling design associated with this change, however, outweighed any cost of breaking what was yet a very short time series of fixed-site data. In the case of the 2002 gear reduction, data continuity back to 1993 (SRS era) was nearly perfectly preserved (Figure 1.2). Notable exceptions are breaks for the four gears eliminated and the two strata (impounded offshore and backwater contiguous offshore strata) sampled exclusively by two of the four gears eliminated. Assessments revealed, however, that the four gears and two strata did not provide any unique information not captured in other gears or strata (Ickes and Burkhardt 2002).

Statistical sampling design and general field methods

Sampling procedures for the LTRMP fish component are standardized and are based on commonly accepted methods. Collections are stratified over space and season. The basic unit of measurement is the individual sample, defined as all of the fishes collected during a single deployment of a sampling gear at a defined place and time. Community sampling requires the use of multiple sampling gears, because no single gear is effective at characterizing this diverse community. Although each gear differs in its selectivity for species and size classes (Ickes and Burkhardt 2002), each is standardized in its physical dimensions and the manner in which it is deployed and retrieved over time and across space (Gutreuter et al. 1995). A summary of LTRMP fisheries component procedures is provided below. A complete description can be found in Gutreuter et al. (1995).

In 1993, a discrete sampling frame (i.e., the aquatic areas making up the sampling universe, see Gutreuter 1993) was chosen for each study reach. The sampling frame was encoded into a spatial database using a Geographic Information System (GIS). The sampling frame was then stratified into several aquatic area types based on the LTRMP aquatic areas database. A database of these aquatic areas (termed sampling strata in the statistical design) was developed (Owens and Ruhser 1996), and each stratum was further partitioned into 50-m^2 sampling grids using GIS software. Annually, sampling sites were randomly generated from this grid for three time periods: 15 June–31 July, 1 August–15 September, and 16 September–31 October. A separate randomization was conducted for each sampling period. In addition, a number of historic LTRMP fixed-sites were retained from pre-1993 sampling for each study area.

Sampling was conducted in eight strata, although not all strata were present in all study areas (Table 1.2). These strata include contiguous backwater offshore, contiguous backwater shoreline, impounded offshore, impounded shoreline, main channel border unstructured, main channel border wingdam, side channel border and tailwater zone (fixed-site sampling only). Fish were collected using standardized gears described in Gutreuter et al. (1995). These

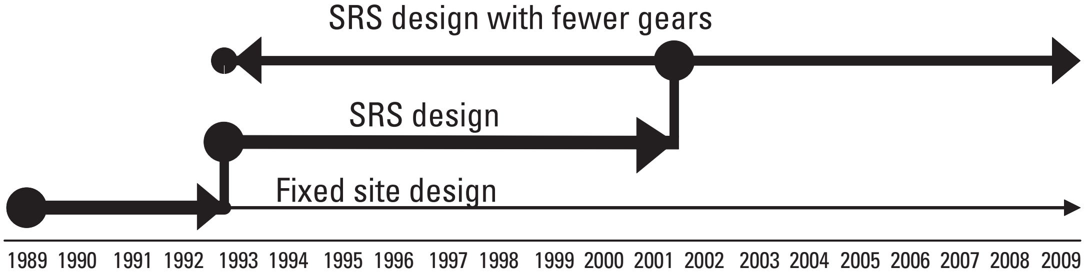


Figure 1.2. Graphical depiction of major changes to the sampling design and data continuity for the fisheries component of the Long Term Resources
continuity relative to the previous design. Stratified random sampling (SRS) was instituted in 1993. To increase efficiency, the number of gears was reduced in 2002, but data continuity was maintained for all remaining gears.

Table 1.2. Area (ha) of different sampling strata within each of the six study areas monitored by the Long Term Resources Monitoring Program on the Upper Mississippi River System.

Sampling strata[a]	LTRMP study area					
	Pool 4	Pool 8	Pool 13	Pool 26	La Grange Pool	Open River
MCB-O	372	408	882	2508	1207	2500
MCB-S	192	189	228	800	1234	648
SCB	722	1037	690	1418	163	468
BWC-O	1268	495	1469	90	1737	0
BWC-S	965	859	934	191	904	0
IMP-O	0	3301	2501	147	0	0
IMP-S	0	124	110	43	0	0

[a] Strata are main channel border open (MCB-O), main channel border structured (MCB-S), side channel border (SCB), backwater contiguous offshore (BWC-O), backwater contiguous shoreline (BWC-S), impounded offshore (IMP-O), and impounded offshore (IMP-O).

gear types included day electrofishing, fyke nets, gill nets, hoop nets (large and small hoops), mini-fyke nets, night electrofishing, seines, tandem fyke nets, tandem mini-fyke nets, trammel nets, and trawls.

Sampling gears were deployed independently within strata. Randomly selected sampling sites were generated for each gear type. Because some gears could not be deployed under certain conditions, not all gears were deployed in each stratum. However, each stratum was sampled with at least three gears. Because the proportions of different strata varied among study reaches, gear effort was allocated on a reach-specific basis (Gutreuter 1995).

Optimal allocation schemes were considered during initiation of SRS protocols, but were abandoned because they required allocating most of the samples to the impounded stratum and neglected ecologically important strata such as side channels and backwaters. Sample allocation affects precision of estimates within and across strata, but does not bias observations derived under a stratified random sampling scheme. Since 1993, allocations of sampling effort among strata has not remained constant through time or among study reaches (Gutreuter 1995), because of budgetary constraints, implementation of program efficiencies (Ickes and Burkhardt 2002), and occasional equipment failure. Summaries of annual gear allocation and the number of completed samples for each study area are contained in Appendix A.1.

Database used in this report

Most of the results in this report are based on a 10-year subset (1993–2002) of LTRMP fisheries database covering the first 10 years of stratified random sampling. The database is housed at the Upper Midwest Environmental Sciences Center (UMESC) and is available at: *http://www.umesc.usgs.gov/data_library/fisheries/fish1_query.html*. Only individual fishes identified to species were included in our analyses. Common and scientific names used in this report follow Robins et al. (1991) and are listed in Appendix A.2.

Statistical Methods

Mean catch-per-unit-effort (CPUE) was used as an index of population density (Ney 1999). The units of effort were specific to particular gears. Catch and effort were recorded for each species from individual samples. Whenever a species was not caught in a sample, the catch for that species in that sample was zero. The estimates of annual reach-wide mean CPUE were obtained from the conventional design-based estimator for stratified random samples (Cochran 1977). The mean CPUE of stratified samples, $\bar{y}_{st}$, was given by

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

where N_h is the number of sampling units within stratum h, L is total number of strata, $N = \Sigma^{L}_{h=1} N_h$, 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

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

is the usual estimator of the variance of $\bar{y}_h$, and n_h is the number of samples taken in stratum h (Cochran 1977). The standard error of $\bar{y}_{st}$ *is* therefore $s(\bar{y}_{st})$. For LTRMP fish monitoring, the sampling units were 50-m^2 sampling grids.

In this report, CPUE statistics are reported primarily for stratified random sampling. In random samples, equation (1) yields unbiased estimates of the pooled means regardless of the probability distribution of y (Cochran 1977). An unbiased, reach-wide (all strata) mean CPUE and variance (standard error; equation 2) were calculated for bighead carp, black crappie, blue catfish, bluegill, common carp, channel catfish, emerald shiner, flathead catfish, freshwater drum, gizzard shad, largemouth bass, northern pike, sauger, smallmouth buffalo, walleye, white bass and white crappie from selected gear types. These species were previously identified as of specific interest to river managers. Mean CPUE and variance were calculated for shovelnose sturgeon from tailwater (fixed-site) trawling. For all species, a median CPUE was calculated over all years with 10% and 90% quartiles. Estimates for the species noted above are presented in Chapter 7 and in Appendixes B.1–B.26.

Annual proportional stock densities (PSD; Anderson 1976) were calculated for black crappie, blue catfish, bluegill, channel catfish, common carp, freshwater drum, largemouth bass, northern pike, sauger, smallmouth buffalo, walleye, white bass, and white crappie (Appendixes C.1–C.15 and D.1–D.21) based on stock and quality lengths (Gabelhouse 1984) for selected study areas and gear combinations. PSDs were calculated for flathead catfish using size designations proposed by Quinn (1991). Eighty-percent confidence intervals were constructed for PSD estimates using the following formula from Gustafson (1988):

$$\mathrm{CI} = \pm\, t_{(\alpha,\, N-1)}\left\{\left[\sqrt{\frac{P(1-P)}{N-1}}\right] + \frac{1}{2N}\right\} \times 100$$

In the above formula CI = confidence interval estimate, P = estimated PSD as a decimal fraction, N = number of stock-length fish in the sample, t = Student's t for α confidence level with N-1 degrees of freedom (two-tailed).

Annual relative stock density indices (Gabelhouse 1984) of preferred-length (RSD-P), memorable-length (RSD-M), and trophy-length (RSD-T) were used to quantify the size distribution of selected fishes, and were combined with stock and quality length values to plot length-frequency histograms (Appendixes E.1–E.191). These length distribution analyses were performed for thirteen selected fish species and selected gear types: black crappie (day electrofishing, fyke nets, and all gears combined; all study areas), blue catfish (all gears combined; Pool 26 and the Open River), bluegill (day electrofishing, fyke nets, and all gears combined; all study areas), channel catfish (small and large hoop nets and all gears combined; all study areas), common carp (day and night electrofishing and all gears combined; all study areas), freshwater drum (day and night electrofishing and all gears combined; all study areas), largemouth bass (day electrofishing and all gears combined; all study areas), northern pike (day electrofishing, fyke netting; Pools 4, 8, and 13), sauger (day and night electrofishing, and all gears combined; Pools 4, 8, and 13 and La Grange Pool), smallmouth buffalo (large hoop nets and all gears combined; all study areas), walleye (day and night electrofishing and all gears combined; Pools 4, 8, and 13 and La Grange Pool), white bass (day and night electrofishing, and all gears combined; all study areas), and white crappie (day electrofishing, fyke nets, and all gears combined; all study areas). Similarly, relative frequency histograms for flathead catfish (large hoop nets and all gears combined; all study areas) were derived from length designations taken from Quinn (1991). Standard-length frequency histograms were produced for bighead and silver carp (all gears combined; Pool 26, Open River, and La Grange Pool) for all years combined.

Summary of Collections

Systemic data summary

Since 1993, LTRMP staff have completed 24,791 samples (Appendix A.1) in the six study areas and collected more than 3 million fish of 134 species (Appendix A.2 and A.3). Persistent high water in 1993 significantly disrupted sampling in the lower four study areas (70% of the allocated samples could not be completed in the Open River; Appendix A.1). From 1993 to 2002, the most fish species (98) were collected in the Open River with the fewest species collected in Pool 13 (83; Figure 1.3). Forty-seven fish species were common to all six study areas. Annual summaries for total number of fish species collected, percentage of the overall catch, and 10-year numeric ranks are contained in Appendixes A.4–A.9 for each study area. Emerald shiner was numerically the most abundant fish among all study areas and accounted for 27% of the total catch (Figure 1.4). Gizzard shad, bluegill, freshwater drum, mimic shiner, threadfin shad, white bass, common carp, spotfin shiner, and river shiner were the next most abundant fishes among all study areas (Figure 1.4).

Pool 8 had the highest diversity of fishes annually, averaging 74 species per year (Figure 1.3). The Open River, which had the highest cumulative number of species in this 10-year span, had the lowest diversity of fishes annually, averaging 62 species per year (Figure 1.3).

Of the 157 fish species listed as existing in the UMR by Pitlo et al. (1995), 127 were collected for the LTRMP fisheries component. LTRMP personnel collected seven fish species not listed by Pitlo et al. (1995): bigeye chub, bleeding shiner, greenside darter, redspotted sunfish, rudd, silver carp, and white perch. Riverine species such as Alabama shad, alligator gar, flathead chub, greater redhorse, pallid sturgeon, and sturgeon chub were listed as present in

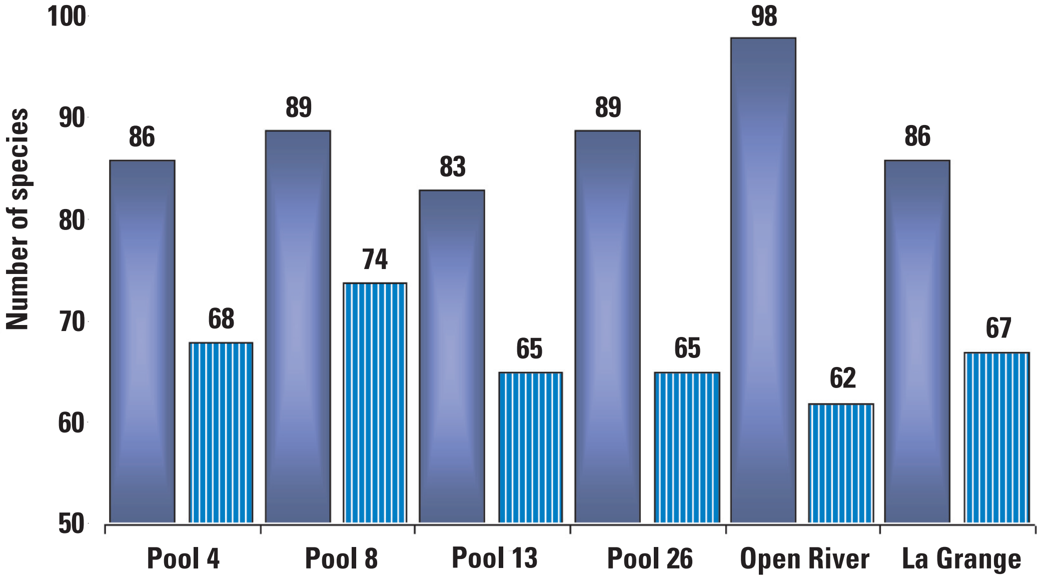


Figure 1.3. Total number of fish species (solid bar) and mean annual number of species (hatched bar) collected by the Long Term Resources Monitoring Program Fisheries Component, 1993–2002.

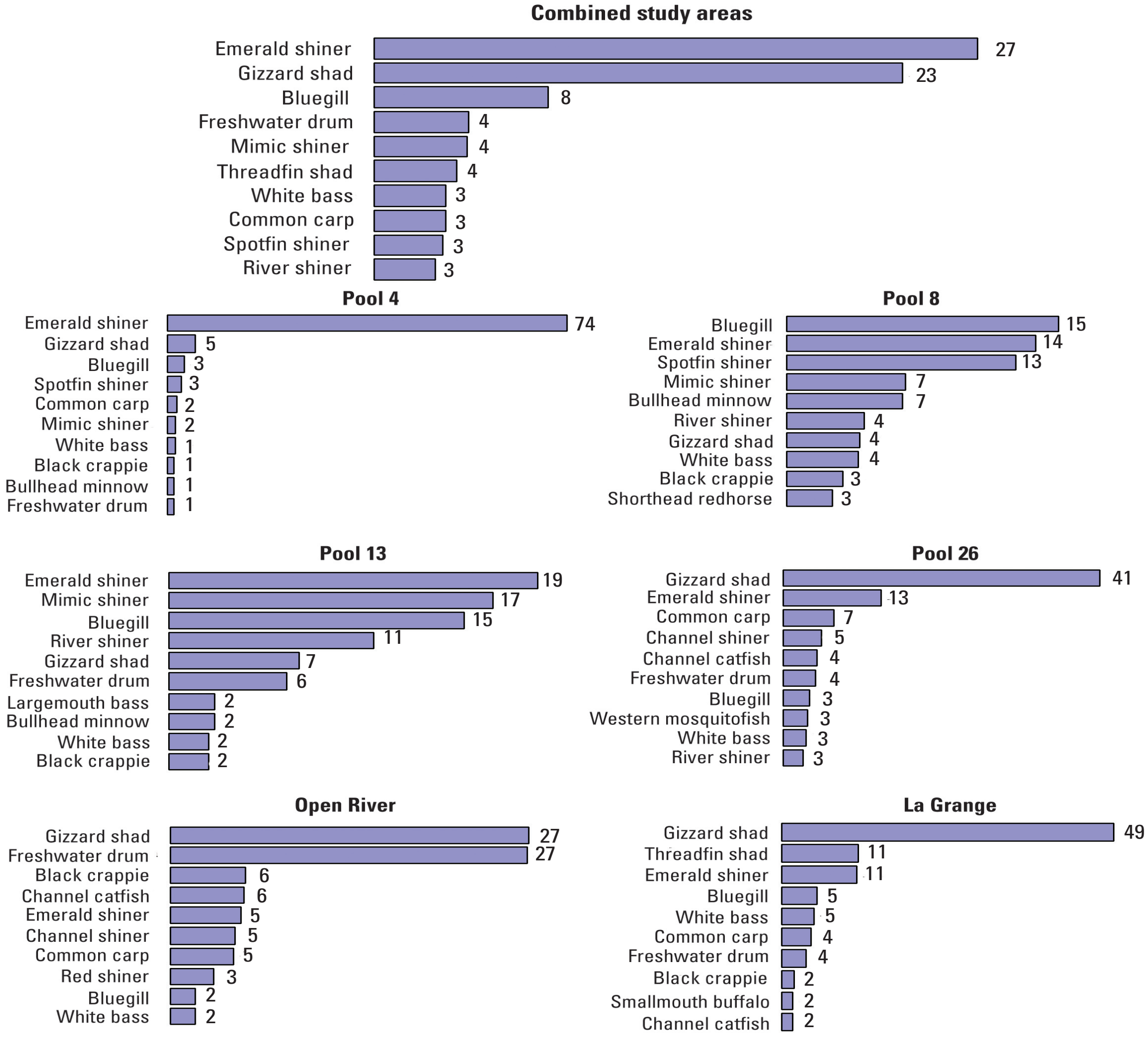


Figure 1.4. Percentage of total catch accounted for by the top ten numerically abundant fishes collected from each Long Term Resources Monitoring Program study area and for all study areas combined, 1993–2002. Percentages rounded to nearest whole number.

the UMR by Pitlo et al. (1995), but have not been observed by the LTRMP. Alligator gar probably have been extirpated from the UMRS. Seventeen other fish species listed by Pitlo et al. (1995) not collected by the LTRMP likely exist only occasionally in the UMRS as strays from tributaries. Of the fish species collected for the LTRMP fisheries component, 39 are listed as endangered, threatened, special concern or rare by one or more of the five UMR states (Table 1.3, discussed in Chapter 5).

Study reach summaries

In Pool 4, 701,507 fish of 86 species were collected from 1993 to 2002 (Appendix A.4). The number of species ranged from 58 in 2002 to 74 in 1994 and averaged 68 species per year (Figure 1.5A). Emerald shiner was numerically the most abundant fish collected in Pool 4 and accounted for 74% of the total catch (Figure 1.4). Gizzard shad, bluegill, spotfin shiner, common carp, mimic shiner, white bass, black crappie, bullhead minnow, and freshwater drum were numerically the next most abundant fishes (Figure 1.4).

In Pool 8, 535,275 fish of 89 species were collected from 1993 to 2002 (Appendix A.5). The number of species ranged from 65 in 2002 to 77 in 1993 and averaged 74 species per year (Figure 1.5B). Bluegill was numerically the most abundant fish collected in Pool 8 and accounted for 15% of the total catch (Figure 1.4). Emerald

Table 1.3. Fish species with status as listed by Federal and Upper Mississippi River state agencies.

	Jurisdiction[a]					
Fish species	**Federal**	**Minnesota**	**Wisconsin**	**Iowa**	**Illinois**	**Missouri**
Alabama shad						T
American eel		*	SC*		*	*
Bigeye shiner					E*	*
Black buffalo		*	T*	*	*	*
Blacknose shiner				T	E	T
Blue catfish		SC			*	*
Blue sucker		SC*	T*	*	*	SC*
Bluntnose darter		SC	E	E*	*	*
Brown bullhead		*	*		*	SC*
Burbot		*	*	T		
Central mudminnow		*	*	*		E
Chestnut lamprey		*	*	T*	*	*
Crystal darter		SC*	E*		X	E
Flathead chub					E	E
Freckled madtom				E*	*	*
Ghost shiner			X		*	T*
Goldeye		*	E*	*	*	*
Grass pickerel				T*	*	*
Gravel chub		SC	E			
Greater redhorse			T		E	
Highfin carpsucker		*	*	*		T
Iowa darter		*	*		E	
Lake sturgeon		SC*	SC*	E*	E*	E*
Longear sunfish			T		*	*
Mississippi silvery minnow		*	*	*	*	R*
Mooneye		*	*	*	*	SC*
Mud darter		*	SC*	*	*	*
Orangethroat darter				T	*	*
Ozark minnow			T			
Paddlefish		T*	T*		*	SC*
Pallid shiner		SC*	E*			X
Pallid sturgeon	E			E	E	E
Pearl dace				E		
Pirate perch		SC*	SC*	SC	*	*
Pugnose minnow		SC*	SC*	SC*	*	R*
Pugnose shiner		SC	T	E	E	
Redfin shiner			T			
River darter		*	*	*	*	SC*
River redhorse		*	T*		T*	*
Shovelnose sturgeon		SC*	*	*	*	*
Sicklefin chub	C				*	SC*
Silver chub		*	SC*	*	*	*
Skipjack herring		SC*	E*		*	*
Speckled chub		*	T*	*	*	*
Starhead topminnow			E		*	T*
Sturgeon chub	C				E	SC
Trout-perch		*	*		*	E*
Weed shiner		*	SC*	E	E	
Western sand darter		*	SC*	T*	*	T*
Yellow bass		SC*	*	*	*	*

[a] Listing codes are rare (R), endangered (E), threatened (T), extirpated (X), special concern (SC), or a candidate (C) for endangered status in the Mississippi River. An asterisk (*) means the species was collected in that state at some time by the Long Term Resource Monitoring Program.

shiner, spotfin shiner, mimic shiner, bullhead minnow, river shiner, gizzard shad, white bass, black crappie, and shorthead redhorse were numerically the next most abundant fishes (Figure 1.4).

In Pool 13, 498,635 fish of 83 species were collected from 1993 to 2002 (Appendix A.6). The number of species ranged from 59 in 1996 and 2002 to 69 in 1999 and 2000 and averaged 65 species per year (Figure 1.5C). Emerald shiner was numerically the most abundant fish collected in Pool 13 and accounted for 19% of the total catch (Figure 1.4). Mimic shiner, bluegill, river shiner, gizzard shad, freshwater drum,

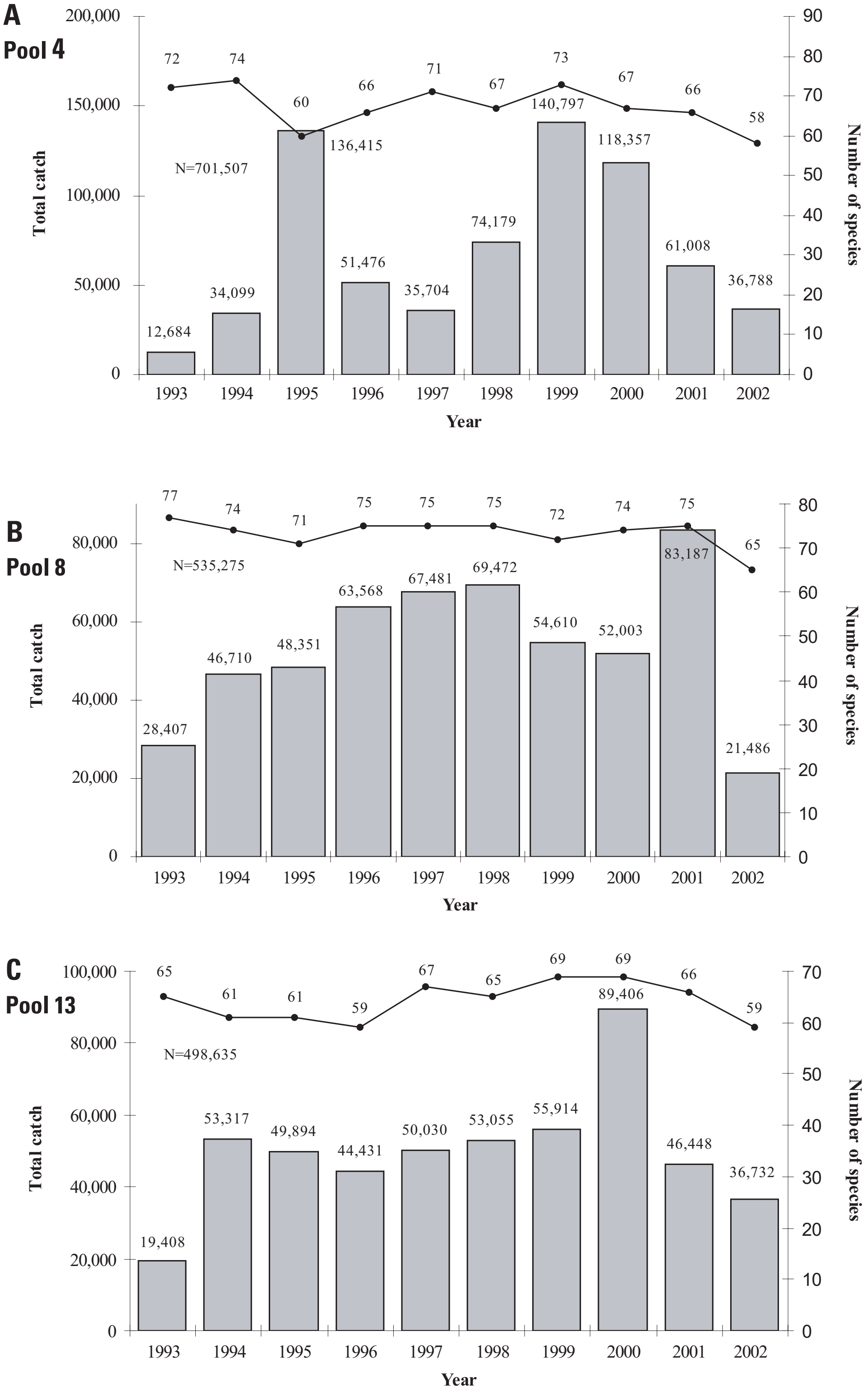
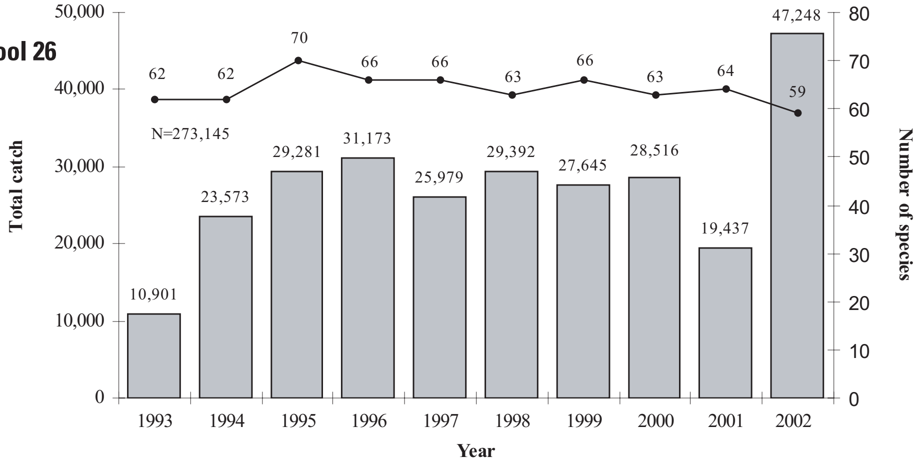
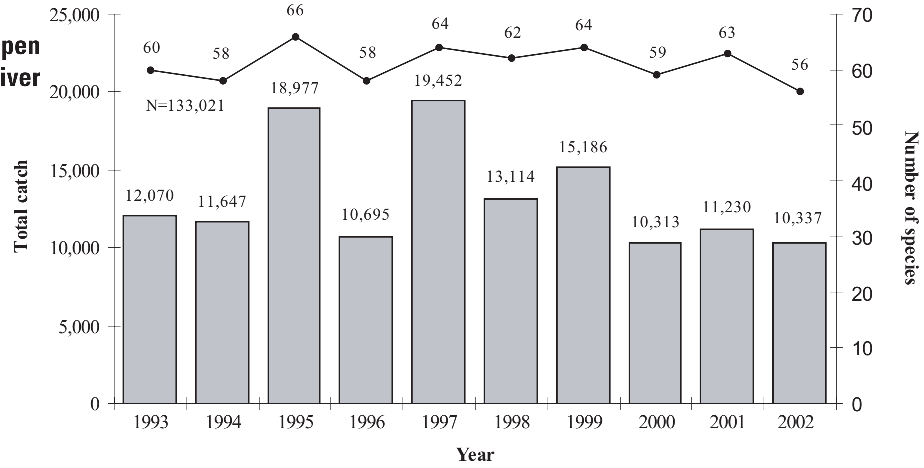


Figure 1.5. Total annual catch (bars) and number of fish species (line) collected in (A) Pool 4, (B) Pool 8, (C) Pool 13, (D) Pool 26), (E) Open River, and (F) La Grange Pool, Upper Mississippi River, by the Long Term Resources Monitoring Program's Fisheries Component during routine monitoring activities, 1993–2002. N is total catch over all years. In 2002, sampling was modified by eliminating night electrofishing, seines, tandem fyke nets, and tandem mini-fyke nets.

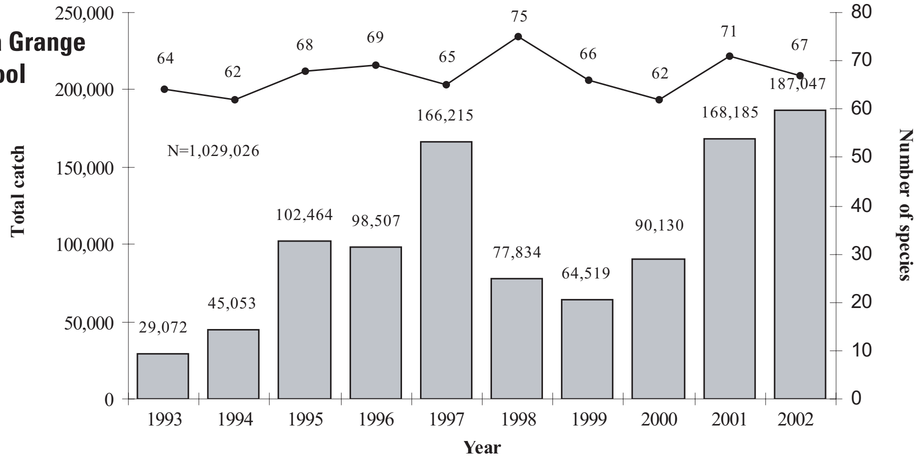
D
Pool 26



E
Open River



F
La Grange Pool



largemouth bass, bullhead minnow, white bass, and black crappie were numerically the next most abundant fishes (Figure 1.4).

In Pool 26, 273,145 fish of 89 species were collected from 1993 to 2002 (Appendix A.7). The number of species ranged from 59 in 2002 to 70 in 1995 and averaged 65 species per year (Figure 1.5D). Gizzard shad was numerically the most abundant fish collected in Pool 26 and accounted for 41% of the total catch (Figure 1.4). Emerald shiner, common carp, channel shiner, channel catfish, freshwater drum, bluegill, western mosquitofish, white bass, and river shiner were numerically the next most abundant fishes (Figure 1.4).

In the Open River reach, 133,021 fish of 98 species were collected from 1993 to 2002 (Appendix A.8). The number of species ranged from 56 in 2002 to 66 in 1995 and averaged 62 species per year (Figure 1.5E). Gizzard shad was numerically the most abundant fish collected in the Open River and accounted for 27% of the total catch (Figure 1.4). Freshwater drum, black crappie, channel catfish, emerald shiner, channel shiner, common carp, red shiner, bluegill, and white bass were numerically the next most abundant fishes (Figure 1.4).

In La Grange Pool of the Illinois River, 1,029,026 fish of 86 species were collected from 1993 to 2002 (Appendix A.9). The number of species ranged from 62 in 1994 and 2000 to 75 in 1998 and averaged 67 species per year (Figure 1.5F). Gizzard shad was numerically the most abundant fish collected in La Grange Pool and accounted for 49% of the total catch (Figure 1.4). Threadfin shad, emerald shiner, bluegill, white bass, common carp, freshwater drum, black crappie, smallmouth buffalo, and channel catfish were numerically the next most abundant fishes (Figure 1.4).

Chapter 2: Community Ecology

Introduction

Rivers are fundamentally hierarchical in their physical organization (Northcote 1988; Tarboton et al. 1988), resulting in multiple scales of organization. Thus, investigations on large rivers must inherently deal with issues of spatial and temporal scales coinciding with scales of physical organization in the river itself. This hierarchy derives from many sources of both natural (e.g., geomorphology, latitudinal gradients in temperature, regional differences in precipitation rates) and anthropogenic origin (e.g., changes in land use, mainstem impoundment, various river engineering structures). Both natural and anthropogenic sources are important in the present day physical organization of the UMRS.

Fish communities in large-river ecosystems respond to environmental variation at multiple scales (Gammon and Simon 2000; Schiemer 2000; Schmutz et al. 2000). Therefore, the ability to detect fish community responses at multiple scales is a desirable feature of long-term monitoring programs in large rivers. The LTRMP fish monitoring design permits investigations of fish community responses at several spatial scales (e.g, the entire system, regional groups of study areas, each study area, and sampling strata within and among study areas), as well as two temporal scales (e.g., annual and seasonal scales). Understanding how communities are similar or different at these various scales is critical for evaluating stressors on fisheries resources throughout the UMRS. Understanding how communities respond to ecosystem changes over time is critical for adaptive management of the UMRS.

In this chapter we present key findings from several community-based investigations recently completed. These investigations address several different spatial and temporal scales and focus on several different aspects of fish communities. These studies are exploratory in nature, seeking to identify patterns in fish communities across the UMRS, and to associate observed patterns with environmental characteristics. Results from these initial analyses can provide direction for more detailed modeling and research.

Spatial Patterns in Species Richness

Species richness is defined as the number of species in a given area, and thus represents a simple measure of diversity. Species richness is generally impossible to know precisely because rarer species are less likely to be observed than more abundant species (Legendre and Legendre 1998). Thus, species richness is typically estimated using a combination of theoretical models and field observations.

Koel (2004) investigated spatial patterns in species richness using LTRMP fish component data and rarefaction models that estimate species richness as a function of sample size. The investigation focused on two spatial scales: differences in species richness among the six LTRMP study reaches and among macrohabitat classes (e.g., sampling strata) independent of study reach. Koel (2004) found species richness to differ significantly among macrohabitat classes. Species richness was highest in contiguous backwater habitats and lowest in main channel border habitats. Among study reaches, Koel (2004) found Pools 4, 8, and 13 exhibited significantly greater species richness than Pool 26, La Grange, or the Open River study areas. Investigation of species evenness and diversity indices demonstrated results similar to species richness. Native fish species richness and habitat diversity were significantly and positively related. Koel (2004) recommended Pools 4, 8, and 13 should serve as relative reference conditions for restoration efforts aimed at enhancing species richness throughout the UMRS.

Community Composition

Community composition is measured as the presence or absence of a species in a community sample. As such, community composition data are binary and provide no information on the relative importance of individual species in the community. However, community composition data are useful for describing similarities or differences in overall assemblage composition among locations.

Chick et al. (2005) investigated patterns in UMRS fish community composition using a nonparametric form of indirect ordination known as nonmetric multidimensional scaling (NMDS). They found notable spatial variation in community composition at two scales; among individual study areas, and among regional groupings of study areas. Among year (temporal) variation was only marginally significant in explaining patterns in community composition and its effect was small in comparison to effects attributable to spatial differences. Spatially, the greatest variation was between upper (Pools 4, 8, and 13) and lower (Pool 26, Open River, and La Grange Pool) regional groups of study areas (Figure 2.1). Also, community composition was more similar among the three upper study areas than among the lower three study areas (Figure 2.2).

These results suggest community composition varies most at the largest spatial scales investigated in this study (e.g., among regional groupings of LTRMP study areas). Moreover, the northern study areas share most of the species comprising each of their communities. Conversely, the southern study reaches differ notably from one another and the northern study areas in species comprising their respective communities. These results are supported by the results of spatially expanded sampling conducted in 2000 (Chick and Pegg 2004).

Community Structure

Community structure is measured as the relative abundance of species in a community sample (Legendre and Legendre 1998). Thus, data are counts (e.g., catch per unit effort) used to characterize the relative importance of each species in the overall community. Species are much more likely to change in abundance within the overall community than in whether they are present or not. Consequently, community structure is generally more variable than community composition, both spatially and temporally (Legendre and Legendre 1998). This variability can arise, for example, from differential population rate processes, environmental variation, and harvest. Thus, community structure data tend to be much more

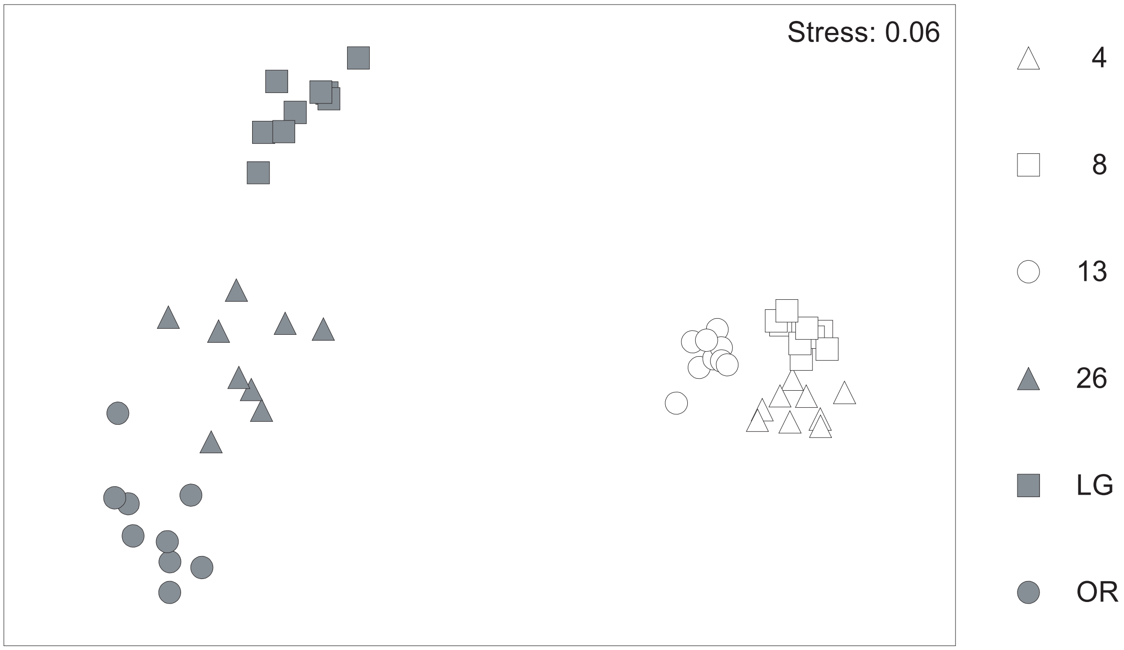


Figure 2.1. Nonmetric Multidimensional Scaling ordination for Upper Mississippi River System fish community composition data (presence/absence) collected by the Long Term Resources Monitoring Program, 1994–2002. Ecological similarity was measured by Euclidean Distance. The upper Resource Trend Areas (Pools 4, 8, and 13) are represented by open symbols whereas the lower Resource Trend Areas (Pool 26, Open River, and La Grange Pool) are represented by shaded symbols. (Chick et al. 2005)

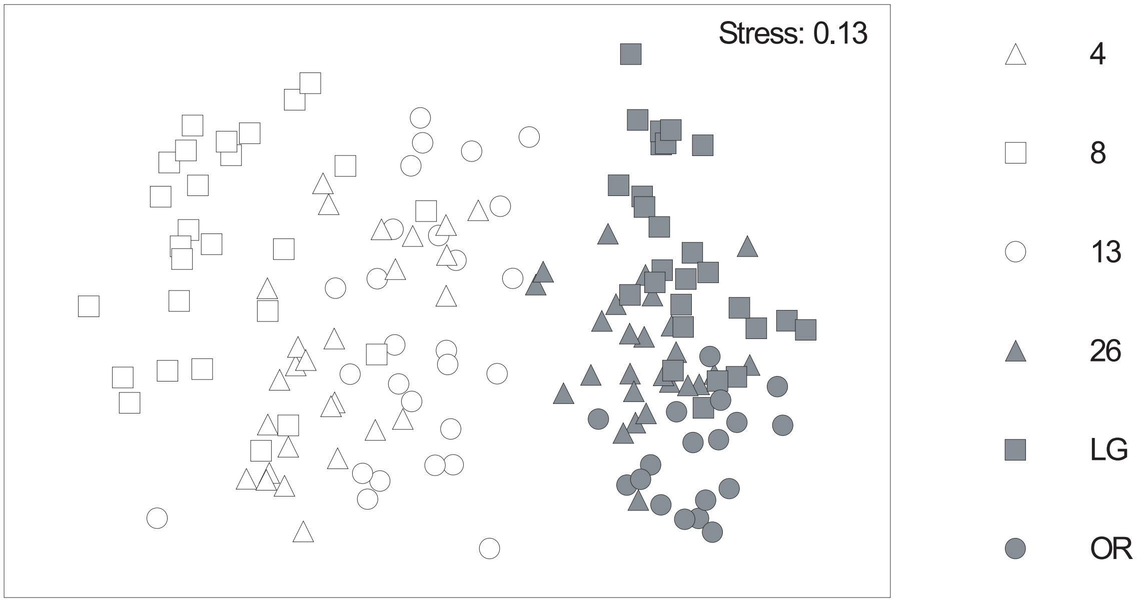


Figure 2.2. Nonmetric Multidimensional Scaling ordination for Upper Mississippi River System fish community structure data (square root catch / 15 minutes) collected with day electrofishing by the Long Term Resources Monitoring Program, 1994–2002. Ecological similarity was measured by Bray-Curtis Similarity. The upper Resource Trend Areas (Pools 4, 8, and 13) are represented by open symbols whereas the lower Resource Trend Areas (Pool 26, Open River, and La Grange Pool) are represented by shaded symbols. (Chick et al. 2005)

informative than community composition data for scientific investigations into factors that are correlated with changes in biotic communities.

Chick et al. (2005) investigated spatial and temporal patterns in UMRS fish community structure and relations between observed patterns and various environmental factors. They focused on identifying patterns across the entire sampled UMRS, regional groups of study areas, sampling strata, and time. They reported that community structure of UMRS fishes varies more in space than in time, and that results suggested a hierarchy of spatial dynamics. Observations grouped first according to large scale differences between northern (e.g., Pools 4, 8, and 13) and southern (e.g. Pool 26, Open River, and La Grange Pool) study areas, then at smaller scales including individual study areas or sub-groups of study areas, and finally according to sampling strata. Temporal patterns were largely limited to variations within spatial groupings.

Barko et al. (2005) also investigated patterns in UMRS fish community structure and relations with environmental factors. However, in contrast to Chick et al. (2005), Barko et al. (2005) focused mainly on identifying patterns among sampling strata and over years within each study area independently. Consequently, greater detail is provided at these scales than in Chick et al. (2005). Barko et al (In press) reported that backwater contiguous environments are dominated by Centrarchidae throughout most of the system, although species composition within backwaters changes from north to south. Side channel environments differed notably in their community structure among study areas depending on the condition and connectivity of side channels. Community structure also differed notably among main channel border environments. For example, among the northern study areas where substrates are mostly sand and the banks are not riprapped, community structure was similar. In the southern study areas, where main channel border substrates and physical composition differ more notably, community structure patterns also differed, likely reflecting different habitat quality, suitability and selectivity for different groups of species. Catostomidae was the only family abundant among main channel border wingdam environments in the northern study areas. However, in the southern study areas, where discharge is more variable, and especially in the Open River reach where wing dikes are usually emergent, green sunfish and blue catfish dominated wingdam environments. Impounded environments yielded no significant or interpretable patterns in fish community structure.

The results of Chick et al. (2005) and Barko et al. (2005) lead to the overall conclusion that community structure patterns in the UMRS are largely spatially determined. This conclusion is supported by observed similarities among the northern study areas and among the southern study areas, but notable differences in community structure between northern and southern regional groupings. Temporal dynamics investigated by Barko et al. (2005) were generally study area-specific, reinforcing the conclusion of Chick et al. (2005) that temporal dynamics occur within hierarchical spatial constraints. In other words, how fish assemblages are structured in different portions of the UMRS and how each of these assemblages respond to changes in environmental conditions over time, is likely a reflection of both historical (e.g., regional geomorphology, historical dispersal routes, zoogeographic constraints) and contemporary (e.g., impediments to contemporary dispersal routes, human altered environments) factors that have shaped fish communities in the UMRS. We discuss the implications of these findings in greater detail at the end of this chapter.

Community Patterns in Relation to Habitat Factors

At the study area scale, Barko et al. (2005) investigated associations between fish community patterns and several environmental variables measured concurrently with LTRMP fisheries collections (see Table 3 in Barko et al. 2005). Water velocity and transparency were important in explaining fish community structure patterns among sampling strata classes in each of the six study areas, suggesting future work should focus on spatial patterns and on the interplay between water velocity and transparency among contiguous environments, perhaps best conceptualized as hydraulic retention differences among sampling strata classes.

Water surface elevation helped to explain differences in community structure among sampling strata classes in Pools 8, 26, and La Grange Pool, but was less important in the other three reaches. Temperature was important in Pools 8 and 13 and La Grange Pool. Associations between fish community patterns and several physical features (e.g., closing dams, snags, riprap, etc…) within the river environment (Gutreuter et al. 1995) were also investigated. Generally, in the northern reaches, several structures influenced abundance patterns in both adult and age-0 fishes. In the lower three study areas, a shift towards a predominant structure within each reach was observed. Differences in structure associations among study areas likely reflect differences in structure availability, and differences among size classes of fish likely result from predator-prey interactions.

At the UMRS scale, Chick et al. (2005) reported that fish community structure patterns were well described by several environmental variables. The greatest correlation (R = 0.76) was observed with a combination of Secchi depth (water transparency), water temperature, water velocity, and vegetation abundance. The northern study areas had greater abundance of aquatic vegetation and greater Secchi depths. The southern study areas had faster water velocity and higher temperature. These differences were closely associated with differences in community structure between the northern and southern study areas.

Community Dynamics in Relation to Floods

Chick et al. (2005) and Barko et al (2005) also speculated on the role of floods in community dynamics. Chick et al. (2005) suggested that temporal patterns in fish community structure observed in their study may reflect an effect of the 1993 flood because structure was notably different in 1994 and 1995 from all other years. Observations made during the 1993 flood suggest several fishes took advantage of increased access to floodplain habitats for feeding and reproduction, and many appeared to produce exceptional year-classes (National Biological Service et al. 1994). Many species such as common carp, freshwater drum, and black crappie, exhibited their peak abundance in

1994, possibly as a lagged result of successful reproduction in 1993 (Figure 2.3). Other species had their lowest abundance in 1994, possibly as a result of dramatic changes in habitat associated with the flood, such as reductions in aquatic vegetation (Spink and Rogers 1998) and sedimentation effects (National Biological Service et al. 1994). Although these annual changes were large for some species, the overall difference in fish community patterns was relatively small, further emphasizing the importance of spatial rather than temporal factors in structuring fish communities in the UMRS.

In their study area-specific investigation, Barko et al. (2005) reported both age-0 and adult fish assemblages were affected by flood events of varying magnitude in every study area. Results suggested age-0 fishes inhabiting the southern study areas were more affected by flood events in 1993, 1994, 1995, and 2001 than age-0 fishes inhabiting the northern study areas. For the adult community, a flood year, or a lagged effect of a flood year, was associated with changes in nearly every study area. Adult assemblages within each of the six study areas differed most in 1993 or 1994. Barko et al. (2005) reported the effects of the 1993 flood resonated through 1994, suggesting lag effects as reported by Chick et al. (2005).

Discussion and Management Implications

Fish communities are frequently regarded as indicators of ecological integrity for large-river ecosystems because of their diversity and response to environmental variation at multiple scales (Gammon and Simon 2000; Schiemer 2000; Schmutz et al. 2000). Recent work, highlighted above, has attempted to identify how fish communities differ across the UMRS,

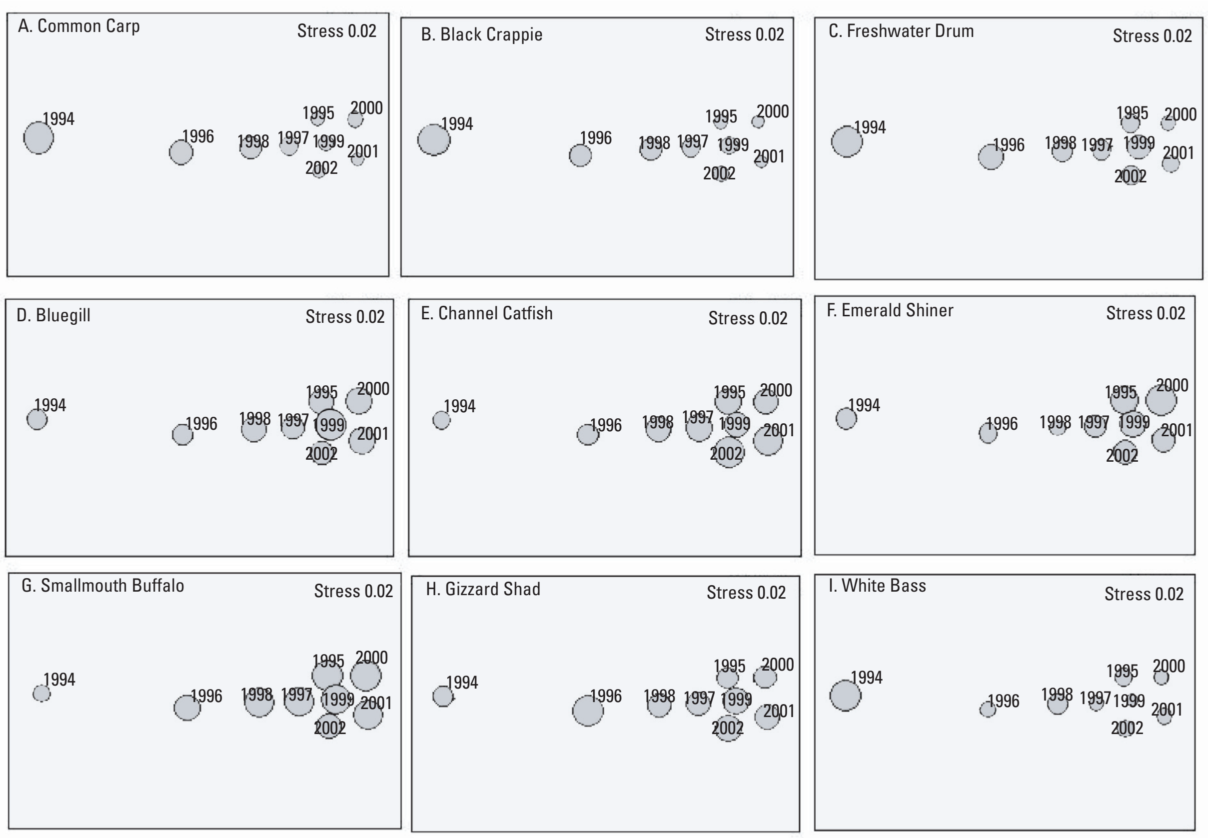


Figure 2.3. Nonmetric Multidimensional Scaling ordination for Upper Mississippi River System fish community structure data, indexed by multiple gear and averaged across all Resource Trend Areas, collected by the Long Term Resources Monitoring Program, 1994–2002. Ecological similarity was measured by Bray-Curtis Similarity. Species scores are overlaid on the ordination for nine species (A = Common Carp, B = Black Crappie, C = Freshwater Drum, D = Bluegill, E = Channel Catfish, F = Emerald Shiner, G = Smallmouth Buffalo, H = Gizza
abundance.

what environmental factors are associated with those differences, and how communities respond over time. Invariably, investigators have found the most important differences in UMRS fish communities occur over large spatial scales. Koel (2004) demonstrated that greater species richness, evenness, and diversity typically occur in the northern reaches of the UMRS rather than the southern reaches. He also found important differences among macrohabitat classes, with greater species richness in off-channel classes such as backwaters and side channels than in main channel environments. The results of Chick et al. (2005) and Barko et al. (2005) echo these findings, but provide more insight into the mechanics underlying observed patterns by providing details on how environmental factors are associated with patterns in fish communities.

Clarifying community patterns and dynamics in the UMRS is not a trivial task. Several factors make analyses such as those presented above challenging. First, the multiple gears used in LTRMP fish sampling differ in their selectivity for different species and size classes of fish. We are uncertain how this affects our inferences about fish community dynamics. Chick et al. (2005) proposed a methodology for using all of the information from all of the gears. This approach initially appears somewhat robust, but additional research is needed in this area. In addition, LTRMP gears do not sample deep channel habitats. We are uncertain if information from these habitats would modify our inferences. Second, because of the size of the UMRS, several species reach the northern or southern limits of their range within the UMRS. Such geographic range limitations can potentially confound results and must be carefully considered. Alternatively, the potential for analyses based on functional groups rather than species should be explored. Third, habitat factors and possibly contemporary or historical barriers to migration likely influence differences in fish composition and community structure between upper and lower reaches. More directed study is needed to assess the significance of these features. Finally, results of Barko et al. (2005) suggest juvenile fishes differ notably from adults in their community level responses. Consequently, future studies should consider partitioning UMRS fish communities by size classes to control for such differences.

Chapter 3: Single Species Ecology

Introduction

Fundamentally, communities of organisms are composed of numerous single species that can interact in complex ways through a variety of abiotic and biotic compensatory mechanisms (e.g., environmental change, predator–prey interactions, inter- and intra-specific competition, differential growth, recruitment, and mortality.). How species respond to system dynamics over time can tell us a lot about the nature of the population we are studying and the portion of the UMRS within which we are studying it (Van Den Avyle and Hayward 1999). For example, is abundance largely invariant over time, suggesting stable populations, or is it highly dynamic, suggesting instability? Moreover, do different areas of the UMRS contain populations that respond similarly, suggesting that some common factors shared among the study areas are associated with single species dynamics, or do some species differ among study areas, suggesting that different factors are operating at different scales on each population? Answering such questions has important implications for identifying and informing rehabilitation efforts within the UMRS basin.

Thus, single species dynamics can be powerful indicators of environmental stresses in the system, and analysis of these dynamics can identify species that would serve as good indicators for rehabilitation efforts. Such an approach also aids in "weeding out" what factors could be operating on different species within the system and permits informed modeling efforts that attempt to explain what factors are associated with changes in abundance. Such models will be important components in the development of effective management tools.

In the sections below, we present results and conclusions from a series of single species studies recently conducted by the LTRMP. The first section quantifies measures of "commonness" for all species observed in LTRMP collections. Species "commonness" (e.g., prevalence) data are simplistic, but provide important and critical insight into systemic processes that shape fish communities. The second section presents results from an analysis of spatial patterns in length frequency distribution and proposes competing hypotheses that could account for observed differences. The third section presents results from an investigation into spatiotemporal patterns in length/weight relations. Spatial differences in length–weight relations may provide insight into mechanisms responsible for among area variability in additional population parameters, such as density dependent resource limitation, whereas temporal differences in length–weight relations provide insight into environmental conditions (e.g., water levels, climate) providing optimum conditions for fish growth and health. The fourth section presents key results and conclusions from an investigation into how single-species abundance varies among years, among study areas, and among aquatic areas (e.g., backwaters, main channel, and side channels) for a host of species in the UMRS. This approach provides an opportunity to assess the presence and relative importance of longitudinal (i.e., among study area), lateral (i.e., among aquatic area), and temporal (i.e., among year) variation in the relative abundance dynamics of numerous UMRS fish species. Quantifying how fish populations vary across space and time can isolate factors responsible for observed patterns in fish abundance, aiding future abundance modeling efforts, and assisting fisheries managers in the identification of species most likely to respond to local habitat modifications, climatic variability, or degradation of specific types of aquatic areas. Our final section discusses the management implications of our findings.

Species Distribution and Prevalence

Where (distribution) and how often (prevalence) a species is present can provide important insight into processes shaping fish communities. Fish communities are, in part, a reflection of habitat availability and the habitat requirements of individual species. The presence of a species in one study area and absence in another suggests the species habitat requirements are being met in the first instance, but perhaps not the latter.

Kirby and Ickes (In press) classified UMRS fish species based on quantitative measures of their distribution and their prevalence in standardized LTRMP monitoring collections. Whereas previous attempts have been made to develop a similar classification system, they were based on disparate data sources developed using nonstandardized methods (e.g., Smith et al. 1971; Rasmussen 1979; Pitlo et al. 1995). Thus, Kirby and Ickes (In press) offer an alternative classification system not suffering from some of the concerns inherent in previous systems, but also is somewhat more spatially constrained (e.g., based on data from six LTRMP study areas rather than all river reaches).

Kirby and Ickes (In press) classified species based on criteria presented in Appendix A.2. Detailed information on species distribution and prevalence in standardized monitoring collections can be found in Kirby and Ickes (In press, Table 2).

Of the 134 species detected by LTRMP from 1993 to 2002, 18 were present in all years of sampling in all study areas and classified as common and widespread in the UMRS. Twenty-nine additional species were captured in all study areas, but not in all years, and were classified as widespread. The remaining species were observed only in particular regions or study reaches and considered uncommon, rare, or strays (Kirby and Ickes In press).

The 47 species exhibiting a widespread distribution in the UMRS represent taxa with the ability to survive in a wide variety of habitat conditions. The loss of any of these species from a reach of the UMR would be indicative of major habitat alteration or degradation. Alternatively, species particular to certain areas within the UMRS will likely serve as important indicator species for environmental conditions within their area of distribution. Such species tend to be more specific in their habitat requirements than the widely distributed species, and thus can be used to gauge changes in the system that may not be reflected in the widely distributed species class. This point is important because these less common species represent a significant fraction of the overall diversity of ichthyofauna in the UMRS.

Spatial Patterns in Length Frequency Distributions

Length frequency distributions are sensitive empirical indicators of population size structure. The form of the length frequency distribution is often used as a first order indicator of population health. For example, a population with a broad, smooth length frequency distribution is indicative of a population that is recruiting year classes regularly, as well as a population exhibiting sufficient survival rates to maintain itself. Alternatively, a length frequency distribution that is truncated suggests size-selective mortality (e.g., as occurs with selective harvest) whereas an irregular one (e.g., missing size classes) suggests periodic recruitment failure. Such profiles are important population characteristics used to assess the health of the population under study.

Kirby and Ickes (In press) tested for differences among LTRMP study areas in length frequency distributions for several UMRS recreationally and commercially exploited fish species. Details on methods and results can be found in Kirby and Ickes (In press). In general, spatial differences in length-frequency distributions were most pronounced for common carp, flathead catfish, shortnose gar, and smallmouth buffalo (commercial species) and least pronounced for black crappie, bluegill, largemouth bass, sauger, and white bass (recreational species). Also, with the exception of bowfin, all species examined in the most northerly study area (Pool 4) exhibited length-frequency distributions composed of a higher proportion of large fish than in the other study areas. Commercial species in the southern reaches, where commercial fishing effort is greatest, had lower proportions of large fish than commercial species in the northern study areas. So why should commercial and recreational species differ in their length frequency distributions? Two alternative hypotheses are

> **H_o1:** Commercial species generally attain a greater maximum length and age than recreational species, which magnifies the

effects of subtle environmental differences affecting reproduction, recruitment, growth, and mortality when comparing among study areas, and

H_o2: Commercial exploitation influences the length-frequency distribution of populations and harvest is different among study areas, but recreational exploitation either has comparatively little influence on size structure or is relatively similar among study areas.

One or a combination of both of these mechanisms could explain observed differences in size structure among study areas. Previous studies suggest that commercial fishing has the ability to truncate size structures in large river fish populations (Mestl 1999; Timmons and Hughbanks 2000; Travnichek and Clemons 2001), however, it is inconclusive whether this is the mechanism operating on the results of Kirby and Ickes (In press). For example, reach-specific growth rates can also contribute to spatial differences is size structure within a river system (Kirby 2001). Additional research into the reproduction, recruitment, growth, and mortality of species exhibiting significant spatial variability in size structure will be required to further discriminate between the competing hypotheses.

Temporal and Spatial Trends in Length–Weight Relations

Length–weight relations of fish populations are helpful for determining body condition or general "well-being" and can be a robust predictor of growth (Anderson and Neumann 1996). Methods generally use linear regression to model the relation between length and weight. The slope of this relation is viewed as the population rate of gain (i.e., increase in weight per unit increase in length). Populations with a high rate of gain are adding weight at a faster rate than populations with a low rate of gain. Length–weight regression parameters can be used to predict the weight of fish, at a given length, for the population. Increased predicted weight for a population at a given length suggests increased fat reserves are present and available for somatic and gonadal growth. Factors affecting population length–weight relations include physiological stress, competition for resources, habitat suitability, and prey availability. Spatial comparisons of length–weight relation provide insight into mechanisms responsible for differences in population dynamics among study areas. Temporal comparisons of length–weight relations provide insight into environmental conditions (e.g., water levels, climate) providing optimum conditions for fish growth and health.

Kirby and Ickes (In press) tested for differences in length–weight relations among the six LTRMP study areas and among years (1993–2002) for six UMRS species (black crappie, channel catfish, common carp, highfin carpsucker, sauger, and walleye) using analysis of covariance methods. Species were chosen based on availability of coincident length and weight data in the LTRMP database.

Rate of gain differed nonrandomly among study reaches for all species tested, but differences were most pronounced in La Grange Pool, Illinois River. La Grange Pool was the only study area to contain populations with a rate of gain significantly higher than the pooled trend for a given species across all study areas. Moreover, higher rates of gain in La Grange Pool black crappie, channel catfish, and sauger were caused by a decreased plumpness of small fish and an increased plumpness of large fish, suggesting the presence of biological factors (e.g., food availability, competition, climate, hydrology) in La Grange Pool that differ from the mainstem UMR.

The Illinois River became degraded because of human influences (levees, pollution, sediment contamination) during the 1950s through early 1970s, coinciding with a decreased condition factor in common carp (Theiling 1999). Kirby and Ickes' (In press) findings, based upon fish collections from 1993 to 2002, indicate that the condition of common carp in the Illinois River remains below average. However, for the other species studied, condition compared favorably between La Grange Pool and mainstem UMR sites. Further investigation into bioenergetics and growth of these species could identify potential causes for the observed spatial patterns in length–weight relations.

The rate of gain was significantly different among years for black crappie, channel catfish, common carp, and walleye, but not for sauger. In 1993, the rates of gain for black crappie and common carp were significantly lower than the overall rate of gain trend, caused by an increased plumpness of small fish. In 1997, the rate of gain for black crappie and common carp was significantly higher than the overall rate of gain trend, caused by an increased plumpness of large fish. Black crappie and common carp were the only species exhibiting a similar rate of gain response to temporal variability (both down in 1993 and both up in 1997).

Black crappie and common carp are most closely associated with backwater and side channel habitats in the Upper Mississippi River System, whereas channel catfish, highfin carpsucker, walleye, and sauger are most closely associated with main channel and side channel environments. Previous researchers (i.e., Bartels 1995; Gutreuter et al. 1999) have tested the flood pulse concept (Junk et al. 1989) with respect to fish productivity in the Upper Mississippi River and have concluded that fish growth is increased for littoral fish species in flood years when compared to drought years. However, results from these investigations were inconclusive for fish species with limited use of littoral areas.

The Mississippi and Illinois River surpassed flood stage in all study areas during both 1993 and 1997, but the timing of the flood events differed. The 1993 flood event occurred during late June and early July (with a smaller flood in April), but the 1997 flood event was primarily in April. This suggests that the timing of flood events may be as important to fish productivity as is the flood itself. Future conceptual models for fish productivity in large rivers may be improved by incorporating flood frequency and flood predictability (as done for community structure in smaller rivers by Poff and Ward 1989), as well as a measure of flood timing. The ability to test such models with LTRMP data will be enhanced with additional years of monitoring data and a larger sample of observed flood events.

Temporal and Spatial Trends in Abundance

In large river systems, species abundance varies temporally (i.e., from year to year), longitudinally (i.e., from upstream to downstream), and laterally (i.e., among macrohabitats at the same latitude). Longitudinal variation typically reflects systemic factors (e.g., hydrology, watershed use, degree days, floodplain morphology), whereas lateral variation reflects differences in local factors (e.g., depth, temperature, hydrologic connections, dissolved oxygen). Risotto and Turner (1985) suggested that factors affecting fish catch on the UMR could be divided into short-term factors and long-term factors based upon the type of influence imposed by the factor. Short-term factors, such as rainfall and water temperature, affect fish catch on an annual basis, and long-term factors such as latitude and geomorphology determine overall productivity, which influences long-term trends in abundance (Risotto and Turner 1985). Quantifying how fish populations vary across space and time can isolate factors responsible for observed patterns in fish abundance and help group species according to their variance signatures. This information can help in modeling fish abundance and in identifying species most likely to respond to local habitat modifications, climatic variability, or degradation of specific types of aquatic areas. Moreover, indicator species can be identified for rehabilitation efforts directed at different spatial scales in the Upper Mississippi River System.

Kirby and Ickes (In press) used a variance partitioning method called Multi-factoral Analysis of Variance to measure the role that temporal (year-to-year), longitudinal (among study areas) and lateral (among macrohabitats within study areas) factors play in determining abundance dynamics for several UMRS species. This method partitions the total variation in abundance into portions associated with each main factor and the interaction terms among those factors (e.g., year * longitudinal; Figure 3.1). When possible, fish were classified by size classes and analyzed separately because abundance dynamics often differ by size class.

In general, Kirby and Ickes (In press) found that species differed markedly in the amount

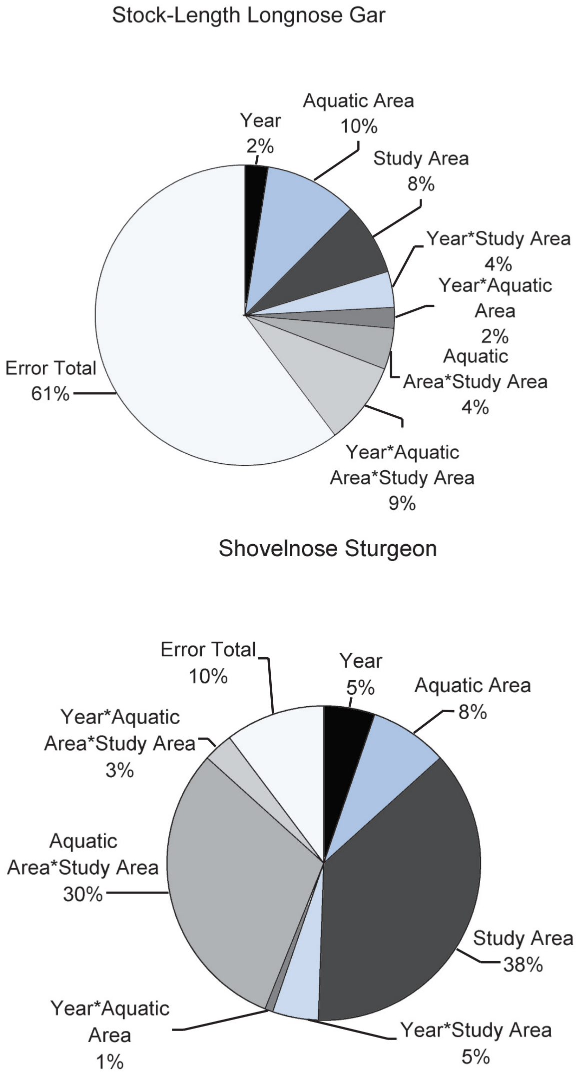


Figure 3.1. Pie charts representing the results of variance decomposition for the relative abundance of stock-length longnose gar and shovelnose sturgeon captured by electrofishing from five study areas in the Upper Mississippi River. Pie charts represent the portion of total sum of squares accounted for by error sum of squares and seven model factors. The proportion of total sum of squares accounted for by model factors was used to ordinate and group species based on lateral-spatial (aquatic area), longitudinal-spatial (study area), and temporal (year) variance patterns.

of variation in relative abundance caused by longitudinal factors, differed to a lesser extent in variation caused by lateral factors, and were most similar with respect to temporal variation. Figure 3.2 portrays the relative roles of temporal, longitudinal, and lateral factors in determining size-structured species abundance dynamics in the UMRS, as measured by the LTRMP.

Fish management on large rivers is often centered on improving the abundance of desirable fish populations by minimizing temporal variability (e.g., water level management and harvest regulations), enhancing lateral habitats (e.g., increasing connection between channel and off-channel habitats, and improving backwater overwintering habitat), or addressing longitudinal-spatial factors (e.g., optimizing hydrology and land-use practices). Thus, the success of a management initiative is contingent on addressing factors responsible for variation in abundance. Longitudinal variation is, in most instances, a reflection of systemic factors (e.g., hydrology, water chemistry, nutrient dynamics, floodplain morphology) not easily controlled through direct management intervention for the obvious reasons of scope and cost. For this reason, management actions typically focus on controlling year-to-year variation and lateral habitat improvements in an effort to mitigate for undesirable systemic factors.

Those species identified by Kirby and Ickes (In press) as exhibiting the highest levels of variation due to aquatic area type (lateral factors) would be most likely to show a relative abundance response to habitat improvements focusing on specific types of macrohabitats. Generally, such species were predominantly Centrarchids. Centrarchids remain the primary target of many aquatic habitat rehabilitation projects (HREPs) on the UMR, and have shown positive abundance responses to HREPs focused on backwater habitat (Gent et al. 1995). Kirby and Ickes (In press) suggest that bowfin, emerald shiner, substock-length flathead catfish, golden shiner, stock-length longnose gar, river shiner, and yellow perch would also be likely to respond positively to HREPs applied to key macrohabitats in river reaches at hospitable latitudes (Figure 3.2). Conversely, abundance of important recreational species such as channel catfish, sauger, and walleye was poorly predicted by lateral factors, suggesting that HREPs focused on single macrohabitats are less likely to initiate an abundance response for these species (Figure 3.2).

Interactions among lateral, longitudinal, and temporal factors were also common for many

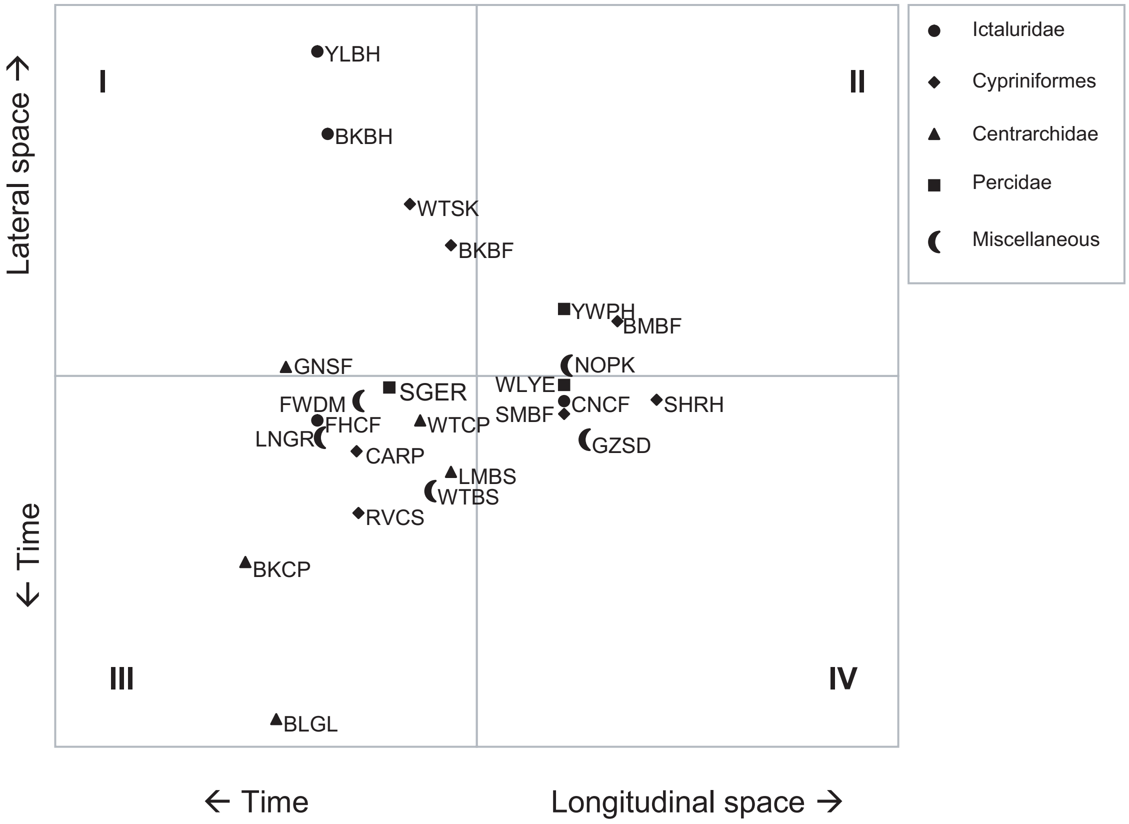


Figure 3.2. Results of multivariate analysis of variance for relative abundance of 24 selected fish species of stock size (see Gablehouse 1984) in the Upper Mississippi River System based on data from the Long Term Resource Monitoring Program, 1993-2002. Variance is portioned into temporal (year-to-year), longitudinal (among study areas) and lateral (among strata within study areas) factors. Species in panels I
variance -
letter codes for

species. Interaction terms identify species that exhibited different responses to levels of a factor dependent upon levels of another factor. For example, stock-length channel catfish exhibited temporal (i.e., year-to-year) variation in macrohabitat use. This suggests that channel and off-channel habitat use by some species is dependent upon short-term factors (e.g., hydrology, rainfall). Such complexity in relative abundance patterns is not surprising given the size and dynamic nature of the UMR, and suggests it is important to consider the influence of temporal variability in river conditions when assessing lateral-spatial abundance patterns.

Kirby and Ickes (In press) conclude that the influence of systemic longitudinal factors on species abundance was greatest among factors considered. However, when viewed from a smaller, pool-level scale (35–100 river kilometers), lateral-spatial and temporal factors are primarily responsible for short-term abundance patterns. Despite this, river managers must remain cognizant that the long-term abundance of fish populations is ultimately confined by systemic processes and the longitudinal placement of a river reach.

Discussion and Management Implications

The LTRMP, as a community-centric monitoring program, is necessarily constrained in how it can approach single species responses to important issues such as habitat changes and exploitation. This is because only the most basic population information is provided by the LTRMP design, namely count and length observations. Whereas populations are certainly affected by abiotic factors that may be associated with trends in abundance, biotic factors such as density-dependent growth, prey density, or habitat availability are also important determinants of population responses over time. Modeling population responses can benefit substantially from rate-dependent process data such as growth, mortality, recruitment, and age at maturity. However, such data are not presently available from LTRMP.

In the absence of such data, Kirby and Ickes (In press) have used available data to identify how several different species of ecological, recreational, and commercial significance respond generally over time and across important spatial scales. With more than 130 species in the UMRS, this approach provides a foundation for identifying species sharing similar abundance patterns. This implies that species sharing similar abundance responses are likely to be influenced by similar environmental factors operating at scales revealed in their analysis as important in determining abundance dynamics. Knowing which scales are important for which species will lead to informed model development in the next phase of research. Knowing which species share similar abundance patterns may also greatly simplify future modeling efforts, as one species can be chosen to represent other species within a similar response group.

Figure 3.2 also provides a blueprint for measuring fish responses to present and future habitat rehabilitation efforts within the UMRS. For example, Kirby and Ickes (In press) suggests that bowfin, emerald shiner, substock-length flathead catfish, golden shiner, stock-length longnose gar, river shiner, and yellow perch would also be likely to respond positively to HREPs applied to key macrohabitats in river reaches at hospitable latitudes. This assertion could be tested by studying the responses of these species to future HREP actions, in an adaptive management framework. Similarly, species exhibiting strong longitudinal associations in their abundance responses should be biological indicators of rehabilitation efforts at the largest scales in the system (e.g., hydrograph naturalization, floodplain reconnection). In these ways, the results of Kirby and Ickes (In press) have important applied management implications for adaptive management of the UMRS.

Chapter 4: Nonnative Species

Introduction

The effect of nonnative species has emerged as one of the most serious environmental problems in the 21st century (Mooney and Hobbs 2000; Carlton 2001; Mills et al. 1994). The economic cost of invasive species to Americans is estimated at $137 billion annually (Pimentel et al. 2000), but this estimate includes only those damages for which market values exist. Nonnative species can also negatively affect native species. For instance, up to 46% of the plants and animals listed as federally endangered species have been negatively affected by invasive species (Wilcove et al. 1998). Nonnative species and habitat degradation are routinely ranked as the top two threats to aquatic biodiversity (Tockner and Stanford 2002).

A 1997 survey by the Mississippi Interstate Conservation Resources Association (MICRA) indicated that 163 nonnative species were established in the Mississippi River basin. Most of these species (83) were fishes. The 163 nonnative species in the Mississippi River Basin is virtually identical to the 162 species established in the Great Lakes, an ecosystem often described as highly altered by numerous invasions of nonnatives.

The Nonindigenous Aquatic Species information resource, maintained by the U.S. Geological Survey at the Center for Aquatic Resource Studies in Gainesville, Florida (http://nas.er.usgs.gov/fishes/index.html), reports that at least 18 nonnative fishes have been introduced to the UMRS (Table 4.1). These species have entered the UMRS basin through numerous dispersal routes and have had different effects on the ecology of the system. In this chapter, we briefly summarize data on nonnative fish species observed by the LTRMP.

Detection of Nonnative Species in Long Term Resource Monitoring Program Collections

As a community monitoring program, the LTRMP is not optimized for the detection and enumeration of nonnative species. Because of its multiple gear design, however, the LTRMP has proven effective at documenting the presence and distribution of many nonnative species within the areas monitored. This information is valuable for identifying general patterns in distribution and abundance, identifying effective sampling methods for focused monitoring or study, and for describing general macrohabitat associations of established nonnative species. In the following sections, we identify nonnative species detected by LTRMP during 1999–2002 and provide information on their spatial distribution and trends in abundance and biomass. More detailed information on nonnative fishes in the UMRS can be found in Irons et al. (In press).

Number of Nonnative Species and Their Relative Prominence

Since 1989, the LTRMP has detected 11 nonnative species and 3 additional hybrids with nonnative species (Table 4.2). Several nonnative species detected by LTRMP have only been collected once or twice and can be characterized as incidental, such as rainbow smelt and brown trout. These species are probably strays from tributaries because the UMRS does not provide appropriate habitat for rainbow smelt or brown trout. Two additional species, tiger musky and muskellunge, have also been observed infrequently and in low abundance. These species are considered nonnatives because their presence arises from stocking efforts within the UMRS. Muskellunge is native to Mississippi River reaches north of Minneapolis, Minnesota; however, it is not expected to appear in LTRMP-monitored reaches without local or regional stocking efforts. Threadfin shad is native to the southern regions of the Mississippi River basin, but is expanding its range northward because of stocking. Thus, it is nonnative to most LTRMP study areas. The remaining nonnative species in Table 4.2 have achieved some level of abundance and maintain populations within some or all of the LTRMP study reaches.

Of particular concern is a recent increase in the rate of nonnative introductions to the UMRS. Records indicate that common carp, goldfish, and brown trout were the first nonnative fishes established in the UMRS. The introduction and establishment of these species throughout North America is closely associated with European settlement. After these early introductions, only three additional fishes became established in the UMRS prior to the 1970s: ninespine stickleback (*Pungitius pungitius*), probably from bait bucket release, and white catfish (*Ameiurus catus*) and threadfin shad through authorized introductions (Table 4.1). None of these species are currently considered a nuisance in the UMR. Thus, before 1970, only six nonnative fish species had become established. Since 1970, however, an additional nine fishes have become established (Table 4.1). With 15 introduced fishes and 137 native fishes, nonnative species do not dominate fish biodiversity in the UMRS as they do in some systems. However, nonnatives can represent a sizeable fraction of total fish abundance and biomass. The increased rate of invasion by nonnative fishes and the ability of some nonnative species to achieve high abundance and biomass highlights the need to better understand the pathway of these introductions and their effects on the ecosystem.

Spatial Patterns in Distribution

Notable differences exist in the spatial distribution of nonnative species among the six LTRMP study areas. The majority of nonnative species detected by LTRMP were in the three southern study areas with eight nonnatives in Pool 26, nine in the Open River, and 10 in La Grange Pool; Table 4.2). Conversely, monitoring in Pool 4, Pool 8, and Pool 13 have documented from three to four nonnative species per pool. Many nonnatives in Pools 4, 8, and 13 were incidental species (e.g., brown trout, rainbow smelt, rudd), whereas most nonnative species in the southern reaches have established populations (e.g., threadfin shad, goldfish, grass carp, silver carp, bighead carp, white perch; Table 4.2). Common carp were abundant throughout the system.

Differences in spatial distribution can arise from several factors. For example, differences may suggest more degraded aquatic environments in southern versus northern study areas, resulting in greater invasion potential in southern areas. Differences may also be partially attributable to invasion pathways. Aquaculture operations in the southern United States and invasions from the Great Lakes (through the Chicago canal to the Illinois River) have been the source for many recent nonnatives. Thus, the southern LTRMP reaches are closer to these sources and would be expected to exhibit higher invasion rates. Relative absence of nonnatives in the northern areas may also be related to dispersal barrier effects of dams. The LTRMP data are currently too limited to identify the relative roles of each of these potential causes in creating differences in spatial distribution. Understanding why such differences arise, and the mechanisms leading to these differences will require additional data and directed study.

La Grange Pool exhibits the highest number of established nonnatives among LTRMP study areas, likely because of its location between two major drainage basins, the Mississippi River and the Great Lakes. Thus, La Grange Pool is a sentinel point for monitoring nonnative exchanges between these connected basins. In addition, control measures can be implemented on the Illinois River to control movement of nonnative species between basins. A good example is the electronic barrier established in 2002 in the Cal-Sag Canal section of the Illinois River, near Chicago, Illinois, to control exchange of fishes between the Mississippi River and Great Lakes basins. This site is an area of active research on the control of nonnative species in North America.

Spatial Patterns in Numerical Abundance

The percentage of abundance accounted for by nonnative species in the LTRMP catch ranged from 3 to 12% during 1993–2002 and was generally flat or declining (Figure 4.1). One notable exception is a sharp increase in 2001. This increase was entirely attributable to record catches of threadfin shad in La Grange, resulting in a nonnative fraction of 27% of the total program catch in 2001.

Table 4.1. Year, pathways of introduction, and e

Common name	Scientific name	Year introduced into UMRS	Pathway	Effect in UMRS
Common carp	Cyprinus carpio	Unknown, but long ago (in Illinois by 1908; Burr et al. 1996)	Primarily by authorized releases; natural dispersion thereafter (Fuller et al. 1999)	High—abundant and change habitats
Goldfish	Carassius auratus	Unknown, but long ago (Burr et al. 1996)	Primarily by authorized and unauthorized release; natural dispersions thereafter (Fuller et al. 1999)	Low—not usually a pest
Brown trout	Salmo trutta	Unknown, but long ago	Primarily by authorized releases; natural dispersion thereafter (Fuller et al. 1999)	Low--can be high elsewhere
American shad	Alosa sapidissima	1872 and 1873 (Smith 1896)	Authorized releases (Fuller et al. 1999)	Failed introduction
Black-banded rainbowfish	Melanotaenia nigrans	Collected in 1930s (O'Donnell 1935)	Aquarium release or escape from retail outlet (O'Donnell 1935)	Failed introduction
Ninespine stickleback	Pungitius pungitius	Unknown, but prior to 1979 (Smith 1979)	Unknown, but by bait bucket release elsewhere in U.S.[a]	Low
White catfish	Ameiurus catus	Unknown, but prior to 1979 (Smith 1979)	Authorized release for food and sport (Fuller et al. 1999)	Low—but high in California (McCarraher and Gregory 1970)
Threadfin shad	Dorosoma petenense	Unknown, but probably in the 1960s (Burr and Page 1986)	Authorized release for forage enhancement (Fuller et al. 1999)	Low—but can be high elsewhere
Grass carp	Ctenopharygodon idella	Early 1970s (Pflieger 1975)	Authorized and unauthorized releases, aquaculture escapes (Fuller et al. 1999)	High—abundant and spread quickly; change habitat
Inland silverside	Menidia beryllina	First collected in 1977 (Burr and Page 1986)	Natural dispersal after change in water quality (Burr et al. 1996)	Low—can be high elsewhere (Gomez and Lindsay 1972)
Rainbow smelt	Osmerus mordax	Late 1970s (Burr and Mayden 1980)	Dispersion by canal (Burr and Mayden 1980)	Low
Mosquitofish	Gambusia affinis	Early 1980s (Pflieger 1997)	Natural dispersion and unauthorized releases (Fuller et al. 1999)	Low—high in Western U.S.
Bighead carp	Hypophthalmichthys nobilis	Early 1980s (Jennings 1988)	Aquaculture escapes	High—abundant and spreading fast
Silver carp	Hypophthalmichthys molitrix	First collected in 1980s	Aquaculture escapes	High—abundant and spreading fast
Pirapatinga	Piaractus brachypomus	Caught in 1988 (Anonymous 1988)	Aquarium release (Fuller et al. 1999)	Failed introduction
White perch	Morone americana	First collected 1990 (Burr et al. 1996)	Dispersion by canal	High--abundant; spread far
Rudd	Scardinius erythrophthalmus	First collected in the 1990s (not established in 1992—Burr et al. 1996) – in Rasmussen 1998	Bait bucket release	Low—not abundant and hasn't spread far
Striped bass	Morone saxatilis	Unknown, but recent (LTRMP dataset)	Authorized release	Low--can have negative impacts on small fish (Bailey 1975)

[a] Walker, P., 1993, A list of the endemic and introduced fishes of Colorado- March 1993. Colorado Division of Wildlife, Aquatic Resources Unit. Unpublished manuscript. 16 pp.

Table 4.2. Nonnative species collected for the Long Term Resource Monitoring Program (LTRMP) on the Upper Mississippi River System, including year of first capture, total catch, and LTRMP study areas in which each species has been observed during 1989–2002.

				LTRMP study areas where caught					
Species	**Scientific name**	**First year captured by LTRMP**	**Total catch**	**Pool 4**	**Pool 8**	**Pool 13**	**Pool 26**	**La Grange**	**Open River**
Threadfin shad	Dorosoma petenense	1989	140,000				X	X	X
Goldfish	Carassius auratus	1989	930				X	X	X
Common carp	Cyprinus carpio	1989	135,000	X	X	X	X	X	X
Grass carp	Ctenopharyngodon idella	1991	900	X			X	X	X
Silver carp	Hypopthalmichthys molitrix	1998	205				X	X	X
Bighead carp	Hypopthalmichthys nobilis	1991	2500				X	X	X
Rudd	Scardinius erythrophthalmus	2002	2			X			
Muskellunge	Esox masquinongy	1996	1						X
Tiger musky	E. masquinongy x E. lucius	1992	4					X	
Rainbow smelt	Osmerus mordax	1993	1		X				
Brown trout	Salmo trutta	1992	7	X	X	X			
White perch	Morone americana	1992	237				X	X	
Striped bass	Morone saxatilis	1991	59					X	X
Wiper	M. saxatilis x M. chrysops	1993	139			X	X	X	X

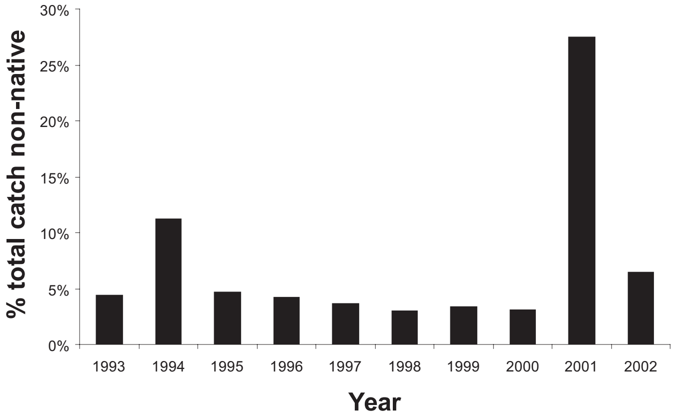


Figure 4.1. Percentage of total annual catch accounted for by nonnative species in the Long Term Resource Monitoring Program Fisheries Component, 1993–2002.

Among study areas, abundance can differ notably. Generally, abundances tend to be greatest in La Grange Pool of the Illinois River, followed by Pool 26 and the Open River reach. The northern study areas typically exhibit very low abundances of nonnative species. However, LTRMP methods may not provide accurate abundance estimates for some species, notably bighead and silver carp. These species are pelagic and are not efficiently captured by standard LTRMP gears. Thus, abundance indices for these species will likely underestimate the true abundance but can be useful for determining relative abundance between study areas.

Spatial Patterns in Biomass

In 2003, we developed length–weight equations from empirical data sources and the open literature for 100 UMRS fish species representing > 98% of the total catch from 1993 to 2002. We used these models to estimate biomass for native and nonnative fishes to investigate patterns in the proportion of nonnative fishes across the six LTRMP study areas (Figure 4.2).

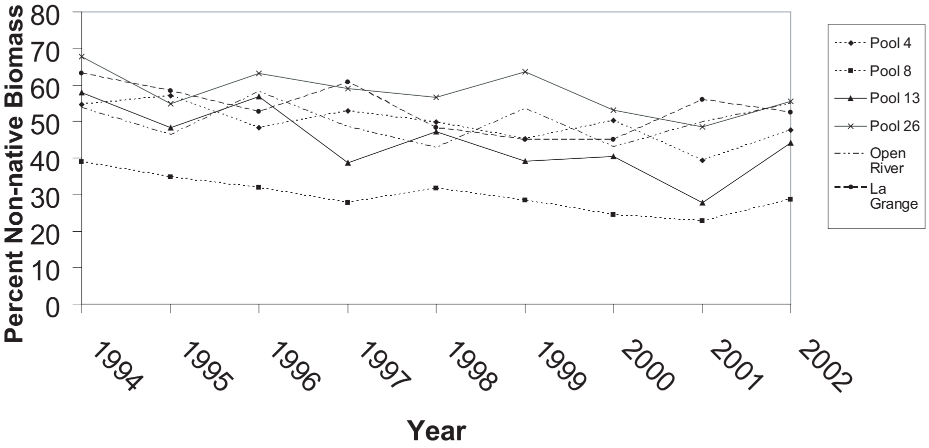


Figure 4.2. Percentage of total annual biomass accounted for by nonnative species in the catch of the Long Term Resource Monitoring Program Fisheries Component, 1994–2002.

Three general findings are immediately apparent. First, whereas nonnatives represent only a fraction of the total catch, they represent a substantial portion of fish biomass in the system. Across study areas and years, nonnative species averaged 48% of the total biomass observed in LTRMP collections, ranging between 23% and 68%. The majority of this biomass is in common carp, a naturalized nonnative species. Second, the northern study areas tended to exhibit lower proportional biomass of nonnatives than the southern study areas; specifically, Pool 8 exhibited a consistently lower proportion than all other study areas. This difference between northern and southern reaches may be even greater than observed because LTRMP methods likely underestimate abundance of bighead and silver carp, which have been increasing in the three southern reaches. Finally, since 1994 (1993 data excluded because of sampling difficulties; see Appendix A.1), there has been a system-wide decline in the proportional biomass of nonnative species in LTRMP collections. This trend reflects a system-wide decline in common carp abundance (Appendix B.10) and size structure (Appendix C.7).

This analysis provides a good example of how LTRMP data can be used to gain new insights into important issues on the UMRS. For example, competing hypotheses for why Pool 8 would have a lower proportion of its fish biomass in nonnative species include (a)

Pool 8 has higher standing stocks of predators than crop nonnatives at higher rates than other areas; (b) nonnative species typically achieve their greatest success in impaired systems, thus Pool 8 is less impaired in some way than the other study reaches; or (c) disease or parasitism is greater on Pool 8 nonnatives (principally common carp) than other areas, suppressing the nonnative component of total biomass. Similar hypotheses could be developed for the systemic decline in proportional nonnative biomass and for spatial contrasts between the northern and southern study reaches. LTRMP data are crucial for framing these questions and hypotheses, and further analyses of these data can begin to address which hypotheses seem most likely.

Nonnative Fishes of Concern in the Near Future

The ecological and economic costs of nonnative species can be substantial, and once established, mediating their effects can be both difficult and expensive. Recently established species, such as bighead and silver carp, are of acute concern to natural resource managers, as these species have the potential to compete with nearly every native fish species and in particular other filter-feeding species such as paddlefish (Chick and Pegg 2001; Chick 2002; Figure 4.3). Unfortunately, the rate of introduction continues to increase.

For example, the black carp (*Mylopharyngodon piceus*) and giant snakehead (*Channa micropeltes*) were collected within the UMRS basin for the first time in 2003. Also, the round goby (*Neogobius melanostomus*) has been collected in the Calumet and Des Planes Rivers near Chicago since 1993. The black carp was first imported into the United States accidentally in grass carp stocks. Later, it was introduced intentionally as a food fish and for use in catfish aquaculture in southern states. Scientists and natural resource managers are concerned that black carp may become established in the UMRS and the U.S. Fish and Wildlife Service is considering listing black carp as an injurious species. Black carp are molluscivores and therefore a threat to freshwater mussel populations, which are one of the most endangered groups of aquatic biota in North America.

The giant snakehead was collected in the Rock River, Wisconsin, a tributary of the UMRS by a Wisconsin Department of Natural Resources (WDNR) survey in September 2003, and from the Illinois River in 2004. This large predator, if established in the UMRS, could prey on most the native fishes. Although the giant snakehead would not normally survive winter temperatures at UMRS latitudes, abundance of warm water discharges may aid in overwintering of this species and other potential aquaria releases.

The round goby has slowly been expanding its distribution down the Calumet and Des Planes Rivers toward the Illinois and Mississippi Rivers since 1993. This benthic fish is likely to negatively affect native sculpins and other benthic fishes as its range expands (Laird and Page 1996).

Figure 4.3. Raising a trammel net with bighead carp in Pool 26, Upper Mississippi River. Photo courtesy E. Gittinger, Illinois Natural History Survey

Chapter 5: Species with Status

Introduction

Species with status are those listed as endangered, threatened, special concern, rare, or extirpated by state or federal authorities. Such species are always relatively rare or have limited distributions, but LTRMP fish sampling has collected many of these species within the UMRS. In some instances, LTRMP data have provided the only information within a state on the status of such species, and LTRMP data have even been used in delisting species. Although LTRMP data cannot provide detailed information on the distribution and relative abundance of these rare species, even presence/absence data are valuable to resource management agencies. In this chapter, we review basic information on current state and federal listings, and summarize the catches and locations of listed species during 1993 to 2002.

Summary of Observations by the Long Term Resource Monitoring Program

Federally listed fishes

Presently only pallid sturgeon are federally listed as endangered in the UMRS (Grady et al. 2001; Table 1.3). Pallid sturgeon have not been observed in routine LTRMP sampling from 1993 to 2002. Personnel at the Open River field station, however, collected pallid sturgeon during sampling for special studies from 1996 to 2002. Also, in routine monitoring activities, the Open River field station personnel collected nine sicklefin chub, which had been listed as a federal candidate species prior to 2002.

State listed fishes

Within the UMRS, 50 fish species have some form of conservation status in one or more states (Table 1.3). Since 1993, the LTRMP has collected 39 of those species (Table 1.3).

Nine species of fish with status in Minnesota were collected in Pool 4 (Table 1.3 and Appendix A.3) and included: four paddlefish (threatened); 26 blue sucker, five crystal darter, 12 lake sturgeon, one pallid shiner, two pirate perch, 2,525 pugnose minnow, 127 shovelnose sturgeon, and two skipjack herring (special concern). Fifteen species of fish with status in Wisconsin were collected in Pool 8 (Table 1.3 and Appendix A.3) and included four crystal darter, 17 goldeye, six pallid shiner, and one skipjack herring (endangered); two black buffalo, 56 blue sucker, 700 river redhorse, and 12 speckled chub (threatened); two American eel, one lake sturgeon, 534 mud darter, five pirate perch, 11,485 pugnose minnow, 199 silver chub, 3,039 weed shiner, and 868 western sand darter (special concern). Seven species of fish with status in Iowa were collected in Pool 13 (Table 1.3 and Appendix A.3) and included eight bluntnose darter, one freckled madtom and one lake sturgeon (endangered); four chestnut lamprey, one grass pickerel, and 39 western sand darter (threatened); and 1,087 pugnose minnow (special concern). Two species of fish with status in Illinois were collected in Pool 26 (Table 1.3 and Appendix A.3) and included: 6 bigeye shiner, and 8 lake sturgeon (endangered). Nine species of fish with status in Missouri were collected in the Open River (Table 1.3 and Appendix A.3) and included: 1 trout perch (endangered); 2 western sand darter (threatened); 64 blue sucker, 81 mooneye, 35 paddlefish, 18 river darter, 9 sicklefin chub (special concern); 355 Mississippi silvery minnow and 13 pugnose minnow (rare). No species of fish with status in Illinois were collected in La Grange Pool (Table 1.3 and Appendix A.3).

Discussion and Management Implications

The multiple gear design and the standardized monitoring methods of the LTRMP provide benefits beyond community-based assessments. Documenting the presence of species of special conservation concern is one such benefit. These species represent an important fraction of the diversity of fishes in the UMRS. The UMRS is a nexus of freshwater fish diversity in North America, with nearly one third of the entire North American fauna endemic to the Mississippi River Basin. The conservation of this diversity is critical for maintaining healthy, diverse ecosystems into the future.

Chapter 6: Nongame Species

Introduction

Nongame species represent more than one half of species found in the UMRS (Figure 6.1), and thus are critical components of faunal diversity. Nongame species are often important components of food webs supporting species valued by humans. Many nongame species are fairly specific in their habitat requirements, making them excellent candidates for diagnosing changes in habitat condition. In addition, nongame species, by definition, are not subject to exploitation, which may confound interpretation of status and trends data for recreational and commercial species.

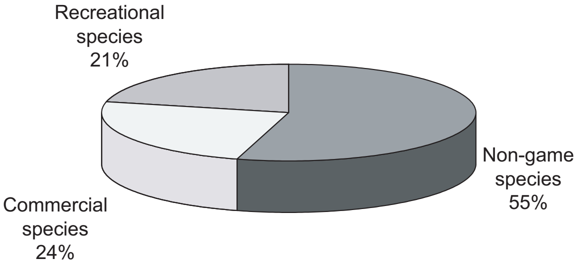


Figure 6.1. Contribution of nongame, recreational, and commercial fish species to the total fish catch by the Long Term Resource Monitoring Program, 1993–2002. Nongame species have no direct use by recreational or commercial fisheries. Any species exploited commercially was considered a commercial species, and any species not commercially exploited but captured occasionally or often with recreational tackle was considered a recreational species.

Within the LTRMP, several manuscripts have been published regarding nongame species during 1993–2002 (Hrabik 1996a, 1996b, 1997; Tucker and Cronin 1996; Tucker et al. 1996; Bowler 2001, 2003). Also, written summaries of nongame species abundance have been provided annually (e.g., Burkhardt et al. 2000) and data on nongame fishes are served to the public on the World Wide Web (see Chapter 9).

Our goal in this chapter is to make this unique information resource known to river managers. Within natural resource agencies, nongame initiatives are frequently under-funded, but LTRMP data can be an important source of information for assessing the status and management options for nongame species. We demonstrate the potential of the LTRMP data to help understand the ecology of nongame fishes by presenting three case study examples.

Case study 1

In Chapter 5, we reported that 50 fish species in the UMR are listed as endangered, threatened, or special concern (Table 1.3), and that the LTRMP has collected 39 (78%) of the 50 listed species. Because abundance and occurrence data collected by LTRMP are geographically referenced, we have the opportunity to assess changes in population status and gain insight into the habitat requirements of rare fish. In Case Study 1, we show how LTRMP data can be used to understand the habitat requirements of one such fish, the weed shiners (Figure 6.2).

Case study 2

The habitat preferences of many common nongame fish are not well understood within the UMRS. As with the more extensively studied recreational and commercial fishes, some nongame species are habitat generalists whereas other species have specialized habitat requirements. Habitat generalists are typically more evenly distributed among habitats within study areas, when compared to habitat specialists. LTRMP data can be used to gain insight into the habitat associations of nongame fish, then be used to form and test hypotheses concerning habitat quality, fish community composition, and habitat limitations. In Case Study 2, we show how LTRMP data can illustrate the habitat associations of three nongame fishes: pugnose minnow, river shiner, and bullhead minnow (Figure 6.3).

Case study 3

Many nongame fish can serve as indicators of aquatic habitat integrity, because of their relatively short life spans and close associations with specific habitat types. Changes in the

Figure 6.2. Case study 1: Weed shiners in the Upper Mississippi River

Weed shiners (*Notropis texanus*; Figure 6.2.1) are listed as a species of special concern by the state of Wisconsin, and are listed as endangered by the states of Iowa and Illinois. The natural range of weed shiners in North America includes the entire mainstem Mississippi River. Weed shiners are sensitive to environmental changes, although the factors affecting populations are not well understood (Becker 1983).

Figure 6.2.1. Weed shiner (*N otropis texanus*). Photo by Florida Fish and Wildlife Conservation Commission.

Since 1993, the LTRMP has collected 3,135 weed shiners, accounting for 0.1% of fish collected. To date, weed shiners have been collected exclusively from Pool 4 and Pool 8 study areas. The relative abundance of weed shiners in Pool 4 and Pool 8 has varied considerably across years with few specimens captured from either pool in 1994–1998 (Figure 6.2.2).

Collections containing weed shiners were mostly (70%) from sites with some submersed aquatic vegetation present (Figure 6.2.3). Seventy-one percent of weed shiner collection sites were in backwater or side channel border aquatic areas, and most collections (70%) were from locations with current velocities of 0.10 m/s or less. Backwater and side channel areas with low current velocities typically have soft substrates, but over half (54%) of weed shiner collection sites contained predominately hard substrate. Weed shiners appear sensitive to local changes in aquatic vegetation. During years with reduced levels of submersed aquatic vegetation in Pool 8 (i.e., 1994 and 1995), weed shiners were confined to mid-pool locations, but have since expanded to sites throughout the pool (Figure 6.2.4).

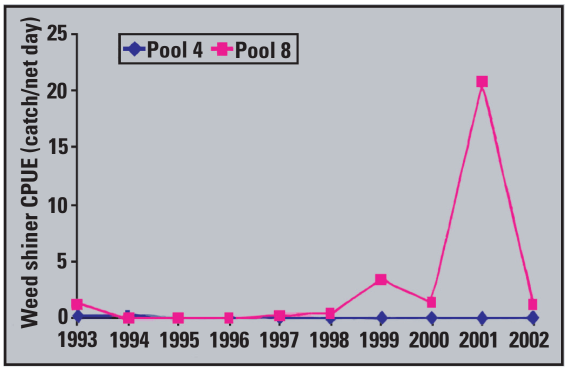


Figure 6.2.2. Weed shiner catch in mini-fyke nets 1993–2002 in Pool 4 and Pool 8 of the Upper Mississippi River.

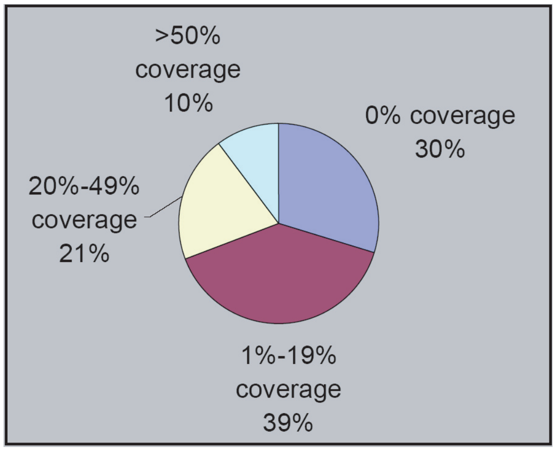


Figure 6.2.3. Weed shiner habitat preference. The percent coverage of aquatic vegetation at sites containing weed shiners in the Upper Mississippi River.

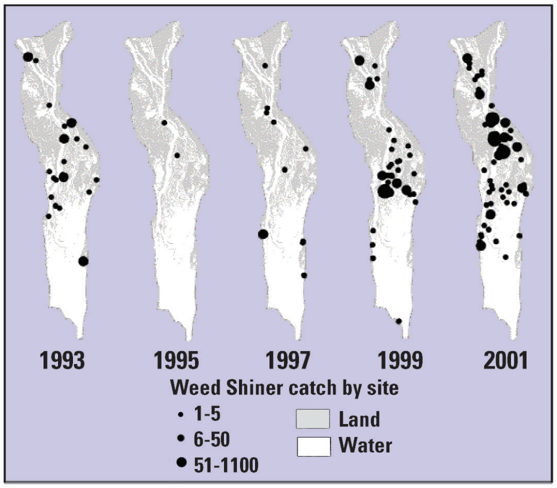


Figure 6.2.4. Weed shiner collection sites in Pool 8, Upper Mississippi River during years 1993, 1995, 1997, 1999, and 2001 as part of the Long Term Resource Monitoring Program.

Figure 6.3. Case study 2: Habitat Specialists Versus Habitat Generalists

Species comprising the UMRS fish community can be split into two basic groups, habitat specialists and habitat generalists, based upon habitat use. Habitat generalists possess adaptations (e.g., high fecundity) that promote success across multiple habitats, while habitat specialists possess adaptations that provide a competitive advantage within specific habitat types (e.g., dorsal-ventral flattening, highly developed olfactory organs, tolerance to low dissolved oxygen).

Understanding the habitat-use is an essential component of evaluating the significance of trends in the abundance and distribution of fish species. For example, an increasing trend in the abundance of a habitat generalist, such as fathead minnows (*Pimephales promelas*), may signal temporal instability or decreased habitat heterogeneity. Conversely, an increasing trend in a habitat specialist, such as western sand darters (*Ammocrypta clara*), may signal temporal stability and the increased presence of a specific habitat (western sand darters prefer silt-free channel border habitat with sand/cobble substrate and low turbidity).

Pugnose minnows, river shiners, and bullhead minnows were three of the forty-one nongame species collected from Pool 4, during 1993–2002. All three species were collected from main channel, side channel and backwater aquatic areas, but the relative importance of the aquatic areas as habitat differed markedly among species (Figure 6.3.1).

Based upon aquatic-area use and the distribution of collection sites within the pool, bullhead minnows are habitat generalists (Figure 6.3.2). Pugnose minnows and river shiners exhibited more specific habitat preferences, with pugnose minnow collected predominately in backwater areas and river shiner collected predominately in channel habitats (Figure 6.3.3). This information suggests that pugnose minnows, river shiners, and bullhead minnows would be expected to respond differently to habitat change in channel or backwater areas.

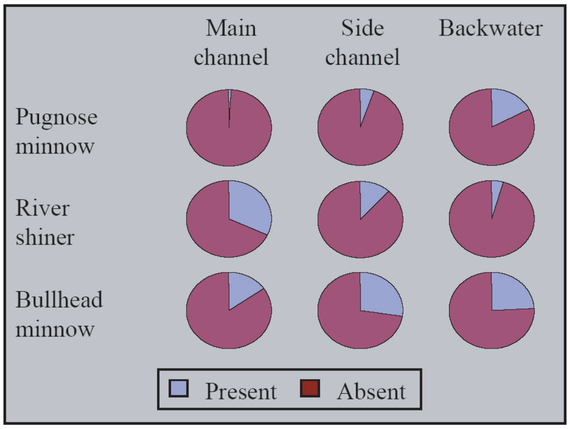


Figure 6.3.1. Frequency of occurrence of three non-game fish species in day electrofishing samples from main channel, side channel, and backwater shorelines in Pool 4, Upper Mississippi River during years 1993–2002.

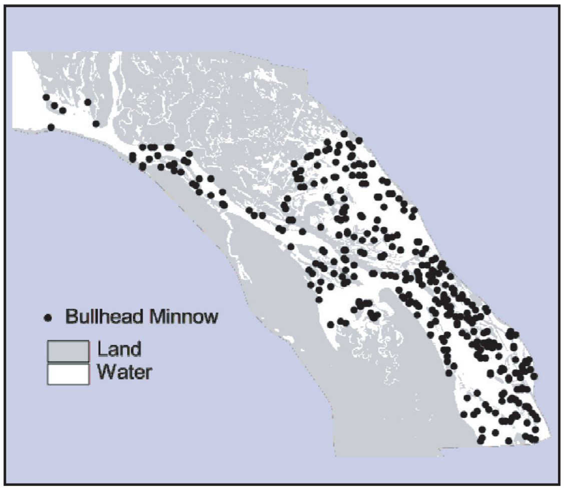


Figure 6.3.2. Bullhead minnow collection sites in lower Pool 4 (Lock and Dam 4 to Lake Pepin), Upper Mississippi River during years 1993–2002, as part of the Long Term Resource Monitoring Program.

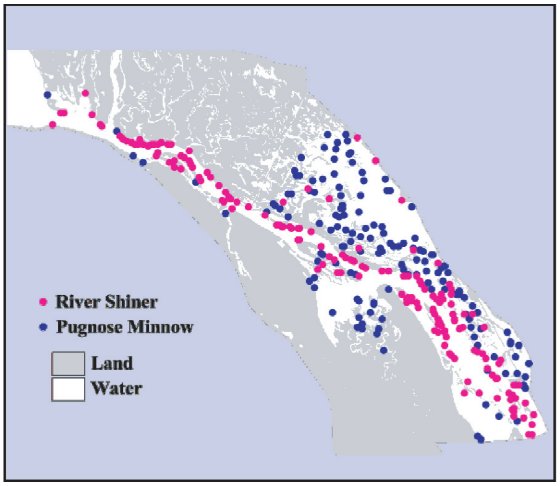


Figure 6.3.3. River shiner and pugnose minnow collection sites in lower Pool 4 (Lock and Dam 4 to Lake Pepin), Upper Mississippi River during years 1993–2002.

Figure 6.4. Case study 3: The Effect of Habitat upon Fish Species Distributions

Fish population abundance and distribution within the Upper Mississippi River System (UMRS) is largely determined by habitat suitability. Habitat suitability is a product of two factors, (1) the physiology and adaptations of the species, and (2) the available aquatic habitats. Aquatic habitat conditions in any given area of the UMRS are determined by local factors (e.g., current velocity, water depth, substrate) and systemic factors (e.g., climate, geology, land-use). The relationship between fish species distribution and habitat suitability provides an opportunity to assess UMRS habitat integrity and the relative importance of system and local controls.

Golden shiners (*Notemigonus crysoleucas*) and western mosquitofish (*Gambusia affinis*) were two of the seventy-five nongame fish collected by the Long Term Resource Monitoring Program (LTRMP) in years 1993-2002. Both western mosquitofish and golden shiners are most commonly associated with backwater habitats having low current velocities and dense vegetation. However, golden shiners are typically most abundant in backwaters with low turbidities and western mosquitofish are typically most abundant in shallow marginal areas (Pflieger 1997).

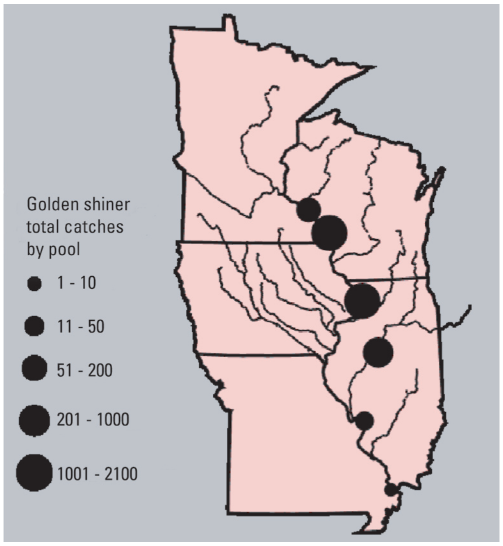


Figure 6.4.1. Golden shiner total catch from the six Long Term Resource Monitoring Program study areas during years 1993–2002.

Golden shiners were captured from all six LTRMP study areas, but were most abundant in Pools 4, 8, and 13 of the UMR and the La Grange Pool of the Illinois River (Figure 6.4.1). The study areas with the highest total catch of golden shiners were also the study areas with the highest portion of aquatic area comprised of contiguous backwater (Table 6.4.1).

Table 6.4.1. Composition of floodplains and aquatic areas within Long Term Resource Monitoring Program study areas. Data on floodplain composition are from Laustrup and Lowenburg (1994). Data on aquatic area composition are from the Long Term Resource Monitoring Program aquatic areas spatial database.

	Floodplain composition (%)		Aquatic area composition (%)	
Study area	**Open water**	**Aquatic vegetation**	**Contiguous backwater**	**Main channel**
Pool 4	51	10	21	11
Pool 8	40	14	31	14
Pool 13	30	9	29	25
Pool 26	13	1	17	54
Open River	10	1	2	79
La Grange Pool	16	2	52	21

Western mosquitofish have a limited distribution within the UMRS and were captured only within the three study areas located in the southern half of the UMRS (Figure 6.4.2). Mosquitofish are intolerant of water temperatures found in the northern study areas, and were absent from collections there despite an abundance of backwater habitat. Mosquitofish were most abundant in Pool 26, likely due to a combination of adequate amounts of backwater habitat and temperatures within thermal limits. The contrast between the distribution of golden shiners and western mosquitofish within the basin, highlights how species physiology and habitat dynamics combine to determine species distribution patterns and community composition. For example, temperature increases associated with global warning might allow western mosquito fish to expand their range into the northern UMRS.

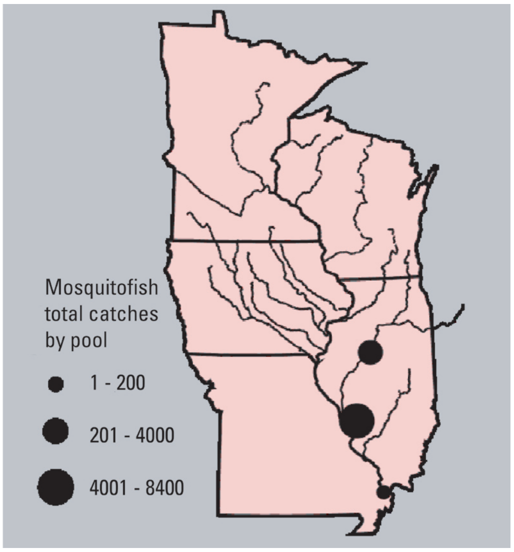


Figure 6.4.2. Western mosquitofish total catch from the six Long Term Resource Monitoring Program study areas during years 1993–2002. Western mosquitofish were not captured from Pools 4, 8, and 13.

abundance or distribution of nongame fish can be used to assess changes in local or systemic habitat features. The LTRMP sampling design permits unbiased assessment of reach-specific and systemic influences on nongame abundance. Coupled with range information, these data can be used to identify local and systemic habitat conditions responsible for population and community spatial patterns. In Case Study 3, we illustrate this potential by comparing catches of golden shiner and western mosquito fish (Figure 6.4).

Discussion and Management Implications

The LTRMP fish sampling design is primarily aimed at community assessment, but these data can be used to gain a better understanding of temporal and spatial patterns of nongame populations within the UMRS. Comparisons of current and future data will provide a valuable tool for assessing ecosystem health and habitat change.

The case studies presented illustrate the utility of making nongame distinctions in the context of a wider community-based monitoring initiative. To date most research effort has been directed at understanding community patterns and dynamics. However, future attempts to develop biological indicators of system health within the UMRS would likely benefit by focusing on nongame species.

Chapter 7: Exploited Species

Introduction

Many fish species within the UMRS are subject to recreational or commercial exploitation (Appendix A.2). These species represent a significant portion of the economic value of fishery resources in the UMRS; thus, natural resource managers are interested in tracking trends in these species to ensure exploitation is sustainable over time. Changes in abundance or size structure can help diagnose over-exploitation and determine the effects of management actions initiated to improve populations.

In the sections below, we present summarized data for selected species regarding abundance and spatial and temporal patterns in size structure. Our interpretation is necessarily limited because the large number of species combined with multiple river reaches and gears results in too many combinations of data to interpret within this document. However, we have provided graphics showing abundance and size structure for most of these combinations in appendixes accompanying this report on CD-ROM access data for all species, in raw and summarized forms, using the LTRMP Web-based data browsers (see Chapter 9).

Temporal Trends in Abundance

Data from stratified random sampling under LTRMP protocols are available beginning in 1993. The ability of the program to assess trends with 10 years of data is limited, but to make more meaningful interpretations will be substantially enhanced by additional years of data (see Chapter 8).

Annual abundance data are provided for 15 exploited species (black crappie, blue catfish, bluegill, channel catfish, common carp, flathead catfish, freshwater drum, largemouth bass, northern pike, sauger, shovelnose sturgeon, smallmouth buffalo, walleye, white bass, and white crappie) and two keystone forage species (emerald shiner and gizzard shad) from by a variety of gears in Appendixes B.1–B.26.

In general, no notable systematic trends were evident. However, some general trends for some species in particular study reaches were apparent. For example, common carp appeared to decline in abundance in many reaches (Appendix B.10), perhaps as a population level response to record high abundances recorded following the Great Flood of 1993. Both largemouth bass (Appendix B.15) and bluegill (Appendix B.5) showed notable increases in abundance in Pool 8, whereas populations show little trend in the remaining study areas. Pool 8 has been the site for numerous large scale habitat rehabilitation projects and whereas the upward trend in largemouth bass and bluegill cannot be directly attributed to these restoration efforts, trends indicate there may be an association. More detailed study will be required to determine the role of these projects in largemouth bass and bluegill responses. Finally, blue catfish have increased appreciably since 2000 in Pool 26 (Appendix B.4) for unknown reasons.

Spatial and Temporal Patterns in Size Structure

In Appendixes C.1–C.15 and D.1–D.21, we present 10-year trends in proportional stock density for bluegill, black crappie, largemouth bass, white crappie, common carp, channel catfish northern pike, flathead catfish, smallmouth buffalo, freshwater drum, sauger, walleye, and white bass for each LTRMP study area and for selected gears. Also, relative length frequency plots are provided for the same species for all LTRMP study areas and selected gears in Appendixes E.1–E.191. These tables and plots show patterns over time, and allow for spatial comparisons among LTRMP study areas. However, for some study areas and species-by-gear combinations, sample sizes were small, thus caution should be used when interpreting the relative frequency histograms, PSDs, and confidence intervals (see Anderson and Neumann 1996). In some instances, sample size was too small to calculate confidence intervals. Results from analyses that tested for spatial differences in size structure for several of the species are summarized in Chapter 3 and in Kirby and Ickes (In press).

Establishment of Benchmarks of Resource State

Although 10 years of data may be too short to reliably detect trends over time, they can be used to develop benchmarks for the mean abundance and range of variation of many fish species. The graphs in Appendix B show median abundance of selected fish species from 1993 to 2002 and the 10th and 90th percentiles as a measure of the observed variation. Data from future years can be compared to these baseline conditions to determine if they are outside the expected range of variation. Such comparisons can provide an early warning, or "red flag" system to identify situations when abundance of a particular species is outside its normal range. A red flag may not require immediate action, but would indicate an unusual condition needing further analysis or more attention in future years (Figure 7.1). The LTRMP data could define benchmark conditions for a large number of combinations of species, sampling area, strata, and gears. Certainly more interaction would be needed between research and managers to determine which of these combinations are most meaningful and what level of change would constitute a red flag. The criteria defining a red flag could vary based on the sensitivity of the species, but might include an absolute level of abundance, degree of change among successive years, and number of years abundance is outside the expected range. Different agencies might propose different thresholds for red flags specific to their needs.

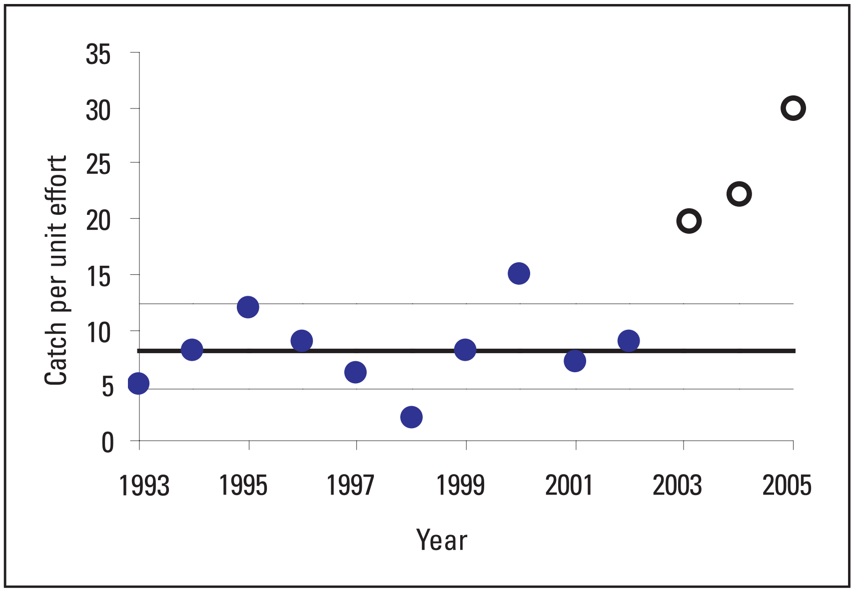


Figure 7.1. Heuristic example demonstrating how Long Term Resources Monitoring Program (LTRMP) fish data can be applied for identifying management relevant changes in resource state. The solid black line is the median catch per unit effort (CPUE) of a hypothetical species from one of the LTRMP fish sampling gears. The dashed lines are the 10th and 90th percentiles, defining the observed range of natural variation. The black dots are observed CPUE statistics for the 10-year benchmark period. The black open circles are hypothetical future observations, which are well above the 90th percentile. These observations might indicate the need for management action or more focused analyses of the situation.

Chapter 8: Statistical Considerations and Evaluations

Introduction

The primary goal of an ecological monitoring program such as the LTRMP is to detect changes in a measured response of interest, such as abundance of a species. This is typically accomplished using inferential statistics to determine if a change is significant or could have arisen simply by random chance. The ability to determine significant change based on statistical inferences depends on the statistical methods chosen, attributes of the data (e.g., type of data, sample size, the magnitude of the change, and variance), and the level of probability used to define significance. In this chapter we consider the ability to determine significant differences among various spatial units within the UMRS and the ability to detect significant changes over time. We also summarize results from a recent statistical assessment focusing on methodological redundancies.

Spatial Inferences

Several recent studies used LTRMP data to investigate spatial differences in fish species and community within the UMRS. Callahan (1998) provided the earliest assessment of the ability of LTRMP fisheries data to discriminate spatial differences. Using cluster analysis methods, Callahan (1998) investigated differences in fish communities among study areas. He concluded that the northern study reaches (Pools 4, 8, and 13) were more similar in their fish communities than the southern study areas (Pool 26, La Grange Pool, and Open River) and that fish communities in the northern study areas differed notably from the southern study areas. However, he also concluded that each study area differed in some important way from all others and thus each area provided unique information on UMRS fish communities. Similar findings were reported by Chick and Pegg (2004), Chick et al. (2005), and Barko et al. (2005).

Koel (2004) investigated differences in species richness estimates among LTRMP study areas and among sampling strata within and among study areas. Richness measured by day electrofishing was significantly higher in the northern study areas than the southern study areas, and also significantly higher in contiguous off-channel habitats than in channel habitats, irrespective of study area. Recent studies have also demonstrated differences in community level responses as a function of spatial patterns in habitat among keypools (Chick et al. 2005; Chick and Pegg 2004).

Kirby and Ickes (In press) investigated differences in single species abundance among study areas and among sampling strata within and among study areas. Spatial differences were found in the abundance dynamics for 75 different species partitioned by size classes.

Thus, the LTRMP data appear adequate for detecting and modeling differences in fish communities across space. Also, the data can provide sufficient ability to detect and model single species responses for many species of interest. Data from a community monitoring program, however, will probably be insufficient for reliably detecting spatial differences of species collected in low numbers, such as rare, threatened, and endangered species (Lubinski et al. 2001).

Temporal Inferences

Lubinski et al. (2002) investigated the statistical power of LTRMP fish component data to detect changes of 20% and 50% in species abundance from one year to the next. Statistical power is a function sample size, desired level of significance, and the size of the effect one wants to detect.

Lubinski et al. (2002) found that power varied considerably among sampling methods and species. Electrofishing tended to provide the greatest power to detect inter-annual changes in abundance. However, for some species, fyke nets or hoop nets provided greater power than electrofishing. Forty-one species exhibited substantial power, defined as greater than 70% power to detect a 20% change in abundance from one year to the next at $\alpha = 0.05$ in at least one study area. Doubling sample size resulted in 54 species exhibiting substantial power, whereas halving sampling size reduced the number to 25 species. Power to detect change in uncommon species was poor at any sample size.

The ability to detect inter-annual change is important for the early warning functions of a monitoring program, but equally important is the ability to detect trends over time. In 2004, LTRMP researchers began investigating how long it will take to achieve acceptable levels of power to detect long-term trends for selected species and water quality parameters.

Preliminary results from these investigations can be found on the Web at http://www.umesc.usgs.gov/ltrmp/power_plots.html (Brian Gray, Upper Midwest Environmental Sciences Center, personal communication). For fishes, the power to detect a trend in bluegill catch-per-unit-effort in Pool 4 resulting from an underlying 5% annual change was 60% after 14 years and 80% after 17 years. However, with a 10% annual change, power reached 60% in 9 years and 80% in 11 years. Among LTRMP sampling areas, power to detect trends in bluegill CPUE under the standard fish sampling design was highest in Pools 4 and 8 and La Grange Pool, lowest in the Open River, and intermediate in Pools 13 and 26. In all cases, doubling or halving the sampling effort had negligible effects on either power or the time it takes to achieve such power. Thus, the general conclusion is that annual sample size or effort has relatively little effect on the ability to detect trends and that power is primarily a function of the number of years in the time series.

Methodological Redundancies

Lubinski et al. (2002) concluded that the LTRMP fish sampling design may exhibit methodological redundancies because some sampling gears provided very low ability to detect annual changes in abundance for all species. However, detecting annual change is only one perspective from which to consider the value of multiple gears in a community-based sampling design. Other criteria would include characterizing community composition and structure, measuring change in single species detection frequencies, and measuring species size distributions. Thus, an in-depth study was initiated in 2001 to determine if different sampling methods provided redundant information regarding the biological metrics (Ickes and Burkhardt 2002).

Ickes and Burkhardt (2002) used a retrospective simulation analysis, in which past observations were used to predict future observations under different gear reduction scenarios. Differences in community composition and structure, and single-species catch per unit effort, size structure, and trend detection were the criteria for comparing alternative designs. Selection of reduction scenarios to consider was conducted in concert with program partners.

Based on statistical analysis of the monitoring data and program partner input, Ickes and Burkhardt (2002) concluded that 4 of 10 sampling gears historically used could be removed from the sampling protocols with minor effects on the quantity and quality of information provided by the fish component. These changes, implemented in 2002, represented about a 33% reduction in sampling effort across the program. By redirecting that effort into scientific investigations on the monitoring data themselves, these changes have enhanced the fiscal and scientific efficiency of the program.

In any long-term monitoring program, breaks in data continuity can potentially invalidate assessments of the status and trends of the resource, and significantly hamper efforts to model ecological responses and to assess the effects of management actions. These were serious considerations for Ickes and Burkhardt (2002). They reported that data continuity back to 1993, when stratified random sampling began, was nearly perfectly preserved (Figure 1.2). Notable exceptions are breaks for the four sampling gears removed from the program and the elimination of two sampling strata (impounded offshore and backwater contiguous offshore strata) sampled exclusively by two of the four gears eliminated. Assessments revealed, however, that these offshore strata did not provide any unique information not captured in the nearshore counterpart of each stratum (Ickes and Burkhardt 2002).

Chapter 9: Quality Assurance and Data Serving Objectives

Introduction

One of the primary goals of LTRMP is to maintain and serve quality data in ways that are accessible and useful to a broad community of data users. All LTRMP data are subjected to well-documented quality control procedures. Below we briefly discuss the evolution of quality assurance standards for the fisheries component, describe how data are served to data users, and highlight new approaches that have been developed to serve program data in alternative, intuitive ways. The LTRMP stands as a national leader in serving complex monitoring data to the public.

Evolution of Quality Assurance Procedures

Sampling protocols, data standards, and quality assurance methods were developed and implemented at the earliest stages of the program in the late 1980s and have changed little in substance or scope since then. These aspects of the program are well-described by Gutreuter et al. (1995). What has changed is how data flow through this process. These changes have resulted in significant efficiencies being realized, resulting in lower costs, lower error rates, and reduced log times for making new data publicity available. Below, we briefly contrast the quality assurance process in the earliest stages of the program against the process used today.

The journey of all data through the LTRMP fish component quality assurance process begins at the point of collection. Each gear deployment, in one place and time, represents a sample. Each sample is uniquely identified in the central database by a barcode and is also geo-referenced to the location where the sample was collected.

Early in the program, data were collected on paper data sheets in the field. Each sample had a unique data sheet associated with it. At the end of the sampling year, these data sheets were copied for archiving and shipped to a data entry contractor for conversion to electronic files. Upon completion of data entry, databases were shipped back to UMESC and computer programs were run to flag suspect observations based on sampling protocol codes and methods (e.g., unrecognized codes, discrepancies in data tracking fields, etc.). Flagged records were sent back to the field stations for data reconciliation. The exchange between UMESC and the field stations would continue until each error was resolved. This process usually took months to complete.

Beginning in 2002, the LTRMP developed specialized computer software running on rugged laptop computers to enter data in the field, thus removing the need for a data entry contractor. The software conducts real-time error detection based on logic inherent in the sampling protocols and in the historical quality control programs. The result, therefore, is data quality audits occur instantaneously in the field, where they can be most accurately addressed. Early in the program, it was not uncommon for 50% or more of the data sheets to be flagged for data errors. Today, that error rate is well below 1%, and data quality assurance audits now take about a week to complete.

These changes have produced multiple benefits. The evolution of the quality assurance process has saved thousands of dollars annually, reduced error rates, decreased the time it takes to assure the quality of program data, and freed human resources for other tasks, such as analysis of monitoring data. Data also are now served to program partners and the public much more quickly, allowing the most recent data to enter into management decisions within the UMRS basin.

Serving Program Data to Partners and the Public

Since its inception, the LTRMP has continually improved the methods by which data are collected, processed, and served. Users have ready access to what is perhaps the world's best source of ecological data on large rivers through the World Wide Web. Web-based browsers have been developed that provide simple and flexible query tools for the entire LTRMP fish component database housed at UMESC. This interface is available at: http://www.umesc.usgs.gov/data_library/fisheries/fish1_query.html. This browser returns raw data to the user. Turning these raw data into useful information requires summarization, analyses, and interpretation. Thus, LTRMP staff also produce annual summaries, technical reports, and professional papers that synthesize and interpret monitoring data in a variety of ways. These resources are available at http://www.umesc.usgs.gov/reports_publications/ltrmp_rep_list.html.

Although raw data are very useful for research purposes, analyzing these data is computer-intensive and requires a detailed understanding of the LTRMP sampling design. Many users do not have the time or resources to do this. Thus, in 2002, we developed a new approach to serving LTRMP data that complements existing methods described above. We chose to test the new approach on the LTRMP fisheries database because this large, complex database provided a good test of our concepts. To demonstrate the complexity, consider that since 1993 LTRMP fish component personnel have made more than 25,000 samples and collected more than 3 million fish of 134 different species. These observations are spread across 6 study areas and are collected using 10 different gear types deployed within eight different sampling strata.

We developed a new tool for serving summarized status and trend data known as the Graphical Fish Database Browser. For this tool, we summarized the fisheries database to derive a suite of population and community metrics, generated new databases containing these metrics, and then built a Web application to search and display information from these new databases. The Graphical Fish Database Browser features an easy-to-use interface and requires only basic computer knowledge. It is accessible at http://www.umesc.usgs.gov/data_library/fisheries/graphical/fish_front.html.

Six population and community metrics are available to search. Population metrics focus on abundance (catch per unit effort), size structure (proportional stock density), and how often a species is collected (frequency occurrence). Community metrics focus on patterns in the individual species collected each year within a study reach (species list), comparisons of the different species collected across study reaches (community composition), and trends in the total number of species collected annually within each study reach (species richness).

After the user selects a metric, a more detailed search interface is provided that allows the user to select data fields from a series of three to five drop-down lists. Results of the search are provided as an interactive graphic, or a data table, depending on the metric selected. The results page has many additional features, including the ability to print the graphics generated, view an interactive map of the study reaches, and download a text file of the search results for more detailed analysis or presentation quality plotting.

The Graphical Fish Database Browser helps fulfill a primary LTRMP goal of providing ready access to monitoring data. This new tool does not replace the former browser interface, but supplements and enhances it. Users can still perform detailed searches on the full dataset using the old browser utility. However, the new browser allows easy access to summarized data that can answer many common questions about the status and trends of fishes within the UMRS.

Chapter 10: Future Directions

A rationale for Continued Standardized Monitoring

The Upper Mississippi River System is a national treasure, both for the social services it humanity (e.g., commercial navigation, recreation, aesthetics) as well as for its ecological significance. Monitoring is a fundamental tool in expanding our knowledge of the ecology of the UMRS and for understanding and managing multiple use demands on its ecosystem.

The LTRMP continues to stand as a national model for ecosystem monitoring. Most significant is the role that LTRMP plays in the adaptive management of the UMRS. At the most basic level, monitoring provides the foundational data for understanding of how ecological attributes are distributed across space and how they vary over time in response to both natural and anthropogenic influences. Detection of such responses is essential for identifying and developing alternative management solutions and for measuring the success of management actions.

The capability of a monitoring program to provide such functions is entirely dependent on its scope, rigor, and the length of time it has existed. In the LTRMP, standardized protocols are well documented and adhered to, ensuring unbiased, scientifically defensible data. The distribution of LTRMP study areas across the UMRS provides sufficient scope to detect local and regional influences on the ecology of the UMRS. At 10 years, the LTRMP is transitioning from a period of maturation in data collection, processing, and serving into a period of enhanced understanding through research and analyses using the monitoring data. These capabilities and the unique insights they provide will only continue to enhance the value of the LTRMP to managers, scientists, and the public. However, realizing these benefits will require continued commitment to the role of monitoring in the adaptive management of the UMRS.

Toward an Integrated Understanding

As the LTRMP transitions into a period of enhanced understanding, we will need to integrate knowledge across all of the ecological components. The first step toward such integration lies in understanding patterns and dynamics within each of the ecological components LTRMP monitors (fish, aquatic vegetation, water quality, aquatic invertebrates). Indeed, this report summarizes material from several recent studies that investigated patterns and dynamics within the fish component (Chick et al. 2005; Barko et al. 2005; Kirby and Ickes In press; Irons et al. In press).

Central to nearly all of these studies was the relative role that space and time play in determining fisheries dynamics at both community and population. By understanding how fish responses are structured across space and how they respond over time, we can begin to integrate ecological knowledge. For example, if some given fisheries response is spatially repeatable, the attributes of this response are likely spatially determined. Knowing this has two primary benefits.

First, if other components monitored by LTRMP demonstrate similar patterns and dynamics and these are also spatially repeatable, then such patterns suggest that ecological responses are dependent on different aspects of physical organization within the system. This is a powerful perspective from which to approach integrated understanding. Second, if responses are spatially repeatable, investigators can choose to cautiously ignore temporal dynamics because they are a minor component of overall variation in the response of interest. The consequence of this is that sample size, or data density per unit area, increases significantly (e.g., analyzing 10 years worth of data versus 1 year for any given spatial extent), resulting in greater statistical power to make inferences. Also, understanding spatial scale in ecological responses permits informed modeling of processes (see Chapters 2 and 3).

Within the fisheries component, greater integrated understanding can arise from developing new ways to recast LTRMP data to gain additional insights. As an example, the fisheries component is actively developing a life history database that describes for each fish species in the UMRS, its reproductive and feeding strategies, as well as a host of other species-specific traits. Species sharing similar traits can be classified together into ecological guilds (e.g., reproductive guild, feeding guild, etc.), and analyses can then focus on functional aspects of fish communities. For example, are there significant spatial differences in the biomass of zooplanktivores and insectivores? Do any differences correlate with measures of system productivity, or food web structure? In this way, additional integrated understanding is achieved.

Enhancing Management and Scientific Relevance

Ultimately, the truest test of a monitoring program is whether it is relevant to those who use the data and the information it provides; namely, natural resource managers and scientists. Certainly, the relevance of a monitoring program increases over time, as changes in status and trends of important resources can be more reliably detected (see Chapter 8), and this information can be directly incorporated into management actions and question-driven scientific investigations. Program relevance also is enhanced by serving data to different audiences in different formats (e.g., the Graphical Fish Database browser, see Chapter 9). The LTRMP has actively pursued alternative, useful ways to serve program data over the past 10 years and stands as a national leader in developing and implementing such methods. Finally, as enhanced understanding of the ecology of the UMRS is derived from the LTRMP data, the monitoring program will become central to inquiry-based scientific investigations throughout the basin.

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References

Anderson, R. O. 1976. Management of small warmwater impoundments. Fisheries 1(6):5–7.

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447–482 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques. 2nd edition. American Fisheries Society, Bethesda, Maryland.

Anonymous. 1988. Mighty Mississippi is full of secrets. Chester Herald Tribune (Randolph County Herald Tribune), 21 September 1988.

Bailey, W. B. 1975. An evaluation of striped bass introductions in the southeastern United States. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 28:54–64.

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. A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP 2005-T002. 27 pp.

Bartels, A. D. 1995. Growth of selected fishes in Navigation Pool 8 of the Upper Mississippi River: A test of the flood-pulse concept. M.S. Thesis, University of Wisconsin-La Crosse, La Crosse, Wisconsin. Reprinted by U.S. Geological Survey, Environmental Management Technical Center, Onalaska, Wisconsin.

Becker, G. C. 1983. The fishes of Wisconsin. University Press, Madison.

Bond, C. E. 1979. Biology of fishes. Saunders College Publishing. Philadelphia.

Bowler, M. C. 2001. Recent observations of the distribution and status of bluntnose darters and crystal darters in Iowa. Journal of the Iowa Academy of Science 108(1):15–18.

Bowler, M. C. 2003. Recent observations of the distribution and status of freckled madtom and first record of spotted gar in Iowa. Journal of the Iowa Academy of Science 110(3–4):40–43.

Burkhardt, R. W., S. DeLain, E. Kramer, A. Bartels, M. C. Bowler, F. A. Cronin, M. D. Petersen, D. P. Herzog, T. M. O'Hara, and K. S. Irons. 2000. 1998 Annual status report: A summary of fish data in six reaches of the Upper Mississippi River System. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, June 2000. LTRMP 2000-P004. 14 pp. + Chapters 1–6.

Burr, B. M., D. J. Eisenhour, K. M. Cook, C. A. Taylor, G. L. Seegert, R. W. Sauer, and E. R. Atwood. 1996. Nonnative fishes in

Illinois waters: What do the records reveal? Transactions of the Illinois State Academy of Science 89(1/2):73–91.

Burr, B. M., and R. L. Mayden. 1980. Dispersal of rainbow smelt, *Osmerus modax*, into the Upper Mississippi River (Pisces: Osmeridae). American Midland Naturalist, 104(1):198–201.

Burr, B. M., and L. M. Page. 1986. Zoogeography of fishes of the Lower Ohio-Upper Mississippi Basin. Pages 287–324 *in* C. H. Hocutt and E. O. Wiley, editors. The zoogeography of North American freshwater fishes. John Wiley & Sons, New York.

Callahan, E. 1998. Similarities between Upper Mississippi River pools included in the Long Term Resource Monitoring Program (LTRMP). Unpublished. Environmental Statistics, P.O. Box 563, Fountain City, Wisconsin 54629.

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.

Carlton, J. T. 2001. Introduced species in U.S. coastal waters: Environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia.

Chick, J. H. 2002. Asian carp in the Upper Mississippi River System. Illinois Natural History Survey Report. Spring 2002.

Chick, J. H., and M. A. Pegg. 2001. Invasive carp in the Mississippi River Basin. Science 292:2250–2251.

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 2004-T001. 21 pp.

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. A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP 2005-T002. 15 pp.

Cochran, W. G. 1977. Sampling techniques, 3rd edition. John Wiley and Sons, New York. 428 pp.

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.

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication Number 27, Bethesda, Maryland.

Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273–285.

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.

Gent, R., J. Pitlo, Jr., and T. Boland. 1995. Largemouth bass response to habitat and water quality rehabilitation in a backwater of the upper Mississippi River. North American Journal of Fisheries Management 15: 784–793.

Gomez, R., and H. L. Lindsay. 1972. Occurrence of Mississippi silversides, *Menidia audens*

(Hay), in Keystone Reservoir and the Arkansas River. Proceedings of the Oklahoma Academy of Sciences 52:16–18.

Grady, J., J. Milligan, C. Gemming, D. Herzog, G. Mestl, L. Miller, D. Hernig, K. Hurley, P. Wills and R. Sheehan. 2001. Pallid and shovelnose sturgeon in the lower Missouri and Middle Mississippi rivers. Final Report Prepared for Mississippi Interstate Cooperative Resource Association. Bettendorf, Iowa. 45 pp.

Gustafson, K. A. 1988. Approximating confidence intervals for indices of fish population size structure. North American Journal of Fisheries Management 8:139–141.

Gutreuter, S. 1993. The need for stratified spatially randomized sampling of fishes in the Long Term Resource Monitoring Program. Report to the LTRMP Analysis Team. U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin.

Gutreuter, S., A. D. Bartels, K. Irons, and M. B. Sandheinrich. 1999. Evaluation of the flood-pulse concept based on statistical models of growth of selected fishes of the Upper Mississippi River system. Canadian Journal of Fisheries and Aquatic Sciences 56: 2282–2291.

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.

Hrabik, R. A. 1996a. A new distributional record of *Notropis topeka* (Teleostei: Cypriniformes) from the Mississippi River drainage in Missouri. Transactions of the Missouri Academy of Science 30:1–5.

Hrabik, R. 1996b. Taxonomic and distributional status of *Notropis volucellus* and *Notropis wickliffi* in the Mississippi River drainage: A literature review. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, July 1996. LTRMP 96-S001. 15 pp.

Hrabik, R. A. 1997. Distributional status of uncommon fishes and an amphibian from northeastern Missouri. The Prairie Naturalist 29(3):151–169.

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 Science Center, La Crosse, Wisconsin, October 2002. LTRMP 2002-T001. 17 pp. + Appendixes A–E.

Irons, K. S., S. DeLain, E. Gittinger, B. S. Ickes, C. Kolar, D. Ostendorf, and E. Ratcliff. In press. Nonnative fishes in the Upper Mississippi River System. A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP.

Jackson, G. A., C. E. Korschgen, P. A. Thiel, J. M. Besser, D. W. Steffeck, 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.

Jennings, D. P. 1988. Bighead carp (*Hypophthalmichthys nobilis*): A biological synopsis. U.S. Fish and Wildlife Service, Biology Report 88: 1–35.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pages 110–127 *in* D. P. Dodge, editor. Proceedings of the international large river symposium. Canadian Special Publication of Fisheries and Aquatic Sciences 106.

Kirby, D. J. and B. S. Ickes. In press. Temporal and spatial trends in the frequency of occurrence, length-frequency distributions, rate of gain, and relative abundance of upper Mississippi River fish. A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP.

Kirby, D. J. 2001. An assessment of the channel catfish population in the Big Sioux River, South Dakota. M.S. Thesis, South Dakota State University, Brookings, South Dakota.

Koel, T. M. 2004. Spatial variation in fish species richness of the Upper Mississippi River System. Transactions of the American Fisheries Society 133:984–1003.

Laird, C. A., and L. M. Page. 1996. Nonnative fishes inhabiting the streams and lakes of Illinois. Illinois Natural History Survey Bulletin 35(1):1–51.

Laustrup, M. S., and C. D. Lowenberg. 1994. Development of a systemic land cover/land use database for the Upper Mississippi River System derived from Landsat Thematic Mapper satellite data. National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin.

Legendre, P., and L. Legendre. 1998. Numerical ecology. Second edition. Elsevier, Amsterdam, The Netherlands.

Lubinski, K. R., R. Burkhardt, J. Sauer, D. Soballe, and Y. Yin. 2001. Initial analyses of change detection capabilities and data redundancies in the Long Term Resources Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, September 2001. LTRMP 2001-T001. 23 pp. + Appendixes A–E.

McCarraher, D. B., and R. W. Gregory. 1970. Adaptability and current status of introductions of Sacramento perch, *Archoplites interruptus*, in North America. Transactions of the American Fisheries Society 99:700–707.

Mestl, G. 1999. Changes in Missouri River channel catfish populations after closing commercial fishing. Pages 455–460 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1994. Exotic species and the integrity of the Great Lakes. BioScience 44:666–676.

Mooney, H. A. and R. J. Hobbs (eds.). 2000. Invasive species in a changing world. Island Press, Washington, D.C. 457 pp.

National Biological Service, Illinois Natural History Survey, Iowa Department of Natural Resources, and Wisconsin Department of Natural Resources 1994. Long Term Resource Monitoring Program 1993 Flood Observations. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, LTRMP 94-S011.

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.

Northcote, T. G. 1988. Fish in the structure and function of freshwater ecosystems: A “top-down” view. Canadian Journal of Fisheries and Aquatic Sciences 45:361–379.

O’Donnell, J. J. 1935. Annotated list of the fishes of Illinois. Illinois Natural History Survey Bulletin 20:473–500.

Owens, T., and J. J. Ruhser. 1996. Long Term Resource Monitoring Program standard operating procedures: Aquatic areas database production. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, March 1996. LTRMP 95-P008-6. 4 pp. + Appendix.

Patrick, R. 1998. Rivers of the United States. The Mississippi River and Tributaries.

Volume 4, Parts A & B. John Wiley and Sons, New York.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53–65.

Pitlo J., A. Van Vooren, and J. Rasmussen. 1995. Distribution and relative abundance of Upper Mississippi River fishes. Upper Mississippi River Conservation Committee, Rock Island, Illinois. 20 pp.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation, Jefferson City. 343 pp.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation, Jefferson City.

Poff, N. L., and J. V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. Canadian Journal of Fisheries and Aquatic Sciences 46: 1805–1817.

Quinn, S. P. 1991. Evaluation of a length-categorization system for flathead catfish. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 43(1989):146–152.

Rasmussen, J. L. 1979. A compendium of fishery information on the Upper Mississippi River. 2nd edition. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Rasmussen, J. L. 1998. Aquatic nuisance species of the Mississippi River Basin. 60th Midwest Fish and Wildlife Conference, Hyatt Regency Hotel, Cincinnati, Ohio. December 7, 1998.

Risotto, S. P., and R. E. Turner. 1985. Annual fluctuation in abundance of commercial fisheries of the Mississippi River and tributaries. North American Journal of Fisheries Management 5: 557–574.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. Common and scientific names of fishes from the United States and Canada. 5th edition. Special Publication 20. American Fisheries Society, Bethesda, Maryland. 183 pp.

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.

Smith, H. M., 1896. A review of the history and results of the attempts to acclimatize fish and other water animals in the Pacific states. Bulletin of the U.S. Fish Commission for 1895, 40:379-472.

Smith, P. W. 1979. The fishes of Illinois. University of Illinois Press, Urbana, Illinois. 314 pp.

Smith, P. W., A. C. Lopinot, and W. L. Pflieger. 1971. A distributional atlas of upper Mississippi River Fishes. Biological Notes Number 73, Illinois Natural History Survey, Urbana, Illinois.

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.

Spink, A., and S. Rogers. 1996. The effects of a record flood on the aquatic vegetation of the Upper Mississippi River System: some preliminary findings. Hydrobiologia 340:51–57.

Tarboton, D. G., R. L. Bras, and I. Rodriguez-Iturbe. 1988. The fractal nature of river networks. Water Resources Research 24:1317–1322.

Theiling, C. 1999. The Illinois River. Chapter 14 *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.

Timmons, T. J., and T. A. Hughbanks. 2000. Exploitation and mortality of paddlefish in the lower Tennessee and Cumberland Rivers. Transactions of the American Fisheries Society 129: 1171–1180.

Tockner, K. and J. A. Stanford. 2002. Riverine flood plains: present state and future trends. Environmental Conservation 29:308–330.

Travnichek, V. H., and H. D. Clemons. 2001. Utility of tournament data for assessing effects of eliminating commercial catfish harvest in the Missouri River. North American Journal of Fisheries Management 21: 688–691.

Tucker, J. K., and F. A. Cronin. 1996. The western sand darter (*Ammocrypta clara*) in Pool 26 of the Mississippi River in Missouri and Illinois. Transactions of the Illinois State Academy of Science 89(3 and 4):221–224.

Tucker, J. K., F. A. Cronin, R. A. Hrabik, M. D. Petersen, and D. P. Herzog. 1996. The bighead carp (*Hypophthalmichthys nobilis*) in the Mississippi River. Note in Journal of Freshwater Ecology 11:241–243.

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.

Van Den Avyle, M. J. and R. S. Hayward. 1999. Dynamics of exploited fish populations. Pages 127–163 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607–615.

Appendix A

Annual allocation of fish sampling effort (Appendix A.1); list of fish species collected with four-letter codes and exploitation status (Appendix A.2); and number caught of each fish species, percentage of total catch, and numerical rank over all years and study areas (Appendix A.3) and annually for each study area (Appendixes A.4–A.9) in the Long Term Resource Monitoring Program, 1993–2002.

(Appendixes A–E are presented on the accompanying CD-ROM)

Appendix B

Mean annual catch-per-unit-effort, median catch, and 10% and 90% quartiles for selected fish species captured by various gears in each of the six study areas of the Long Term Resource Monitoring Program, 1993–2002 (Appendixes B.1–B.26).

(Appendixes A–E are presented on the accompanying CD-ROM)

Appendix C

Graphs of annual proportional stock density for selected combinations of fish species and gear in study areas of the Long Term Resource Monitoring Program, 1993–2002 (Appendixes C.1–C.15).

(Appendixes A–E are presented on the accompanying CD-ROM)

Appendix D

Tables of proportional stock density with 80% confidence interval for selected fish species captured in various gears in each of the six study areas of the Long Term Resource Monitoring Program, 1993–2002 (Appendixes D.1–D.21).

(Appendixes A–E are presented on the accompanying CD-ROM)

Appendix E

Length frequency histograms for selected fish species captured by various gears in each of the six study areas of the Long Term Resource Monitoring Program, 1993–2002 (Appendixes E.1–E.191). Length intervals are based on sizes used for determining stock density relations.

(Appendixes A–E are presented on the accompanying CD-ROM)

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13. ABSTRACT (Maximum 200 words)

Abstract: Fisheries data are collected in the Upper Mississippi River System (UMRS) under the Long Term Resource Monitoring Program (LTRMP). From 1993 to 2002, monitoring activities were conducted at six primary study areas in the UMRS, Navigation Pools 4, 8, 13, 26, and the Open River reach in the Mississippi River and the La Grange Pool in the Illinois. The monitoring began with LTRMP in 1989 for all study areas except the Open River reach, which began in 1991. Since 1993, LTRMP staff have completed 24,791 samplings in the 6 study areas and collected more than 3 million fish of 134 species. From 1993 to 2002, the most fish species (98) were collected in the Open River reach and the fewest species (83) collected in Pool 13.

14. SUBJECT TERMS Fish community structure, habitat, Illinois River, Long Term Resource Monitoring Program, Mississippi River, native species, nonnative species, stratified random sampling.	15. NUMBER OF PAGES 60 pp + Appendixes A–E
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The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP 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 is a cooperative effort by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.