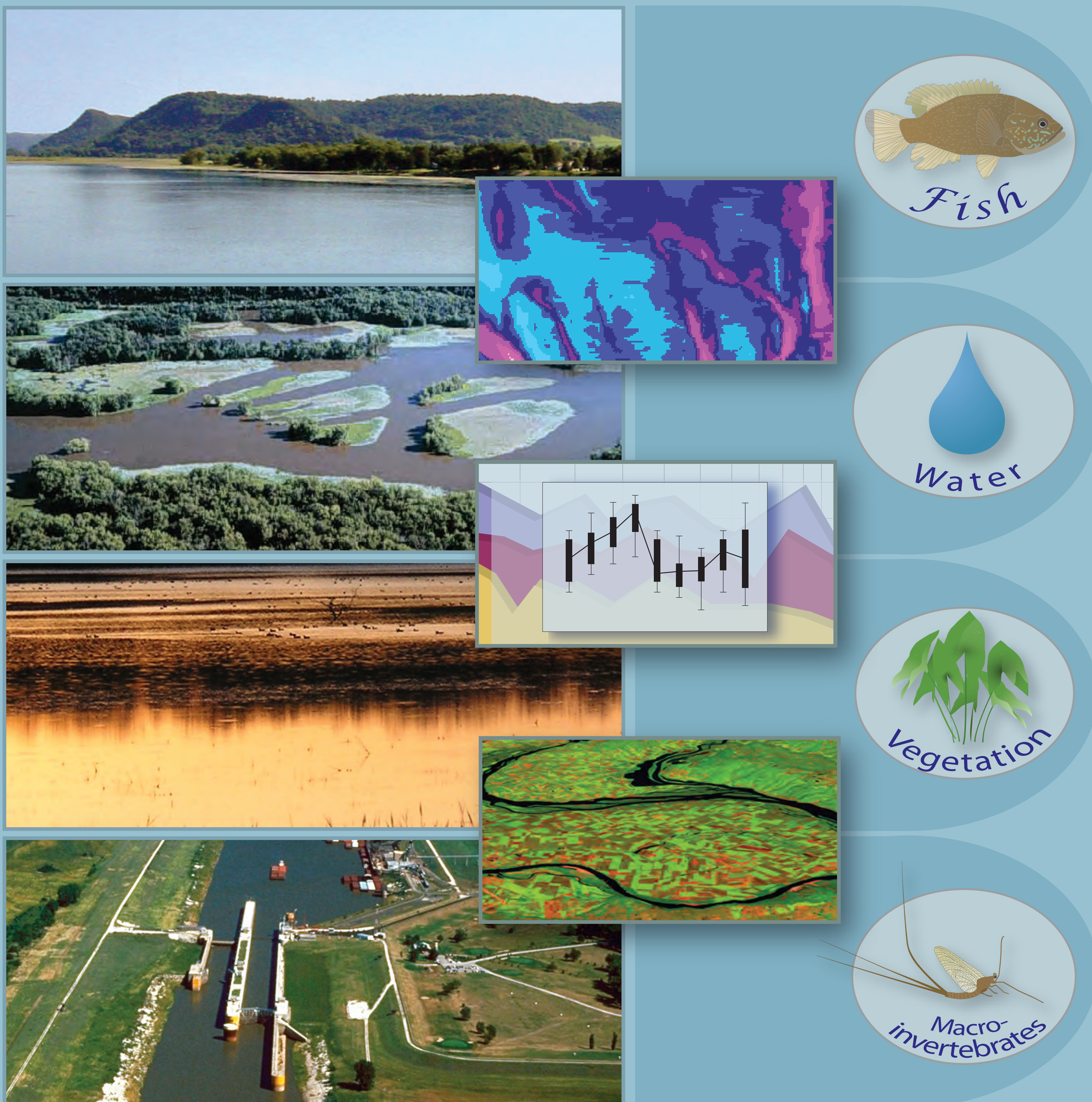
Long Term Resource Monitoring Program

Status and Trends of Selected Resources of the Upper Mississippi River System



Status and Trends of Selected Resources of the Upper Mississippi River System

A Synthesis Report of the
Long Term Resource Monitoring Program

Edited by

Barry L. Johnson and Karen H. Hagerty

U.S. Geological Survey
Upper Midwest Environmental Sciences Center
2630 Fanta Reed Road
La Crosse, Wisconsin 54603

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Edited by
Barry L. Johnson
U.S. Geological Survey, Upper Midwest Environmental Sciences Center
2630 Fanta Reed Road, La Crosse, Wisconsin 54603
and
Karen H. Hagerty
U.S. Army Corps of Engineers, Rock Island District
Clock Tower Building, P.O. Box 2004, Rock Island, Illinois 61204

Section Authors
Robert F. Gaugush, Jeffrey N. Houser, Brian S. Ickes, Kirk Lohman, John C. Nelson,
Larry R. Robinson, James T. Rogala, Jennifer S. Sauer, and Yao Yin
U.S. Geological Survey, Upper Midwest Environmental Sciences Center
2630 Fanta Reed Road, La Crosse, Wisconsin 54603

Sandra K. Brewer
U.S. Army Corps of Engineers, Rock Island District
Clock Tower Building, P.O. Box 2004, Rock Island, Illinois 61204

J. Therese Dukerschein and James R. Fischer
Wisconsin Department of Natural Resources, Onalaska Field Station
2630 Fanta Reed Road, La Crosse, Wisconsin 54603
and
John H. Chick
Great Rivers Field Station, Illinois Natural History Survey
8450 Montclair Avenue, Brighton, Illinois 62012

U.S. Geological Survey
Upper Midwest Environmental Sciences Center
2630 Fanta Reed Road
La Crosse, Wisconsin 54603

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Executive Summary

The Upper Mississippi River System

Like other large rivers, the Upper Mississippi River System (UMRS) serves a diversity of roles. The UMRS provides commercial and recreational fishing, floodplain agriculture, drinking water for many communities, an important bird migration pathway, a variety of recreational activities, and a navigation system that transports much of the country's agricultural exports. These multiple roles present significant management challenges.

Regular assessment of the condition of the river is needed to improve the design of conservation and management plans and evaluate their effectiveness. This report provides a summary of the recent status (mean and range of conditions) and trends (change in a consistent direction over time) for selected indicators of the ecological condition of the Upper Mississippi and Illinois Rivers. Data collected by the Long Term Resource Monitoring Program (LTRMP) are used to describe biological, physical, and chemical indicators of river condition over 9–12 years in most instances.

The UMRS, as defined by Congress in the Water Resources Development Act of 1986, includes the Upper Mississippi River from Minneapolis, Minnesota, to Cairo, Illinois (854 river miles); the Illinois Waterway from Chicago to Grafton, Illinois (327 miles); and navigable tributaries (76 miles). The system consists of the floodplain and all associated aquatic and terrestrial habitats, which covers approximately 2.6 million acres and includes 10 National Wildlife Refuges. The UMRS can be divided into four major reaches based on physical and ecological conditions: (1) the Upper Impounded Reach (Pools 1–13), (2) the Lower Impounded Reach (Pools 14–26), (3) the Unimpounded Reach (below Pool 26), and (4) the Illinois Waterway.

Historical and Existing Conditions

The UMRS has been modified extensively since the mid-1800s. Modifications for navigation included removal of fallen trees, use of channel training structures (wing dikes, closing dams) to force water into the main channel, dredging, and a series of 37 locks and dams constructed above St. Louis in the 1930s. Also, extensive levees were constructed, mainly south of Rock Island, Illinois, on the Mississippi River, and Peoria, Illinois, on the Illinois River, to provide flood protection for urban areas and floodplain agriculture. In 1900, the Illinois River was connected to Lake Michigan by the Des Plaines River to divert the discharge of Chicago's sewage to the Illinois River. This change increased nutrient inputs to the UMRS and allows exchange of species, including invasive species, between the UMRS and the Great Lakes.

The UMRS drainage basin has also been substantially altered by intensive forestry, draining of wetlands, and farming, which increased soil erosion, runoff, and sediment input to the UMRS. Increasing urbanization and industrialization combined with inadequate wastewater treatment resulted in substantial water pollution affecting both human health and river biota. River water quality has improved because of better environmental regulation since the 1970s.

The current condition of the UMRS is heavily influenced by its agriculture-dominated basin and by the dams, channel training structures, dredging, and levees that regulate flow distribution during most of the year. Although substantial improvements in some conditions have occurred since the 1960s because of improvements in sewage treatment and land use practices, the UMRS still faces substantial challenges including

1. High sedimentation rates in some backwaters and side channels;
2. An altered hydrologic regime resulting from modifications of river channels, the floodplain, and land use within the basin, and from dams and their operation;
3. Loss of connection between the floodplain and the river, particularly in the southern reaches of the UMRS;
4. Nonnative species (e.g., common carp [*Cyprinus carpio*], Asian carps [*Hypophtalmichthys* spp.], zebra mussels [*Dreissena polymorpha*]);
5. High levels of nutrients and suspended sediments; and
6. Degradation of floodplain forests.

Monitoring and Managing the River: The Environmental Management Program

The Environmental Management Program (EMP) was established by the Water Resources Development Act of 1986. The EMP is managed by the U.S. Army Corps of Engineers (USACE) and implemented in cooperation with the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, U.S. Department of Agriculture Natural Resources Conservation Service, and the five UMRS states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin). The EMP consists of two principal components. The Habitat Rehabilitation and Enhancement component works to rehabilitate the system through implementing projects to improve habitats or modify river management practices.

The other component of EMP is LTRMP. The LTRMP is a multipurpose program of monitoring, applied research, and management evaluation designed to achieve the following broad goals (U.S. Geological Survey 1997):

1. Develop a better understanding of the ecology of the UMRS and its resource problems,
2. Monitor resource change,
3. Develop alternatives to better manage the UMRS, and
4. Provide for the proper management of monitoring information.

The LTRMP is implemented by the USGS Upper Midwest Environmental Sciences Center (UMESC) and six field stations (Figure 1.1; Lake City, Minnesota, Pool 4; La Crosse, Wisconsin, Pool 8; Bellevue, Iowa, Pool 13; Alton, Illinois, Pool 26; Havana, Illinois, La Grange Pool; and Cape Girardeau, Missouri, Open River) operated by staff from the UMRS states. The Program supports a variety of monitoring, data serving, and research efforts. Monitoring data, results of various analyses and focused studies, and management tools and models developed under LTRMP are publicly available on the World Wide Web. The data and information generated by the LTRMP have been used in designing habitat rehabilitation projects and in developing various ecosystem restoration plans, including the Upper Mississippi River and Illinois Waterway Navigation Study and the Illinois River Basin Restoration Comprehensive Plan. The monitoring component of LTRMP is not designed to evaluate individual projects, but to assess changes over time in response to larger scale influences such as natural fluctuations and cycles, multiple rehabilitation projects, or modifications to the watershed, as these effects become evident at the scale of a pool or river reach.

The core monitoring effort for LTRMP sampled four primary ecological components (fisheries, water quality, aquatic vegetation, and aquatic macroinvertebrates) from six 30–60 mile river sections that embody the wide range of environmental gradients within the UMRS. Within these six locations, data were collected with a random sampling design and standardized methods, which permit rigorous comparisons between locations and over time. Data on land cover, hydrology, and bathymetry were also collected, permitting the development of landscape indicators for comparison with biological and chemical indicators.

Ecosystem Goals and Indicators

This report focuses mainly on measuring changes in potential indicators of system health as derived from LTRMP data. Ideally, indicators should be derived from management objectives that define desired future conditions for the UMRS and identify target levels for those indicators. However, no common set of goals and objectives has been formally adopted by UMRS stakeholders. Informally, river managers have indicated that the future should be characterized by improved habitat quality and diversity, a closer approximation of the predevelopment hydrologic regime, and a diverse biotic community composed mainly of native species. River regulation, sedimentation, and floodplain development are generally considered the primary stressors affecting river habitats. Clearly articulating ecosystem goals and objectives for a system as large, diverse, and complex as the UMRS is exceedingly difficult, yet critically important for assessing management options and, ultimately, defining success.

Status and Trends of Indicators of System Health

For this report, scientists and partners within LTRMP identified 24 potential ecosystem indicators. These indicators were chosen because they relate to many of the primary resource problems or outcomes important to managers. The 24 indicators are grouped into seven categories: hydrology, sedimentation, water quality, land cover, aquatic vegetation, invertebrates, and fish. Each indicator is evaluated for status across locations and for trends over time, with estimates of uncertainty when possible. If quantitative targets for indicators have been recommended by managers or in the literature, we identified them (mainly available for water quality). For most indicators, however, internal comparisons are used to identify areas that were "better" or "worse" than other parts of the river. In some instances, we try to link indicators to suspected drivers or stressors, but the collective knowledge base is currently too incomplete to determine causes for the patterns observed in most indicators. This is a fertile area for future analyses and research.

River Hydrology

Dams on the UMRS were built mainly to facilitate commercial navigation. They were not designed for flood control and have little effect on total discharge (Chen and Simmons 1986; Sparks 1995); thus, changes in annual discharge are mainly related to precipitation. The eastern United States experienced increased discharge since 1970 (McCabe and Wolock 2002), which was evident in all reaches of the UMRS (Figure 2.1). During 1993–2004, when the LTRMP data used in this report were collected, flows were slightly higher than 1970–1992 in the impounded reaches, but were similar on the Illinois River and the Unimpounded Reach. Within this period, discharge varied substantially with record or near record flow in 1993 and relatively low flows in 2000 and 2003. Thus, most of the indicators presented in this report (those covering 1993–2004) represent conditions generally wetter than historically on the UMRS.

Hydrologic data show that, compared to pre-dam conditions, the impounded reaches had higher average water elevations, especially during low flow periods (Figure 2.2). This reflects the main purpose of the dams, which was to increase water depth at low discharges. This effect can be countered somewhat by changing dam operation to reduce water levels during summer while maintaining navigation. In the Open River Reach, the annual cycle of water elevations was similar between pre- and post-dam periods (Figure 2.2), but channel shape and hydraulics have been substantially altered from historical conditions. Some of the effects of changes in hydraulics can be countered by re-engineering channel training structures to recreate diversity in flows and depth within the main channel and side channels. All reaches have experienced increased short-term variation in water levels. In some pools, changing from a mid-pool control point to a dam control point for water levels may reduce short term variation. However, much of this problem is related to changes in the basin that deliver water to rivers more quickly and is outside of the control of UMRS managers.

Substantial changes in annual discharge are not expected in the near future, but in the long term, discharge will be linked mainly to climate. If changes in discharge occur, managers will need to develop strategies to either maintain critical ecological processes or adapt to changes in those processes in ways that allow the river to continue providing the ecological goods and services desired by the public. A combination of analyses of LTRMP data and focused research studies should help reveal linkages between discharge and ecological processes.

Water Quality

Water quality among the four river reaches can be considerably different for some indicators, but similar for others. The most striking difference is in the concentration of total suspended solids (TSS). In Pool 4, TSS are greater in upper Pool 4 than in lower Pool 4 because of settling in Lake Pepin, then increase from about 20 mg/L in lower Pool 4 to 200 mg/L in the Open River Reach, and are intermediate in the Illinois River (Figure 2.6). In lower Pool 4 and Pool 8, TSS are generally less than the recommended maximum concentration for plant growth (25 mg/L) and show a downward trend since 1994 for unknown reasons. Other reaches exceed this maximum in most years with no trends evident. A downstream increase in TSS is a common feature of rivers but is likely exacerbated in the UMRS by runoff from agricultural watersheds, which are more prevalent in Illinois and Iowa. Reducing the TSS load coming into the UMRS will be difficult but may result from increased use of best management practices on the watershed or from restoration of tributary deltas in the UMRS floodplain to trap sediments before they enter the river.

The nutrients nitrogen and phosphorous were at relatively high levels throughout the UMRS. Nitrogen concentrations increase from about 2 mg/L in the Upper Impounded pools to 3 mg/L in the lower reaches (Figure 2.3). Phosphorus increased downstream from about 0.1 mg/L in the Upper Impounded pools to 0.25 mg/L in the Open River Reach (Figure 2.4). The Illinois River generally had the highest concentrations of both nitrogen (4 mg/L) and phosphorous (0.4 mg/L). Mean nitrogen concentrations were more than the suggested upper limit (2.18 mg/L) in the Upper Impounded pools about 50% of the time, but in the lower reaches, nearly all the time. Mean phosphorus concentrations were more than the suggested upper limit (0.08 mg/L) for nearly all reaches and years. We found no trends over time.

Nitrogen levels can be reduced in the UMRS by storage in plants (e.g., forest trees) or by diverting more water into off channel areas and wetlands where natural processes can release the nitrogen to the atmosphere. However, increasing these processes within the floodplain of the UMRS alone will not reduce nitrogen enough to eliminate hypoxia in the Gulf of Mexico. That will almost certainly require reducing nutrient inputs to the river through more effective treatment of point source inputs and reducing losses of nutrients applied to farm fields and lawns.

High nutrient concentrations can cause excess algal growth. Yet all reaches of the UMRS generally had medium levels of chlorophyll (a measure of algal abundance) in the main channel (Figure 2.5), indicating that algal growth was typically not excessive. However, algae blooms (a locally high abundance of, typically, blue-green algae) do occur in the UMRS, usually during periods of low flow. Blooms, whose value as food is generally quite low, can reduce light penetration, which reduces growth of rooted aquatic plants. More work is needed on the species composition and production of the algal community under different combinations of flow and nutrient loads to determine potential ecological effects.

Dissolved oxygen levels were generally good throughout the system (Figure 2.7), but with occasional episodes of low oxygen (<5 mg/L) in backwaters and in the main channel in La Grange Pool of the Illinois River (Table 2.2). Low oxygen in backwaters typically occurs during low flow periods when backwaters are poorly mixed and zones of high oxygen demand develop. Managers have been successful at changing water flow patterns to introduce more oxygen rich water into critical backwaters and increase oxygen levels.

Winter habitat conditions can cause stress, or even mortality, for fish in rivers. Research supported by the LTRMP identified suitable winter conditions for sunfishes in backwaters as dissolved oxygen concentration >5 mg/L, temperature >1.0°C, and water depth >0.33 m. In the UMRS, only a small percentage of the total backwater area meet these criteria in the upper pools, but percentages are much higher in lower pools (Figure 2.8). However, despite relatively little suitable winter habitat, bluegills (*Lepomis macrochirus*), a typical backwater species, are abundant in the upper pools; thus, the usefulness of this metric as an indicator is questionable. Suitable winter habitat is relatively rare in many river systems (Cunjak 1996), but suitable areas often support high densities of fish during winter (Carlson 1992; Raibley et al. 1997). We do not know how much suitable winter habitat is needed within a river reach, nor how well fish survive in areas that do not meet the suitability criteria. More investigation is needed of the effect of winter habitat suitability compared to other factors affecting the abundance of sunfishes.

Sedimentation and Habitat Diversity

In all reaches, sedimentation has filled-in many backwaters, channels, and deep holes. In the lower reaches, sediments have completely filled the area between many wing dikes producing a narrower channel and new terrestrial habitat. Erosion has eliminated many islands, especially in impounded zones. Although annual rates of sedimentation and erosion were highly variable (Figure 2.11), the net effect over 50 years was a substantial loss of habitat diversity (Figure 2.10).

We expect sediment inputs to the system to remain high and expect both filling and erosion to continue, but at slower rates. Habitat diversity can be increased through constructing islands, dredging backwaters, and restoring floodplain connections. Actions such as reclaiming a levee district may produce quick and substantial changes in habitat diversity, whereas smaller-scale projects like dredging and island building will likely require multiple projects to significantly change habitat diversity at the pool or reach scale. Managers are designing projects that modify river flows and hydraulics in ways that directly affect the sedimentation and erosion and can help sustain habitat diversity naturally.

Land Cover and Land Use

Floodplain forests in the UMRS cover only a small portion of the area that they did before European settlement (Nelson et al. 1994; Yin et al. 1997). Between 1989 and 2000 forest area further declined by 5% (17,000 acres) system wide (Figure 2.12). By reach, there was a 2% increase in the Unimpounded Reach, but a 4–9% decrease in other reaches. Early forest losses were mainly due to logging for steamboat fuel and lumber and subsequent conversion to agricultural and urban uses. Impoundment flooded many acres of forest and remaining areas are adjusting to the ecological effects of changes in water levels. Maintaining high water elevations at low flows has increased the ground water elevation and caused a shift to trees that can tolerate wetter conditions, mainly silver maple (*Acer saccharinum*). In addition, short-term variation in water levels and high sedimentation rates on the floodplain have reduced recruitment of trees in some locations. These stressors are likely to continue. Reforestation efforts can have positive effects locally, but large scale effects will likely require changes in underlying ecological conditions.

The amount of floodplain area sequestered behind levees shows a distinct gradient from 4% sequestered in the Upper Impounded Reach to 60–70% in the Unimpounded Reach and lower portions of the Illinois River (Figure 2.14). Most of these levees protect land used for agriculture or urban areas, but a few are managed as moist soil units for waterfowl habitat. It is unlikely that many new levees will be built in the UMRS, although some expansion is still occurring in urban areas. Most existing levees are likely to be maintained for the foreseeable future, but some may revert to public ownership (if both funding and willing sellers are available) to be managed for ecological benefits. However, conversions of leveed areas to public land are expected to occur slowly and large changes in this indicator are not expected in the near term.

Floodplains are an important, natural element of the UMRS, but the amount of floodplain required to maintain critical ecosystem services, such as waste assimilation, biotic diversity, and water supply is unknown. Thus, no specific targets exist for the amount of active (unleveed) floodplain required. Management experiments and focused research are needed to determine relations between flood frequency and ecological responses. However, any management targets for amount of active floodplain are likely to differ among river reaches given the economic realities of current land ownership patterns.

Submersed and Emergent Vegetation

Aquatic vegetation can play an important role in river ecosystems in a variety of ways including nutrient cycling and hydraulics and can provide both a food source and physical habitat. Submersed aquatic vegetation was common in shallow backwaters in the Upper Impounded Reach (Figure 2.15), but decreased rapidly below Pool 13 and was seldom detected in Pool 26 or the Illinois River, except in isolated lakes. Submersed vegetation was common historically in all reaches except the Open River Reach, which had little appropriate habitat. In upper Pool 4 (upstream of Lake Pepin) submersed vegetation has declined steadily since 1991, which may be associated with relatively high levels of nutrients and turbidity from urban areas and the Minnesota River. Lower Pool 4, Pool 8, and Pool 13 experienced fluctuations in submersed vegetation, but appeared to be highly resilient. In Pool 26 and La Grange Pool, small increases in submersed vegetation occasionally occurred following lower water levels, but they did not persist.

The percentage of total area in emergent vegetation averaged about 5% (range 0–10%) among reaches and was greatest in the Upper Impounded Reach (Figure 2.13). Between 1989 and 2000, coverage decreased by about 5000 acres in the Upper Impounded Reach, but increased in all other reaches. Changes were most striking in the Illinois River pools (increase of about 7,500 acres), but the areal extent of emergent vegetation was still relatively small at about 3%. Some of this increase may represent recovery of emergent vegetation following drought conditions experienced during 1987–89.

It appears that low water clarity, consistent inundation of shorelines, and high short-term variation in water levels are the primary factors limiting distribution of aquatic vegetation. These factors are especially evident below Pool 13 and are expected to continue. Large scale techniques such as summer drawdowns and changes in dam operations that reduce short-term water level variation can enhance conditions for aquatic vegetation. Locally, building islands can create areas that are sheltered from current and wind, which allows suspended sediments to settle out thus increasing water clarity and plant growth. These techniques have worked well in the Upper Impounded Reach and should be evaluated in lower reaches.

Macroinvertebrates

Abundance of mayflies (*Hexagenia* spp.) and fingernail clams (*Musculium transversum*) showed a distribution similar to other biotic indicators with high densities in the upper pools but consistently lower densities in Pool 26, La Grange Pool, and the Open River Reach (Figures 2.16, 2.17). The only significant trend observed was an increase in fingernail clam density in Pool 8. Historically, macroinvertebrate numbers have been highly variable and both mayfly and fingernail clam densities are generally within the ranges reported in past studies on the UMRS. Many factors could affect annual abundance on mayflies and fingernail clams, but the variation seen both in LTRMP data and historically indicate that these organisms are resilient and able to rebound if conditions are right.

Fish

The LTRMP data indicate that most fish species known from the UMRS over the past 100 years still occur in the river today, although 39 species collected by the LTRMP were considered rare, endangered, or threatened by state or Federal agencies. Species richness (the number of species collected annually) was similar among study reaches (Figure 2.23) with means ranging from about 60 to 70 species. However, there was a general north-south dichotomy in UMRS fish communities reflecting habitat differences. A northern fish community, dominated by fish associated with backwater and lake-like habitats (e.g., bluegills, largemouth bass [*Micropterus salmoides*], various minnows and shiners) differs from the southern fish community that is more associated with main channel and side channel habitats (e.g., gizzard shad [*Dorosoma cepedianum*], buffalo [*Ictiobus* spp.], white bass [*Morone chrysops*]).

For individual fish species, some significant trends were identified. For example, smallmouth buffalo (*Ictiobus bubalus*) increased in all study areas except Pools 8 and 13 (Figure 2.21), channel catfish increased in Pool 4 and La Grange Pool (Figure 2.19), and bluegills increased in Pools 4 and 8 (Figure 2.18). A composite indicator for native sport fishes increased in Pool 4, but decreased in La Grange Pool and the Open River Reach (Figure 2.25). The reasons for these changes in a single species or assemblage are difficult to determine, but in Pool 8, two specific management actions (island construction and summer water level drawdowns) were implemented to improve backwater habitat and may be at least partially responsible for increases in bluegill abundance. However, bluegills also increased in Pool 4; thus, the changes in Pool 8 may be due to larger scale factors. Additional island building is planned for Pool 8 in the next few years. Continued data collection by the LTRMP and specific analyses within Pool 8 will increase our ability to identify the large-scale effects of rehabilitation projects as more islands are built.

Nonnative fishes composed a high percentage of total fish biomass (about 30–60%, Figure 2.24) in all locations. A high percentage of nonnative fishes in the community is generally considered an ecological impairment, although no specific targets have been identified for this indicator in the UMRS. Most of the nonnative biomass is from common carp, but recently the numbers and biomass of invading Asian carps have increased substantially. A positive note is that

Pools 4, 8, and 13 showed significant decreases in percentage of nonnative biomass over time. Further analyses of LTRMP data may reveal factors that correlate with nonnative biomass and suggest management strategies to reduce their abundance. Monitoring data alone, however, cannot confirm cause-and-effect relations. Field experiments will be needed to evaluate the effectiveness of proposed techniques to reduce nonnative biomass.

Overall Condition

Taken together, these indicators document ecological impairments in all parts of the system, but show a gradient of river health ranging from a relatively healthy system in the northern reaches, to one that is much less healthy in the south. A positive note is that, compared to many of the world's temperate-zone rivers, many parts of the UMRS still retain the underlying features that define river ecosystem integrity, such as a fairly natural discharge regime, ability to move sediments through most dams, a nearly complete species complex, and fairly good water quality. These features are most evident in the Upper Impounded Reach where habitat diversity is greatest and the river maintains more of its connection to the floodplain. However, sedimentation and nutrient levels are a problem throughout much of the system. Comparing among reaches, suspended solids are consistently high in lower reaches but are declining in Pools 4 and 8 (Figure 2.6); submersed aquatic vegetation is virtually absent from the lower reaches (Figure 2.15); aquatic invertebrates associated with soft sediments are much less abundant in lower reaches (Figures 2.16 and 2.17); the percentage biomass of nonnative fishes is high system wide but is declining (i.e., improving) in the upper reaches (Figure 2.24); the abundance of recreational fishes is declining in La Grange Pool and the Open River Reach (Figure 2.25); and isolation of the floodplain from the river is much more prevalent in the lower reaches (Figure 2.14). Some of these conditions may be associated with natural gradients within the river system, but in general, the LTRMP data show more impaired ecological condition in the lower reaches relative to the upper reaches. Rehabilitating the system will require effort in all reaches; however, the challenges appear to be more daunting in the lower reaches as many of the stressors and drivers are more highly modified there.

Refining Ecosystem Indicators

This report is an initial comparison of conditions over space and time within the UMRS based on data from the LTRMP. The indicators included represent only a few of many that could be developed. Potential new indicators can be initially assessed through additional analyses of data from LTRMP and other sources. In addition, this report provides critical baseline information for helping set management objectives and for making effective decisions about options for river management. River managers should seek to strengthen linkages among ecosystem goals, ecosystem objectives, and ecosystem indicators. Addressing these issues is not simply a matter of data analysis, but requires discussion and consensus among river stakeholders, managers, and scientists.

The Future Role of the Long Term Resource Monitoring Program

The LTRMP has developed one of the most extensive and comprehensive data sets on any large river system in the world. The early years of the program were devoted to developing the infrastructure and methods to collect data in a consistent manner over space and time. That system is now in place and operating effectively. Although we should always be searching for ways to improve the efficiency of the program, any changes should consider the integrity of existing data and seek to maintain or enhance our ability to detect trends, identify cyclical phenomenon, and assess success at rehabilitating the system.

To manage effectively, managers must improve their understanding of how the UMRS functions and reduce uncertainty in their ability to predict the effects of management actions. To help achieve this, the LTRMP database provides a unique resource for analyses that can identify patterns and relations among components, quantify dynamics of critical variables, and provide inputs for developing computer models. This information can be directly incorporated into management actions and question-driven scientific investigations. Results of analyses become the basis for designing focal studies to answer specific questions and field experiments to test hypotheses about system function in an adaptive management context. These field experiments can be implemented through habitat rehabilitation projects as part of the EMP.

A well-designed monitoring program is the first step in documenting efforts toward improving the ecological integrity of large ecosystems. The LTRMP stands as a national leader in developing and implementing a successful multi-partner collaboration that transcends traditional geo-political boundaries that often hamper environmental programs. Historical observations and current LTRMP data clearly indicate that the UMRS has been changed by human activity in ways that have diminished the ecological integrity of the river. The LTRMP data indicate that status and trends differ among regions, and we expect that regional responses to various ecological rehabilitation techniques will differ as well. The scientific evidence provided in this report indicates that the river requires further rehabilitation and continued monitoring. The continuing role of the LTRMP will be to provide the data needed to assess the results of management actions and how these changes should be viewed in the context of the ecological integrity of the river system.

Chapter 1. Introduction

1.1 The Upper Mississippi River System

The Upper Mississippi River System (UMRS) is a unique economic, environmental, and recreational resource. The UMRS basin drains 189,000 square miles and includes major portions of five states (Minnesota, Wisconsin, Iowa, Illinois, and Missouri; WEST 2000). The UMRS is one of a small number of large river floodplain ecosystems still characterized by annual flood pulses that advance and retreat over the floodplain and temporarily expand backwaters and floodplain lakes (Sparks et al. 1998; Gutreuter et al. 1999). The UMRS provides habitat for a wide array of fish and wildlife species distributed among a complex arrangement of flowing channels, floodplain lakes, backwaters, wetlands, and floodplain forests (Patrick 1998). The river supports a diverse mussel fauna, contains more than 25% of North America's freshwater fish species, and is an internationally recognized flyway for migrating birds (Upper Mississippi River Conservation Committee [UMRCC] 2000).

The UMRS has been interlaced with the economy and culture of the basin for thousands of years (Fremling 2005). Currently, the services the river provides include a navigation system that transports much of the country's agricultural exports, commercial and recreational fishing, drinking water for many communities, and a variety of recreational activities, including 10 National Wildlife Refuges within its boundaries (UMRCC 2000; U.S. Fish and Wildlife Service 2006).

Like other large rivers, the UMRS serves a diversity of roles and presents significant management and conservation challenges. There is a need for regular quantitative assessment of the condition of the river to improve the design of conservation and management plans and evaluate their effectiveness. This report addresses that need by providing extensive information about the current status and trends in ecological conditions of the UMRS.

1.2 Purpose and Scope of the Status and Trends Report

The initial Status and Trends Report (U.S. Geological Survey [USGS] 1999) provided a thorough introduction to the UMRS including extensive descriptions of historical context, watershed geology and land use, floodplain forests, bird populations, water quality, fishes, aquatic vegetation and macroinvertebrates. In doing so, that report provided the background information upon which the present report builds. The present report is more focused, more quantitative, and incorporates substantial new Long Term Resource Monitoring Program (LTRMP) data. The purpose of the report is to provide a concise summary of the recent status of, and trends in, selected indicators of the ecological condition of the Upper Mississippi and Illinois Rivers as observed through data collected for the LTRMP. It focuses on a quantitative description of biological, physical, and chemical indicators of river health using 9–12 years of LTRMP data. Describing the status (range of conditions observed) and trends (change in a consistent direction over time) observed over this period provides critical information on water quality, biota, and landscapes in the UMRS.

1.3 The Ecosystem of the Upper Mississippi River System

The UMRS, as defined by Congress in the Water Resources Development Act of 1986, includes the Upper Mississippi River (UMR) from Minneapolis, Minnesota, to Cairo, Illinois (854 river miles); the Illinois Waterway (IWW) from Chicago to Grafton, Illinois (327 miles); and navigable portions of the Minnesota (15 river miles), St. Croix (24 river miles), Black (1 river mile), and Kaskaskia Rivers (36 river miles; Figure 1.1). The Missouri River, which flows into the Mississippi River just below St. Louis (Figure 1.1), was not included in this Congressional definition of the UMRS. The UMRS encompasses a total area of approximately 2.6 million acres of land and water in public and private ownership. This includes the floodplain and all associated aquatic and terrestrial habitats that are critically important to large river ecosystems.

The geomorphology of the UMRS changes substantially along its course, generating longitudinal differences in river characteristics. The overall profile of the UMRS can be divided into 12 reaches (10 UMR reaches; 2 IWW reaches) based on geomorphology (U.S. Army Corps of Engineers [USACE] 2000; WEST 2000). In regional discussions of the river, these 12 reaches are often aggregated to 4 major reaches based on general geomorphic and ecological considerations (USGS 1999; Koel 2001; Chick et al. 2006). These reaches are (1) the Upper Impounded Reach, (2) the Lower Impounded Reach, (3) the Unimpounded Reach, and (4) the Illinois Waterway (Figure 1.1; Box 1.1).

1.3.1 Historical Conditions

Prior to European settlement, the UMR was broad and shallow and consisted of extensively braided channels flowing past countless islands (Fremling 2005). Abundant leaning and fallen trees (snags) provided habitat for a diverse flora and fauna. However, the shallow water and abundant snags severely impeded navigation and from 1866 through 1940 the river was fundamentally altered by a series of modifications to make large-scale commercial navigation possible. Initial efforts to facilitate navigation consisted of removing overhanging trees and snags and dredging (Anfinson 2003). Channel training structures, such as wing dams and closing dams, were subsequently added to increase the depth of the main channel. By 1940, construction of a series of 29 locks and dams was completed between Minneapolis, Minnesota, and St. Louis, Missouri, creating a 9-foot navigation channel for the length of the UMR. Below St. Louis, "open channel" techniques, such as stone dikes, bank revetment, and dredging have been used to maintain the navigation channel.

Similar modifications were made to the IWW where eight navigation dams were constructed during the 1930s as part of the 9-foot channel project. The IWW was also connected to Lake Michigan via the Chicago and Des Plaines Rivers to divert the discharge of Chicago's sewage from Lake Michigan to the Illinois River. Initially completed in 1900, this modification has ongoing implications for the IWW, including elevated water levels and nutrient concentrations and invasive species exchanges between the UMRS and the Great Lakes.

In addition to the internal modifications to the UMRS to create the 9-foot navigation channel, its drainage basin has experienced considerable change. Beginning around 1840, land use in the basin of the UMRS was fundamentally altered by intensive farming and forestry (Fremling 2005). Vast pine forests of northern Wisconsin and Minnesota were nearly logged in their entirety between 1835 and 1915. The conversion of land from prairie and savannah to agriculture substantially increased soil erosion and sediment input to the UMRS. Wetlands were drained and other vegetation that slowed runoff was removed to increase the land available for farming. These changes, along with stream channelization and urbanization, increased the speed with which runoff reached the UMR, which increased the stage height and duration of flooding. River stage at high discharge has been further magnified in some places by channel training structures and levees constructed to facilitate agriculture on the broad, fertile floodplains, primarily south of Rock Island, Illinois (UMRCC 2000; Pinter 2005a; Pinter et al. 2006).

From the early 1900s through the mid-1970s, the UMRS suffered extensive pollution from inadequately treated municipal and industrial wastewater. For example, low dissolved oxygen concentrations, large fish kills, mussel die-offs, and the disappearance of burrowing mayflies (*Hexagenia* spp.) were documented below Minneapolis, Minnesota (U.S. Environmental Protection Agency [USEPA] 2000b). Prior to wastewater treatment improvements in the 1950s, the Illinois River was degraded to the point that most native plants and animals were eradicated for more than 100 miles downstream of Chicago (Starrett 1972). Recognition of the human health and safety risks of pollution prompted significant environmental regulations (e.g., Water Pollution Control Act of 1972) and improvements in

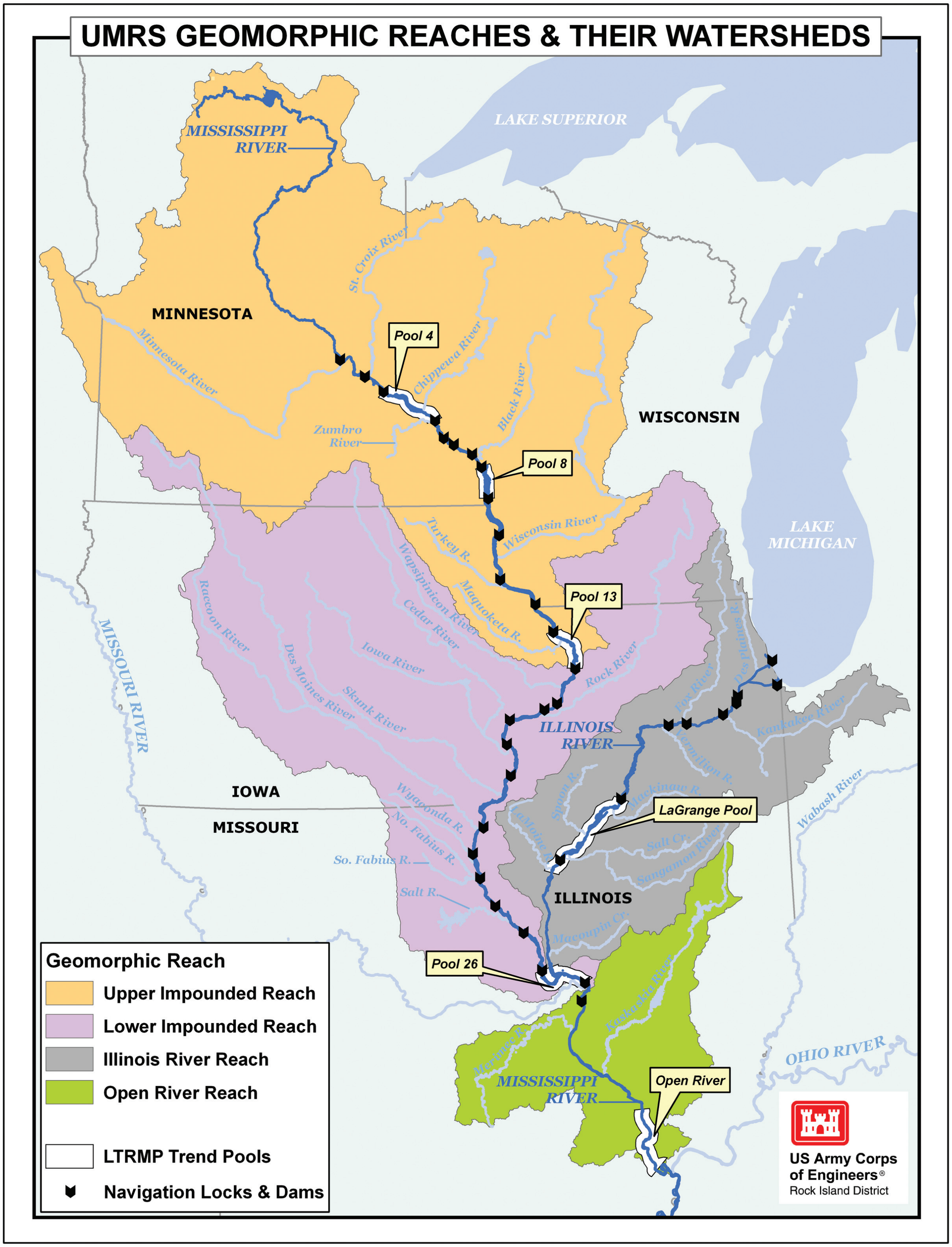

Figure 1.1. Map of the basin of the Upper Mississippi River System (UMRS) showing the four major geomorphic reaches and their watersheds, locations of navigation dams, and the six study areas for the Long Term Resource Monitoring Program. The UMRS was defined by legislation and does not include the Missouri River, which joins the Mississippi River just below Pool 26.

Box 1.1. Descriptions of the Four Major Floodplain Reaches Composing the Upper Mississippi River System.

Upper Impounded Reach

1. Extent: Mississippi River Pools 1-13.
2. LTRMP focal areas within the reach: Pools 4, 8, and 13.
3. Geomorphology: island-braided channels, islands are relatively common.
4. Effect of locks and dams: substantially expanded the extent of surface waters in most navigation pools by creating large impoundments.
5. Levee extent: Relatively few levees. Floodplain generally remains hydrologically connected to the river.
6. Floodplain characteristics: narrow (1–3 miles); high proportion of public land (e.g., USFWS National Wildlife and Fish Refuge) that supports forests, wetland, and other high quality habitats; Urban development in some floodplain areas.
7. Backwater areas: Abundant.

Lower Impounded Reach

1. Extent: Mississippi River Pools 14–26.
2. LTRMP focal area within the reach: Pool 26.
3. Geomorphology: Variable. Pools 14–16—a narrow gorge; Pools 17–26—spread out into a broad floodplain.
4. Effect of locks and dams: stabilized depth of navigation channel but because of levees, did not greatly expand surface waters in most of the reach.
5. Levee extent: approximately 50% of the floodplain is isolated behind levees.
6. Floodplain characteristics: broad floodplain (5–7 miles) below Pool 16; area behind levees has largely been converted to agriculture; riparian forests and forested islands persist riverward of the levees.
7. Backwater areas: Fewer than Upper Impounded Reach.

Unimpounded Reach

1. Extent: Below Chain of Rocks dam (River mile 203) to the confluence with the Ohio River (river mile 0).
2. LTRMP focal area within the reach: Open River Reach located between river miles 80 through 29 (near Cape Girardeau, Missouri).
3. Geomorphology: Largely a single main channel constrained by training structures with side channels of varying habitat quality.
4. Effect of locks and dams: There are no locks and dams. The navigation channel is maintained solely with channel training structures (e.g., stone dikes, closing structure, etc.) and dredging that have substantially modified this river reach.
5. Extent of levees: The main stem levees are large and isolate more than 67% of the floodplain except during the most extreme floods.
6. Floodplain characteristics: Original floodplain is broad, up to 50 miles wide near the confluence with the Ohio River; the floodplain is predominately agricultural except for a narrow riparian corridor between the levees and river channel and a few aquatic habitat patches within agricultural levee districts.
7. Backwater areas: Few.

Lower Illinois River Reach

1. Extent: Chicago, Illinois, to confluence with Mississippi River.
2. LTRMP focal area within the reach: La Grange Pool.
3. Geomorphology: Lower river is low gradient, with an average fall of 1.8 inches per mile; consists of channels, backwaters, managed wetlands and a broad floodplain.
4. Effect of locks and dams: influence is limited by the exceptionally long pools in lower river.
5. Extent of levees: Most of the lower pool floodplain areas are leveed.
6. Floodplain characteristics: Broad floodplain dominated by agriculture.
7. Backwater areas: Abundant, but many are separated from the channel by levees.

wastewater treatment since the 1970s. River water quality has improved as a result (USEPA 2000b).

1.3.2 Existing Conditions

The current condition of the UMRS is heavily influenced by its agriculture-dominated basin and the dams and channel training structures that regulate flow distribution during most of the year. In most areas, the landscape, tributaries, and river are still adjusting to the changes that have occurred over the last 150 years. The overall condition of much of the UMR has improved substantially since the 1960s due to improvements in sewage treatment and land use practices. However, the UMRS still faces substantial challenges concerning its overall condition, including

- high sedimentation rates in some backwaters and side channels (Rogala et al. 2003);
- an altered hydrologic regime resulting from modifications of the river to improve navigation and modifications of the floodplain and basin for agriculture (Pinter et al. 2006);
- loss of connection between the floodplain and the river, particularly in the southern reaches of the UMRS (see Box 1.1);
- nonnative species (e.g., zebra mussels [*Dreissena polymorpha*] and Asian carp *Hypophtalmachthys* spp.]; Tucker et al. 1993; Chick and Pegg 2001);
- high nutrient and suspended sediment concentrations (Goolsby and Battaglin 2001); and
- degradation of floodplain forests (Yin and Nelson 1995).

The cumulative results of these impacts continue to affect the ecological integrity of the UMRS (WEST 2000).

Some effects of the navigation locks and dams were initially perceived as ecologically beneficial because newly created aquatic habitats were quickly colonized by fish and aquatic plants, resulting in a short-term increase in river productivity (Fremling 2005). However, the aquatic habitats created by lock and dam construction are aging rapidly. Sediments from upland sources and eroding islands and riverbanks are reducing the depth of many backwater areas (Bhowmik and Adams 1989; Rogala et al. 2003). Wind and boat generated waves in large open water habitats created by the dams contribute to island erosion and sediment resuspension (Bhowmik et al. 1992; Chamberlin 1994; Knight and Parchure 2004). The resulting increases in turbidity reduce light penetration inhibiting aquatic plant production (Korschgen 1990; UMRCC 2003; Kreiling et al. 2007). Backwater sediments have become increasingly unconsolidated because the dams have eliminated the summer low flow river stage that historically allowed backwater and shoreline sediments to be exposed and compacted (Rogala et al. 1999). The unconsolidated sediments are more easily resuspended, further reducing water clarity. In addition, high water levels have reduced the amount of floodplain forests, either by direct mortality or by creating conditions in much of the floodplain that favor wetlands or grasslands. Navigation dams also reduce fish movement by reducing or blocking fish passage (Chick et al. 2006).

Nonnative fish species are a substantial fraction of the biomass, particularly in the southern reaches and are a growing problem for the UMRS (Chick and Pegg 2001; Ickes et al. 2005). Zebra mussels and round goby (*Neogobius melanostomus*), introduced via the IWW from the Great Lakes, are also a concern (e.g., Tucker et al. 1993). Sedimentation and excessive nutrient and pesticide runoff continue to be sources of critical ecological impacts in the main stem rivers.

The factors affecting water quality concerns in the river have shifted since the 1960s and 1970s. Treatment of municipal and industrial wastewater discharges is greatly improved and these “point sources” contribute much less to the nutrient and suspended solid load in the UMRS today than previously. As a result, some aspects of water quality, such as dissolved oxygen concentrations, have improved substantially, and sensitive species, such as burrowing mayflies are again relatively common in much of the river (USEPA 2000b; Sauer 2004). However, the intense human land use in the UMRS basin still results in excessive nutrient and sediment inputs from nonpoint sources such as runoff from agricultural fields and urban areas (Engstrom et al. 2000; UMRCC 2000; Donner et al. 2004).

1.4 Monitoring and Managing the River: The Environmental Management Program

The Environmental Management Program (EMP) was established by Section 1103 of the Water Resources Development Act of 1986. A fundamental tenet of this program, as stated in the legislation, was the recognition by Congress that the UMRS is a "nationally significant ecosystem and nationally significant commercial navigation system" —the only river in the United States to be formally recognized as such— that should be managed to support multiple uses. The EMP is managed by the U.S. Army Corps of Engineers and implemented in cooperation with the five UMRS states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin) and several Federal resource agencies (U.S. Geological Survey, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, and the U.S. Department of Agriculture Natural Resources Conservation Service). In addition, the EMP works in coordination with a variety of nongovernmental agencies such as state universities, the Upper Mississippi River Basin Association, the National Audubon Society, and The Nature Conservancy. The collaborative relationships among these Federal agencies, states, nongovernmental organizations, and other stakeholders, including commercial interests developed by the EMP provide a national model for large-scale restoration and monitoring work.

The EMP consists of two principal components (1) the Habitat Rehabilitation and Enhancement Projects (HREP) and (2) the LTRMP. The HREP component of EMP is managed by the U.S. Army Corps of Engineers in consultation with the U.S. Fish and Wildlife Service and the natural resource agencies of the five UMRS states. Through HREP, the Corps and its partners rehabilitate aquatic habitats degraded by navigation development and other changes to the river and its basin. Some of these projects and their outcomes have been described extensively in several reports and publications (e.g., Belanger et al. 1990; Richardson and Clemment 1993; Lubinski and Gutreuter 1994; Theiling 1995).

The LTRMP component of the EMP is a multipurpose program of monitoring, applied research, and management evaluation designed to achieve the following broad goals (USGS 1997):

1. Develop a better understanding of the ecology of the UMRS and its resource problems,
2. Monitor resource change,
3. Develop alternatives to better manage the UMRS, and
4. Provide for the proper management of monitoring information.

In support of these goals, data collection, analysis, presentation, and publication are carried out by the staff of the USGS Upper Midwest Environmental Sciences Center (UMESC) and six LTRMP field stations operated by staff from the UMRS states. Overall Program responsibility rests with the U.S. Army Corps of Engineers, whereas the USGS UMESC provides science leadership and administers the LTRMP. The USGS implements the LTRMP in cooperation with the conservation agencies of the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, which operate six field stations on the river system.

The LTRMP employs a variety of monitoring, data serving, and research efforts. The LTRMP core monitoring program collects biological, chemical, and physical data on the river using a variety of field, laboratory, and remote-sensing methods. Monitoring data from the past 12 years have been analyzed using a diverse array of approaches to improve our understanding of the ecology of the UMRS. For example, statistical models have been used to determine important predictors of the abundance and distribution of vegetation (Yin and Langrehr 2005), multivariate analyses have been used to show how fish community composition differs among the study reaches (Barko et al. 2004; Chick et al. 2005; Ickes et al. 2005), and spatial and temporal patterns within the UMRS have been analyzed to better understand longitudinal patterns in the river and differences among various aquatic areas (e.g., main channel, impoundment, and backwater areas; Koel 2001; Sauer 2004; Houser 2005; Ickes et al. 2005). Indicators of ecosystem health have been analyzed to determine the current condition of the UMRS and how it is changing over time (USGS 1999). The results of this research are provided to the management and scientific community through presentations, 324 technical reports, and more than 65 peer-reviewed publications (http://www.umesc.usgs.gov/ltrmp.html). Management tools, models, and information building on this research are also served through the UMESC Web site.

The LTRMP data collected on the UMRS, including the ecological response to HREP projects, have also served as the springboard for restoration efforts. Design and construction methods, information on habitat response, monitoring data, interagency coordination, and public input mechanisms created by the Program have informed the development of the ecosystem restoration plan of the Upper Mississippi River and Illinois Waterway Navigation Study (USACE 2004) and the main stem component of the Illinois River Basin Restoration Comprehensive Plan (USACE 2006a).

1.5 Desired Future Conditions: Providing the Foundation for Developing Objectives

This information provided in this report is an essential contribution for the ongoing discussion of desired river conditions among stakeholders, managers, and scientists. Central to these discussions is the topic of appropriate reference conditions. There are multiple approaches for determining reference conditions that can help define desired future conditions and set targets for ecosystem rehabilitation (Stoddard et al. 2006). Ideally, a similar but undisturbed river would serve as a reference system against which the UMRS could be compared (Hughes et al. 1986). For large, unique ecosystems, such as the UMRS, there are no suitable “reference” systems, but there are alternative approaches that use a subset of the data from the UMRS to determine the “reference” condition (Stoddard et al. 2006). One such approach is to use the “historical condition” of the river, that is, the condition prior to current disturbances (i.e., the condition before agriculture dominated the landscape and navigation channel maintenance dominated the river). However, data on “pre-disturbance” conditions are limited for most of the indicators in this report. An alternative approach is to use “minimally disturbed” or “least disturbed” areas to determine the goals for restoration for more degraded parts of the river (Stoddard et al. 2006). Note that these alternative approaches to establishing goals for rehabilitation require extensive data on the river system combined with some agreement on how to evaluate “best condition.” Thus, evaluating ecosystem health requires (1) identifying and quantifying societal values concerning the health of the system and (2) measuring indicators that reflect those values and are expected to respond to management actions. This report focuses on measuring indicators. The results presented here will contribute to discussions among stakeholders and managers regarding societal views of ecosystem health. Those discussions should aim to explicitly link field observations of select ecosystem attributes to stakeholder values.

1.6 Ecological Drivers, Stressors, and Indicators

Attempts to link field observations to stakeholder values often benefit from developing a conceptual framework. One such conceptual framework provides a structure for identifying and evaluating (1) the primary ecosystem drivers; (2) stressors imposed upon the system due to human uses of the system (Figure 1.2); and (3) indicators that can be conceived, developed, and analyzed to inform decision makers in the management of the system (Box 1.2). U.S. Geological Survey (1999) provided the initial conceptualization of the drivers and stressors approach to indicator development and provided considerable information and detail concerning historical and contemporary drivers and stressors acting upon the UMRS.

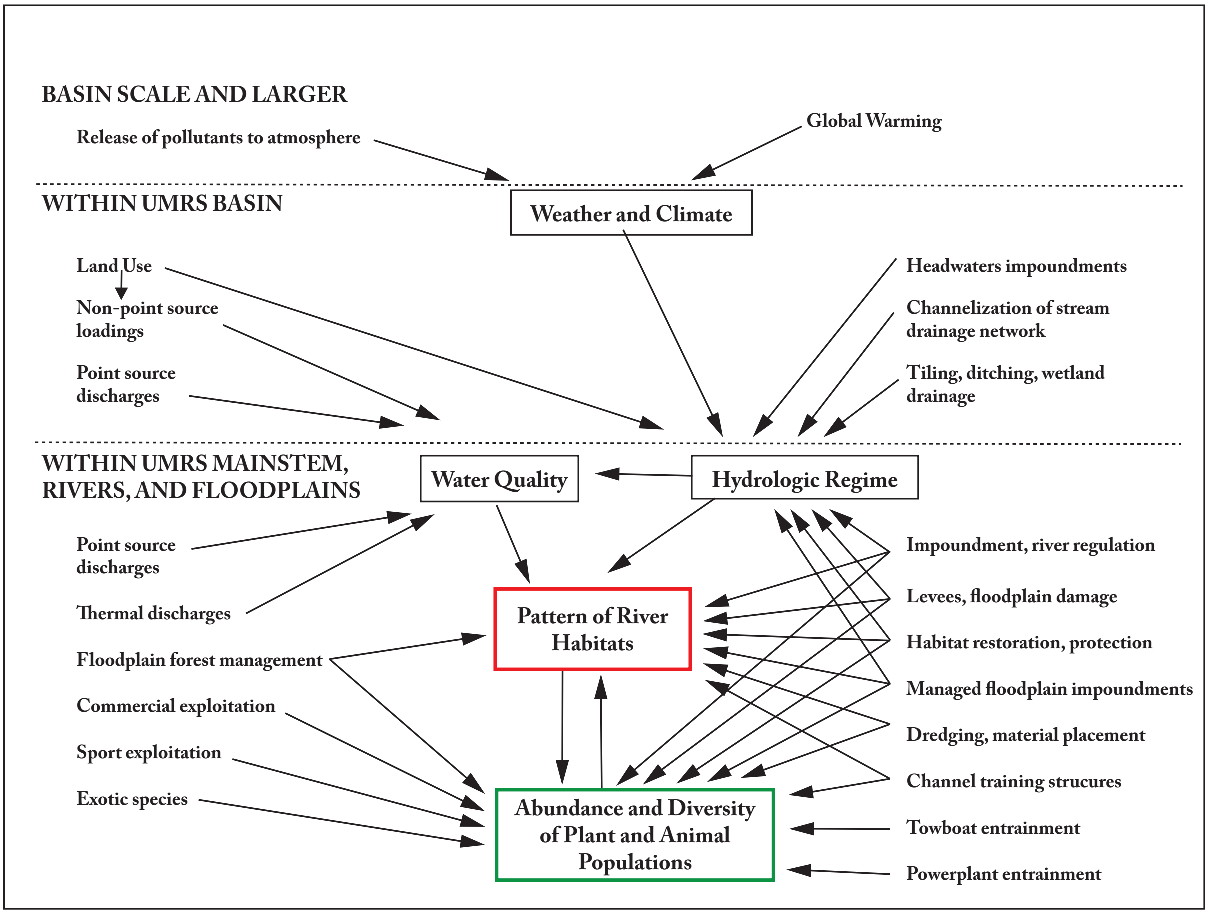

Figure 1.2. Human stressors on the Upper Mississippi River ecosystem (WEST 2000; USACE 2004).

1.6.1 Indicator Development

The balance of this report focuses on presenting quantitative indicators developed from LTRMP data sources and expected to reflect UMRS ecosystem health as described in the first Status and Trends report (USGS 1999; see Chapter 2). In Chapter 3, information presented in Chapter 2 is integrated into an overall ecosystem health evaluation.

Data Sources

The LTRMP intensively samples four primary ecological components (fisheries, water quality, aquatic vegetation, and aquatic macroinvertebrates) from six 30–60 mile river sections that traverse the geomorphic and human disturbance gradients described in Section 1.3.1 (Figure 1.1). Data are collected using a random sampling design, permitting unbiased evaluation of selected biological, chemical, and physical indicators. Sampling methods are standardized for each component (Gutrueter et al. 1995; Thiel and Sauer 1999; Yin et al. 2000; Soballe and Fischer 2004) permitting rigorous comparisons between locations and over time. Also, the LTRMP staff collects data on land cover and bathymetry for the entire UMRS, permitting the development of landscape indicators and comparisons with biological and chemical indicators.

Indicator Selection and Analysis

Scientists within LTRMP, in conjunction with the EMP partnership, identified 24 ecosystem indicators to include in this report (Table 1.1). The indicators are divided into six categories and can be related to previous documents and to system stressors (Fig 1.2). These selected indicators derive from a broader pool of potential indicators monitored by LTRMP. Collectively,

Box 1.2. Conceptual Definitions of Drivers, Stressors, and Indicators.

Drivers are the major external forces that have large-scale influences on ecosystems. For example, they affect disturbance regimes (e.g., floods and droughts), material transport and flux (e.g., nutrients and sediments), and production potential. Examples in the UMRS include geology, climate and hydrology (Figure 1.2).

Stressors are physical, chemical, or biological changes that exceed the natural assimilative capacity of the ecosystem. Stressors can cause significant changes in biological communities, ecosystem function, and ecosystem services at various scales (e.g., local, watershed, regional, basin). Stressors may be of natural or human origins; both are important in the contemporary UMRS ecosystem. Examples of natural stressors may include physical or biological responses to floods (e.g., erosion, sediment suspension, or floodplain forest mortality), and physiochemical responses to drought (e.g., low oxygen levels, thermal stress). Examples of human made stressors may include excessive nutrient inputs associated with past and present land use decisions (e.g., agricultural fertilizers and waste treatment effluent), invasive species, and altered hydrology arising from the combined effects of river impoundment, system engineering for commercial navigation, and/or flood control measures (Figure 1.2).

Indicators are selected attributes or elements of the system that are (1) sensitive to system drivers and stressors, and (2) sensitive to management efforts to mediate undesirable ecosystem conditions. Thus, indicator selection and development depends upon (1) identifying relevant drivers and stressors; (2) selecting ecosystem indicators that are sensitive to primary drivers, stressors, and management actions; and (3) generating quantifiable statements concerning societal values that identify both “healthy status” and “actionable trends” in selected indicators. Such quantifiable statements on societal values are often termed “benchmarks” or “endpoints” and are crucially important to define. Generalized examples of indicators include population levels (e.g., number of bluegill or the amount of nutrients or pollutants), biotic community metrics (e.g., biomass of nonnative species, number of floodplain dependent species, proportion of pollution tolerant species, or floodplain forest community composition), or metrics of ecosystem processes (e.g., biological production rates, sedimentation rates, and nutrient assimilation rates).

the intent of the selected indicators is to provide an assessment of the current health of the UMRS.

In Chapter 2, each indicator is evaluated for differences in indicator status across locations within the UMRS and for trends over time (9–12 years). When possible, annual estimates of uncertainty for each indicator (represented as error bars around each annual estimate), and uncertainty in trends (represented by curves bounding a best fit trend line), were calculated (Cochran 1977; Gutreuter et al. 1995).

This report makes use of several approaches to evaluate the selected indicators. There are a few instances wherein historical data were accessible in published reports and these data are discussed in the evaluation of the indicator (e.g., total nitrogen, depth diversity). For a few indicators (e.g., total nitrogen, total phosphorus), regulatory agencies have recommended specific quantitative targets, which are used in indicator evaluation. However, few regulatory standards currently exist for indicators of ecosystem health for the UMRS. Thus, for most of the indicators, comparisons within the UMRS are used to identify areas that were “better” or “worse” than other areas in the river. In some instances, indicators were correlated with suspected drivers or stressors, or with information from recent research studies, to more clearly link system responses and relations. However, the collective knowledge base is currently too incomplete to determine causes for the patterns observed in most indicators.

1.6.2 Linking Ecosystem Goals, Objectives, and Indicators

Whereas ecosystem indicators convey quantitative information on ecosystem

Table 1.1. Ecological context of indicators derived using data from the Long Term Resource Monitoring Program (LTRMP) and their relation to previous documents.

Ecological Characteristic	UMRCC[a] (2001)	Health Criteria (USGS[b] 1999)	Indicator Category	LTRMP Indicator
Hydrology	More natural hydrograph; Flow distribution on floodplain	Floodplain connectivity; Value of natural disturbances	Hydrology	Mean annual discharge Seasonal water elevation
Water Quality	Improve water quality	Function as part of a healthy basin; Viable populations	Water Quality	Major nutrients Chlorophyll *a* Total suspended solids Dissolved oxygen Suitable winter habitat for sunfishes
Habitats	Reduce sediment impacts; Restore natural floodplain; Connect backwaters; Side channel, island habitat	Ecosystem sustainability; Viable populations	Sedimentation	Depth diversity in impounded areas Net sedimentation in backwaters
		Viable populations; Floodplain connectivity	Land cover/Land use	Floodplain forest Emergent vegetation Area of floodplain behind levees
Abundance and Diversity	Restore natural floodplain; Provide fish passage at dams; Monitor exotics	Viable populations	Aquatic Vegetation	Submersed aquatic vegetation
			Macroinvertebrates	Burrowing mayflies (*Hexagenia* spp.) Fingernail clams (*Musculium transversum*)
			Fisheries	Bluegill (*Lepomis macrochirus*) Channel catfish (*Ictalurus punctatus*) Sauger (*Sander canadense*) Smallmouth buffalo (*Ictiobus bubalus*) Forage fish index Species richness Nonnative fishes Recreationally harvested fishes Commercially harvested fishes

[a]UMRCC = Upper Mississippi River Conservation Committee
[b]USGS = U.S. Geological Survey

condition, ecosystem goals and objectives convey information concerning how society values ecosystem condition. Clearly articulating such value-based perspectives on a system as large, diverse, and complex as the UMRS is exceedingly difficult, yet critically important.

Ecosystem Goals

Informally, broad goals for ecosystem health have been adopted by many river managers and scientists over time, but no common set of goals and objectives has been formally adopted by stakeholders. Still, many ecosystem goals for the condition of the UMRS ecosystem have been proposed in various management proposals and plans, particularly as related to the abundance and distribution of habitat. There are ongoing collaborative efforts to set goals and objectives for the UMRS ecosystem that include participation of the stakeholder community (The Nature Conservancy 1998; UMRCC 2000; USACE 2000, 2004; Lubinski and Barko 2003; U.S. Fish and Wildlife Service [USFWS] 2006).

Six criteria of ecosystem health for the UMRS were stated in the 1998 Status and Trends Report (USGS 1999). These six criteria comprise three general criteria identified for their value in characterizing basic ecosystem health (Criteria 1–3 below; Grumbine 1994) and three additional criteria developed specifically for floodplain rivers (Criteria 4–6 below). Collectively, these six criteria formed the basis of the first ecosystem health evaluation for the UMRS.

1. The ecosystem supports habitats and viable native animal and plant populations similar to those present before any disturbance.
2. The ecosystem is able to return to its pre-existing condition after a disturbance, whether natural or human-induced.
3. The ecosystem is able to sustain itself.
4. The river reach functions as part of a healthy basin.
5. The annual flood pulse connects the main channel to its floodplain.
6. Infrequent natural events, such as floods and droughts, are able to maintain ecological structure and processes within the reach.

In their broadest sense, these criteria reflect ecosystem conditions valued by society. For example, Goal 1 ensures natural heritage conservation, sustainable consumptive uses of river biota (e.g., hunting and fishing), and sustainable nonconsumptive uses (e.g., boating, photography, and bird watching). Note, however, that some goals, such as Goal 3, are unlikely to be reached in the foreseeable future for a heavily managed system, such as the UMRS. Such ecosystem goals provide a vision for desired future conditions, but they lack specificity about how to achieve that vision. Therefore, objectives must be explicitly stated. Objectives provide a qualitative or quantitative statement that describes desired future conditions against which indicators can be evaluated for progress or attainment.

Ecosystem Objectives

There have been at least two previous and extensive efforts to define ecosystem objectives for the UMRS. The Habitat Needs Assessment (HNA; Theiling et al. 2000) was the first multiagency sanctioned effort by the scientific community to set objectives for aquatic and terrestrial habitat protection and restoration for the UMRS. The HNA focused on identifying the desired future mix of habitats throughout the UMRS. Resource managers and scientists indicated that the future should be characterized by improved habitat quality, habitat diversity, and a closer approximation of predevelopment hydrologic regime. River regulation, sedimentation, and floodplain development were rated as the primary stressors affecting river habitats (Theiling et al. 2000). A similar effort is now needed concerning the desired future condition of water quality and biotic diversity and abundance.

Shortly after publication of the first Status and Trends report in 1999 (USGS 1999) and building on the HNA (USACE 2000), the Upper Mississippi River Coordinating Committee (UMRCC) proposed nine river ecosystem objectives. These objectives addressed management needs to sustain and restore the structure and function of the UMRS (UMRCC 2000). These objectives were

1. Improve water quality for all uses;
2. Reduce erosion and sediment impacts;
3. Restore floodplains to allow channel meanders and habitat diversity;
4. Provide for seasonal flood pulses and periodic low flows to improve nutrient base, plant growth, and succession;
5. Enable connectivity of backwaters to the main channel; and
6. Provide for opening of side channels, create islands, shoal and sandbar habitat.
7. Improve channel maintenance and dredge disposal practices in ways that support ecosystem objectives.

8. Sever pathways of exotic species introductions and spread within the UMRS.
9. Provide native fish passage at dams.

Linking Goals, Objectives, and Indicators

Past attempts to develop goals and objectives for the UMRS ecosystem proceeded without benefit of the information provided by this report. This synthesis of LTRMP data provides basin scientists, managers, and stakeholders with an unprecedented opportunity to further refine ecosystem health evaluations for the UMRS. In doing so, partnering agencies and individuals should seek to strengthen linkages among ecosystem goals, ecosystem objectives, and ecosystem indicators. Addressing these issues is not simply a matter of data analysis, but requires discussion and consensus among river stakeholders, managers, and scientists.

Achieving consensus on ecosystem objectives may be the most difficult part of developing a process to evaluate ecosystem health on the UMRS. Management authority is spread among several Federal and state agencies, each with a different management mandate. These different mandates will need to be both reconciled and accommodated in future evaluations of ecosystem health. Indicators must then be reassessed or revised to better align them with ecosystem objectives such that they permit tracking progress toward attaining desired future conditions.

To this end, the EMP provides a base of field science and management capability that is critical to defining, developing, measuring, and meeting ecosystem objectives for the UMRS. The management experience gained through HREP activities, and the technical capabilities developed through LTRMP activities, provide a solid foundation upon which to further develop, evaluate, and track progress toward UMRS ecosystem health objectives.

Chapter 2. Status and Trends of Resources in the Upper Mississippi River System

2.1 Introduction

This chapter contains information on various indicators of ecosystem condition. It begins with a discussion of two indicators of river hydrology using data collected by the U.S. Army Corps of Engineers and U.S. Geological Survey at long-term gaging stations within the system. The remaining 22 indicators use data collected by the LTRMP at five sampling areas on the Upper Mississippi River (UMR) and one on the Illinois River (Figure 1.1). Each indicator is displayed for those sampling locations with data available. Not all locations were sampled for every indicator. Most indicators present annual data from the main period of LTRMP sampling under current methods (early 1990s through about 2004). Data for sedimentation and land cover are comparisons at one or more points in time derived from more intensive sampling efforts. Assessments of condition are made across sampling locations and across the four main geomorphic reaches (see section 1.2) when appropriate. The sampling design and techniques used for each component are documented on the LTRMP web site at http://www.umesc.usgs.gov/ltrmp.html.

Each indicator is presented with

- An assessment of the status and trends for the period covered;
- A description of the purpose and importance of the indicator;
- An assessment of the state of the ecosystem relative to that indicator with historical context, when known;
- A description of future pressures that may affect levels and trends of the indicator along with potential management actions; and
- Graphs of data available.

These data provide a baseline of information on levels and trends for each indicator. The process of developing indicators for large rivers is in its infancy, however, and for most of the indicators in this report, there is little information on what levels are appropriate in large rivers. We have suggested some levels based on information from the literature, but any attempt to define specific levels should consider the concerns and needs of river users and the large variability over space and time evident in all large rivers. Acceptable levels may be different in different parts of a river or in different seasons.

This report is an initial attempt to compare conditions over space and time within the UMRS based on data from the LTRMP. Most of these data were collected from multiple locations throughout the system that encompass a wide range of underlying drivers and stressors. The baseline information derived from these data is critical for helping set management objectives and for making effective decisions about options for river management. Future information will build upon these data to show changes in condition of the river over time and to look at long-term dynamics, such as cycles of abundance. Many of these indicators are linked by various processes and interactions at work in the river ecosystem. We discuss some of those linkages, but this is a fertile area for additional analyses and research.

2.2 River Hydrology Indicators

Rivers are inherently flowing water systems. A river's hydrology, or flow dynamics, integrate the effects of climate, land forms, land use, and river management. Periodic changes in the amount of flow and in water elevations are key elements of a river's hydrology. Flowing water transports dissolved and suspended materials continually within channels and periodically within the floodplain as the river floods, then drains off-channel areas. Changes in water elevation result in changes in water depth and wetted area. Plants and animals in the UMRS have adapted to a natural regime of relatively predictable seasonal and annual changes in flow and water elevation. In the UMRS, hydrology has been affected by changes in both the watershed and channel, including changes in land cover (especially conversion to agriculture, loss of wetlands, and drain tiling of farm fields) that increased runoff, construction of dikes in channels and levees on the floodplain that constrict flows, and construction of dams on the UMRS in the 1930s that increased water elevations. The indicators chosen for hydrology were annual discharge and the seasonal pattern of water elevations.

For these indicators, we identified four gaging stations with sufficient data to examine water elevations before and after dam construction and discharges since 1950 (Table 2.1). For elevation data, the pre-dam period for the Mississippi River sites began between 1861 and 1888, depending on availability of data, and ended in 1929. On the Illinois River, the preconstruction period was 1885–1899 because in 1900 the river system was modified by a diversion channel from Lake Michigan at Chicago. Postconstruction dates begin in 1940 except for the St. Louis site where 1960 was used to account for construction of storage reservoirs on the Missouri River (which enters the Mississippi River above St. Louis). These data provide historical context for the hydrologic conditions existing during 1993–2004, when the LTRMP data used in this report were collected.

2.2.1 Mean Annual Discharge

Assessment

Status: Good. The range of annual discharges throughout the UMRS is similar to historical ranges.

Table 2.1. Gaging stations on the Upper Mississippi River System used for analyses of elevations and discharge.

Station name	Station code[a]	Location	River mile[b]	Years used for elevation data[c]	
				Pre-dam	Post-dam
Mississippi River					
Winona, Minnesota	05378500	Control point of Pool 6	701	1888–1903 1928–1929	1940–2004
Keokuk, Iowa[d]	05474500	Dam 19	352	--	--
Louisiana, Missouri[d]	0282A	Control point of Pool 24	273	1879–1929	1940–2004
St. Louis, Missouri	07010000	Open River	173	1861–1929	1960–2004
Illinois River					
Valley City, Illinois	05586100	Upper portion of Alton Pool	60	1885–1899	1940–2004

[a]Station codes are from U.S. Geological Survey, except the Louisiana, Missouri, station, which is a Corps of Engineers code.
[b]River mile on the Mississippi River is above the confluence with the Ohio River and on the Illinois River is above its mouth at the Mississippi River.
[c]Years used for discharge data were 1950–2004.
[d]The gage at Keokuk, Iowa, was used only for discharge and the gage at Louisiana, Missouri, was used only for elevation.

Trend: Stable to slightly increasing. Mean annual discharge increased throughout the system after about 1970, similar to all of the eastern U.S. During 1993–2004, mean discharge increased slightly in the impounded portion of the Mississippi River compared with the previous 22 years, but was stable in the Unimpounded Reach and in the Illinois River.

Purpose

Mean annual discharge is a measure of the average amount of water flowing through a river in any one year. It integrates the effect of flood flows and low flow periods within each year. Changes in flow affect a variety of physical processes and features, including transport of waterborne materials (sediments, nutrients, etc.), water depths, the total amount of aquatic area, access to floodplains, current velocity, scouring, and retention time of water, all of which can affect ecological processes and abundance of biota.

State of the Ecosystem

Dams on the UMRS were built mainly to facilitate commercial navigation. They were not designed for flood control and have little storage capacity. Thus, these dams have little effect on total discharge (Chen and Simmons 1986; Sparks 1995), which is managed on a run-of-the-river basis (Landwehr et al. 2005). Large changes in discharge associated with rivers dammed for storage reservoirs (e.g., Colorado River) are not evident on the UMRS.

The UMRS has experienced increased discharge since 1970 (Figure 2.1). This increase appears to be part of a broader trend that affected the entire eastern United States (McCabe and Wolock 2002). After 1970, the discharge during years of low flow was similar to that observed during 1950–1969, but there were more years of high discharge. Thus, the mean and range of discharges during 1970–1992 were higher than for 1950–1969 at all locations. During the period 1993–2004, when the LTRMP data used in this report were collected, flows were slightly higher than 1970–1992 in the Impounded Reaches of the UMR, but were similar on the Illinois River and the Unimpounded Reach. Thus, the period 1993–2004 was generally wetter than historical conditions on the UMRS, especially in the Upper Impounded Reach. Within that period, discharge varied substantially with record or near record flows in 1993 and relatively low flows in 2000 and 2003. In addition, this period followed 3 years of low flows in 1987–1989 experienced throughout the system.

Plants and animals within the UMRS are constantly adapting to changing flows. High mean annual discharge indicates that biota have faced generally wetter conditions in recent years. However, extreme discharge events occurring over short periods may create unusual conditions that can have substantial effects on a variety of ecological processes. A combination of analyses of LTRMP data, which are collected annually, and focused research studies that investigate short-term changes produced by extreme events, should help reveal linkages between discharge and ecological processes.

Future Pressures

Building of additional dams that would affect discharge on the UMRS or its tributaries is unlikely. Substantial changes in annual discharge are not expected in the near future, but in the long term, discharge on the UMRS will be linked mainly to climate. Predictions of how climate change might affect the UMRS are difficult because of the variety of interacting factors involved and the multiple scales at which they operate. These factors include total amount and timing of rainfall, number and timing of extreme events, temperature effects on snowmelt and evaporation, potential changes in land cover in the watershed, and changes in ground water tables. Climate change models are uncertain regarding whether mean annual precipitation and discharge will change in the UMRS basin, but the region is expected to see more variability in precipitation (Kundzewicz et al. 2007). Global effects on climate change are outside the direct control of UMRS managers. However, if changes in discharge occur, managers will need to develop strategies that can be applied to the watershed and the UMRS to either maintain critical ecological processes or adapt to changes in those processes in ways that will allow the

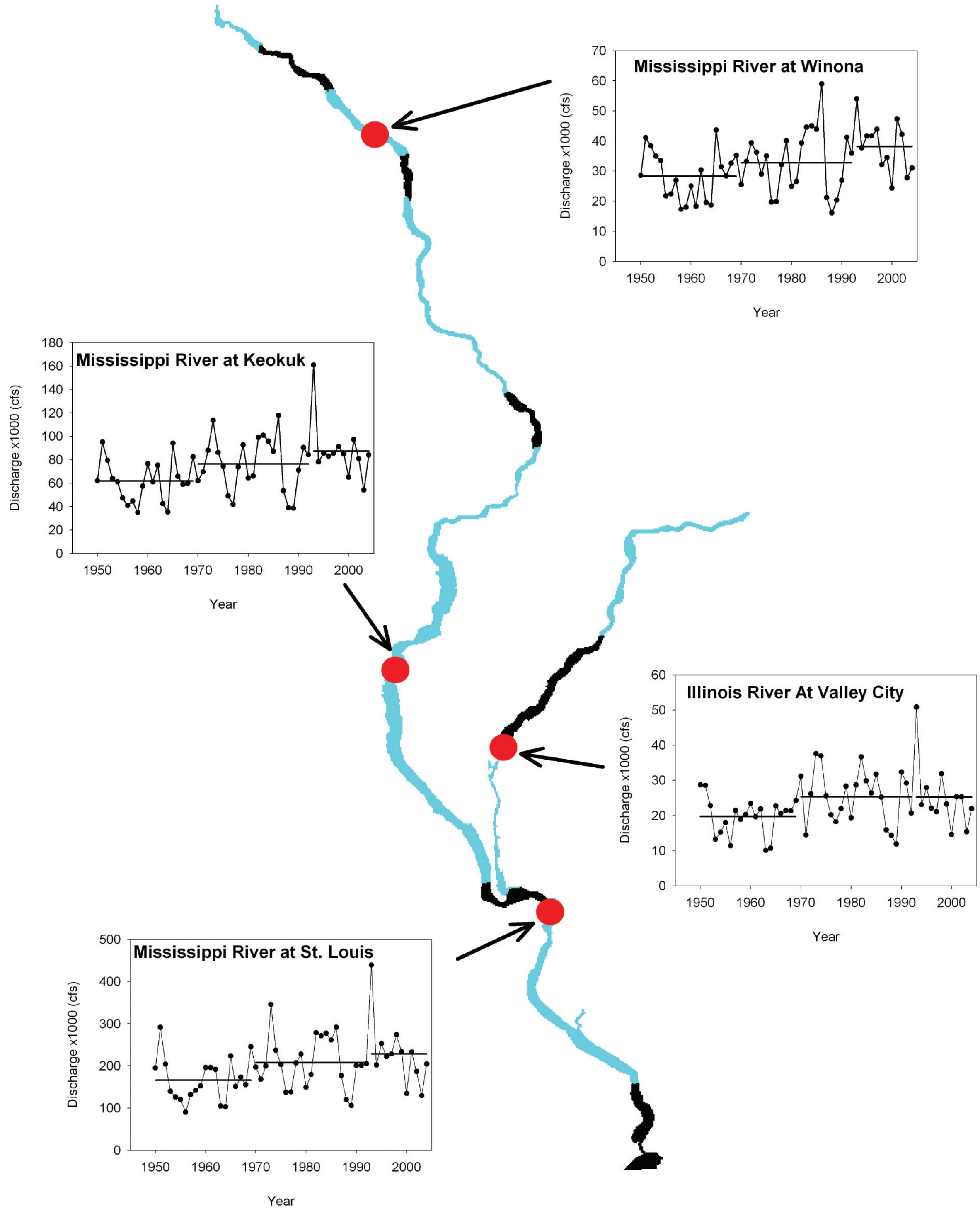

Figure 2.1. Mean annual discharge (1,000s of cubic feet per second) on the Upper Mississippi River System from 1950 to 2004 for gages at Winona, Minnesota; Keokuk, Iowa; and St. Louis, Missouri, on the Mississippi River and Valley City, Illinois, on the Illinois River. Horizontal lines on the graphs indicate mean discharge during 1950–1969, 1970–1992, and 1993–2004.

river to continue to provide the ecological goods and services desired by the public.

Authors

Robert Gaugush and Barry Johnson.

2.2.2 Seasonal Cycle of Water Elevation

Assessment

Status: Fair to Poor. All reaches have maintained seasonal cycles with spring flooding. In the impounded reaches, mean water elevation is higher than pre-dam levels, especially during low flow periods. In the Unimpounded Reach, water elevations are similar to historical levels. Short-term variation in elevation is also a concern in all reaches.

Trend: Stable. There are, however, opportunities for improvement with management strategies that allow lower water levels during low flows in many impounded reaches, which may lead to improvements in this indicator in those locations.

Purpose

Plants and animals in the UMRS have adapted to a relatively predictable seasonal cycle of water elevations, which is reflected in their life history strategies. Changes in the seasonal cycle (timing, increase or decrease in range of elevations, etc.) can affect a variety of ecological functions including access to floodplains, timing of reproduction, drying of soils, seed germination, and production of plants as food for migrating waterfowl. Annual variation in water elevation is always evident and biota must adapt continuously, but this indicator considers the average conditions faced by biota over multiple years and multiple life cycles.

State of the Ecosystem

Annual hydrographs show clear differences over time between the impounded reaches and the Unimpounded Reach. In the impounded reaches, dams have increased water elevations up to 3 m, primarily during low flow periods (summer and winter, Figure 2.2). These dams were not designed for flood control and their effect on elevations is much less during spring floods. The overall effect on the impounded reaches has been to effectively remove the lower water elevations experienced during the pre-dam period. This has two primary effects, permanently inundating the area immediately behind each dam and reducing current velocities behind the dams. Reduced current velocities promote increased sedimentation rates and filling of impounded areas and backwaters. The permanently inundated areas no longer experience the annual cycle of wetting and drying that existed before dam construction, which has resulted in substantial losses of aquatic vegetation along shorelines and in shallow wetland areas. In addition, the open expanses of water above dams are now subjected to the erosive force of wind-induced waves, which has resulted in loss of islands and filling of deeper areas by sediment in these zones. The physical changes in hydrology produced by the dams were essentially immediate. The resulting geomorphic changes (loss of islands and reduced depth diversity) were probably rapid immediately after the dams were built, but are now occurring at slower rates.

In the Unimpounded Reach, the mean annual hydrographs at St. Louis were similar between pre- and post-dam periods and show only slight changes in the annual cycle of elevation. This site is not affected by a downstream dam, but is affected by other factors (Simons et al. 1974). Beginning in the mid-1800s, numerous dikes stretching from the shoreline into the channel were built throughout the UMRS to force water into the middle of the channel at low flows (Brauer et al. 2005). The dikes in the Unimpounded Reach had greater ecological effects than in the impounded reaches. In the Unimpounded Reach, dikes were much longer and higher and the area between dikes filled with sediment to create dry land. This permanently constricted the channel and greatly reduced the amount of shallow and off-channel aquatic habitats. This constriction created a narrower channel with increased water depth and current velocity. Also, in the 1950s, dams constructed on the Missouri River substantially reduced the amount of sediment delivered by the Missouri River to the Mississippi (Meade 1995). The combination of a constricted channel and reduced

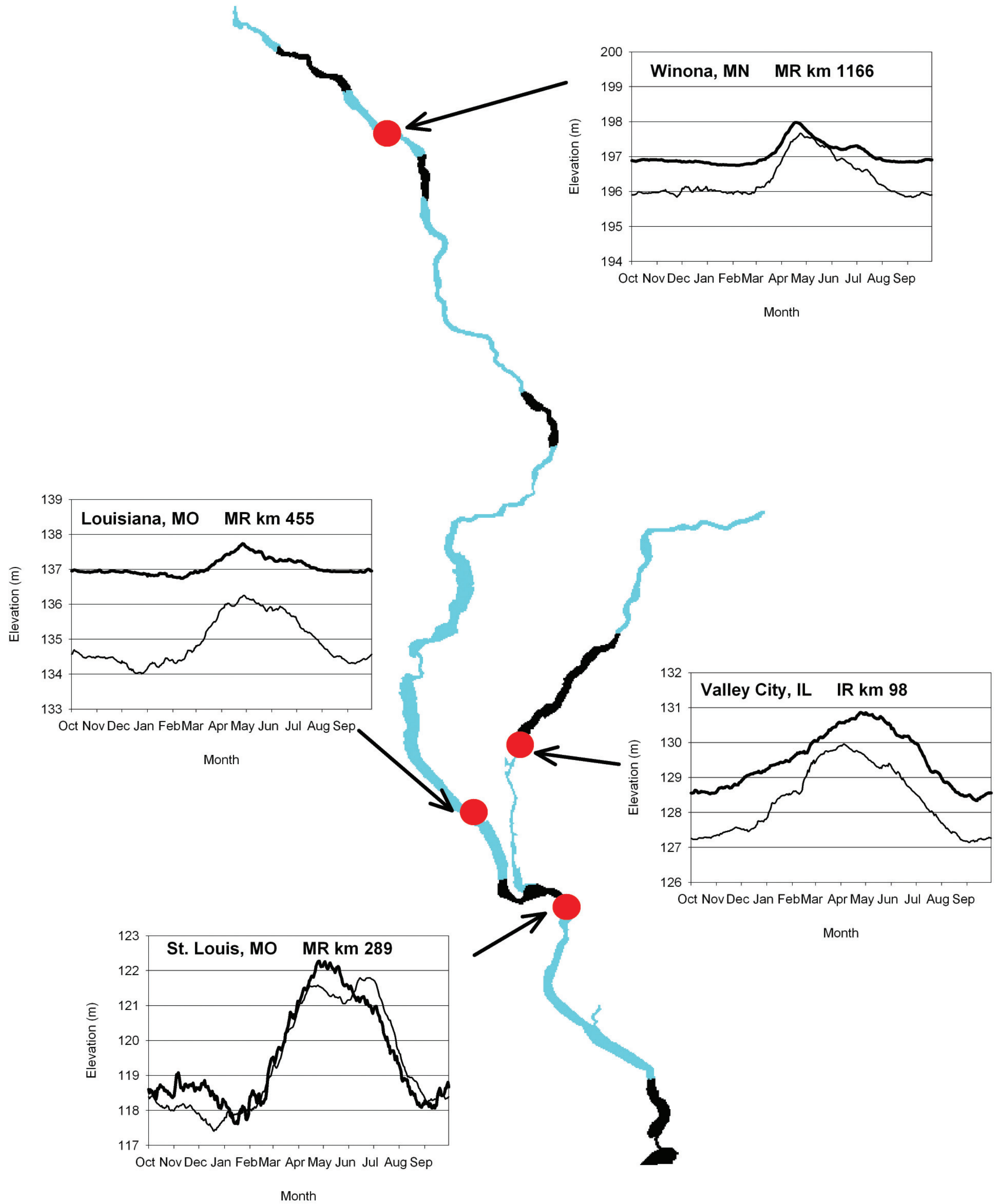

Figure 2.2. Average annual hydrographs of water elevation (m above mean sea level) on the Upper Mississippi River System before dam construction (*narrow line*) and after dam construction (*bold line*). Gage locations are Winona, Minnesota, and Louisiana and St. Louis, Missouri, on the Mississippi River, and Valley City, Illinois, on the Illinois River. See Table 2.1 for specific dates used for each gage.

sediment delivery resulted in erosion of the Mississippi River bed, which reduced the bed elevation. Compared to historical conditions, the channel in the Unimpounded Reach is now narrower and deeper, and current velocities have increased. In addition, comparisons of water elevation at identical discharges indicate that at low discharge, water elevation is lower than historically observed and at high discharge is higher than historically observed (Wlosinski 1999; Pinter et al. 2001). These changes, combined with an extensive levee system in the Unimpounded Reach (see section 2.5.3) have greatly reduced the connection of the river to its floodplain.

In addition to seasonal cycles, short-term (daily to weekly) variation in water levels has also increased substantially within the UMRS (R. Gaugush, unpublished data). The magnitude of these elevation changes is greater in the lower reaches. Short-term variation can have negative effects on reproduction and survival of many plants and animals that need relatively constant water levels, especially during critical early life stages. Factors that increase short-term variation in water levels include changes in land use that increase runoff and result in more rapid delivery of water to the UMRS. In addition, some dams on the UMRS are operated to control water elevations at a point in the middle of a pool, which increases short-term variation in the lower portions of the pool. In the Unimpounded Reach, the narrower channel also increases short-term variation in water levels because any change in discharge through the constricted channel produces a proportionally larger change in water elevation compared to a wider channel.

Future Pressures

Any long-term change in discharge will also affect mean water elevations. However, other factors and management decisions are likely to have more immediate effects. In the impounded reaches, experiments using modified procedures for dam operations and channel dredging have allowed managers to reduce water levels during summer (drawdowns) on Pools 5, 8, 24, and 25. These drawdowns have shown promise for producing ecological benefits with little effect on commercial and recreational users. Managers are using the results of these experiments to begin developing strategies for using drawdowns as long-term management tools. In addition, changes in dam operations may allow managers to reduce short-term variation in water elevations by using more frequent changes of dam gates, or by managing water levels using a control point at the dam rather than at mid-pool. The loss of morphological complexity due to island erosion and sedimentation of deeper areas may be partially addressed through management actions, such as island construction and dredging. Management of land use and land cover in the watershed to reduce runoff would help to reduce short-term variation in discharge and water levels, but actions on the uplands are outside the control of managers in the EMP.

In the Unimpounded Reach, hydrologic conditions are not expected to change in the near future. Managers will need to develop strategies for ecological rehabilitation within the constraints of a constricted channel and leveed floodplain. Management strategies that create more shallow areas within the main channel are of particular interest. Side channels are the primary type of off-channel habitat within this reach and rehabilitation of side channels, or creation of new channels within old dike fields, will be critical to increasing habitat diversity. Strategies for reducing short-term variation in water levels within this reach are limited; thus, side channel rehabilitation will likely focus on ways maintain a connection to the main channel, and to maintain acceptable conditions of flow and water depths at some location within side channels, at different river discharges.

Authors

Robert Gaugush and Barry Johnson.

2.3 Water Quality Indicators

Water quality indicators relate mainly to the concentrations of important constituents in the water column. Nutrients and dissolved oxygen are critical elements in the survival and growth of aquatic organisms, but high nutrient levels can cause excessive plant growth. Chlorophyll *a* is a common pigment in phytoplankton, tiny plants that live suspended in the water and form the base of many aquatic food chains. Thus, the concentration of chlorophyll *a* is a measure of phytoplankton abundance. Suspended solids are a measure of the amount of material suspended in the water, which includes both soil particles and biological materials. High concentrations of suspended solids, whether due to high phytoplankton abundance or high silt loads, reduce light availability, which can reduce growth of rooted aquatic plants. An indicator of suitable winter habitat for fishes in backwaters uses a combination of temperature, dissolved oxygen concentrations, and water depth. The right combination of these three factors produces optimal conditions for fish survival in backwaters during winter.

2.3.1 Major Nutrients (Total Nitrogen and Total Phosphorus)

Assessment

Status: Fair in the upper reach, and fair to poor in the lower reaches and Illinois River. In the Upper Impounded Reach (three upper pools) total nitrogen concentrations exceeded suggested guidelines about 50% of the time. In Pool 26, the Open River Reach, and La Grange Pool, total nitrogen concentrations exceeded suggested guidelines most of the time. Total phosphorus concentrations almost always exceeded suggested guidelines in all LTRMP study areas.

Trend: Stable in all reaches.

Purpose

Nitrogen and phosphorus are essential plant nutrients required for the growth of algae and aquatic plants. Nutrient inputs from sewage effluent and urban and agricultural runoff can result in excessive nutrient concentrations. Excessive nutrients can cause a range of problems in aquatic systems (Smith et al. 1999).

One effect of high nutrient concentrations is high rates of production. These high rates of production produce a large amount of organic material that causes low oxygen concentrations as it decomposes. A second effect of high algal abundance is that light does not penetrate deeply into the water and this can have a negative effect on the abundance and distribution of submersed aquatic vegetation. High nutrient concentrations can also promote the occurrence of abundant filamentous algae, which can have detrimental effects on submersed vegetation. In addition, high nutrient concentrations may also promote rapid growth of duckweed, a small aquatic plant that floats on the surface. When duckweed is abundant, little light penetrates into the river. This may reduce submersed vegetation and promote conditions of low dissolved oxygen. In summary, excessive nutrients can lead to reduced submersed vegetation and dissolved oxygen through a variety of mechanisms. Because vegetation is important as fish habitat and as food for waterfowl, excess nutrient concentrations may lead to less favorable habitats for fish and waterfowl.

High rates of algal production caused by high nutrient inputs can also cause problems when rivers are used as a drinking water source. Algal blooms can lead to taste and odor problems and increase the frequency with which intake filters need to be cleaned (Descy 1992). In addition to the impacts of nutrient inputs on algal production in the river, delivery of excess nutrients to the Gulf of Mexico by the Mississippi River causes widespread hypoxia (low oxygen concentrations) resulting in an extensive “dead zone” in the areas of the Gulf that receive nutrient input from the Mississippi River (Rabalais et al. 2002).

State of the Ecosystem

Total nitrogen (TN) concentrations in the main channel have increased substantially in the UMR in the last century because of the emergence of agriculture as the dominant land use and associated high rates of fertilizer application, and increased urban inputs. In the early 1900s, TN concentrations in the UMR near Grafton (near the southern end of the Illinois River) were approximately 1.8 mg/L (Goolsby and Battaglin 2001). From 1994 to 2002, concentrations in the UMRS ranged from approximately 1 to 8 mg/L (Figure 2.3). Currently, the suggested range for TN concentrations for the UMRS is 0.6–2.18 mg/L (USEPA 2000a; Smith et al. 2003). This range applies to aquatic life rather than human health. It is based on the USEPA recommended procedure for using the upper quartile of the nutrient concentrations for reference streams (0.6 mg/L) and the lower quartile of sampled streams (2.18 mg/L) to define an appropriate range. We applied this procedure to data from the "Corn Belt and Northern Great Plains" region (Smith et al. 2003), which encompassed several of the sampled reaches. The three northern study reaches exceeded the suggested guidelines about 50% of the time, including at least one season—usually spring or summer—in every year from 1994 to 2002. The three southern reaches exceeded these guidelines most of the time. In La Grange Pool, mean TN concentrations were always greater than the guidelines. There were no significant trends in TN concentration from 1994 to 2002.

For total phosphorus (TP), the suggested guidelines are 0.01–0.08 mg/L as derived from the procedures described above for TN (USEPA 2000a; Smith et al. 2003). Concentration of TP in the UMRS ranged from 0.05 to 0.3 mg/L (Figure 2.4).and almost always exceeded the guidelines. There were no significant trends in TP from 1994 to 2002 for any study reach.

Future Pressures

Future changes in nutrient inputs to the river are difficult to predict. Nutrient inputs are largely a function of outputs from sewage treatment plant and runoff from fertilizer applications on land. Increased human populations along the river would likely increase nutrient inputs. Improvements in treatment of sewage and urban runoff would be needed to counteract the effects of increased population. In many parts of the basin most of the land is already in agricultural production so the land area used for agriculture is unlikely to increase substantially. However, changes in the types of crops grown, fertilizer use, drainage systems, or land management may modify the input of nutrients from fields to waterways.

The last 200 years of changes in agricultural land management and more recently in fertilizer application have led to substantial increases in nutrient concentrations in the UMR (Turner and Rabalais 2003). The changes that have led to current conditions have accumulated over many years and it is almost certain that any changes in land use and management practices undertaken in the future to reduce nutrient concentrations will require many years before the effects of those changes are fully realized (Turner and Rabalais 2003).

It is possible that some changes in management of river flows and floodplains could reduce overall nutrient export from the UMRS to the Gulf of Mexico. Backwater areas are locations of high rates of denitrification, an important nitrogen removal process (Richardson et al. 2004; Strauss et al. 2004). Increasing the flow of river water through backwaters or restoring additional wetlands, particularly where tributaries join the river, may reduce nitrogen transport in the UMRS. Management to increase plant growth, such as summer water level reductions, can also reduce nutrient transport by storing nutrients in plant tissue, at least temporarily. However, the overall magnitude of nutrient reduction that can be achieved by such modifications of river hydrology and habitats is unknown.

Author

Jeffrey Houser.

2.3.2 Chlorophyll *a*

Assessment

Status: Mixed. In all locations chlorophyll concentrations vary from low to high among years and seasons.

Trend: Stable in all reaches.

Purpose

Chlorophyll *a* concentration is a basic measure of the abundance of suspended algae. These algae are an important part of the base of

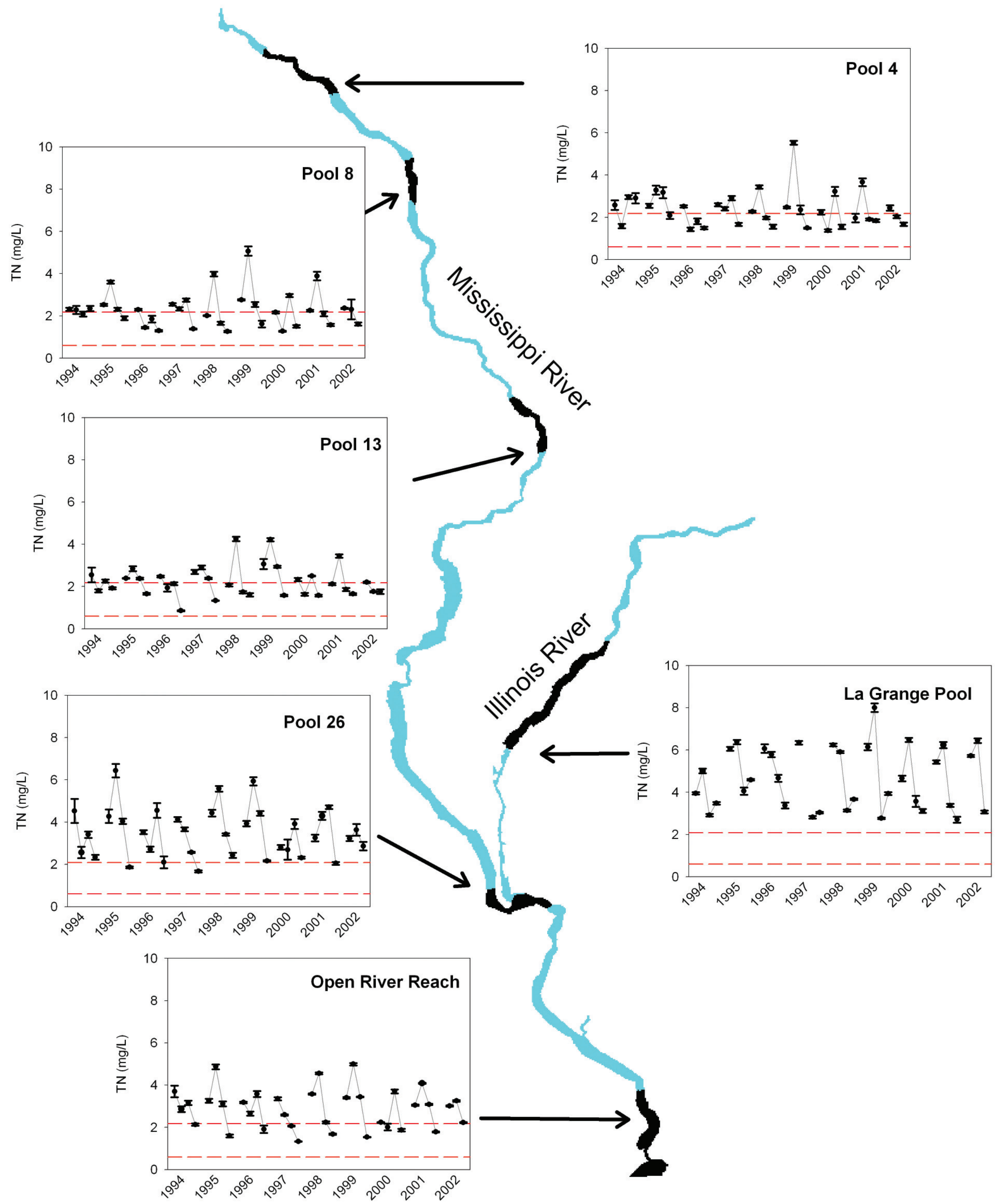

Figure 2.3. Total nitrogen (TN) concentrations in the main channel of the six Long Term Resource Monitoring Program study reaches from 1994 to 2002. Data points are means from stratified random sampling episodes for winter, spring, summer, and fall. Error bars are one standard error. Dashed lines are lower and upper limits of suggested range for TN concentrations (USEPA 2000a; Smith et al. 2003). There are no significant trends in TN for the period 1994–2002.

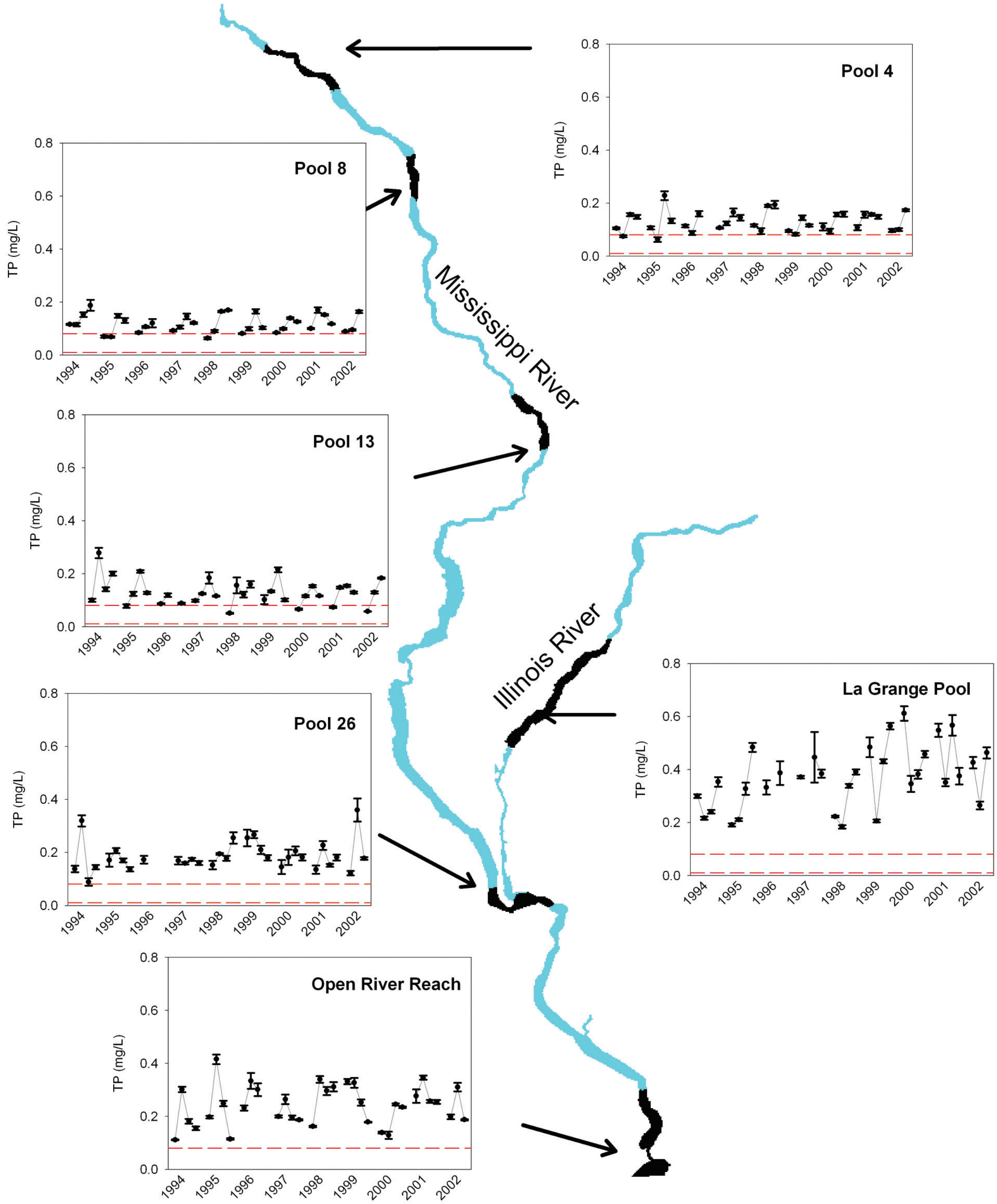

Figure 2.4. Total phosphorus (TP) concentrations in the main channel stratum of the six Long Term Resource Monitoring Program study reaches from 1994 to 2002. Data points are means from stratified random sampling episodes for winter, spring, summer, and fall. Error bars are one standard error. Dashed lines are lower and upper limits of suggested range for TP concentrations (USEPA 2000a; Smith et al. 2003). There are no significant trends in TP for the period 1994–2002.

the river food web, but excessive algal abundance can have negative effects on the river ecosystem. For example, high algal concentrations can reduce light penetration into the water column, which reduces growth of aquatic vegetation; can cause low oxygen conditions when algae die and decay; can increase costs of treatment for drinking water supplies; and may reduce the appeal of the river for recreational uses, such as swimming and boating, because of its negative effect on river aesthetics (Smith et al. 1999).

State of the Ecosystem

Among seasons, years, and pools, chlorophyll concentrations in the main channel vary among what is considered low (<10 μg/L), medium (10–30 μg/L), and high (>30 μg/L; based on the criteria in Dodds et al. 1998). The UMRS main channel concentrations are most often in the medium (mesotrophic) range. Main channel concentrations in the UMRS generally range from near 0 to 70 μg/L (Figure 2.5). Generally, concentrations are lowest in winter. High chlorophyll concentrations were observed in spring 1994 in Pools 13 and 26 and in fall 1996 in Pool 8 and may be the result of an algal bloom during the sampling period. In all three southern study reaches, high chlorophyll concentrations, indicating eutrophic conditions, were more common in 2000–2002 than during the 1990s, however significant trends over the period of 1994–2002 were not observed. In the upper pools eutrophic conditions occurred less often in 2000–2002 than in the 1990s. The reasons for these changes are unclear but they do not appear to be associated with changes in nutrients (Figures 2.3 and 2.4) or total suspended solids (Figure 2.6).

Future Pressures

Chlorophyll concentrations in large rivers are generally determined by light availability (largely determined by total suspended sediment concentrations; see section 2.3.3 below), nutrient availability, and current velocity. Chlorophyll concentrations may respond to changes in nutrients and light availability, but even qualitative predictions of future chlorophyll concentrations are difficult because the relations between nutrients, light availability, current velocity, and algal production in large rivers are not well understood. Grazing by invasive Asian carps (see section 2.8.7) and zebra mussels, which feed mainly by filtering algae from the water, may reduce chlorophyll concentrations in the river as their populations increase.

Author

Jeffrey Houser.

2.3.3 Total Suspended Solids

Assessment

Status: Mixed, ranging from good in the upper reaches to fair-poor in the lower reaches and Illinois River. Lower Pool 4 and Pool 8 were generally below the maximum recommended concentration for total suspended solids of 25 mg/L. Upper Pool 4 and Pool 13 exceeded the recommended concentration more frequently. Pool 26, the Open River Reach, and La Grange Pool almost always exceeded the recommended concentration.

Trend: Stable or improving in Upper Impounded Reach (three upper pools). Stable in all other reaches.

Purpose

Total suspended solids (TSS) are a measure of the concentration of particles in the water column and are frequently cited as a primary water quality concern in the river. The TSS affects aquatic vegetation by reducing light penetration into the water (Barko et al. 1982, 1986; UMRCC 2003), which may reduce plant growth and the feeding efficiency of visual predators (e.g., bluegill [*Lepomis macrochirus*] or bass; Simon 1999). In addition, sediment particles adsorb, transport, and store nutrients and pollutants (e.g., metals and dissolved organic compounds) in aquatic systems (Welch et al. 1998).

Recent recommendations for TSS in the UMRS suggest that concentrations <25 mg/L (as a summer average) are needed to establish desired levels of aquatic vegetation (UMRCC 2003). The 25 mg/L criterion was based on sustaining tuber production of wild celery (*Vallisneria americana* Michx) in areas of 0.8 m depth or less (UMRCC 2003). If the guidelines

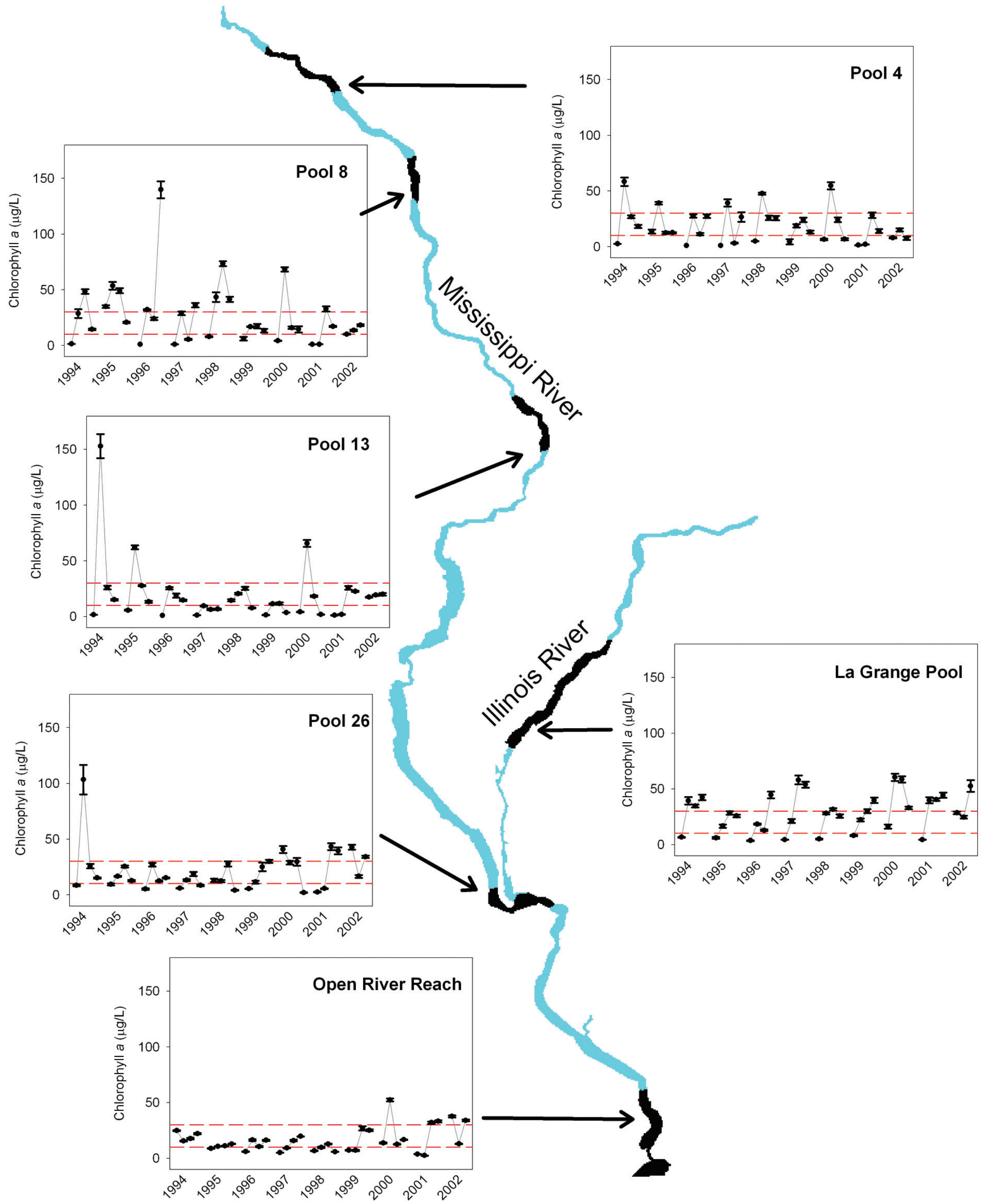

Figure 2.5. Chlorophyll *a* concentrations in the main channel stratum of the six Long Term Resource Monitoring Program study reaches from 1994 to 2002. Data points are means from stratified random sampling episodes for winter, spring, summer, and fall. Error bars are one standard error. Dashed lines represent the upper and lower bounds of "medium" chlorophyll concentrations (mesotrophic conditions) as defined by Dodds et al. 1998. Points above both dashed lines indicate "high" concentrations of algae (eutrophic conditions).

are exceeded, negative effects on wild celery and other vegetation may occur. However, this criterion may be unrealistic in the Unimpounded Reach, where TSS have always been high due to inputs from the Missouri River (Meade 1995). A separate criterion for the Unimpounded Reach should be considered.

State of the Ecosystem

Concentration of TSS generally increased radically from upstream to downstream. Concentrations ranged from about 5 mg/L to as high as 400 mg/L. There was considerable seasonal variation with highest concentrations typically occurring in spring and lowest during winter especially in the northern reaches (Figure 2.6) probably due to low flows, reduced sediment inputs from the frozen watershed, and reduced sediment resuspension under the ice. All pools exceeded the recommended concentration of 25 mg/L on some occasions. Lake Pepin, a natural riverine lake in Pool 4, acts as a natural settling basin, which reduces TSS substantially downstream (Figure 2.6). The TSS concentrations in upper Pool 4 typically ranged from 20–60 mg/L (except during winter), but in lower Pool 4 were reduced to about 5–15 mg/L. Lower Pool 4 and Pool 8 were generally below the 25 mg/L recommendation, though in many years Pool 8 had at least one season with mean TSS concentrations above this level. Upper Pool 4 and Pool 13 were similar and exceeded the recommended maximum concentration more frequently. Further down river, inputs from sediment laden tributaries increase TSS. The three southern study reaches almost always exceeded the recommended concentration. From 1994 to 2002, there was a significant decline in TSS during fall in Pools 4 and 8, but no trends in other locations.

Future Pressures

High inputs of TSS from tributaries draining catchments dominated by agriculture are a major source of TSS in the river (Wasley 2000). Changes in the types of crops grown or in land management may modify sediment inputs to waterways. "Best Management Practices" are often prescribed for uplands with a goal of reducing sediment runoff into streams. However, historical sediment deposits in many tributaries are substantial (Knox et al. 1975; Knox and Faulkner 1994); thus, even if these practices are implemented soon, inputs from tributaries will likely change slowly. In addition, resuspension of sediments by barge traffic (Johnson 1976), recreational boating (Knight and Parchure 2004), wind-generated waves, and bottom feeding fish may also contribute to high concentrations. Future trends in barge traffic are uncertain, but recreational boating is likely to increase.

Some management actions are being undertaken that may help reduce TSS. Construction of islands in large open water areas can reduce wind fetch and resuspension of sediments caused by wind generated waves. Islands can also shelter areas from flow creating quiet water that allows sediments to settle out. These effects can reduce TSS and promote increased plant growth locally, but the effect at the pool-wide scale is uncertain. Reduction of pool water levels during summer (drawdowns) is another management option that may reduce TSS concentrations (Landwehr et al. 2005). These drawdowns expose bottom sediments allowing them to dry and consolidate, and also promote growth of both submersed and emergent plants. As plant beds develop during summer, they help to anchor sediments, especially along shorelines. Plant beds can also help reduce wind fetch and wave energy. This reduces sediment resuspension and increases sedimentation within plant beds, thus reducing TSS.

Author

Jeffrey Houser.

2.3.4 Dissolved Oxygen

Assessment

Status: Generally good, but with occasional episodes of low oxygen (hypoxia) in the upper reaches. Winter hypoxia in the backwaters is much more common in the Upper Impounded Reach than in Pool 26 or La Grange Pool.

Trend: Stable.

Purpose

Sufficient dissolved oxygen (DO) concentration is an important characteristic

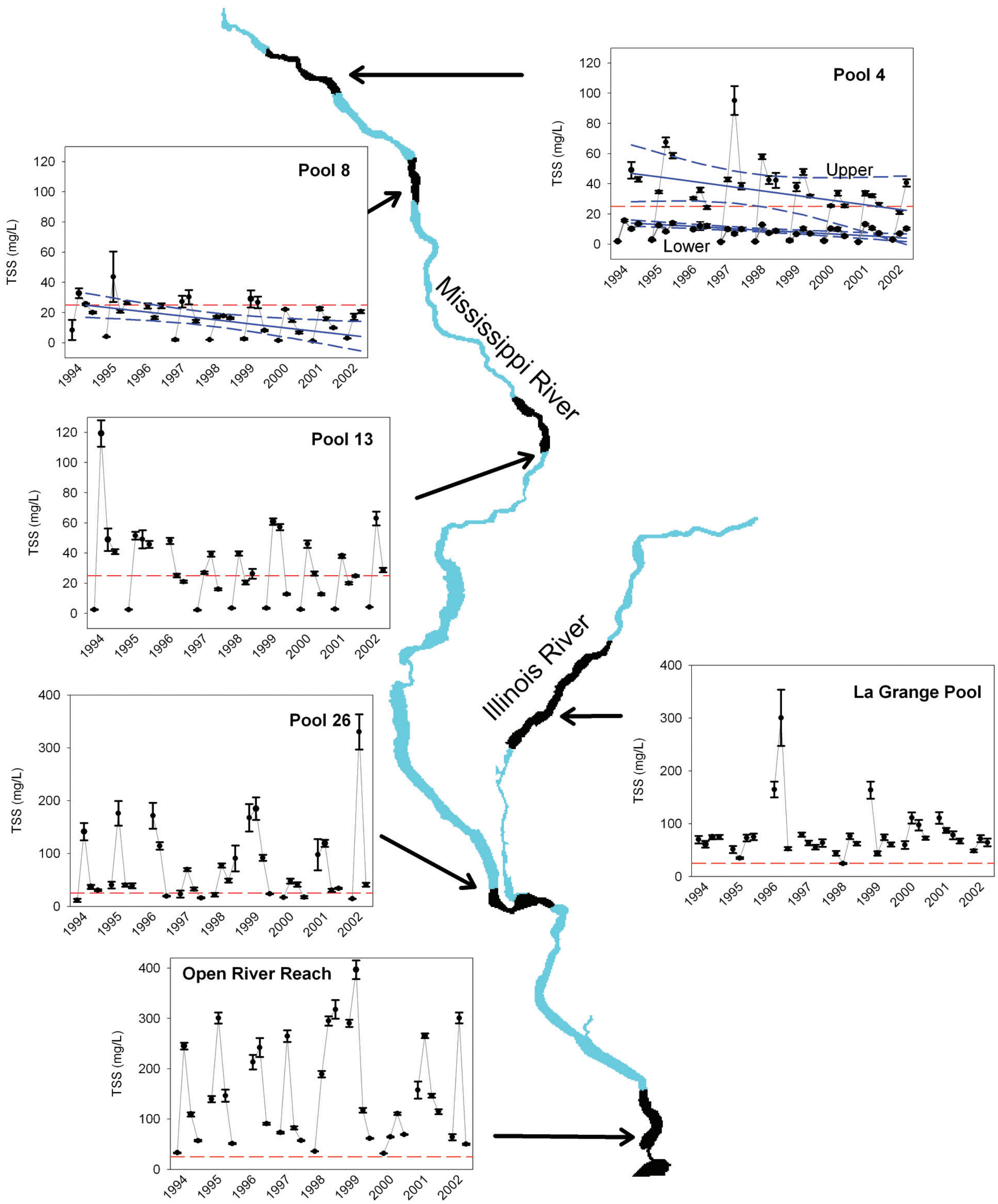

Figure 2.6. Total suspended solids (TSS) concentrations in the main channel stratum of the six Long Term Resource Monitoring Program study reaches from 1994 to 2002. Data points are means from stratified random sampling episodes for winter, spring, summer, and fall. Error bars are one standard error. In Pool 4, data are shown for the upper and lower portions of the pool. These represent areas above and below Lake Pepin, a large, natural lake within the pool that acts as a settling basin. For 1994–2002 there was a significant decreasing trend in TSS in Pools 4 and 8, with no trends in other locations. The horizontal dashed red line represents 25 mg/L, the recommended maximum summer mean concentration of TSS to establish rooted aquatic vegetation (Upper Mississippi River Conservation Committee Water Quality Technical Section 2003). The solid blue lines for Pools 4 and 8 represents the trend in fall TSS concentrations, with 90% confidence intervals (*dashed blue lines*). Note that the scale of the vertical axis is much larger for Pool 26, Open River, and La Grange Pool (0–400 mg/L) than for the upper three pools (0–130 mg/L).

of habitat suitability for aquatic organisms. The DO is determined by the balance between oxygen production by aquatic vegetation and algae and oxygen consumption by plant and animal respiration and decomposition of organic material. Excessive nutrient inputs that lead to excessive vegetation and algal production result in abundant organic material that can reduce DO concentrations to low levels as it is decomposed. The concentration of DO required varies among organisms, but 5 mg/L is used as a water quality standard by all of the UMRS states (Upper Mississippi River Basin Association 2004). In winter, mobility of some fish is limited by temperature so low current velocity environments with adequate DO concentrations are required. As a result, dissolved oxygen concentrations in backwaters during winter are of particular concern.

State of the Ecosystem

The DO data presented here were generally collected between mid-morning and mid-afternoon. Because minimum DO concentration typically occurs just before dawn, these data underestimate the true occurrence of low oxygen conditions. Nonetheless, the data provide important information on when and where low dissolved oxygen is likely to occur and indicate areas where these conditions are present throughout the day.

Low oxygen conditions are more common in backwaters where water is slow moving and rates of oxygen consumption are high. The main channel is generally well mixed and oxygen consumption is relatively low; thus, oxygen concentrations are generally usually above 5 mg/L. However, low oxygen concentrations have occurred in the main channel of La Grange Pool on the Illinois River (Table 2.2). Compared to the Mississippi River, the Illinois River has a lower gradient so the water moves more slowly and a higher load of organic material, which uses substantial oxygen during decomposition.

Analysis of DO concentrations indicates that during winter 10% to 14% of the backwater area in Pools 4, 8, and 13 have mid-day DO concentrations below 5 mg/L and, during summer, 12–21% of the backwater area of Pools 8, 13, and 26 have DO concentrations less the 5 mg/L (Table 2.2; Fischer et al. 2005). In the upper three pools, the proportion of sampled backwater sites with low oxygen during winter is highly variable among years ranging from near zero to almost 40%. There were no trends during 1994–2002 (Figure 2.7). In winter, snow on top of ice decreases light penetration and reduces the production of oxygen through photosynthesis by plants; thus, the depth of snow cover can be a useful predictor of the extent of winter hypoxia in backwaters of the upper pools (Fischer et al. 2005). In the lower pools, backwater winter hypoxia is rare. This is most likely a result of the minimal ice cover in these reaches and low winter water temperatures that increase the solubility of oxygen in water and reduce bacterial respiration and therefore oxygen demand.

Future Pressures

The UMRS has probably always been a system with abundant organic material and may have always experienced some degree of winter hypoxia. Increased inputs of nutrients and organic materials, and reduced water volume in backwaters as they become shallower due

Table 2.2. Mean percentage of stratified random sampling sites with surface dissolved oxygen concentration <5 mg/L in winter and summer from 1993 to 2001.

Study reach	Strata	
	Main channel	Backwater
Winter		
Pool 4	0.4 (1.3)[a]	**14 (14)**[b]
Pool 8	0	**13 (9)**[b]
Pool 13	0	**10 (5)**[b]
Pool 26	0	6 (2)
Open River	0	--[c]
La Grange Pool	0	0.9 (3)
Summer		
Pool 4	0.8 (3)	0.058 (0.07)
Pool 8	0.8 (2)	**12 (8)**[b]
Pool 13	0.3 (1)	**21 (14)**[b]
Pool 26	1.4 (4)	**13 (10)**[b]
Open River	1.3 (4)	--[c]
La Grange Pool	**25 (24)**[b]	6.7 (6.7)

[a]One standard deviation is shown in parentheses.
[b]Bold font indicates locations where the occurrence of low dissolved oxygen is >10% (modified from Fischer et al. 2005).
[c]There is no backwater strata in Open River Reach.

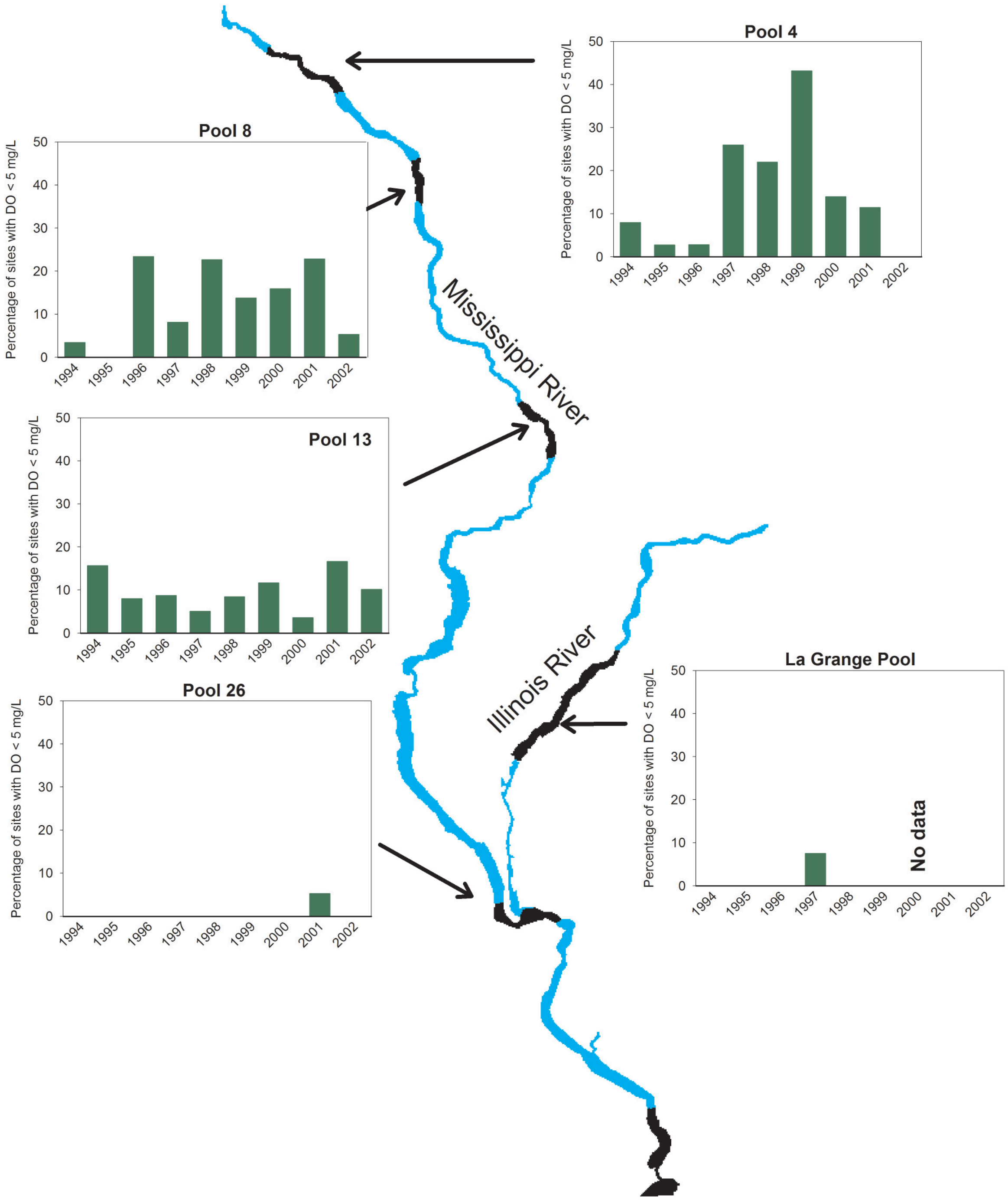

Figure 2.7. The percentage of backwater sampling sites where dissolved oxygen (DO) concentrations during winter, at the surface or just below ice cover, were <5 mg/L (1994–2002) for five study reaches of the Long Term Resource Monitoring Program (there are no backwater sampling areas in Open River Reach). There were no significant trends over the period 1994–2002.

to sedimentation, will likely increase hypoxia. In addition, many modifications to the main channel to facilitate navigation have resulted in less water flowing to backwaters to replenish oxygen supplies; thus, most management actions designed to increase oxygen concentrations focus on adjusting flow rates through backwaters during winter. The goal of this approach is to provide flows that are high enough to maintain sufficient dissolved oxygen concentrations but low enough to maintain suitable habitat for sport fishes, such as bluegills. Reduced inputs of nutrients and organic materials and increasing depth of backwaters by dredging may make it easier to achieve habitat with both suitable DO and current velocity.

Author

Jeffrey Houser.

2.3.5 Suitable winter habitat for sunfishes in backwaters

Assessment

Status: Poor in upper reaches, good in lower pools. There was relatively little suitable winter habitat in the upper reaches, but abundant winter habitat in Pool 26 and La Grange Pool.

Trend: Stable.

Purpose

Winter habitat conditions may cause stress, or even mortality, for fishes in rivers (Johnson and Charlton 1960; Bodensteiner and Lewis 1992; Sheehan et al. 2004). Research has identified suitable winter conditions for sunfishes in backwaters as dissolved oxygen concentration >5 mg/L, temperature >1.0^{o} C, and depth >0.33 m of water (under ice). The LTRMP monitoring design can track these variables and measure changes in the amount of suitable winter habitat through time.

State of the Ecosystem

In the UMRS, only a small percentage of the total backwater area sampled meets winter habitat suitability criteria in the upper pools, but percentages are much higher in lower pools (Figure 2.8). Pools 4, 8, and 13 have years with almost no suitable habitat and percentage of suitable habitat never exceeded 20% in Pools 4 and 8. The estimated area of suitable habitat was <10 ha in a few years for Pools 8 and 13, but never <100 ha in Pool 26 and La Grange Pool. Suitable habitat in Pool 4 area was below 50 ha in a few years during the 9-year period.

Of the three suitability criteria, low water temperature is the most common cause of unsuitable winter conditions (Figure 2.9), followed by depth and dissolved oxygen. Shallow water depths also contribute to the problem, but low dissolved oxygen concentration does not typically cause unsuitability in the UMRS. This combination of habitat characteristics is largely a function of water exchange between channels, where water is cold but with high oxygen levels, and backwaters, where water is slightly warmer but may have low oxygen. The rate of water exchange is affected by levees (natural or human-made) between channels and backwaters, the degree of water level fluctuations during winter, and the water volume in backwaters. Data indicate that backwaters in Pools 4, 8, and 13 are more likely to have lower water temperatures than more southern reaches. This may be due to slightly lower water temperatures typically found in the northern reaches during winter or to differences in rates of water exchange between the main channel and backwaters.

Despite relatively little suitable winter habitat in the northern reaches, the most common sunfish and bluegills (see section 2.8.1) are abundant in the upper pools. Thus, the usefulness of this metric as an indicator is questionable. Obviously fish must survive through winter to maintain their populations, but we do not know how much suitable winter habitat is needed within a river reach, nor how well fish survive in areas that do not meet the suitability criteria. Suitable winter habitat is relatively rare in many river systems (Cunjak 1996), but suitable areas often support high densities of fish during winter (Carlson 1992; Raibley et al. 1997). More investigation is needed of the effect of winter habitat suitability compared to other factors affecting the abundance of sunfishes.

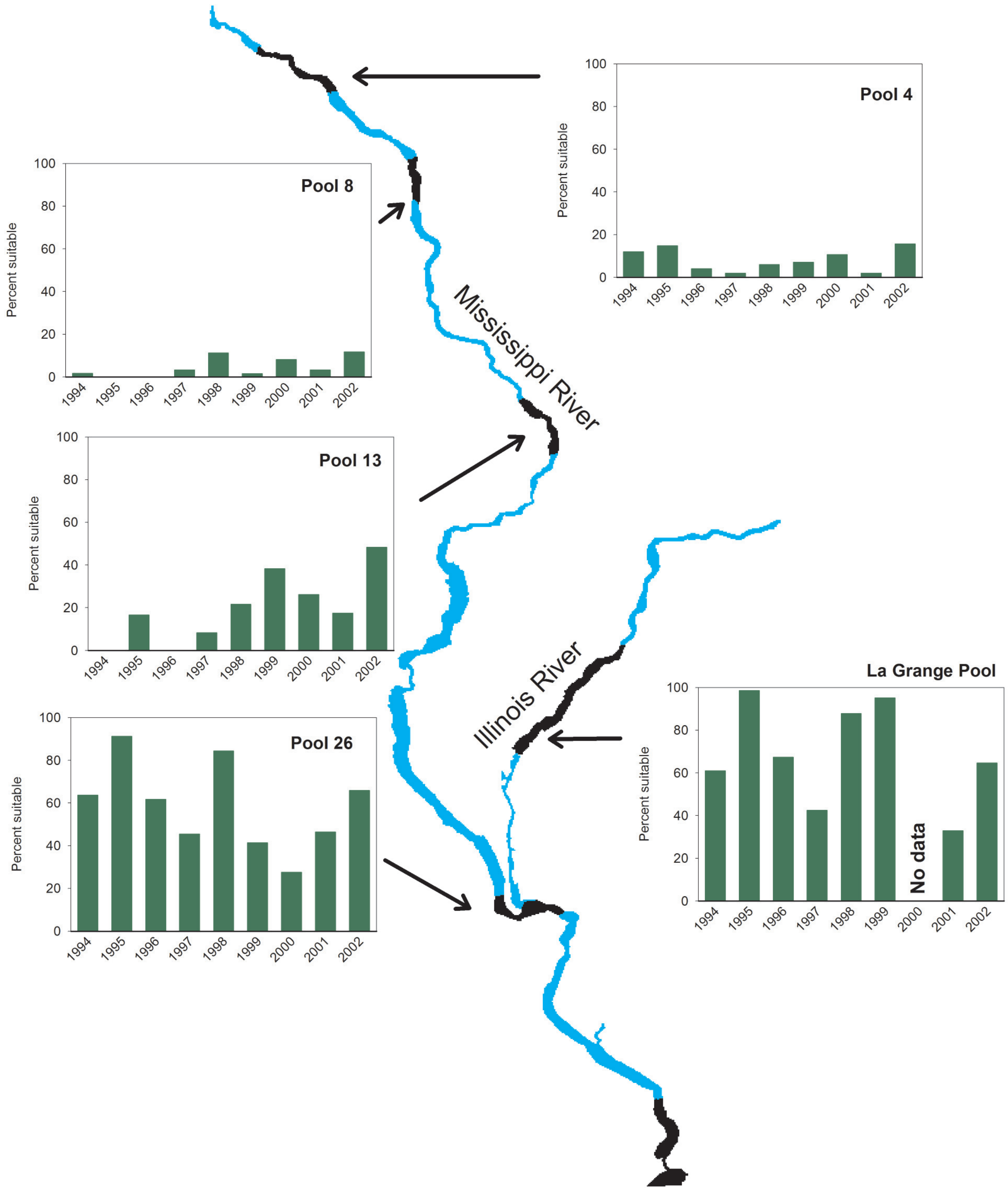

Figure 2.8. Percent of backwaters that contained suitable habitat for sunfishes during winter from 1994 to 2002 based on a combination of temperature, dissolved oxygen, and depth in study reaches of the Long Term Resource Monitoring Program that have backwater habitats.

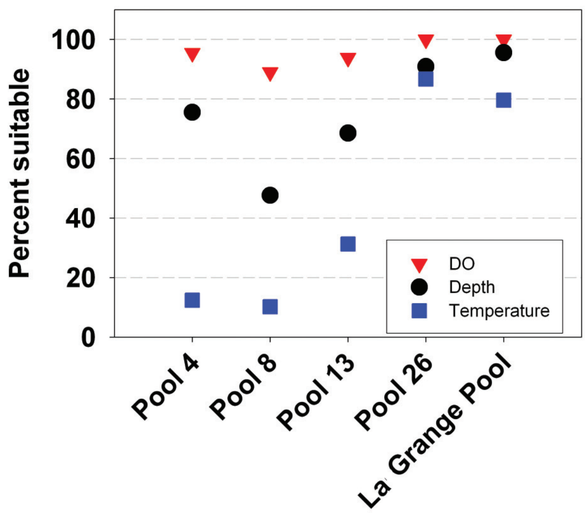

Figure 2.9. Mean percentage of backwater with suitable conditions during winter from 1994 and 2002 for temperature, dissolved oxygen (DO), and depth in study reaches of the Long Term Resource Monitoring Program that have backwater habitats.

Future Pressures

Continued loss of natural levees and decreased volume in backwaters due to sedimentation means that winter habitat suitability will likely remain low in upper pools. Stabilizing water levels in the winter would reduce exchange rates and thereby increase water temperatures, but stable levels may reduce dissolved oxygen concentrations. Habitat construction projects aimed at increasing suitable winter habitat in backwaters must find the right level of water exchange rates to assure a balance between suitable temperature and dissolved oxygen conditions; achieving that balance requires consideration of the geomorphic factors unique to each project area. Projects that increase depth in backwaters should result in more suitable habitat, until the deep areas fill with sediment again. Whether the level of suitability observed in the upper pools will have negative effects on the backwater fish community is unknown. However, projects designed to improve winter habitat may also have positive effects at other times of year and thus improve fish populations.

Authors

James Rogala and James Fischer.

2.4 Sedimentation Indicators

Sediments and sediment transport are integral parts of any large river. The processes of movement, storage, and resuspension of sediments produce the basic landscape mosaic within the river channel and floodplain. But, over time, soil erosion from converting prairies and forests to agriculture and urban areas has increased sediment flow in the river. Impoundments, such as dams, slow the flow and, often, more silt and sand are delivered than can be moved by the river. The resulting sediment accumulation can reduce habitat for plants, invertebrates, and fish; degrade water quality; and restrict opportunities for recreational boating. Changes to water depth as a result of sedimentation are reflected in the indicator of depth diversity in impounded areas (the large open water areas above dams) during the 50 years from 1940, soon after impoundment, to 1990. Sedimentation rates in backwaters reflect increased sediment inflows over time and changes in flow patterns implemented to support navigation. The indicator for net sedimentation in backwaters captures changes in three locations over a recent 5-year period. These indicators were measured only in Pools 4, 8, and 13, but sedimentation is a continuing problem in most of the UMRS.

Both of these indicators are directly related to processes of sediment movements. Hydrology and landscape modifications are important factors underlying these processes. There are management techniques that can be applied to the uplands to reduce inputs of sediment to tributary streams and ultimately to the UMRS. However, due to the substantial amounts of sediment already stored in tributaries, it may take many years before improvements in land management results in substantial reductions of sediment inputs to the Mississippi and Illinois Rivers. There are also a variety of techniques that managers have applied to river channels and floodplains that can have locally positive effects on sediment dynamics (both erosion and deposition) and on habitats.

2.4.1 Depth diversity in upper impounded areas

Assessment

Status: Poor. Above Pool 14 the processes of sedimentation and erosion have reduced depth diversity in the impounded areas since construction of the dams. Conditions in pools below 14, Open River Reach, and the Illinois River were not measured.

Trend: Slightly degrading.

Purpose

Diversity is a positive attribute of healthy, natural systems. Water depth is a critical feature of rivers defining habitat suitability for many biota. Other habitat components, such as water velocity, are correlated to water depth. Therefore, diversity in water depth should produce diversity in vegetation, fish, and wildlife. Water depth is a product of water elevation, which changes seasonally, and elevation of the river bottom and floodplain, which usually changes slowly. Changes in depth diversity over long periods (more than about 20 years) can be detected by repeated bathymetric surveys.

State of the Ecosystem

Large open-water impounded areas were formed in most of the pools above Pool 14 by construction of the dams in the late 1930s. In impounded areas, water velocity slows, which allows sediment to settle out, and wind produces substantial waves, which erode shorelines and resuspends sediments. During the first 50 years since impoundment, the combination of sediment deposition in deep areas and erosion of shallow areas resulted in a extensive loss of depth diversity in these impounded areas (Figure 2.10). In a study area within the impounded area of Pool 13, these two processes seem to be converging to produce a uniform depth of about 1.2 m.

A comparison of lower resolution data from the 1930s for Pools 4, 8, and 13 shows similar change over the same 50-year period (Figure 2.10). To quantify changes in diversity, we compared total length of the contour lines in the impounded areas between 1940 and 1990. Over the 50-year period, Pool 4 showed a 25%

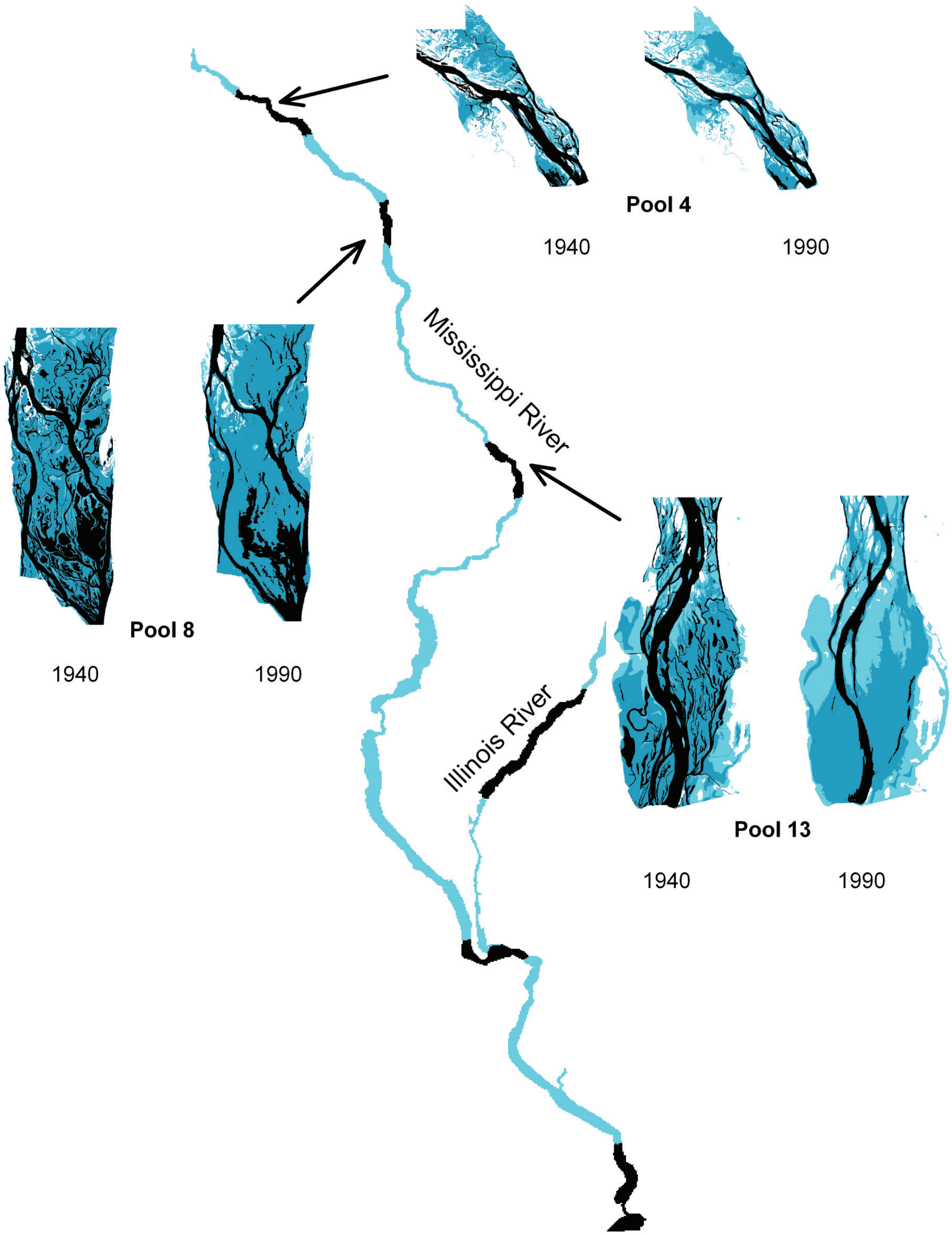

Figure 2.10. Change in water depths for the impounded areas in Pools 4, 8, and 13 of the Upper Mississippi River from 1940 to 1990. Water depth intervals are 1.5 meters, with dark colors depicting deeper areas.

loss in depth diversity, Pool 8 a 49% loss, and Pool 13 a 47% loss. These numbers are likely an under-estimate, as the recent database has a higher resolution; thus, ability to detect the edges is greater.

Though poorly documented in recent years, it is expected the process of erosion in shallow areas and deposition in deeper areas is ongoing. The rate of change has likely decreased as shallow areas eroded and deep areas filled, but considerable island erosion has still been observed recently. Habitat improvements performed by the Environmental Management Program have countered the loss of diversity through island building and dredging projects.

Future Pressures

The physical forces that cause loss of depth diversity will not change in the future, but the question of whether equilibrium between erosion and deposition has been reached remains unanswered. Repetitive surveys in the future will provide those answers. Given the substantial change that has occurred since impoundment, future changes should occur more slowly. Rehabilitation projects can increase diversity directly through island building and dredging. Islands are built using designs that are resistant to erosion. In addition, islands reduce wind-generated wave action and both islands and dredging help to concentrate flows in deep areas; thus, these projects modify the physical forces that cause loss of depth diversity. Restoring low water levels in the summer (i.e., drawdown projects) may have mixed effects on depth diversity. Drawdowns can expose and consolidate fine sediments with high organic content, which increases depth. These consolidated sediments have less potential for resuspension and transport, thus minimizing erosion. But drawdowns may also increase erosion in tributary deltas and in shallow aquatic areas. We will have a greater ability to detect future changes in water depth diversity, as we now have high resolution maps of water depth from 1990 for many pools of the UMRS.

Author

James Rogala.

2.4.2 Net Sedimentation Rates in Backwaters of the Upper Impounded Reach

Assessment

Status: Mixed.

Trend: Overall degrading. Rates of sediment accumulation are highly variable in space and over short periods, but overall accumulation rates are still of concern. Conditions in pools below 14 and the Illinois River were not measured. No backwaters occur in the Open River Reach.

Purpose

Accumulation of sediments in backwaters is a normal process in rivers. However, increased sediment inputs can speed up this accumulation and reduce the amount of deep water habitat, especially in areas with low flow. These changes have consequences for many fish and wildlife that rely on deep, off-channel areas during some portion of their life history. Detecting change through repeated measurement of water depth at specific locations can provide good estimates of change over short periods (5 years or less), but high variability in the data makes detection of overall change difficult.

State of the Ecosystem

Most pre-LTRMP studies found high rates of sediment accumulation after dam construction. However, many of these represent maximum rates in high deposition areas because most studies did not average rates across all backwaters. In addition, sedimentation rates have likely decreased over time due to reduced sediment trapping efficiency as backwaters became shallower. LTRMP monitoring between 1997 and 2001 in backwaters of Pools 4, 8, and 13 indicate that sedimentation rates were highly variable both within and among years (Figure 2.11). Rates were lower than measured in most previous studies but generally increased from Pool 4 to Pool 13.

The work in Pools 4, 8, and 13 indicated that rates of sediment accumulation and erosion were related to discharge and water depth or land elevation. At the time of the surveys, high discharge (e.g., 2001, Figure 2.1) resulted in sediment deposition in terrestrial areas and

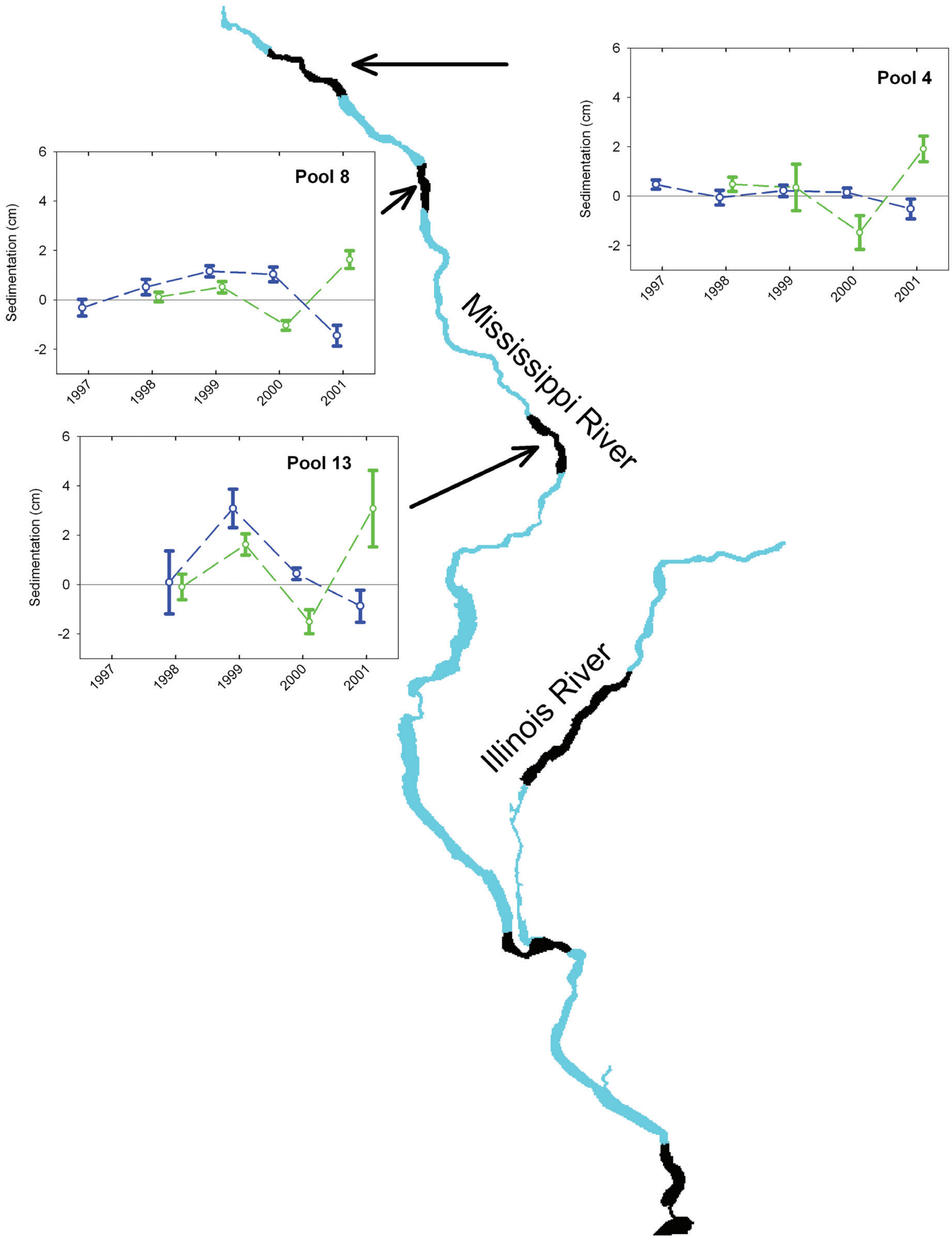

Figure 2.11. Annual net sedimentation rates for aquatic areas (*blue*) and terrestrial areas (*green*) in backwaters of Pools 4, 8, and 13 between 1997 and 2001. A negative sedimentation rate indicates that erosion was greater than sediment deposition in that year. Bars represent standard errors.

sediment erosion in aquatic areas. This relation with discharge was also reflected along the elevation gradient of transects, where deep areas accumulated sediments in low discharge years and were eroded in high discharge years. Changes in these relations between discharge and sedimentation rates would indicate process changes that may have effects across a wide range of physical and biological components.

Future Pressures

Sediment delivery to the UMR is not expected to decline substantially in the near future. The fate of these delivered suspended sediments will depend on sediment transport efficiency. Transport efficiency will change as natural levees protecting backwaters from flow are either created by deposition or removed through erosion. Replacing lost natural levees with human-made structures will maintain present conditions. The future net gain or loss of these protective barriers is unknown. Managers are considering sediment transport in designing habitat rehabilitation projects so that delivery of sediments to backwaters can be reduced and the occurrence of high-velocity flushing flows can be increased. Future changes in the relation between sedimentation, discharge, and water depth will be an indicator of changes in the overall process of sedimentation.

Author

James Rogala.

2.5 Land Cover/Land Use Indicators

The pattern of land cover within a river's floodplain is the result of river dynamics and human intervention. Cities and farm fields behind levees are obvious modifications, but changes in vegetation and habitat types can be the result of more subtle changes in flows or water levels. A healthy river floodplain consists of a diverse matrix of habitat types that are connected to the river by occasional flooding. This connection is critical to maintaining dynamic physical and chemical processes that support diverse plant and animal communities.

The emergent vegetation indicator tracks the amount of aquatic vegetation growing along shorelines and in wetlands, which is affected by variation in water levels, both annually and daily. Changes in the amount of floodplain forest are most indicative of changes in flooding regimes and in ground water levels. The percentage of the floodplain behind levees indicates how much of the historical floodplain no longer receives periodic flooding and has therefore lost much of its ecological connection to the river.

Data for these indicators were derived from land cover maps developed by the LTRMP for 1989 and 2000 that cover the entire river corridor of the UMRS. The graphics for these indicators are depicted within the four major reaches of the system and include data for Pools 1–26, the north and south sections of the Unimpounded Reach, and for the Alton, La Grange, and Peoria Pools of the Illinois River. In the Unimpounded Reach, the south section was from the mouth of the Ohio River north to river mile 80 near Grand Tower, Illinois, and the north section covered river mile 80–230, just below Lock and Dam 26.

2.5.1 Floodplain Forest

Assessment:

Status: Mixed.

Trend: Degrading in impounded reaches, stable in the Open River Reach. Between 1989 and 2000, area of floodplain forest declined in all reaches of the UMRS except for the Open River Reach. Further declines are expected in impounded reaches. Reforestation efforts in the Open River Reach may increase forested area.

Purpose

Floodplain forests are an important component of large river ecosystems. They provide habitat for a broad range of plants and animals and play an essential role in maintaining the biological diversity of the UMRS. In addition, floodplain forests reduce soil erosion and improve water quality by trapping sediment and sequestering plant nutrients.

State of the Ecosystem

Area of floodplain forest declined in 24 of 31 reaches of the UMRS between 1989 and 2000 with a system-wide decrease of 5%, or 17,000 acres (Figure 2.12). The greatest decline was in Pool 18, where forest area decreased by 27% (4,700 acres). When considered by river reach, a decline of 3,400 acres (4%) in floodplain forest coverage occurred in the Upper Impounded Reach (Pools 1–13), 11,600 acres (9%) in the Lower Impounded Reach (Pools 14–26), and 3,200 acres (4%) in the Illinois River pools. In contrast, there was a slight increase of 1,200 acres (2%) in floodplain forest coverage in the Unimpounded Reach.

Floodplain forests in the UMRS cover only a small portion of the area that they did before European settlement (Nelson et al. 1994; Yin et al. 1997). Forest acreage decreased rapidly in the nineteenth century as trees were harvested and land was converted to agricultural and urban uses. Differences in floodplain forest coverage between 1989 and 2000 indicate that, although the rate has slowed, declines in floodplain forest are still occurring in the UMRS. Changes due to conversion to agriculture have slowed, but forests are still adjusting to ecological changes associated with impoundment and water level changes.

Modified processes within the floodplain can have negative effects on forests. Maintaining high water elevations at low flows (see section 2.2.2) has increased the ground water elevation and caused a shift to trees that can tolerate wetter conditions, mainly silver maple (*Acer saccharinum*). In addition, high short-term variation in water levels (daily or weekly) and high sedimentation rates on the floodplain in some years have acted to reduce recruitment of

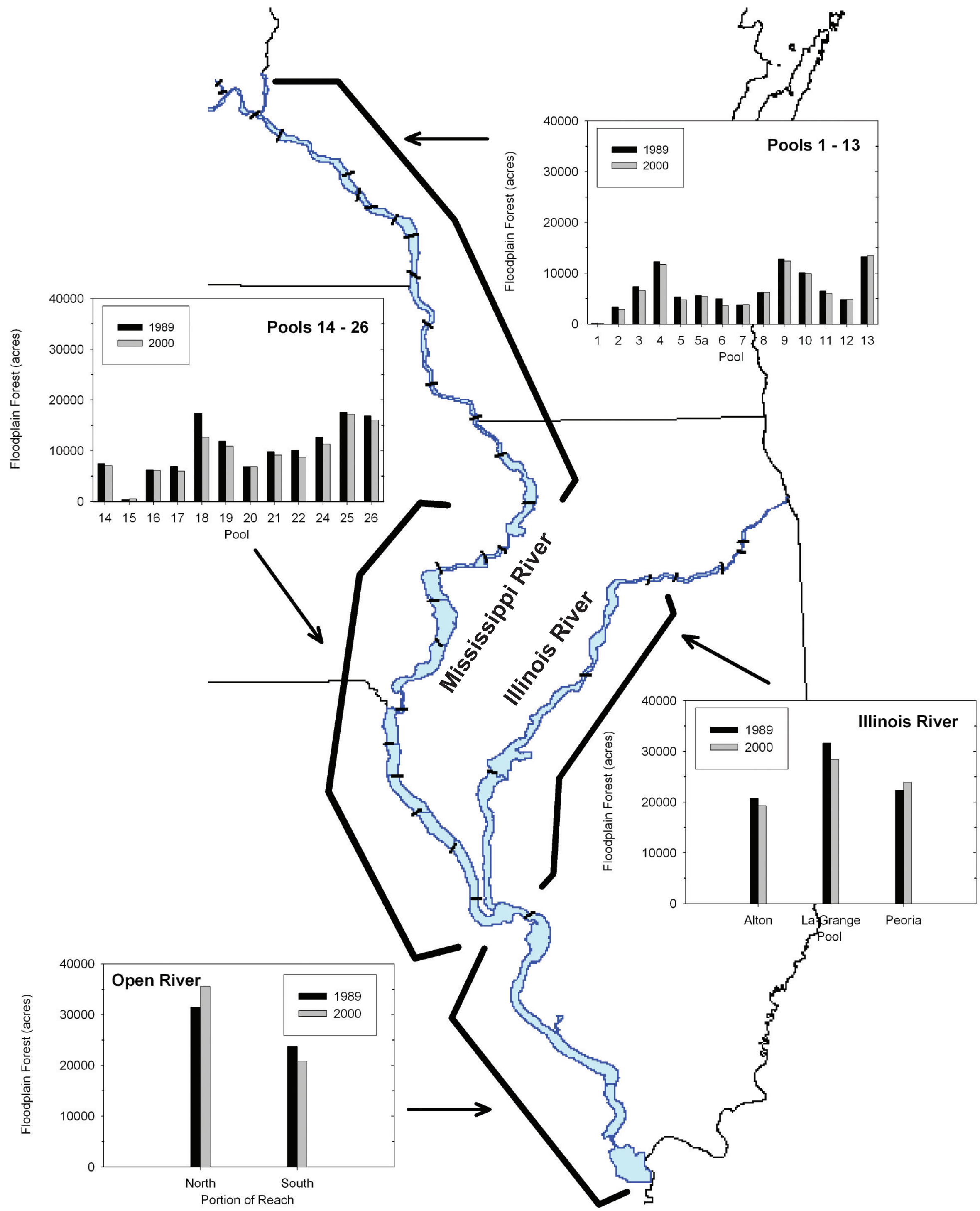

Figure 2.12. The area (acres) of floodplain forest in the Upper Mississippi River System based on 1989 and 2000 land cover maps produced by the Long Term Resource Monitoring Program. Data are presented for Pools 1–26, north and south sections of the Unimpounded Reach (border at river mile 80), and for the Alton, La Grange, and Peoria Pools of the Illinois River.

many tree species. The Great Flood of 1993 was an unusual event because flood waters did not recede until late summer, which killed many trees in the southern reaches of the UMRS. Studies are now under way to determine the extent of forest regeneration in those areas and the effects on species composition in forest communities.

Relating changes in forest acreage to other river components is difficult. Whereas, water quality variables, such as total suspended solids, nutrient concentrations, and sedimentation rates are probably affected by decreases in floodplain forest, these variables are influenced by a wide variety of factors and our ability to isolate the effect of floodplain forests based on monitoring data is limited. In addition, a 5% decline in floodplain forest between 1989 and 2000 is relatively small and might not be expected to produce detectable changes in water quality variables.

Future Pressures

Historically, declines of floodplain forests have occurred in response to agricultural conversion and urban development. These pressures are likely to continue, but at slower rates. The effects of impoundment and of changes in water regime will continue to affect the survival and reproduction of forest trees. These effects may result in changes in the species composition of forests or in conversion of forests to other vegetation types. Reforestation efforts can have positive effects locally, but large scale effects will likely require changes in underlying ecological conditions.

Authors

Kirk Lohman, Larry Robinson, and John Nelson.

2.5.2 Emergent Vegetation

Assessment:

Status: Fair to good. Emergent vegetation is most abundant in the Upper Impounded Reach.

Trend: Mixed. Emergent vegetation has decreased in the Upper Impounded Reach and increased in all other reaches.

Purpose

Emergent vegetation describes a variety of annual and perennial plants that grow in moist or seasonally flooded soils, along shorelines or in marshes. Typical plants include wild rice, cattail, arrowhead, bulrushes, smartweed, and sedges. Emergent plants are an important part of the transition zone between terrestrial and open water habitats and indicate a healthy hydrologic regime in floodplain rivers. They provide important food and habitat resources for a wide variety of fish, amphibians, reptiles, birds, and mammals, help to prevent erosion by holding sediments in place along shorelines, and are indicators of the extent of critical marsh habitats.

State of the Ecosystem

The percentage of total area in emergent vegetation ranged from 0% to 10% among different reaches of the UMRS and averaged about 5%. Emergent vegetation was most prevalent in the Upper Impounded Reach (Figure 2.13). Between 1989 and 2000, coverage of emergent vegetation generally decreased by about 5,000 acres in the Upper Impounded Reach (Pools 1–13), but increased in all other reaches. Changes were most noteworthy in the Illinois River pools (total increase of about 7,500 acres), but the areal extent of emergent vegetation was still relatively small at 1% in Alton Pool, 4% in La Grange Pool, and 3% in Peoria Pool. No goals for abundance of emergent vegetation have been established in the UMRS.

Abundance of emergent vegetation is subject to considerable seasonal and annual variation and is highly dependent on water level fluctuations. Drought conditions preceding the 1989 mapping may have influenced the extent of emergent vegetation and a recovery from those conditions in the lower reaches may be reflected in the 2000 coverage. Increases in the Illinois River pools may be the result of more favorable water regimes for a few years before 2000, as well as management actions, such as planting, to promote the growth of emergent vegetation.

Future Pressures

Abundance of emergent vegetation is highly affected by water levels. Emergent plants have evolved to take advantage of the predictable

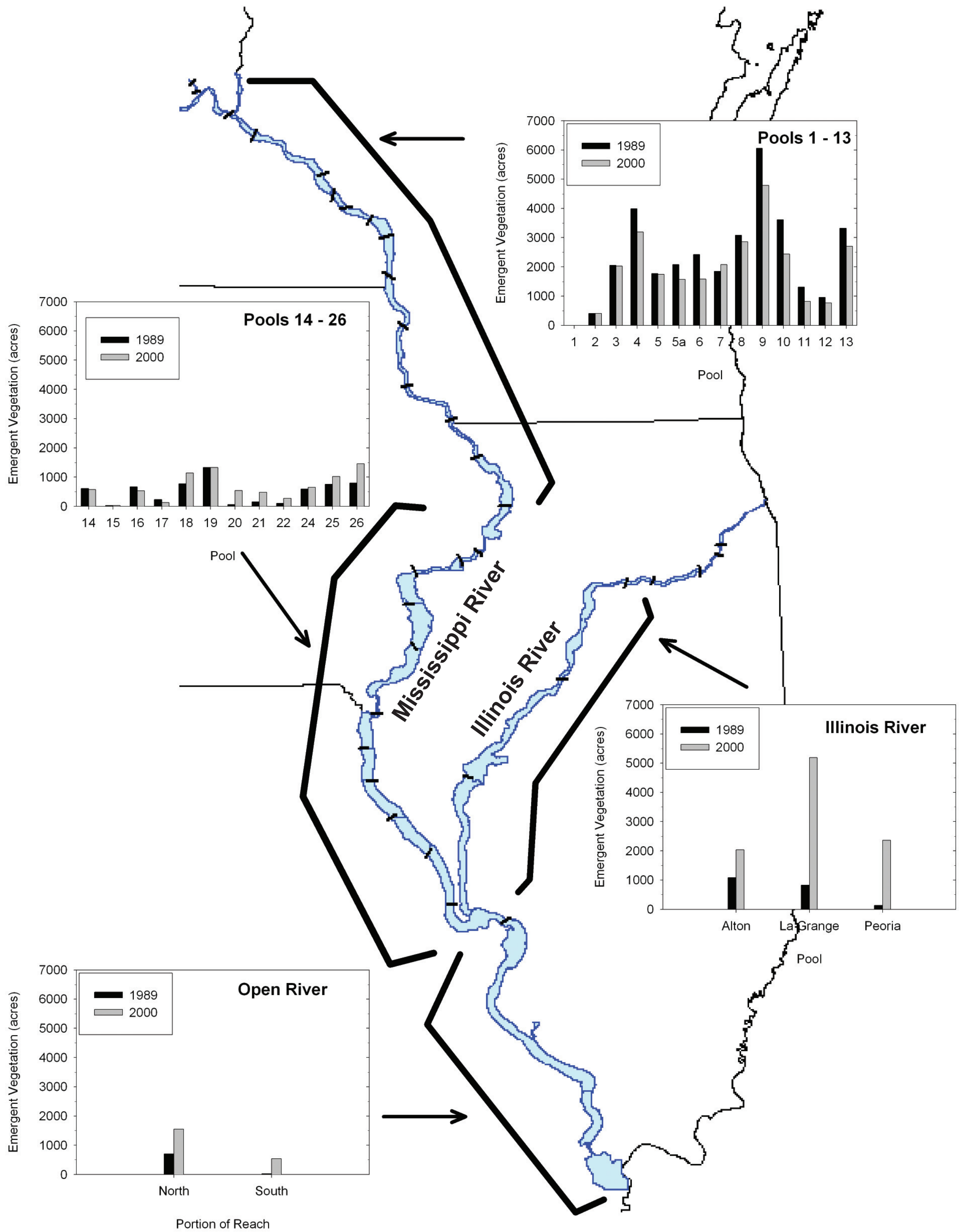

Figure 2.13. The area of emergent vegetation (acres of deep and shallow marsh combined) in the Upper Mississippi River System based on 1989 and 2000 land cover maps produced by the Long Term Resource Monitoring Program. Data are presented for Pools 1–26, north and south sections of the Unimpounded Reach (border at river mile 80), and for the Alton, La Grange, and Peoria Pools of the Illinois River.

annual cycle of high and low water levels that are part of a healthy large river. In the UMRS, the dams hold water levels artificially high during low flows to promote commercial navigation. In some navigation pools, dam operations result in large, short-term fluctuations in water levels. Both are stressors for emergent vegetation, but both can be managed for a better ecological response. Recent management actions to reduce water levels during summer (drawdowns) have been successful at increasing the abundance of emergent plants at locations in both the Upper and Lower Impounded Reaches. Changes in dam operations to reduce short-term variation in water levels are being explored. In addition, habitat rehabilitation projects, such as island building and flow modifications, can promote local conditions to increase growth of emergent vegetation and provide needed habitat and food resources in strategic locations.

Authors

Kirk Lohman, Larry Robinson, and John Nelson.

2.5.3 Area of Floodplain Behind Levees

Assessment:

Status: Mixed. The Upper Impounded Reach has almost no levees and connection to the floodplain is good. The amount of leveed floodplain increases extensively in the lower reaches.

Trend: No trends–Status only. This indicator is based on a single coverage depicting UMRS levees in 1993; thus, calculation of change over time was not possible.

Purpose

The UMRS, like most large rivers, has a floodplain that was historically subjected to annual flooding. Floodwaters bring fresh supplies of nutrients, sediments, and organic matter to terrestrial areas and off-channel water bodies, and sometimes scour and resculpt these areas. Active floodplains are subject to alternate wetting and drying of soils, which produces dynamic chemical and physical conditions. Healthy floodplains are highly productive, contain a wide variety of vegetation and habitat types, and are used by many animals for at least part of their life cycle. In addition, floodplains act as buffers that store floodwaters then release them slowly, which reduces flood heights and subsequent damage to human-made structures in the floodplain.

However, floodplains are also highly valued by humans because they provide fertile, flat lands for agriculture and urban development, and provide direct access to the river for transportation and recreation. To maximize the value of floodplains for human use, landowners often build levees that keep floodwaters out. This has obvious benefits to landowners who can increase the direct economic returns from their property. But, levees also constrict the floodplain and reduce storage of floodwater, which increases flood heights near and upstream of the levee. In addition, levees eliminate the connection of the river to its floodplain, which has negative effects on the ecological processes and services mentioned above.

The data for this indicator were derived by applying a Geographic Information System coverage of levee locations developed by the Scientific Assessment and Strategy Team (available at http://edc.usgs.gov/sast/) following the flood of 1993 to land cover maps generated by the LTRMP for 2000. Because there was only one levee coverage map available, calculating change over time was not possible. Thus, this indicator shows status only.

State of the Ecosystem

The data show a distinct gradient of increasing floodplain area sequestered behind levees from upper to lower reaches of the UMRS (Figure 2.14). The Upper Impounded Reach (Pools 1–13) has little leveed area (about 4% total) and virtually the entire floodplain is connected to the river. In the Lower Impounded Reach, the number of levees increases substantially and leveed area accounts for 48% of the total floodplain. In the Unimpounded Reach, levees are prominent resulting in about 67% of floodplain area behind levees. In this reach, almost all of the active (frequently flooded) floodplain is in narrow strips of land between the river and levees known as batture lands. In the Illinois River, the two lower pools are heavily leveed (about 60% of total area), whereas the

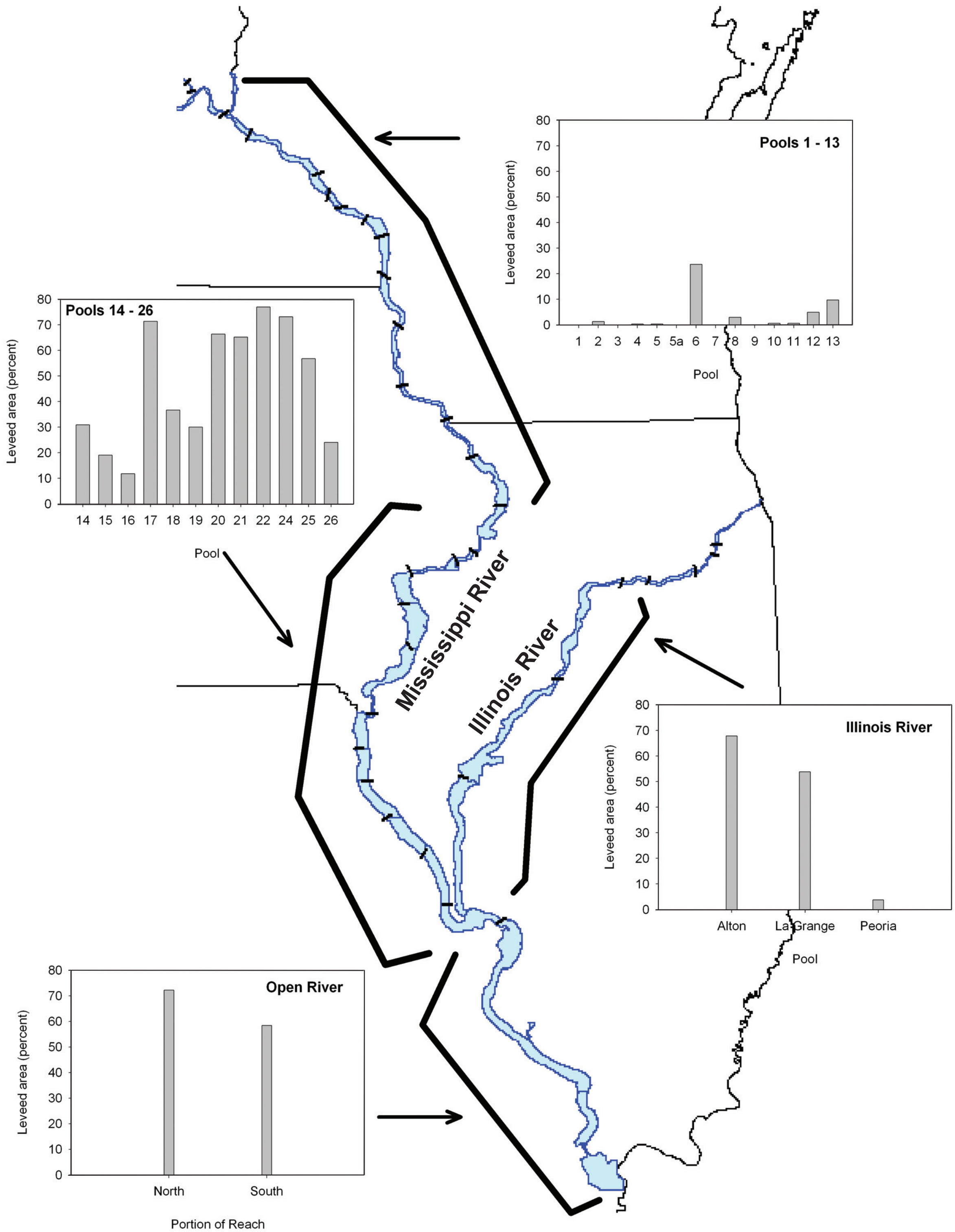

Figure 2.14. The percentage of the total floodplain area that was behind levees within the Upper Mississippi River System based on levee coverage developed by the Scientific Assessment and Strategy Team (available at http://edc.usgs.gov/sast/) then applied to the 2000 land cover maps produced by the Long Term Resource Monitoring Program. Data are presented for Pools 1–26, north and south sections of the Unimpounded Reach (border at river mile 80), and for the Alton, La Grange, and Peoria Pools of the Illinois River.

Peoria Pool and areas above have few levees. Total across all three reaches on the Illinois is about 50%.

Most of the levees on the system protect land used for agriculture or urban areas, but a few are managed by resource management agencies or hunting clubs as moist soil units for waterfowl habitat or for other recreational purposes. A few levee districts have been purchased by agencies or environmental organizations and are being rehabilitated for ecological benefits. Most of these rehabilitation plans involve some type of levee breeching and periodic reflooding of these lands. Examples are the Emiquon and Spunky Bottoms projects on the Illinois River floodplain. These former levee districts are now being restored by a partnership of agencies headed by The Nature Conservancy (see http://www.nature.org/wherewework/northamerica/states/illinois/press/emiquon.html).

Specific targets for the percentage of active (unleveed) floodplain required for a healthy river ecosystem do not exist. The amount of floodplain required to maintain critical ecosystem services, such as waste assimilation, biotic diversity, and water supply, is unknown. In addition, we do not know if river channels should be managed for different ecological responses in locations where connection to the floodplain is high (the Upper Impounded Reach) compared to locations with little floodplain connection (the Unimpounded Reach). Management experiments and focused research are needed to determine relations between flood frequency and ecological responses. However, any management targets for amount of leveed floodplain are likely to differ among river reaches given the economic realities of current land ownership patterns.

Future Pressures

It is unlikely that many new levees will be built in the UMRS, although some expansion is still occurring in urban areas (Pinter 2005b). Most existing levees are likely to be maintained for the foreseeable future, but some may revert to public ownership if both funds and willing sellers are available. Management of reverted levee districts will probably involve some reconnection to river flows, either through permanent breeching of levees or using gates to control water exchange for specific management objectives. However, conversions of leveed areas to public land are expected to be slow and large changes in this indicator are not expected in the near term.

An alternative to public ownership of floodplains is to develop new uses for floodplain lands that are compatible with occasional flooding (The Wetlands Initiative 1997). Such uses might allow landowners to remove levees or to lower them allowing more frequent flooding of the protected lands. Potential new uses could involve growing crops that can withstand occasional flooding, such as forest trees, hay, or native wildflowers and wetland plants, or developing private reserves for fee-based hunting and trapping. In addition, agencies or municipalities could develop fee-based easements with landowners to allow use of leveed areas for storage of floodwaters or nutrients.

Authors

Kirk Lohman, Larry Robinson, and John Nelson.

2.6 Aquatic Vegetation Indicators

Submersed aquatic vegetation consists of the larger plants found under, or floating on, the water. For these plants, light must penetrate the water to provide the sun energy needed to begin growth in spring and maintain it during the entire growing season. Thus, the distribution and abundance of submersed vegetation depends mainly on water depth (which changes with water levels) and transparency (which depends mainly on levels of suspended solids). In the Unimpounded Reach of the UMRS, these conditions are poor and aquatic vegetation has been virtually absent, thus the LTRMP did not sample for vegetation in the Open River Reach. Submersed plants can be a food source for animals, but also provide important physical structure for invertebrates and fish. Many of the management actions implemented on the river include a goal of restoring submersed vegetation.

Sampling for submersed aquatic vegetation by the LTRMP began in 1991 using fixed transects in selected backwaters of Pools 4, 8, and 13. In 1998, stratified random sampling was added in these pools and in Pool 26 and La Grange Pool on the Illinois River. After 3 years of conducting both types of sampling, transect sampling was discontinued in 2000. Data from both sampling designs are included for this indicator.

2.6.1 Submersed Aquatic Vegetation

Assessment

Status: Mixed. Generally good in the Upper Impounded Reach, poor in Pool 26 and La Grange Pool where aquatic vegetation rarely occurs.

Trend: Stable, but with a decreasing trend in the upper portions of Pool 4. Fluctuates annually in the Upper Impounded Reach depending on water levels and water clarity.

Purpose

Submersed aquatic vegetation provides an important food source for migratory waterfowl and habitat for fish. The Illinois River harbored abundant aquatic vegetation in its expansive backwaters until the early twentieth century (Mills 1966; Bellrose et al. 1979). A massive die-out in the mid-1950s was one critical indicator of ecological degradation of the Illinois River (Sparks 1984). Growth of aquatic vegetation, including submersed, emergent, and floating-leaf plants, was excellent in the Upper Impounded pools with lesser amounts in lower pools from the 1940s to early 1970s (Green 1984). Symptoms of deterioration became apparent after the late 1970s. A widespread and sudden decline of wild celery (*Vallisneria americana*) in the late 1980s elevated the concern that the UMR might be on the verge of major shift in vegetation conditions. Monitoring of submersed aquatic vegetation was initiated in 1991 to establish a reference point of status and track future changes. The percentage frequency of occurrence of submersed aquatic vegetation (all species combined) is used as the primary indicator of the status of submersed aquatic vegetation in the system (Rogers et al. 1998; Yin et al. 2000).

State of the Ecosystem

The distribution of submersed aquatic vegetation in the UMR displayed a distinct longitudinal pattern. Submersed aquatic vegetation was common in shallow backwaters in the Upper Impounded Reach (Figure 2.15), but was seldom detected in Pool 26 or the Illinois River. Besides annual sampling in LTRMP reaches, additional sampling conducted in other locations for research studies indicated that submersed vegetation decreased rapidly below Lock and Dam 13 and rarely occurred downstream of Lock and Dam 19 or in the Illinois River. Aquatic vegetation was historically absent from the Open River Reach due to lack of appropriate habitat; thus, sampling was not conducted in that reach.

The LTRMP data revealed that submersed aquatic vegetation in upper Pool 4 (upstream of Lake Pepin) has declined steadily since 1991. Specific reasons for the decline are unknown but may be associated with relatively high levels of nutrients and turbidity associated with inputs from the Minneapolis/St. Paul metropolitan area and from the Minnesota River. Lake Pepin acts as settling basin; thus, water downstream is clearer and more conducive to growing

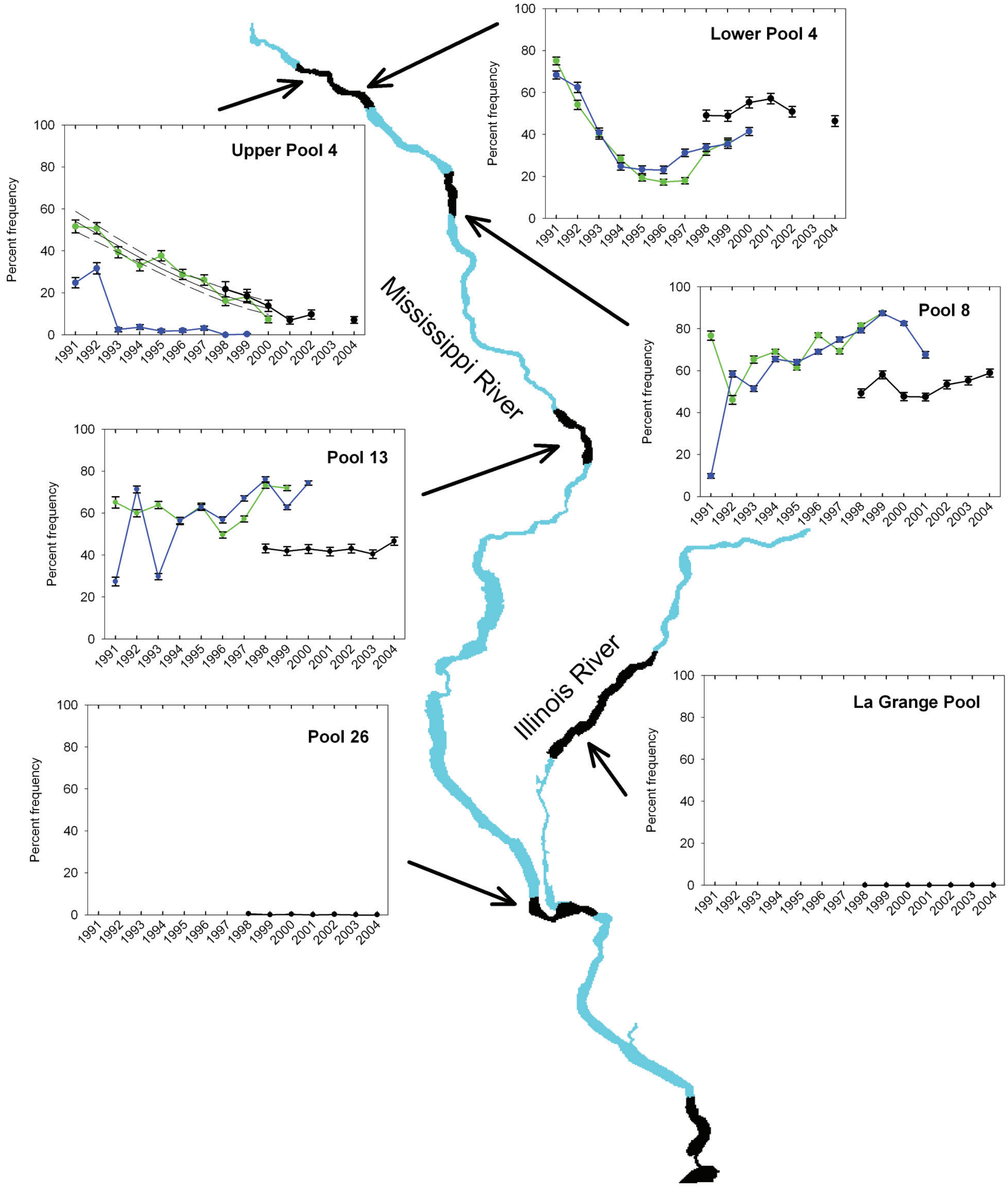

Figure 2.15. Percent frequency of occurrence of submersed aquatic vegetation in the Long Term Resource Monitoring Program sampling pools from 1991 to 2004. Spring (*green lines*) and summer (*blue lines*) transect sampling was conducted in selected backwaters from 1991 to 2000. Stratified random sampling (*black lines*) was conducted in all shallow water areas (≤2.5 m) connected to the river channel beginning in 1998. The gray lines in the graph for upper Pool 4 indicate a significant decreasing trend in vegetation abundance in spring with 90% confidence intervals.

submersed vegetation. Lower Pool 4, Pool 8, and Pool 13 experienced fluctuations in submersed vegetation, but appeared to be highly resilient. Frequency of occurrence of submersed aquatic vegetation in Pool 26 of the Upper Mississippi River and La Grange Pool of the Illinois River was limited. Occasionally, small increases in submersed vegetation occurred immediately following lower water levels, but these seldom persisted.

It appears that low water clarity and short-term variation in water levels are the primary factors limiting distribution of submersed vegetation (Yin and Langrehr 2005). Both factors are especially evident below Pool 13 and are probably the main factors responsible for the reduced occurrence of submersed vegetation in lower reaches. Recent experiments with summer water level reductions (drawdowns) in the impounded reaches have shown mixed responses for submersed vegetation. In the Upper Impounded Reach, drawdowns typically increased occurrence of submersed vegetation in areas where water depth had been limiting, but decreased occurrence in shallow areas where emergent vegetation was reestablished. However, for drawdowns in the Lower Impounded Reach (Pools 24, 25, and 26), response of submersed vegetation was limited due to high turbidity.

Future Pressures

Although upper Pool 4 is only a small section of the key monitoring reaches, the rapid decrease of submersed aquatic vegetation over 12 years demonstrates the fragility of the UMR ecosystem. Focused research is needed to identify environmental factors that caused the progressive degradation so that effective measures can be taken to prevent declining trends over larger areas.

Low water clarity and high variability in water levels are expected to persist below Lock and Dam 13. Habitat enhancement projects, such as island construction, may create protected areas where sediments can settle out and increase water clarity enough to allow plant growth. Both summer drawdowns and changes in dam operations that reduce short-term water level variation can enhance conditions for submersed vegetation in shallow areas.

Author

Yao Yin.

2.7 Macroinvertebrate Indicators

Macroinvertebrates are the small animals that live in the river bottom or on plants and logs in the water. These organisms are important food sources for many fish, shorebirds, and ducks. And, because they live on the bottom, they can be good indicators of healthy conditions in river sediments. However, macroinvertebrate abundance is usually highly variable in rivers, even when populations are healthy. Thus, ascribing changes in abundance to any specific driver can be difficult. Data on the abundance of mayflies and fingernail clams (*Musculium transversum*) is indicative of the amount and quality of soft sediment habitats and water quality within the river. Sampling for invertebrates under the LTRMP was discontinued after 2004 due to budget considerations.

2.7.1 Burrowing Mayflies

Assessment

Status: Mixed. Burrowing mayflies **(***Hexagenia* spp**.)** were relatively abundant in the Upper Impounded Reach but with much lower abundance in Pool 26, the Open River Reach, and La Grange Pool.

Trend: Stable, but with considerable annual variation.

Purpose

The main objective of the LTRMP macroinvertebrate component is to provide a better understanding of the conditions needed to support viable populations of benthic invertebrates that are important foods for native fishes and migrating waterfowl.

A number of studies have shown that burrowing mayflies are ecologically important as food for fish and waterfowl and as biological indicators (Hoopes 1960; Jude 1968; Ranthum 1969; Thompson 1973; Myslinski and Ginsburg 1977; Kushlan 1978; Eldridge 1988; Rosenberg and Resh 1993; Steingraber and Weiner 1995; Tyson and Knight 2001). Mayfly distribution and abundance have been used as indicators of water quality on the UMRS (Fremling 1964; 1989; Johnston and Aasen 1989); thus, the abundance of mayflies is of great interest to managers.

State of the Ecosystem

In the 1950s, much concern arose when mayfly densities dropped extensively in the UMRS and in Lake Erie (Fremling 1964; Mills et al. 1966; Kreiger et al. 1996). Low dissolved oxygen levels due to pollution were thought to be the cause. In 1926, the Mississippi River from St. Paul to Lock and Dam 3 had dissolved oxygen levels <1 mg/L. By 1987, dissolved oxygen levels had rebounded to 7 mg/L or greater following substantial reductions in pollutants (Johnston and Aasen 1989) and increased abundance of mayflies was detected in Pools 2 and 4 (Fremling 1989). Dynamic year-to-year variation in mayfly abundance was also reported in Pool 19 (Carlander et al. 1967) where estimated pool populations ranged from 3.6 billion in 1959 to 23.6 billion in 1962.

The LTRMP data show large differences in mayfly abundances among the study areas. Mayfly densities were relatively high (50 to 250 per square meter) in the upper pools of the UMRS (Pools 4, 8, and 13; Figure 2.16), but consistently lower (generally <25/m^2) in Pool 26, La Grange Pool, and the Open River Reach. There were no trends in mayfly abundance between 1993 and 2004.

The mixed systemic status of mayflies suggests that environmental conditions are better in the upper reaches of the river. Lower reaches have much lower mayfly densities (roughly a factor of 4), which may indicate a population under environmental stress or that environmental conditions simply are not conducive to supporting the larger populations seen in the upper system. Historically, both Pool 26 and La Grange Pool have supported large number of mayflies (Fremling 1964; Mills et al. 1966). Possible reasons for the differences include differences in substrate type and quality, chlorophyll levels, dissolved oxygen levels, discharge levels, or temperatures. The densities of mayflies reported by LTRMP are within the ranges reported in other studies (Sauer 2004). The fluctuations indicate that mayflies are able to rebound if conditions are right even when population levels are low, such as in the southern reaches.

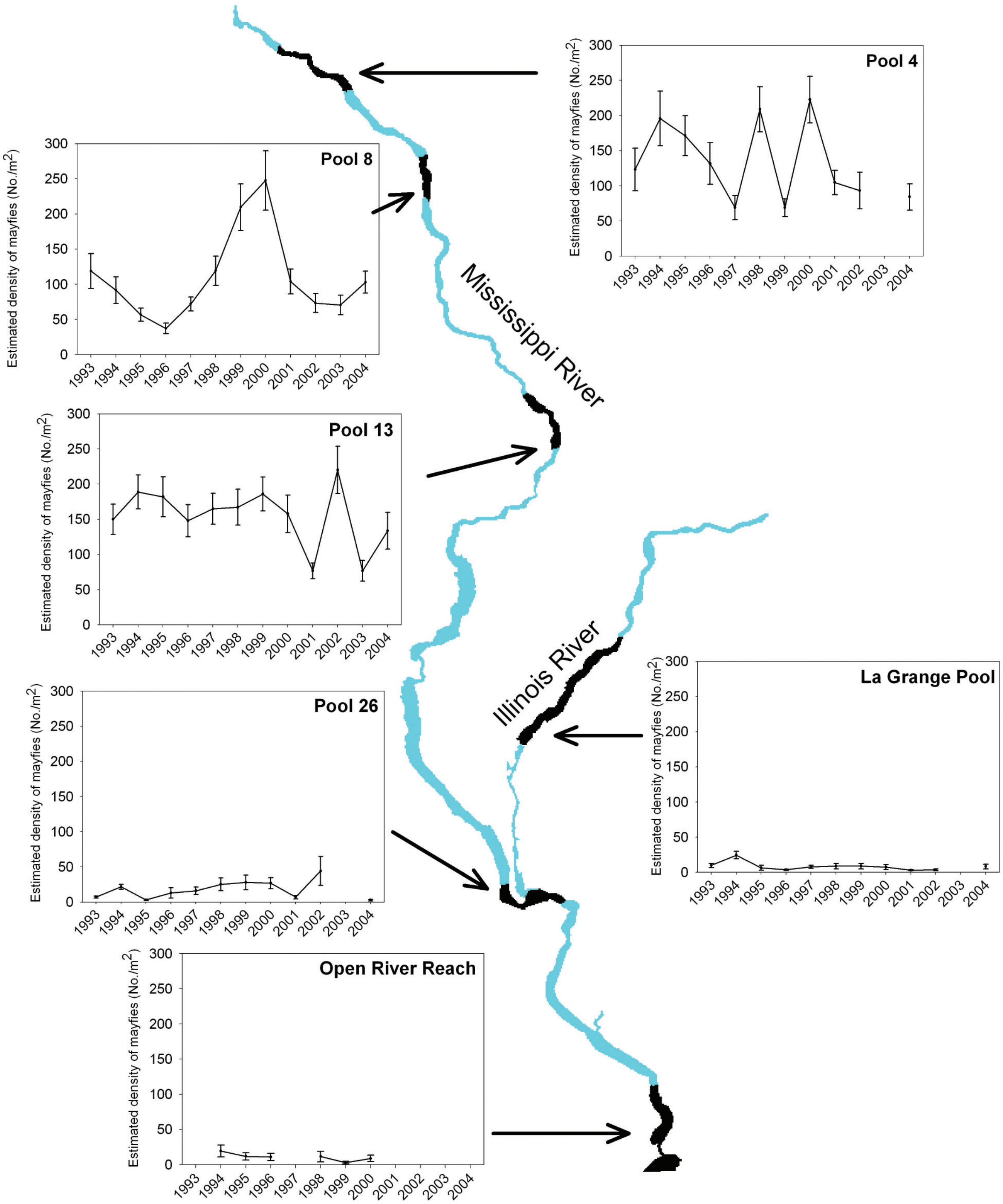

Figure 2.16. Estimated density of mayflies (*Hexagenia* spp; no/m² ±1 standard error) weighted by area of strata within each study area of the Long Term Resource Monitoring Program from 1993 to 2004. In Pools 4 and 26 and La Grange Pool, density of mayflies was not estimated in 2003.

Future Pressures

There is no current management objective for mayfly abundance in the UMRS. Other systems, such as the Great Lakes, have established indicators of ecosystem health for mayflies; however, abundance was used as an indicator of water and sediment quality, not as a measure of food availability. Although LTRMP data yield adequate pool-wide mean estimates for the study reaches, no other comprehensive inventories were made in the past, therefore direct historical comparisons are not possible.

Burrowing mayflies prefer soft, silty substrates that allow them to burrow and they are sensitive to sediment type and quality as well as low oxygen levels resulting from nutrient inputs and toxic pollutants in bottom sediments. Urban, agricultural, and stormwater runoff are currently sources of these nutrient inputs and pollutants. Watershed and regulatory practices that limit inputs of sediments and effluent with high organic loads should increase water and sediment quality and help provide environmental conditions that will support healthy populations of mayflies.

Authors

Jennifer Sauer, Therese Dukerschein, and Sandra Brewer.

2.7.2 Fingernail Clams

Assessment

Status: Mixed. The greatest number of fingernail clams were observed in the Upper Impounded Reach and numbers are low in Pool 26, La Grange Pool, and the Open River Reach.

Trend: Slight improvement in Pool 8, stable in other areas.

Purpose

The main objective of the LTRMP macroinvertebrate component is to provide a better understanding of the conditions needed to support viable populations of benthic invertebrates that are important foods for native fishes and migrating waterfowl.

As with mayflies, a number of studies have shown that fingernail clams are ecologically important as food for fish and waterfowl (Jude 1968; Ranthum 1969; Thompson 1973; Kushlan 1978; Eldridge 1988). Fingernail clams can also be sensitive to periods of low oxygen or high ammonia concentrations, conditions often associated with high temperatures, low flows, or high levels of organic pollutants (Anderson et al. 1978; Sandusky and Sparks 1979; Sparks 1980). Thus, the abundance of fingernail clams is of great interest to managers.

State of the Ecosystem

Similar to mayflies, fingernail clams also experience boom and bust cycles in abundance. For example, Wilson et al. (1995) reported that in 1985 fingernail clam densities averaged 30,000/m^2 in Pool 19. By 1990, no fingernail clams were found, but recently densities have rebounded to about 50,000/m^2 in Pool 19 (Rick Anderson, Western Illinois University, personal communication). Fingernail clam populations were also abundant in the Illinois River before the 1950s (Mills et al. 1966), but densities have been relatively low since then.

The LTRMP data showed large differences in fingernail clam abundances within study areas. Fingernail clams were most prevalent in the upper three pools (Pools 4, 8, and 13; Figure 2.17) with lower numbers in downstream areas, especially Pool 26 and the Open River Reach. The only significant trend observed was a marginally significant positive trend in Pool 8 where fingernail clam density was consistently low (mean 13 m^{-2}) from 1993 to 1998 but increased to a mean of 347 m^{-2} during 1999–2004, a 25-fold increase. Gray et al. (2005) reported mean fingernail clam counts were negatively associated with inorganic suspended solid levels in Pool 8.

The densities of fingernail clams reported by the LTRMP are within the ranges reported in other studies (Sauer 2004). The fluctuations indicate that fingernail clams are able to rebound if conditions are right even when population levels are low, such as in the southern reaches.

Future Pressures

There is no current management objective for fingernail clam abundance in the UMRS. Various factors may have negative effects on fingernail clam populations including high inorganic

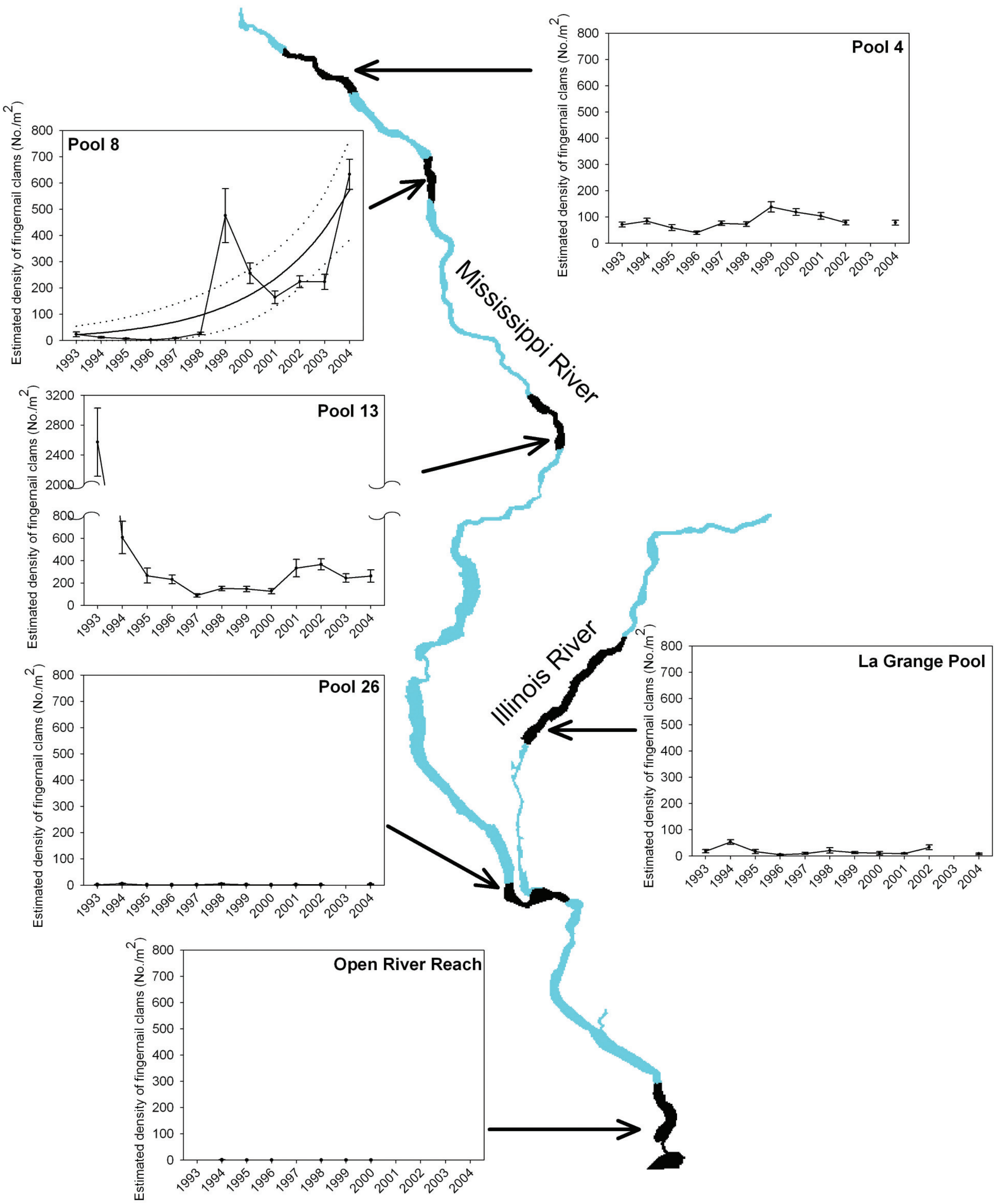

Figure 2.17. Estimated density of fingernail clams (*Musculium transversum*; no/m^2 ±1 standard error) weighted by area of strata within each Long Term Resource Monitoring Program study area from 1993 to 2004. The black lines in the graph for Pool 8 indicate a significant increasing trend with 90% confidence intervals. In Pools 4 and 26 and La Grange Pool, density of fingernail clams was not estimated in 2003.

suspended solids, high un-ionized ammonia and metal concentrations, and low dissolved oxygen (Sandusky and Sparks 1979; Sparks 1980; Gray et al. 2005). Although habitat rehabilitation projects are generally not aimed specifically at fingernail clams, projects that affect any of these factors may help increase abundances.

Authors

Jennifer Sauer, Therese Dukerschein, and Sandra Brewer.

2.8 Fish Indicators

Fishes are among the most importan t river biota from a recreational and economic standpoint. Their distribution and abundance are affected by a wide array of factors that influence their life cycles. A diverse and healthy fish community generally indicates a diversity of habitats and important river functions. Work by LTRMP researchers has shown that in the UMRS, river reaches with the greatest variety of habitats, including main channel, side channels, and backwaters, have the greatest variety of fish species (Koel 2004). Changes in abundance of an individual species may be important for sport anglers, but from a community perspective, when one species is reduced, other similar species can often increase to maintain the important functions within communities. Long term changes or consistent differences among fish populations and communities may indicate differences in fundamental drivers or processes.

The fish indicators in this report represent groups of fishes with different characteristics and roles within the river ecosystem. Bluegills, channel catfish (*Ictalurus punctatus*), and sauger (*Sander canadense*) are important sport fishes. Sauger and catfish represent fishes found mainly in channels, whereas bluegills represent backwater fishes. Channel catfish are also caught commercially as are smallmouth buffalo (*Ictiobus bubalus*), which are fish characteristic of large rivers and are found in both channel and off channel areas. The indicator for recreationally and commercially harvested fishes includes all native species caught for sport or for sale. The forage fish index consists of the fish that are most often food for other fishes. Nonnative fishes are species from other waters that have found their way into the UMRS and established new populations. Species richness is the number of species collected in each study area as an indicator of the diversity of the fish community. When compared to historical records, LTRMP data indicate that almost all fish species known from the UMRS over the past 100 years still occur in the river today, although 39 species collected by the LTRMP were considered rare, endangered, or threatened by Federal or state agencies.

2.8.1 Bluegill

Assessment

Status: Mixed. Bluegills were most abundant in the Upper Impounded Reach and La Grange Pool where backwater habitats are most abundant. Abundance is much lower in Pool 26 and the Open River Reach.

Trend: Mixed. Most areas were stable, but increasing trends were observed in Pools 4 and 8.

Purpose

Bluegills are a major component of the recreational fishery within the UMRS and are a characteristic species of backwater environments because all major life cycles typically occur within these habitats. Correspondingly, the public perceives the ecological health of the UMRS, in part, by the abundance of bluegill. Tracking bluegill catch-per-unit-effort (CPUE) provides direct information on this resource and may provide insight into habitat quality. The indicator is the pool-wide CPUE (number/15 minutes) of adult bluegills >150 mm (the minimum size generally acceptable to anglers) captured by day electrofishing.

State of the Ecosystem

Bluegills are perennially present in all six LTRMP study areas and are not geographically constrained within the UMRS (Ickes et al. 2005). However, the average abundance of bluegill varies notably among the six LTRMP study areas (Figure 2.18). Spatial differences in bluegill abundance reflect, in part, differences in the amount and quality of backwater environments in the UMRS. The 12-year mean CPUE of adult (>150 mm) bluegill is highest and most similar in Pools 8 and 13, marginally lower in Pool 4 and La Grange Pool, and notably low in Pool 26 and the Open River Reach. Thus, bluegills achieve their highest abundance in reaches where backwaters are most prominent (Pools 4, 8, and 13 and La Grange Pool). Differences in bluegill abundance among these four study areas generally corresponds with the presence and abundance of aquatic vegetation (highest in Pools 8 and 13, somewhat lower in Pool 4, and rare in La Grange Pool; see section 2.6.1). Low abundance of bluegills in Pool 26 and the

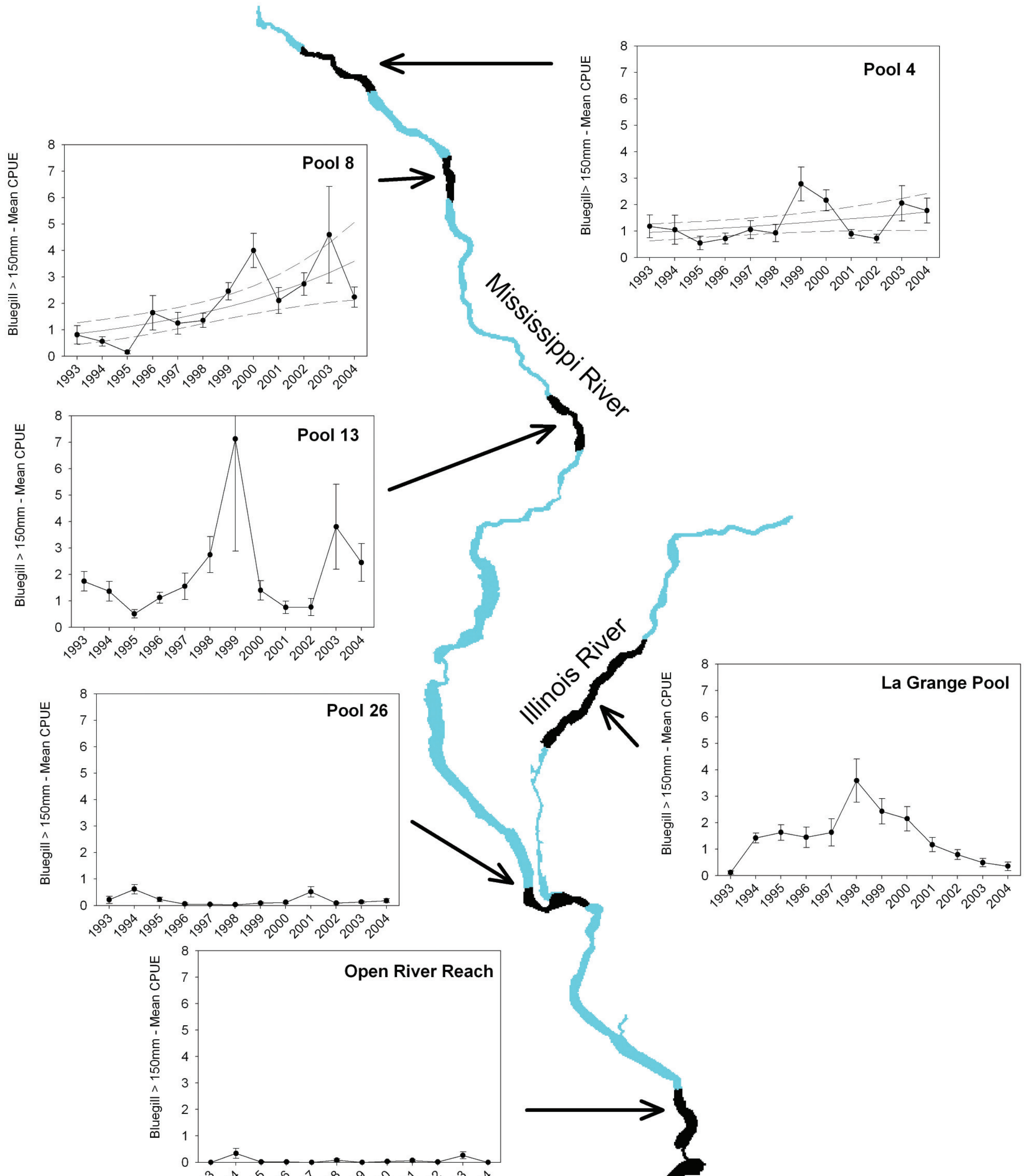

Figure 2.18. Catch-per-unit-effort (CPUE, mean number caught per 15 minutes ± 1 standard error) of bluegill >150-mm total length from 1993 to 2004 in six trend areas monitored by the Long Term Resource Monitoring Program using day electrofishing. Black lines indicate statistically significant trends with 90% confidence limits.

Open River Reach can be attributed to a lack of connected backwaters. The only observed trends in bluegill abundance were increases in Pools 4 and 8. The CPUE of adult bluegill has nearly tripled over the period of observation in Pool 8 and may be a response to habitat rehabilitation efforts in this reach.

Future Pressures

Habitat loss appears to be the major threat to bluegill populations in the UMRS, although exploitation and forage limitations may be important locally. Loss of habitat quality due to sedimentation in backwaters is a significant threat as are levees that eliminate access to backwaters. In the north, sedimentation effects may be most acute during winter as shallower backwaters result in cooler water temperatures, greater biological oxygen demands, and greater flow rates that can lead to high fish mortality. Suitable winter habitat is uncommon in some UMRS navigation pools (see section 2.3.5), however, the extent to which this limits bluegill abundance remains uncertain. In southern portions of the system, backwaters continue to fill with sediment at high rates and aquatic vegetation, which is important for foraging and cover structure, has been almost entirely lost (see section 2.6.1). Many factors may account for changes in bluegill abundance, including habitat loss, forage limitations, exploitation, and predator-prey dynamics (Ickes 2005). Several studies are planned or underway to better determine bluegill population dynamics in the UMRS. These studies will focus on the effects of habitat rehabilitation efforts on bluegill populations, and will determine whether harvest, for which few data are presently available, represents a significant constraint on bluegill populations. Finally, in the southern reaches little improvement in bluegill populations is expected unless backwater areas and aquatic plant communities can be rehabilitated.

Author

Brian Ickes.

2.8.2 Channel Catfish

Assessment

Status: Good.

Trend: Improving in Pool 4 and La Grange Pool, stable elsewhere.

Purpose

Channel catfish is a significant component of the commercial and recreational fisheries in the UMRS. It is a characteristic species of river channels so tracking CPUE of channel catfish may provide insight into habitat quality of channel environments. This indicator is the pool-wide CPUE of adult (>280 mm) channel catfish collected in large hoop nets. Adults were selected because they are the size harvested commercially and recreationally.

State of the Ecosystem

Channel catfish are perennially present in all six LTRMP study areas and are not geographically constrained within the UMRS (Ickes et al. 2005). While perennially present in all study areas, the average abundance of channel catfish varies among the six LTRMP study areas (Figure 2.19). Long-term catch rates range from 0.2 to 1.6 fish per unit of effort. The mean CPUE of adult (>280 mm) channel catfish was highest in Pool 8, marginally lower in Pool 4, La Grange Pool, and the Open River Reach, and notably lower in Pools 13 and 26. In Pool 4 and La Grange Pool, CPUE has increased slightly, but has remained steady elsewhere. It is unknown whether these catch rates are lower than historical rates because no similar data sources are available from earlier periods.

Future Pressures

Channel environments have been significantly altered to accommodate commercial navigation in the UMRS (Dettmers et al. 2001; Gutreuter et al. 2003; Pinter and Thomas 2003; Pinter et al. 2006). It is uncertain whether catch rates of channel catfish throughout the system reflect these alterations. Additional pressures on channel catfish include commercial and recreational harvest, disturbance, or mortality from deep draft tow boats (Gutreuter et al. 2003),

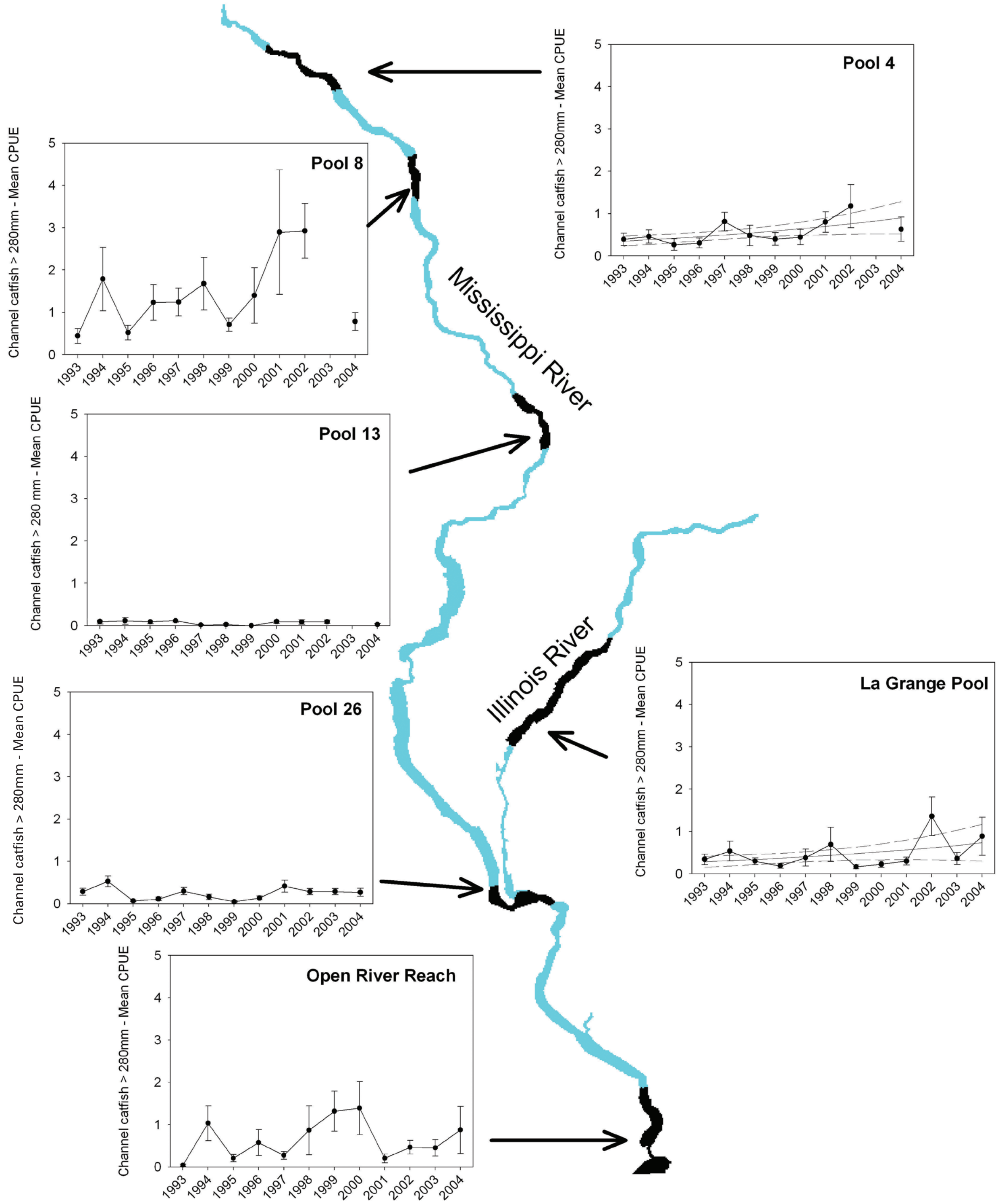

Figure 2.19. Catch-per-unit-effort (CPUE, mean number caught per net day ± 1 standard error) of channel catfish >280 mm total length from 1993 to 2004 in six trend areas monitored by the Long Term Resource Monitoring Program using large hoop nets. Black lines indicate potential trends with 90% confidence limits. In Pools 4, 8, and 13, sampling with large hoop nets was not conducted in 2003.

altered hydrologic regimes, and barriers to longitudinal migration (Wilcox et al. 2004).

Author

Brian Ickes.

2.8.3 Sauger

Assessment

Status: Good.

Trend: Stable in all reaches.

Purpose

Sauger is a characteristic species of river channels and is recreationally exploited throughout the UMRS. Tracking CPUE of sauger provides direct information on the state of this resource and may provide insight into habitat quality of channel environments. This indicator is the pool-wide CPUE of adult (>200 mm) sauger, which is the size available for exploitation.

State of the Ecosystem

Sauger are perennially present in all six LTRMP study areas and are not geographically constrained within the UMRS (Ickes et al. 2005). Long-term catch rates are relatively similar and range between 0.2 and 0.5 fish per unit of effort among LTRMP study areas (Figure 2.20). It is unknown whether these catch rates are lower than historical rates because no similar data sources are available from earlier periods. Whereas CPUE has fluctuated over time, no long-term trends in catch rates were observed.

Future Pressures

Channel environments have been significantly altered to accommodate commercial navigation in the UMRS (Dettmers et al. 2001; Gutreuter et al. 2003; Pinter and Thomas 2003; Pinter et al. 2006). It is uncertain whether relatively low catch rates of exploitable-sized sauger throughout the system reflect, in part, these alterations. Additional pressures on sauger include recreational harvest, disturbance or mortality from deep draft tow operations (Gutreuter et al. 2003), altered hydrologic regimes, and barriers to longitudinal migration (Wilcox et al. 2004).

Author

Brian Ickes.

2.8.4 Smallmouth Buffalo

Assessment:

Status: Good. Pool 26, La Grange Pool, and the Open River Reach exhibit marginally higher catch rates than the Upper Impounded Reach.

Trend: Mixed. Improving in Pool 4, Pool 26, the Open River Reach, and La Grange Pool; stable elsewhere.

Purpose

Smallmouth buffalo is a characteristic large river species and is commercially exploited throughout the UMRS. Tracking CPUE of smallmouth buffalo provides direct information on the state of this resource and may provide insight into habitat quality of large river environments. This indicator is the pool-wide CPUE of adult (>280 mm) smallmouth buffalo, which is the size available for commercial harvest.

State of the Ecosystem

Smallmouth buffalo are perennially present in all six LTRMP study areas and are not geographically constrained within the UMRS (Ickes et al. 2005). Long-term catch rates are similar, ranging between 0.5 and 1.2 fish per unit of effort among LTRMP study areas. Southern study areas exhibit marginally higher catch rates than northern areas (Figure 2.21). From 1993 to 2004, CPUE has increased in four of the six study reaches (Pool 4, Pool 26, Open River Reach, and La Grange Pool) for unknown reasons.

Future Pressures

Smallmouth buffalo were historically much more abundant (Coker 1929), but their populations were reduced by commercial fishing and the establishment of common carp (Fremling et al. 1989). Competition with new exotic species (e.g., silver [*Hypophthalmichthys molitrix*] and bighead carp [*H. nobilis*]) may further marginalize this important native species (Chick and Pegg 2001). Additional future pressures on smallmouth buffalo may include commercial

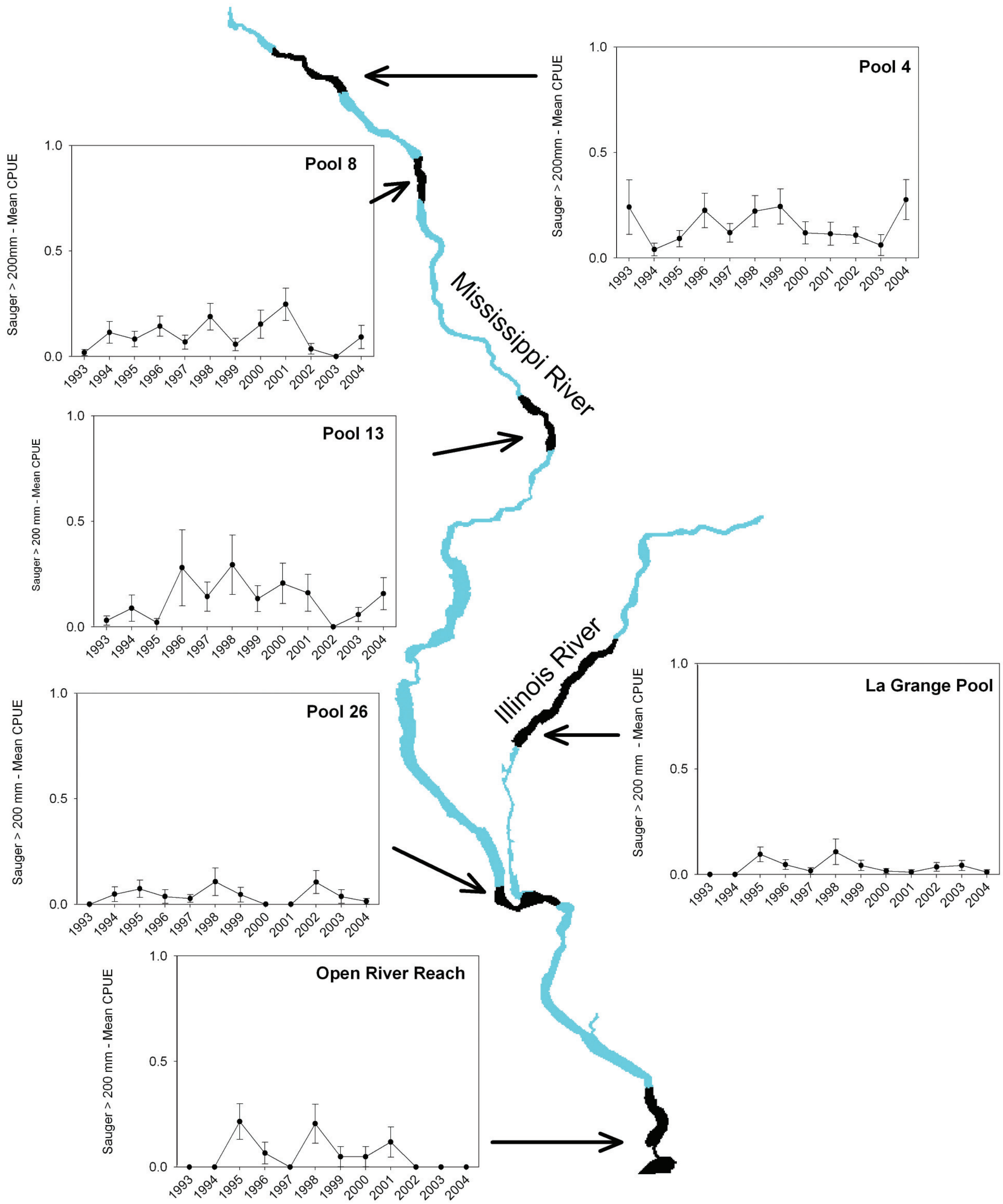

Figure 2.20. Catch-per-unit-effort (CPUE, mean number caught per 15 minutes ± 1 standard error) of sauger >200 mm total length from 1993 to 2004 in six trend areas monitored by the Long Term Resource Monitoring Program using day electrofishing.

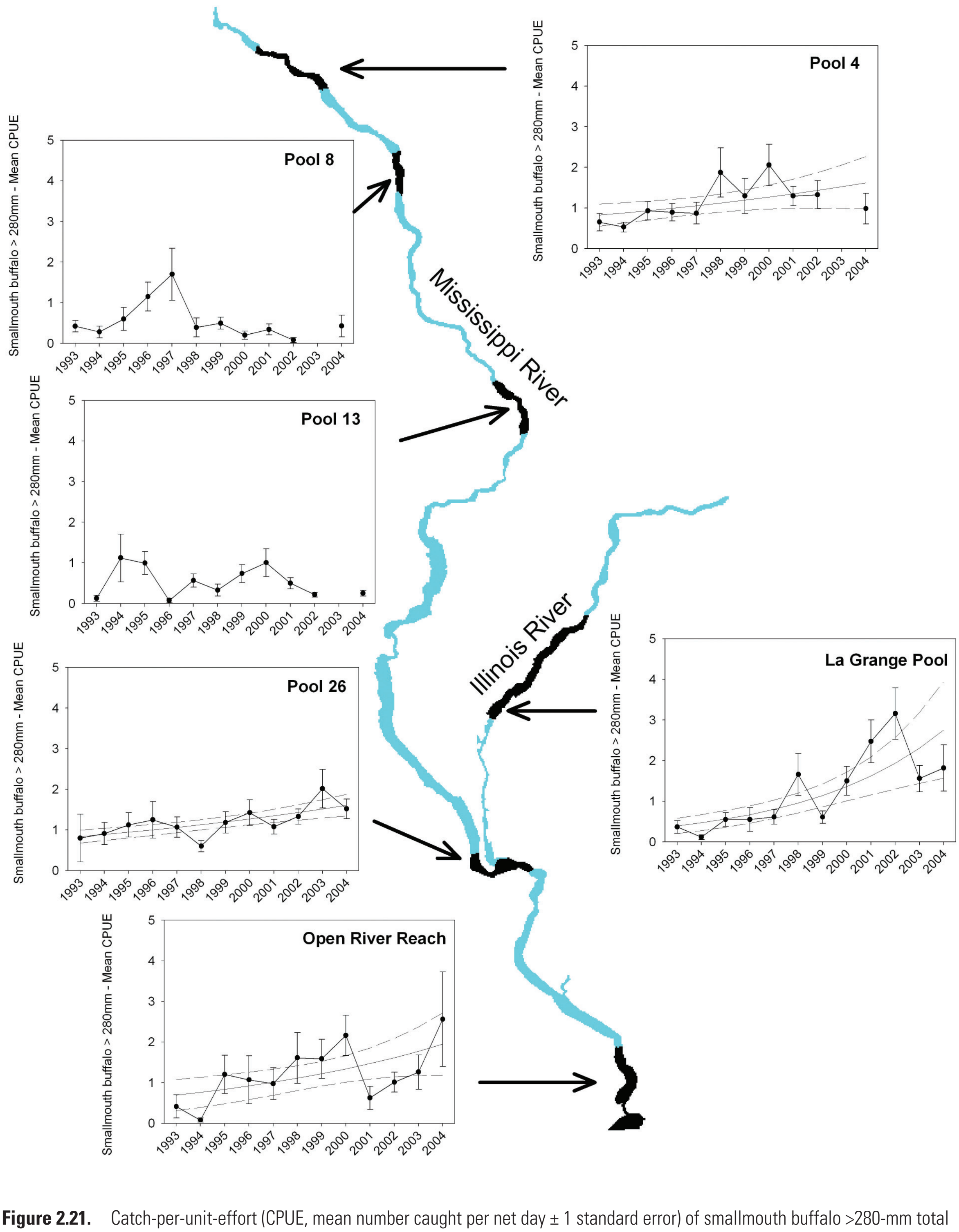

Figure 2.21. Catch-per-unit-effort (CPUE, mean number caught per net day ± 1 standard error) of smallmouth buffalo >280-mm total length from 1993 to 2004 in six trend areas monitored by the Long Term Resource Monitoring Program using large hoop nets. Black lines indicate potential trends with 90% confidence limits. For Pools 4, 8, and 13, sampling with large hoop nets was not conducted in 2003.

harvest, disturbance or mortality from deep draft tow operations (Dettmers et al. 2001; Gutreuter et al. 2003), altered hydrologic regimes, and barriers to longitudinal migration (Wilcox et al. 2004).

Author

Brian Ickes.

2.8.5 Forage Fish Index

Assessment:

Status: Unknown.
Trend: Stable in all reaches.

Purpose

The abundance of forage fishes represents production at lower trophic levels, which provides food for large predatory fish that are important to anglers. Major changes in forage resources could indicate major shifts in ecosystem health and function. This indicator is the pool-wide CPUE of emerald shiner (*Notropis atherinoides*) and gizzard shad (*Dorosoma cepedianum*) combined, the two most prominent forage fishes in the UMRS.

State of the Ecosystem

The forage index is highest in La Grange Pool, suggesting that the Illinois River exhibits greater secondary productivity than the UMR (Figure 2.22). All UMR study reaches had a similar mean forage index during 1993–2004. The forage index has remained stable in all six LTRMP study reaches. The status of forage fish is considered unknown because the adequacy of forage fish production to support predatory fishes has not been determined. Thus, it is not known whether the abundance of forage fish represents a surplus of food for predatory fishes or an inadequate level of food that may limit the production of predatory fish. More work on food web interactions and fish growth and abundance is needed to answer that question.

Future Pressures

Major shifts in forage abundance are only likely to occur if major trophic pathways are altered. Such changes would most likely occur at the base of the food web due to factors affecting primary production (e.g., sedimentation, nutrient loads and uptake rates, water residence times) and may represent profound changes in energy pathways and availability. Alternatively, exotic species may also affect forage fishes in the future by competing directly with them for food. Filter feeders, such as Asian carp, represent the greatest potential future threat among exotic species.

Author

Brian Ickes.

2.8.6 Species Richness

Assessment:

Status: Good.
Trend: Stable in all reaches.

Purpose

The UMRS represents the center of freshwater fish diversity in North America. Collectively, UMRS fish community contains representative species of socioeconomic value, exotic origins, and special conservation status. Thus, the public perceives the ecological health of the UMRS, in part, by the diversity of fishes present. This indicator is the number of fish species observed annually in LTRMP collections.

State of the Ecosystem

Species richness is high and stable in all six LTRMP study reaches, ranging from approximately 55 to 75 species annually per study area (Figure 2.23) with means over the period ranging from about 60 to 70. Annual fluctuations are attributed to random variation, unpredictable rare species occurrences, and variation in sampling effort. The large reduction in species richness seen in Pools 4, 8, and 13 in 2003 was due to a substantial reduction in sampling effort in those pools due to budget cuts. The highest number of species occurred in Pool 8 and the lowest in the Open River Reach.

The species present in each LTRMP study area are similar to the species present 100 years ago. Almost all native species are still present, but their abundances may have been changed from historical conditions due to habitat changes, competition with other species, or changes in river functions. One example is the highly migratory skipjack herring (*Alosa chrysochloris*),

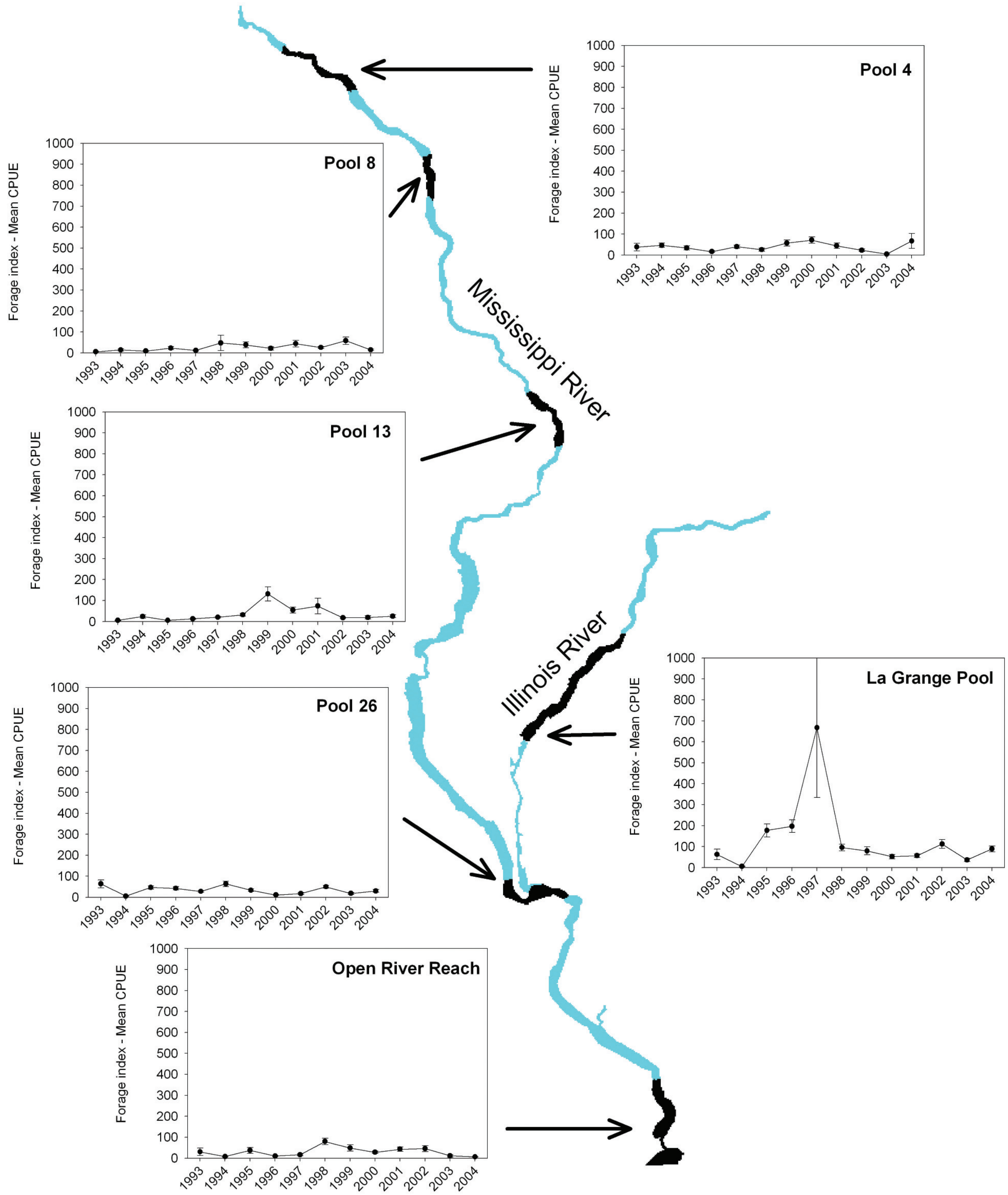

Figure 2.22. Catch-per-unit-effort (CPUE, mean number caught per 15 minutes ± 1 standard error) of the forage index (combined CPUE of emerald shiner (*Notropis atherinoides*) and gizzard shad (*Dorosoma cepedianum*)) from 1993 to 2004 in six trend areas monitored by the Long Term Resource Monitoring Program using day electrofishing.

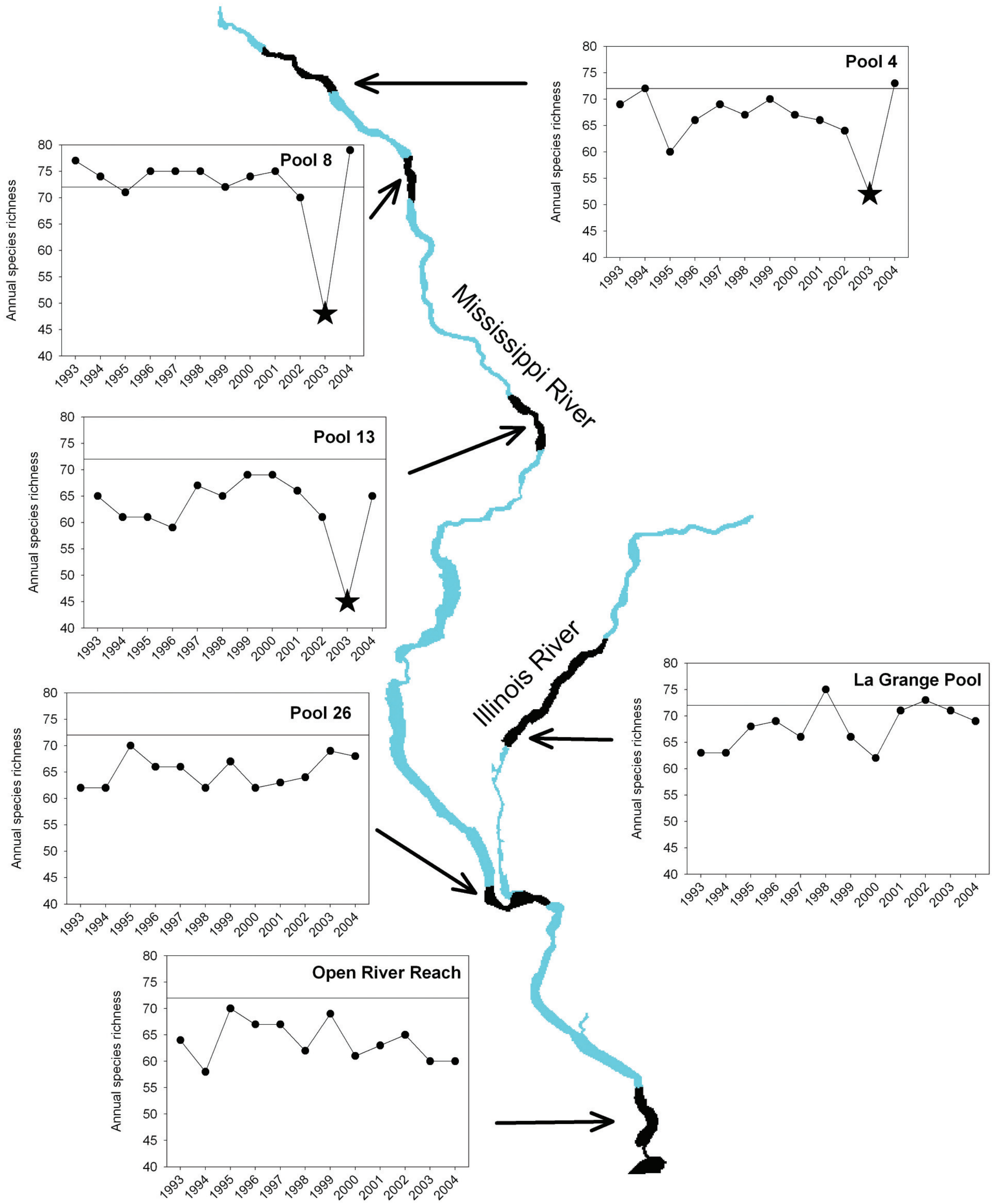

Figure 2.23. Species richness (number of species collected annually in all sampling gears) from 1993 to 2004 in six trend areas monitored by the Long Term Resource Monitoring Program. The horizontal line indicates the highest mean index among all areas (observed in Pool 8) and is provided for reference. Stars indicate significant reductions in sampling due to budget cuts.

which is now rare above Lock and Dam 19 because that dam is an effective barrier to migration except in years of extreme flooding. Of the native fishes observed by the LTRMP, 39 species have been reduced to the point that they have conservation status nationally or in one or more UMRS states.

Several nonnative species have been added to the original UMRS community (see section 2.8.7). Of the 139 fish species collected by LTRMP, 12 (9%) are nonnatives or their hybrids. The exotic common carp (*Cyprinus carpio*) is now abundant throughout the system. Moreover, exotic species introductions continue primarily from the southern reaches and from the connection of the Illinois River with Lake Michigan through the Chicago Sanitary and Ship Canal. Presently, exotic species account for roughly 10% of the species richness in La Grange Pool.

Future Pressures

Habitat losses, impairments to long-ranging migrations, and exotic species represent the most significant future threats to UMRS fish species richness. Loss of habitat diversity, floodplain isolation, and altered hydrology are regionally and systemically important habitat issues. Navigation dams are believed to restrict movements of many migratory species within the UMRS. Data suggest that species are likely to persist, but may be reduced in abundance as a consequence of impoundment. Nonnative and exotic species, such as several recently introduced species of Asian carp, may compete with or regionally displace some native species.

Author

Brian Ickes.

2.8.7 Nonnative Fishes

Assessment:

Status: Poor. Nonnative fishes account for a substantial portion of total biomass in all reaches.

Trend: Mixed. Improving in Upper Impounded Reach, stable in Pool 26, the Open River Reach, and La Grange Pool.

Purpose

Nonnative fishes (species originating from outside the basin) occur in all monitored study reaches. The fraction of nonnative biomass to total fish biomass is frequently regarded as an indicator of ecological impairment. Nonnative species can compete with more desirable native species, thereby reducing abundance and distribution of natives. Tracking nonnative fish biomass provides direct information on the prominence of nonnative species and may indicate stresses on native fish assemblages. This indicator is the proportion of total fish biomass composed of seven nonnative species: goldfish (*Carassius auratus*), grass carp (*Ctenopharyngodon idella*), common carp, silver carp, bighead carp, white perch (*Morone americana)*, and striped bass (*Morone saxatilis)*.

State of the Ecosystem

The annual proportion of nonnative biomass to total fish biomass is sizeable, ranging from 23 to 68%, and rivaling other systems considered highly impaired by nonnative species (e.g., Great Lakes). The majority of nonnative biomass is from common carp (range 72–98% among locations). While the proportion of nonnative biomass is high in the UMRS, this indicator is holding relatively steady in the lower reaches and improving slightly in the upper reaches (Figure 2.24). Notably, Pool 8 generally has a lower proportion of nonnative biomass compared to other reaches and demonstrated a significant decline over 1993–2002. Weaker, yet statistically significant declines occurred in Pools 4 and 13. Reasons for these declines are unknown, but may be a function of habitat rehabilitation, predatory pressures on nonnative species, parasitism, disease, or some combination of these. Research on why the percentage nonnative biomass is lower and declining in upper pools, especially Pool 8, may yield lessons applicable to other river reaches.

Asian carps (bighead and silver carp) are recent invaders to the southern UMRS coming up from the lower Mississippi River. Asian carp were first collected by the LTRMP in Pool 26 in 1993. As of 2004, they have not been collected by LTRMP above Pool 26, but a few individuals

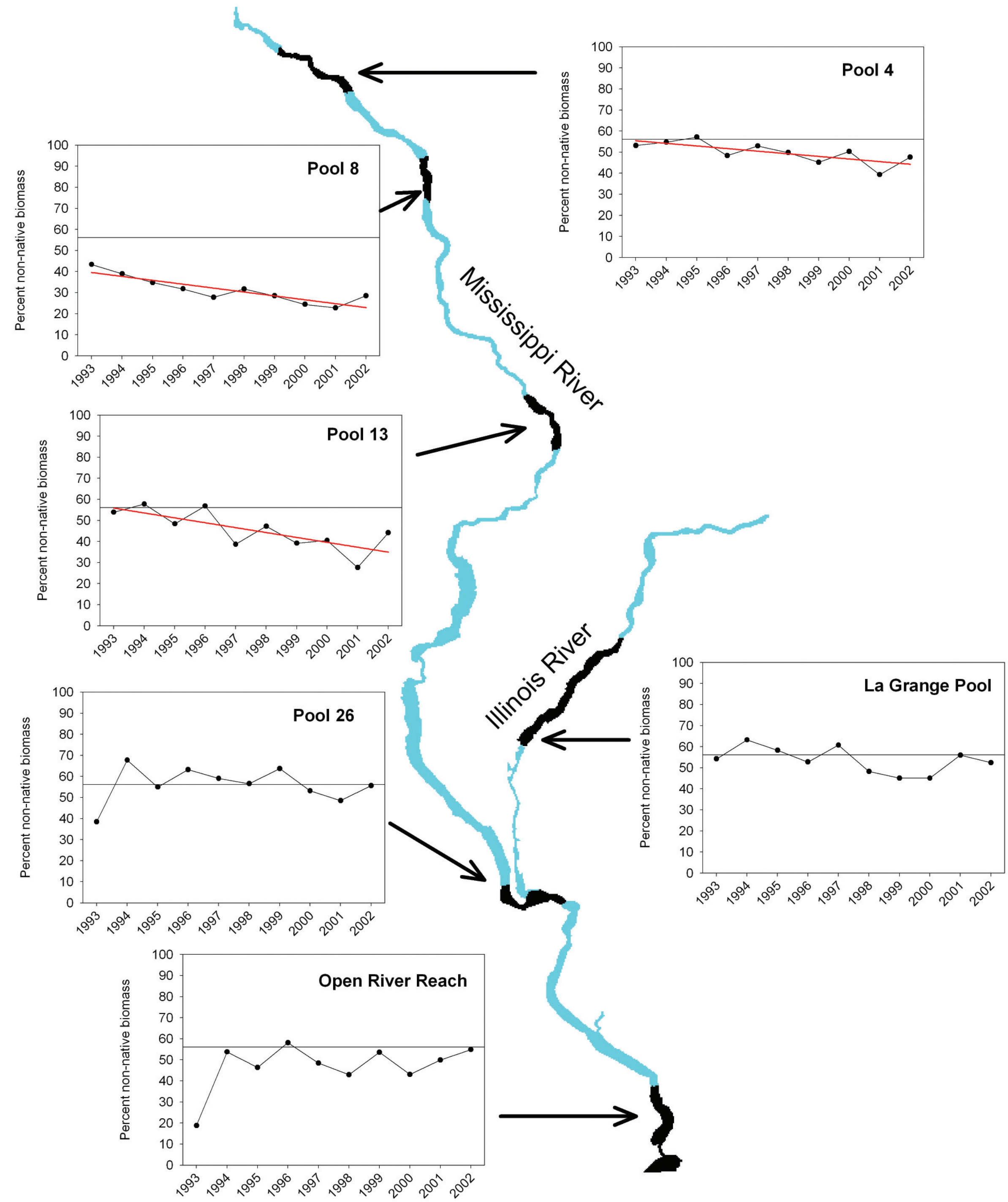

Figure 2.24. Percentage of total fish biomass accounted for by nonnative species from 1993 to 2002 in six trend areas monitored by the Long Term Resource Monitoring Program. Red lines indicate possible trends. The horizontal line indicates the highest mean index among all areas (observed in Pool 26), and is provided for reference.

have been collected by other means as far north as Pool 4. Their dispersal into the Upper Impounded Reach may be slowed at Lock and Dam 19. This dam has the highest head (36 feet) among dams in the mid-portion of the system (higher dams exist at the extreme upper end of the navigation system) and is a more substantial barrier to fish migration than other dams (Wilcox et al. 2004). Asian carps have achieved notable abundance in the lower reaches of the UMRS, which has been widely reported in the media, and are now commercially harvested in those areas. However, LTRMP sampling methods are relatively ineffective at collecting these species, so our estimates of their proportion in the total catch are probably low. Thus, although no trends were apparent in our data from the southern reaches, our estimates of Asian carp biomass may be low and the percentage of nonnative biomass may actually be increasing in these reaches. The LTRMP sampling will continue to provide an index of nonnative biomass useful for comparing among study areas, but questions specific to the abundance of Asian carps may require sampling by other methods.

Future Pressures

Nonnative fishes compose a sizeable fraction of the total fish biomass in the UMRS and new introductions have occurred recently. Once established, nonnative species are nearly impossible to control, and then only at great expense. The Mississippi River and its principal tributaries provide a highway for nonnative species to travel from areas as geographically disparate as the Atlantic Gulf Coast and the Laurentian Great Lakes to the interior of the North American continent. Recently established populations of silver and bighead carp in the southern portions of the UMRS are expected to increase in abundance (as evidenced by more recent data from the lower reaches) and expand their distribution within the UMRS. Additional species including round goby (*Neogobius melanostomus*) and black carp (*Mylopharyngodon piceusare*) are poised to invade the UMRS from Great Lakes and down river sources, respectively. Because of the ability of many nonnative fish species to compete with and displace native species, nonnative species will remain a principal threat to native biodiversity in the foreseeable future in the Mississippi River drainage, home to nearly one-third of the entire North American freshwater fish fauna.

Author

Brian Ickes.

2.8.8 Recreationally Harvested Native Fishes

Assessment

Status: Fair for all reaches. All reaches support recreationally harvested fishes and recreational fisheries.

Trend: Mixed. Stable or increasing in the three upper pools; stable or declining in the lower reaches.

Purpose

The production of recreationally harvestable fishes is one of the important services that the UMRS ecosystem provides to humans. Tracking CPUE of recreationally harvested fishes provides direct information on this resource and may provide insight into habitat quality. This indicator is the combined CPUE from 19 native fish species (Table 2.3) and includes fishes common in backwaters and channel habitats.

Table 2.3. Common and scientific names of the 19 species that were combined to create an index for recreationally harvested fishes.

Common name	Scientific name
Northern pike	*Esox lucius*
Channel catfish	*Ictalurus punctatus*
Blue catfish	*Ictalurus furcatus*
Flathead catfish	*Pylodictis olivaris*
Freshwater drum	*Aplodinotus grunniens*
White bass	*Morone chrysops*
Yellow bass	*Morone mississippiensis*
Smallmouth bass	*Micropterus dolomieu*
Largemouth bass	*Micropterus salmoides*
Rock bass	*Ambloplites rupestris*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Green sunfish	*Lepomis cyanellus*
Bluegill	*Lepomis macrochirus*
Redear sunfish	*Lepomis microlophus*
Pumpkinseed	*Lepomis gibbosus*
Yellow perch	*Perca flavescens*
Sauger	*Sander canadense*
Walleye	*Sander vitreus*

State of the Ecosystem

La Grange Pool of the Illinois River had the greatest average CPUE of recreational fishes (Figure 2.25). Environmental conditions and the overall health of the fish community in the Illinois River have increased since the early and mid-1900s, but are still not comparable to the excellent fishery that occurred in the late 1800s (Pegg and McClelland 2004). Whether populations can be returned to those levels is unknown. The Open River Reach had the lowest abundance of recreational fishes, which would be expected because the lack of backwater habitats in that reach means that the recreational fishes associated with those habitats are virtually nonexistent. Therefore, different levels of this indicator would be expected among study reaches, but all reaches were considered fair because there appears to be potential for improvement in each reach.

Trends for recreationally harvested fishes varied longitudinally. In the three northern LTRMP study reaches (Pools 4, 8, and 13), CPUE levels for recreationally harvested fishes were increasing or holding steady (Figure 2.25). For the three southern LTRMP study reaches (Pool 26, La Grange Pool, and the Open River Reach), CPUE of recreationally harvested fishes is declining or holding steady.

Future Pressures

Habitat degradation and invasive species appear to be the largest threats to recreationally harvested fishes. Backwaters continue to fill with sediment and, in southern portions of the system, aquatic vegetation has been almost completely lost. A variety of habitat rehabilitation projects have been constructed in the UMRS aimed at increasing abundance of recreational fishes. Some of these projects have been successful at increasing fish abundance locally, but their effects at the reach scale or larger are not yet evident. The LTRMP will be able to detect these effects when sufficient numbers of projects have been constructed to elicit reach-wide effects in the LTRMP study areas. Among LTRMP locations, Pools 8 and 13 and La Grange Pool have been the sites of the greatest number of habitat rehabilitation projects and are the most likely candidates for initially detecting a pool-wide effect.

Author

John Chick.

2.8.9 Commercially Harvested Native Fishes

Assessment

Status: Fair for all reaches. All reaches support commercially harvested fishes and commercial fisheries.

Trend: Mixed. Catches have declined in Pool 8, but are stable in all other reaches.

Purpose

Commercial fisheries exist throughout the UMRS, and the production of commercially harvestable fishes is one of the important services provided by this ecosystem. Tracking CPUE of commercially harvested fishes provides direct information on this resource, and may provide insight into habitat quality and the likelihood of overharvest. This indicator is the combined CPUE from seven native fish species (Table 2.4). Common carp and Asian carps are also commercially harvested, but are nonnative species and are not included in this indicator.

Table 2.4. Common and scientific names of the seven native species that were combined to create an index for commercially harvested fishes. Note that some commercially harvested species are also harvested by recreational fishers and are included in the recreationally harvested fishes indicator.

Common name	Scientific name
Bigmouth buffalo	*Ictiobus cyprinellus*
Smallmouth buffalo	*Ictiobus bubalus*
Black buffalo	*Ictiobus niger*
Channel catfish	*Ictalurus punctatus*
Blue catfish	*Ictalurus furcatus*
Flathead catfish	*Pylodictis olivaris*
Freshwater drum	*Aplodinotus grunniens*

State of the Ecosystem

The highest CPUE of commercially harvested fishes occurred in La Grange Pool in the Illinois River (Figure 2.26). Historical commercial fisheries data indicate that the overall productivity of the Illinois River was

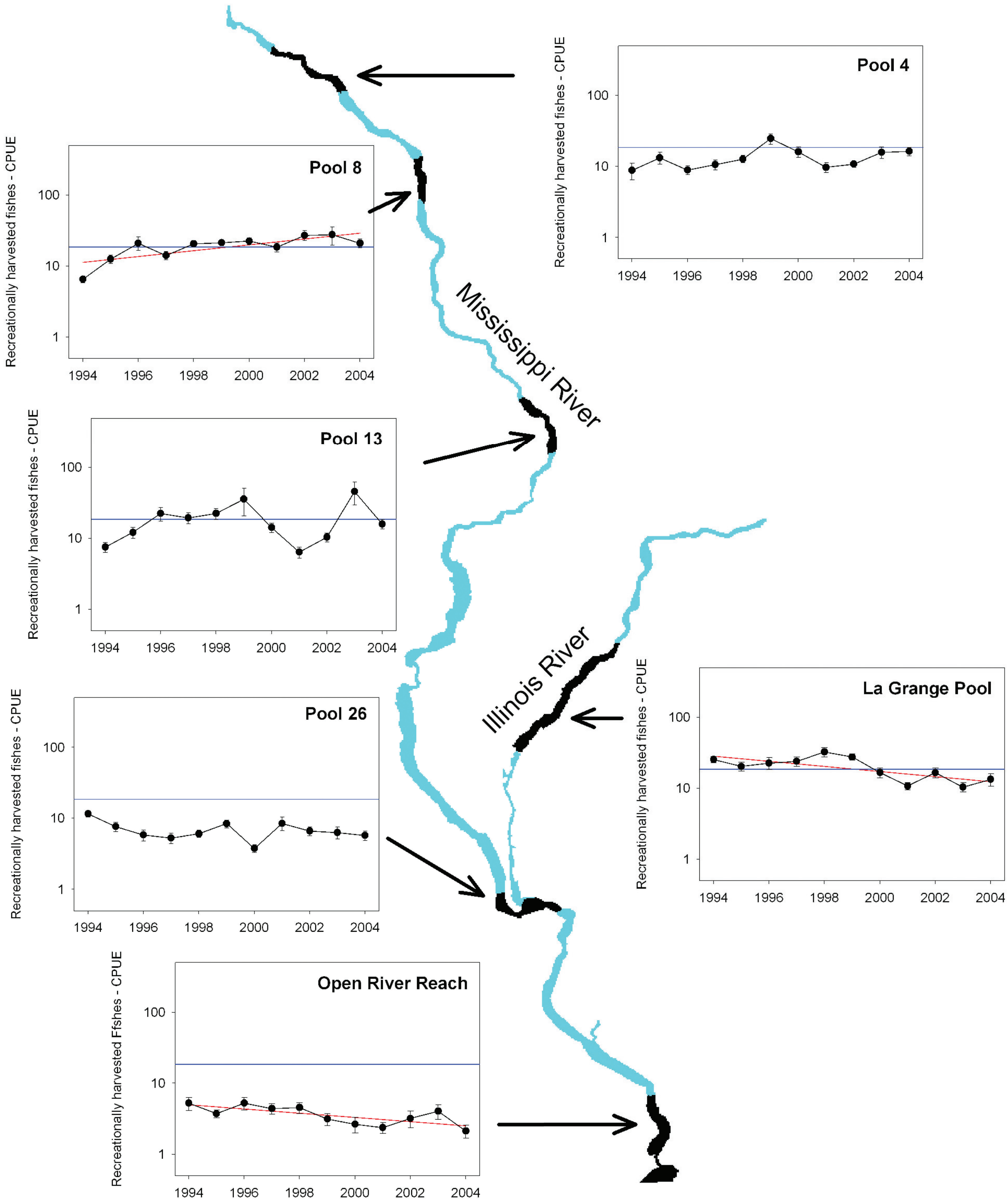

Figure 2.25. Catch-per-unit-effort (CPUE, number/15 min +/- 1 standard error) of recreationally harvested fishes caught with day electrofishing from 1994 to 2004 by the Long Term Resource Monitoring Program. Red lines indicate significant trends. Horizontal lines indicate the overall mean CPUE from La Grange Pool (the highest mean), and are provided for reference.

substantially greater in the late 1800s, with commercial harvest at least 10 times greater than recent catches (Sparks 1992; Pegg and McClelland 2004). Although environmental conditions and the overall health of the fish community in the Illinois River have improved since the establishment of the Clean Water Act (Pegg and McClelland 2004), productivity has not returned to historical levels. The maximum production for commercial fishes in different reaches of the UMRS is unknown. However, based on the history of the Illinois River, there appears to be potential for greater production. Therefore, the status of commercially harvested species was designated fair for all reaches.

In five of the LTRMP study reaches, CPUE levels for commercially harvested fishes were stable (Figure 2.26). Therefore, we have little evidence of habitat problems or overharvest for these reaches. A negative trend was observed in Pool 8 and may be a cause for local concern. Managers may want to assess whether there are habitat issues specific to commercially harvested fishes that need to be addressed in Pool 8.

Future Pressures

The overall effort and infrastructure associated with commercial fisheries in the UMRS are at relatively low levels and are unlikely to expand greatly in the foreseeable future. For the seven species composing this indicator (Table 2.4), habitat degradation and invasive species appear to be the most important future threats. Most of the rehabilitation projects designed to improve fish habitat in the UMRS have been planned for recreational species. It is unknown whether managing primarily for recreational species might increase production of all fishes, or might transfer production from commercial to recreational fishes. If the abundance of commercially harvested species declines in the future as a result of habitat loss, managers may need to develop new types of habitat projects focused on commercial fishes.

Author

John Chick.

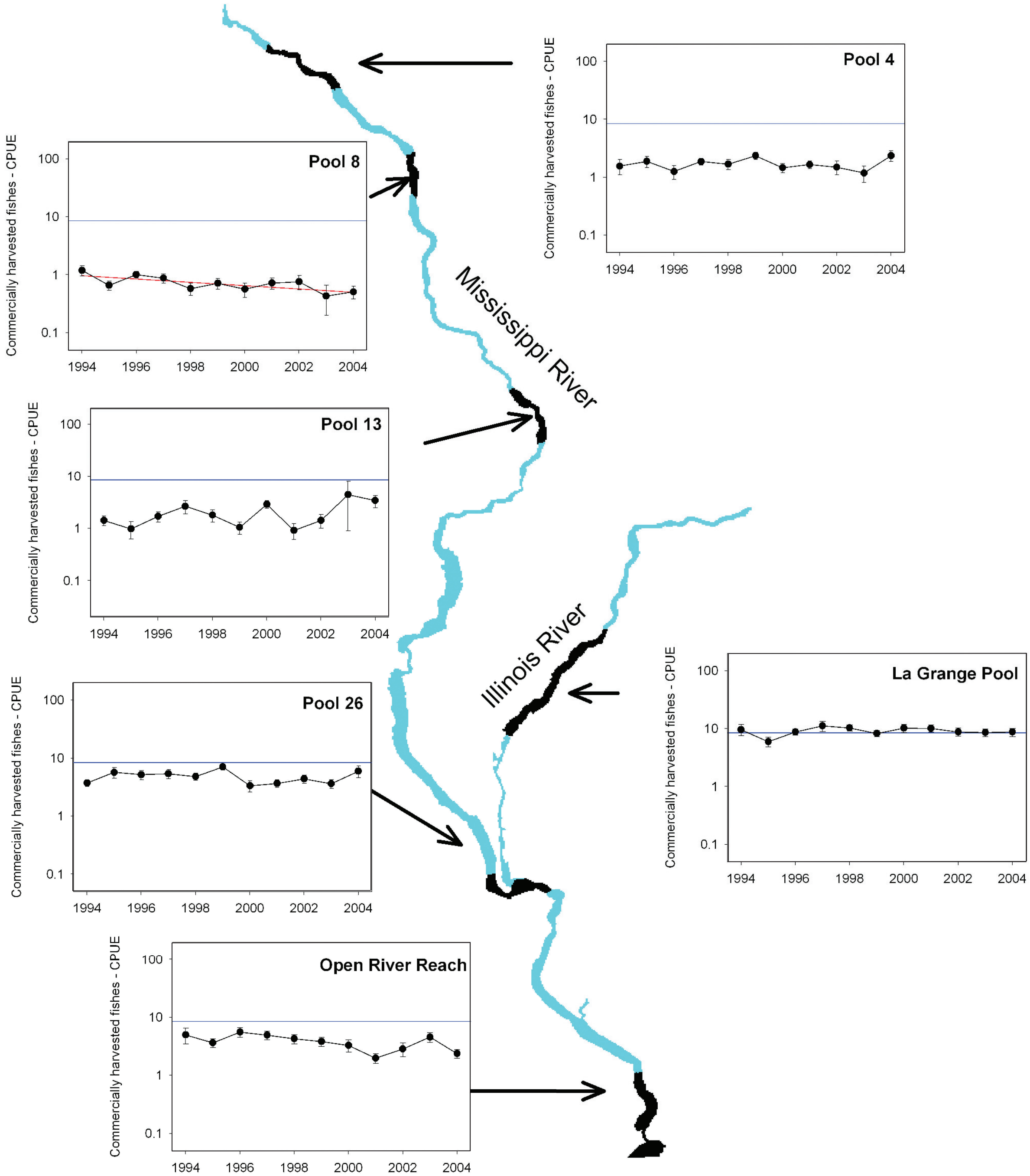

Figure 2.26. Catch-per-unit-effort (CPUE, number/15 min +/- 1 standard error) of commercially harvested fishes caught with day electrofishing from 1994 to 2004 by the Long Term Resource Monitoring Program. Red lines indicate significant trends. Horizontal lines indicate the overall mean CPUE from La Grange Pool (the highest mean) and are provided for reference.

Chapter 3. Discussion, Conclusions, and Recommendations

The Ecological Status and Trends of the Upper Mississippi River 1998 (USGS 1999) provided a broad-based assessment of ecosystem health of the four river reaches within the UMRS. The first report used six criteria for ecosystem health to assess the condition of each reach and to forecast future conditions. The current report builds upon that synthesis by using a 10+year record of data collected by the LTRMP. The report presents measurements of river health through the use of indicators and conveys this information with scientific interpretations that reflect declining, stable, or improving conditions. The findings of this report are being used to track progress toward reaching system goals and objectives, and refining indicators, as needed.

3.1 Integrity and Sustainability of the Upper Mississippi River System

3.1.1 Implications for Ecosystem Integrity and Sustainability

The LTRMP data indicate a gradient of river health within the UMRS ranging from a relatively healthy system in the northern reaches, to a system that is much less healthy in the south. This diversity of conditions makes the UMRS a mirror for many other rivers throughout the world and an excellent laboratory for development of effective restoration strategies. The good news is that, compared to many of the world's temperate-zone rivers, many parts of the UMRS still retain the basic features that define river ecosystem integrity, such as a fairly natural discharge regime, ability to move sediments through most dams, a nearly complete species complex, and a natural range of water temperatures. However, the system has some problems that need to be addressed to improve ecosystem health.

Reducing stressors on the river ecosystem will require a cooperative effort among many agencies, especially for stressors that operate mainly in the uplands and tributaries. However, many stressors that operate within the channel or floodplain can be addressed directly by the EMP through, for example, changes in dam operations, modifications to channel structures, restoring floodplain connectivity, or changing flow distribution. The LTRMP can assess how successful those techniques are at enhancing ecosystem health and sustainability in the long term.

3.1.2 Comparison of Status and Trends among Regions and Indicators

When the indicators used in this report are viewed together, they reveal a system with both good and poor characteristics (Figure 3.1). The indicators for sedimentation, major nutrients, and floodplain forests are poor to mixed throughout the system and in most locations these indicators show a decline in condition. Indicators for dissolved oxygen levels, species richness of fishes, and population of some fish species are good to mixed throughout the system with some increasing trends. All other indicators are fair to mixed, with some indicators showing both positive and negative trends. The spatial differences seen within and among indicators reveal patterns related to the health of specific reaches as detailed below.

Previous analyses of LTRMP data have shown that different reaches of the UMRS can be identified based on geomorphic features (Knox 2000), habitats (Koel 2001), and fish species (Koel 2004; Chick et al. 2006). The data presented in this report support this reach-based approach to understanding and managing the system, but also show that some indicators are fairly consistent throughout the system. Overall, results demonstrate that environmental conditions are best in the Upper Impounded Reach, where habitat diversity is greatest and the river maintains more of its connection to the floodplain. Conditions gradually decline downstream as habitat diversity is lost, the river becomes more isolated from its floodplain, and public land is rare.

Hydrologic data show that, compared to pre-dam conditions, the impounded reaches had higher average water elevations, especially

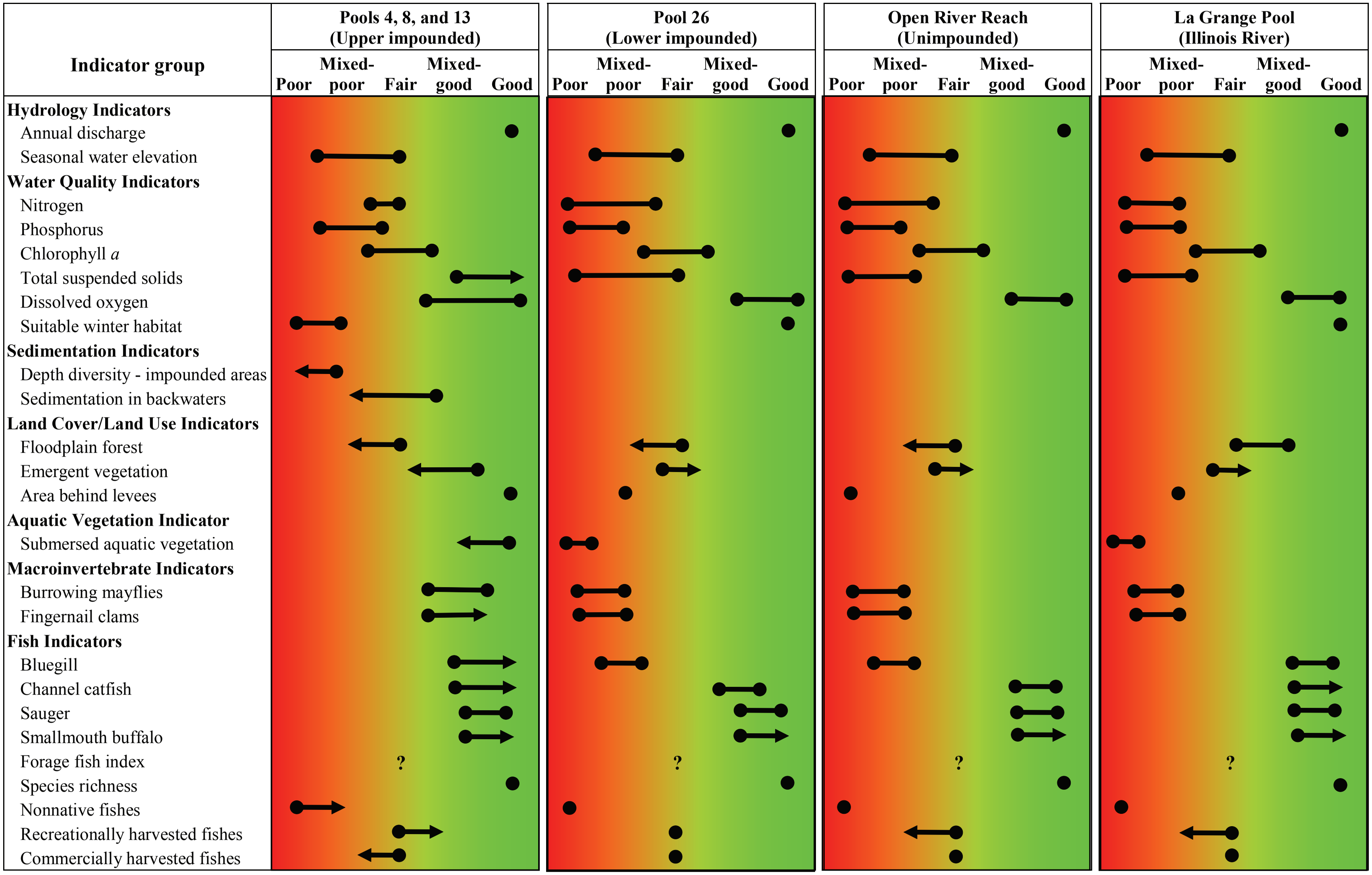

Figure 3.1. Comparison of ratings of the status and trends for resource indicators derived from data collected at the six study areas of the Long Term Resource Monitoring Program (LTRMP) on the Upper Mississippi River System. The black bars indicate the range of status within that LTRMP sampling areas. An arrow at the end of a bar indicates a trend in that direction for that sampling area (or at least one sampling areas in the left panel). A question mark means that rating of that indicator was not possible. See the text for details on the locations of the study areas (Chapter 1) and reasons for specific ratings (Chapter 2).

during low flow periods (Figure 2.2). In the Unimpounded Reach, the annual cycle of water elevations was similar between pre- and post-dam periods (Figure 2.2), but channel shape and hydraulics have been substantially altered from historical conditions. All reaches have experienced increased short-term variation in water levels. Factors contributing to increased variation include increased runoff from uplands and urban areas, dam operations, and channel narrowing. These factors represent hydrologic stressors to the river, but they can be managed to some degree in the impounded reaches by changes in dam operations to dampen water level fluctuations (Landwehr et al. 2005).

When the navigation dams were first built on the UMRS, there was an increase in habitat diversity due to initial flooding of terrestrial areas. However, since that initial increase, habitat diversity has been lost throughout the UMRS. This is a serious management concern because previous analyses have shown that fish species diversity is directly related to habitat diversity (Koel 2004). In the impounded reaches, the dams themselves caused changes in various processes (e.g., sediment dynamics, water levels, wind fetch) that act over the long term to reduce habitat diversity. Obviously, the Unimpounded Reach did not experience the one-time increase in habitat diversity associated with dams, but it has still experienced loss of habitat diversity.

Besides dam building, there are a variety of processes that effect habitat diversity. Most of these processes operate slowly and some can exhibit high annual variation. Building levees, which was more prevalent in the lower reaches, eliminated connections of the river to its floodplain, thus eliminating much of the highly diverse, seasonally flooded habitat from the ecosystem. Channelizing the river with wing dikes and closing structures also reduces the ability of biota to access off-channel habitats. This is evident in all reaches, but especially in the lower reaches where sedimentation has filled in the area between most wing dikes and cut off access to many side channels.

In all reaches, sedimentation has filled-in backwaters and deep areas and erosion has eliminated many islands, especially in impounded areas. Studies by the LTRMP indicate that sedimentation rates are highly variable (Figure 2.11) but the net effect over 50 years was a substantial loss of habitat diversity (Figure 2.10). For highly variable processes, such as sedimentation, the time span of the LTRMP data is not long enough to make definitive statements about present trends. We expect sedimentation to continue, but at a slower rate because as sedimentation continually reduces the volume of pools, trapping efficiency for additional sediment is also reduced. Some of this lost habitat diversity can be restored through management techniques, such as constructing islands, dredging backwaters, and restoring floodplain connections. In some instances, changes in habitat diversity may be substantial and quick, such as removing a levee to reclaim a levee district, which can affect a large area with a single action. However, for smaller-scale projects (e.g., island building), it will likely require multiple projects constructed over many years to produce a significant change in habitat diversity. Both types of change can be identified within LTRMP focal pools as longer data sets are developed.

The LTRMP data show that water quality among the four river reaches can be extensively different for some indicators, but similar for others. The most substantial difference is in the concentration of total suspended solids (TSS). The TSS drop from upper Pool 4 to lower Pool 4 because Lake Pepin, a natural lake on the river, serves as an efficient trap for suspended solids. The TSS then increase from about 20 mg/L in lower Pool 4 to 200 mg/L in the Open River Reach and is intermediate in the Illinois River (Figure 2.6). In lower Pool 4 and Pool 8, TSS are generally below the recommended maximum concentration for plant growth of 25 mg/L (summer average, UMRCC 2003). In Pools 4 and 8, TSS exhibit a downward trend since 1994 for unknown reasons. In upper Pool 4 and in Pool 13, TSS exceed the maximum during spring and summer of most years, whereas the three lower reaches are above the maximum virtually all the time. This downstream increase in TSS is a common feature of rivers but is likely exacerbated in the UMRS by runoff from agricultural watersheds, which are more prevalent in the lower reaches.

Because high TSS concentrations reduce light penetration into the water, they are one of the primary causes of differences in submersed aquatic vegetation among these reaches. Submersed vegetation is virtually absent from the three lower reaches (Figure 2.15) where TSS concentrations are too high to allow light to penetrate and seeds to germinate. In the Unimpounded Reach below the Missouri River, TSS have always been high and vegetation has never been abundant.

Reducing the TSS load to the impounded reaches will be difficult but may result from increased use of best management practices on the watershed or from restoration of tributary deltas in the UMRS floodplain to trap sediments on the land before they enter the river. However, even without reducing the overall sediment load, certain management techniques, such as building islands, can create areas that are sheltered from current and wind, which allows suspended sediments to settle out and increase light penetration. These techniques have worked well in the Upper Impounded Reach and should be evaluated in lower reaches.

The nutrient phosphorous, which is associated with sediment particles, also increases downstream from about 0.1 mg/L in the Upper Impounded Reach to 0.25 mg/L in the Open River Reach (Figure 2.4). Nitrogen concentrations increase from about 2 mg/L in the Upper Impounded Reach to 3 mg/L in the lower reaches (Figure 2.3). The Illinois River generally has the highest concentrations of both nitrogen (4 mg/L) and phosphorous (0.4 mg/L). Mean phosphorus concentrations are above the suggested upper limit (0.08 mg/L; USEPA 2000a; Smith et al. 2003) for nearly all reaches and years. Mean nitrogen concentrations in pools of the Upper Impounded Reach are above the suggested upper limit (2.18 mg/L; USEPA 2000a; Smith et al. 2003) about 50% of the time, but in the lower reaches, nearly all the time.

Reducing nutrient loads to the river could be achieved by more effective waste treatment for point source inputs and by reducing loss of nutrients applied to farm fields and lawns. In addition, because phosphorous is typically adsorbed onto sediment particles, any management that helps to reduce suspended sediments will also tend to reduce phosphorous. Nitrogen can be reduced by management that moves more water through wetlands and shallow aquatic areas (either in the watershed or floodplain) where natural processes will convert the nitrogen to a gas, which is then lost to the atmosphere. Management of the UMRS to divert more water from the main channel into off channel areas will help reduce nitrogen. However, it is highly unlikely that working in the floodplain of the UMRS alone will reduce nitrogen enough to eliminate hypoxia in the Gulf of Mexico (Mitsch et al. 2001; Richardson et al. 2004).

High nutrient concentrations can cause excess plant growth. However, LTRMP data on chlorophyll in the main channel (Figure 2.5) show that all reaches are typically within the medium (mesotrophic) range designated by Dodds et al. (1998). Thus, although nutrient levels in the UMRS are high, algal growth is typically not excessive. However, algae blooms (a locally high abundance of algae) sometimes occur in the UMRS and can have negative effects. Blooms usually occur when flow is low. Low flows mean that water stays in one place longer, which allows algae to grow quickly. Abundant algae, especially in combination with high suspended solids, reduce light penetration and thus, growth of rooted aquatic plants. In addition, blooms are often composed of mainly blue-green algae, whose value as food for other biota is quite low. More work is needed on the species composition and production of the algal community under different combinations of flow and nutrient loads to determine potential ecological effects.

Previous modeling (Best et al. 2004a, b; Yin and Langrehr 2005) has shown that the distribution of submersed aquatic macrophytes can be largely explained by transparency, water depth, and current velocity. As already discussed, some of these relations can be seen in the LTRMP indicator data and in evaluations of rehabilitation projects (Langrehr et al. 2007). But in addition, variation in water levels can reduce abundance of both submersed and emergent aquatic macrophytes.

The LTRMP land cover data indicate that between 1989 and 2000, emergent vegetation decreased in most pools of the Upper Impounded Reach but generally increased in all other reaches. Determining the cause of changes at two points 10 years apart is difficult. However, as more management actions, such as summer drawdowns, island building, and changes in control point are implemented, future data may be able to correlate these actions with changes in land cover. More rapid evaluation will be possible for actions implemented on LTRMP sampling areas, such as island building in Pool 8 (Langrehr et al. 2007) and the summer drawdowns conducted on Pool 8 in 2001 and 2002. The effect of these or any other management actions implemented in LTRMP sampling areas, can be addressed by looking at changes over subsequent years in various indicators, the persistence of any effects through time, and possible time lags of responses.

A primary factor for distribution of benthic invertebrates is substrate type. Densities of fingernail clams and burrowing mayflies have been highly variable over the span of the LTRMP (Figures 2.16 and 2.17) but have been consistently higher in the Upper Impounded Reach where silt-clay substrates are more abundant. These organisms are important foods for fish and waterfowl. For example, data from the U.S. Fish and Wildlife Service indicate that diving ducks in Pool 8 were more abundant in years when fingernail clams were prevalent (Figure 3.2).

Benthic invertebrates are one of the few biological indicators for which quantitative data exist before LTRMP (Sauer 2004). The abundances seen in LTRMP data are within the ranges seen in these earlier studies. These organisms are sensitive to shifts in environmental quality and can rapidly disappear from areas where conditions become unfavorable, but they also have the potential to rebound rapidly if conditions improve.

Analyses of LTRMP data by Gray et al. (2005) showed that abundance of fingernail clams was negatively associated with levels of inorganic suspended solids (silt and clay particles) in Pool 8. This suggests that management to reduce inorganic suspended solids may increase fingernail clam densities. But, given the annual variability in abundance

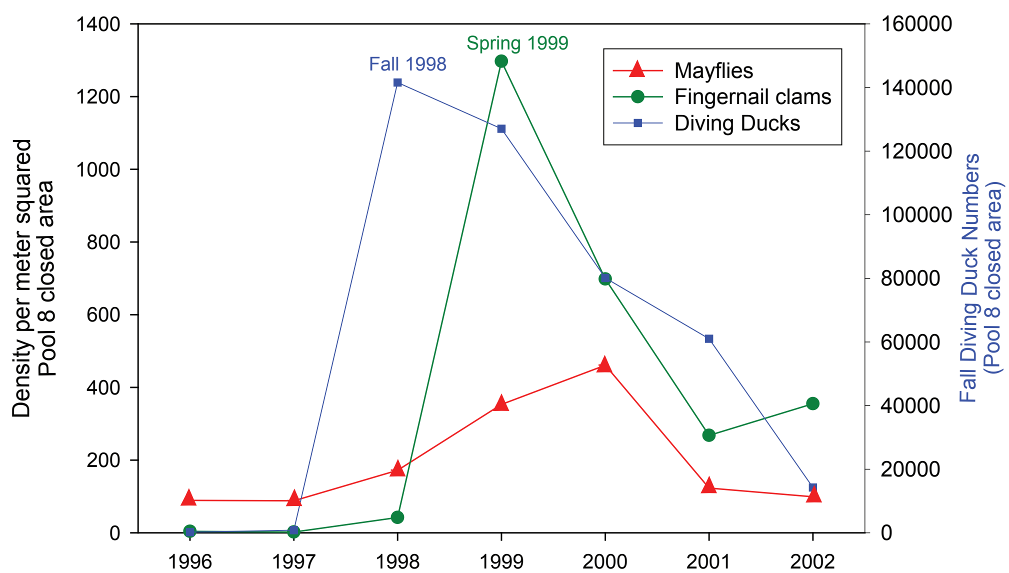

Figure 3.2. Data on density of fingernail clams (*Musculium transversum*) and mayflies (*Hexagenia* spp.) from the Long Term Resource Monitoring Program compared to total number of diving ducks such as scaup (*Aythya* sp.) and ring-necked ducks (*Aythya collaris*) observed (data from U.S. Fish and Wildlife Service) in the area of Pool 8 that was closed to hunting, 1996–2002. Invertebrate sampling is conducted in spring of each year, but indicates abundances the previous fall. Thus, diving duck numbers were correlated with densities of fingernail clams, an important food source for the ducks.

documented by the LTRMP, it would likely take many years to reliably identify any trends in invertebrate abundance resulting from management.

A variety of different analyses of the fish indicators have concluded that at large spatial scales, there is a general north-south dichotomy in UMRS fish communities. A northern fish community, dominated by fish associated with backwater and lake-like habitats (e.g., bluegills, largemouth bass (*Micropterus salmoides*), various minnows and shiners) differs from the southern fish community that is more associated with main channel and side channel habitats (e.g., gizzard shad, buffalo [*Ictibus* spp.], white bass [*Morone chrysops*]). However, species richness (the number of different species collected) was similar and stable among study area ranging from about 55 to 75 per year.

There are many reasons why this north-south gradient might develop, including climate, temperature, and habitat differences. Differences in winter habitat from north to south seem a possible reason. However, LTRMP data show that pools in the Upper Impounded Reach have the least amount of suitable habitat, but support considerably high abundances of bluegills than Pool 26 (Figure 2.18) where winter conditions are more suitable. Biologists know that winter can be a physiologically stressful time for fishes and that fish gather in dense aggregations in suitable habitat during winter. But apparently, a limited area of suitable winter habitat can support relatively large bluegill populations. Previous analyses of LTRMP data investigated the relation between abundance of bluegills and similar fishes to general availability of backwaters, but not winter habitat specifically (Gutreuter 2004). The results indicated that lack of backwaters was a limitation only when backwaters were extremely scarce (less than about 3% of total floodplain area).

Further insight into factors limiting sunfish populations will probably not come from broad analyses of monitoring data, but will likely result from evaluations of management actions within a single pool that are designed to improve backwater habitats. Evaluations of these types of management actions within the UMRS indicate that they can be successful at increasing fish abundance locally. But, to determine if such efforts will result in systemic rehabilitation, we need to know if these actions merely redistribute existing fish populations or can actually increase fish production within an entire reach. Below, we discuss one such possibility in Pool 8.

Among individual species of fish, there were some significant trends identified, but for most the cause is unknown. For example, smallmouth buffalo showed significant increases in catch rates in all study areas except Pools 8 and 13 (Figure 2.21) for unknown reasons. Recreational fishes showed an increase in Pool 8, but decreases in La Grange Pool and the Open River Reach.

Determining the potential causes for changes in a single species or assemblage has many potential pitfalls and is not likely to be an effective exercise unless there is reason to suspect specific factors. That may be the case for bluegills in Pool 8, which showed a significant increase in abundance since the late 1990s (Figure 2.18). This increase may be associated with HREP projects to construct islands in the pool and improve backwater habitats. More specific analyses of Pool 8 data are required to investigate this possibility. Additional island building is planned for Pool 8 in the next few years, which should increase the effect if it exists, and continued LTRMP data collection will increase our ability to identify that effect. However, any such analysis should attempt to account for confounding factors, such as the summer water drawdown conducted on Pool 8 in 2001–2002, and for regional effects by comparing results from other locations (Pool 4 also exhibited a significant increase in bluegill catch during the same period). The 10 years of LTRMP data currently available can suggest potential trends for further investigation (as indicated by the analyses of backwater habitats across pools discussed above), but are not likely to provide definitive results.

The LTRMP data show that nonnative fishes compose a high percentage of total fish biomass (Figure 2.24). A high percentage of nonnative fishes in the community is generally considered an indicator of ecological impairment.

The annual proportion of nonnative biomass in LTRMP catches ranged from 23% to 68% among pools and averaged about 50%. Pool 8 has been consistently lower than other pools, but still ranged from 23% to 44%. Most of the nonnative biomass is due to common carp. Although no specific targets for percentage of nonnative fishes have been identified by managers, it is likely that 50% would be considered too high. A positive note is that the three pools in the Upper Impounded Reach (Pools 4, 8, and 13) all showed significant decreases in percentage of nonnative biomass over time. Further analyses of LTRMP data may reveal possible factors that correlate with nonnative biomass and suggest management strategies that might reduce nonnative abundance. However, the reasons for changes in fish communities are complex and monitoring data alone cannot confirm cause-and-effect relations. Experiments using various techniques to attempt to reduce nonnative biomass will be needed along with focused studies to assess the direct effects of each technique. The LTRMP data will be needed to assess longer-term effects and provide the information needed to turn short-term, local experiments into long-term, reach-wide management strategies for both native and nonnative species.

Taken together, these indicators document ecological impairments in all parts of the system, but show that the health of the system's lower reaches is substantially worse than the Upper Impounded Reach. In addition, a number of improving trends are evident in the upper reach, but few in the lower reaches. Specifically, concentrations of major nutrients (nitrogen and phosphorus) are notably higher in lower reaches compared to upper reaches (Figures 2.3 and 2.4); suspended solids are consistently high in lower reaches but are declining in Pools 4 and 8 (Figure 2.6); aquatic vegetation is virtually absent from the lower reaches (Figure 2.15); aquatic invertebrates associated with soft sediments are much less abundant in lower reaches (Figures 2.16 and 2.17); the percentage biomass of nonnative fishes is declining (i.e., improving) in the upper reaches, but not in the lower reaches; the abundance of recreational fishes is declining in La Grange Pool and the Open River Reach (Figure 2.25); and isolation of the floodplain from the river is much more prevalent in the lower reaches. Some of these conditions may be associated with natural gradients within the river system, but in general, the LTRMP data show more impaired ecological condition in the lower reaches relative to the upper reaches. Rehabilitating the system will require effort in all reaches. However, the challenges appear to be more daunting in the lower reaches as many of the stressors and drivers are more highly modified there.

3.2 Use and Application of LTRMP Component Data

Data collected by the LTRMP staff have been vital for a number of UMRS ecological efforts. The use of this information varies, but can be categorized into three primary areas that include developing a better understanding of the UMRS ecosystem and its condition, improved planning and decision making, and enhanced rehabilitation and management of UMRS ecological resources.

3.2.1 Condition of the Ecosystem

Status and Trends Reports

This report and the 1998 Status and Trends Report (USGS 1999) were developed to provide an assessment of the UMRS ecosystem condition. Data collected by the LTRMP were summarized with an emphasis on describing the status and trends of UMRS natural resources. An effort was made to explain river ecosystem disturbances when possible (i.e., Why was this trend occurring?) to help river stakeholders consider if and what future actions are necessary. These status and trends reports provide information that will help refine future monitoring, research, and rehabilitation efforts.

UMRS Habitat Needs Assessment

The primary objectives of the Habitat Needs Assessment (HNA; Theiling et al. 2000; USACE 2000) were to evaluate the existing habitat conditions throughout the UMRS, forecast future habitat conditions, and quantify ecologically sustainable and desired future conditions. The HNA addressed the system-wide, river reach, and pool level spatial scales, and included the bluff-to-bluff extent of the floodplain. The development of the HNA relied heavily on the long-term monitoring data gathered by the LTRMP. The primary purpose of the HNA was to help guide selection, design, and evaluation of HREPs. The HNA began to identify the long-term habitat requirements at different scales and helped redefine the focus of future system monitoring and research activities conducted by the LTRMP. Finally, the HNA was instrumental in identifying system goals, objectives, and opportunities for habitat protection, enhancement, and rehabilitation projects under the authority of the EMP.

Research Reports

Multiple research papers, articles, and reports have been authored that use LTRMP data to assess UMRS ecological conditions. Topics covered by these documents include water quality, sediment, hydrology, erosion, vegetation, fisheries, macroinvertebrates, wildlife, and the interrelationships between these subjects. The U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, state natural resource agencies, and universities have produced an extensive collection of these research products to help stakeholders better understand and manage UMRS natural resources.

Access to LTRMP USGS reports is available at http://www.umesc.usgs.gov/products.html.

A library catalogue containing about 5,000 documents relating to the UMRS is available from the UMRCC at http://www.mississippi-river.com/umrcc/catalog.html.

3.2.2 Planning and Decision Making

Environmental Pool Plans

Environmental Pool Plans are being developed by state and Federal agencies and the public to establish common habitat goals and objectives for the UMRS. They identify, by navigation pool, resource issues, rehabilitation opportunities and constraints, desired future conditions, and potential actions to achieve desired conditions. Along with experience gained from past habitat projects, observations of river managers, biologists, and members of the public, LTRMP information was used to help describe existing habitat conditions, trends, and opportunities. The Environmental Pool Plans are useful communication and planning tools that will help guide future habitat rehabilitation on the Upper Mississippi River. Environmental Pool Plans have been completed for the Upper Impounded Reach, and similar plans are under development for the Lower Impounded Reach and the Unimpounded Reach. No formal Environmental Pool Plans have been developed for the Illinois River, however, under Section 519 Water Resources Development Act 2000; a comprehensive rehabilitation plan for the Illinois River Basin was completed in 2006 by the Corps of Engineers, Rock Island District.

Navigation and Ecosystem Sustainability Program Reach Planning

The Navigation and Ecosystem Sustainability Program (NESP) was authorized by Congress in fall 2007 and is designed to achieve the dual purposes of UMRS ecosystem rehabilitation and navigation improvements. Environmental reach planning is one of 23 initial NESP environmental projects. This effort builds upon the Environmental Pool Plans with a primary focus of developing a pool-scale process that efficiently coordinates the selection and sequencing of rehabilitation efforts in the Upper Mississippi River Basin. LTRMP information is being used in this process to identify existing conditions and forecast future system conditions. This information has helped develop realistic ecological objectives, identify appropriate rehabilitation actions, and lay out an efficient project sequencing strategy based on opportunity. This planning also builds upon past efforts to develop ecosystem goals and objectives (DeHaan et al. 2003).

U.S. Fish and Wildlife Service Comprehensive Conservation Plan

The Comprehensive Conservation Plans (CCP) for the Upper Mississippi River National Wildlife and Fish Refuge, the Mark Twain National Wildlife Refuge, and Illinois River National Wildlife and Fish Refuges Complex was developed to provide UMRS refuge managers with a 15-year strategy for achieving refuge purposes and contribute to the mission of the

National Wildlife Refuge System. LTRMP data helped support this initiative by providing information about existing ecological conditions and trends (e.g., land cover change and island loss). Using this and other environmental data, the CCP provides a refuge vision, goals, measurable objectives, and outlines strategies for reaching those objectives.

Decision Support System Tools

The vast amount of UMRS data has made ecological planning and decision making more complex. Tools are being developed to help manage and more easily access, query, and model this information. These tools are commonly referred to as decision support systems (DSSs). The DSSs allow users to query large UMRS databases and obtain answers in several formats including text, tables, graphs, and maps. The more advanced DSSs allow users to perform statistical and spatial queries and model if-then scenarios with data. Current DSS tools using LTRMP data include

- Habitat Needs Assessment Geographic Information System (GIS) Query Tool for the UMRS,
- LTRMP Spatial Data Query and Visualization Tool,
- Middle Mississippi River Decision Support System,
- GIS Tools for Conservation Planning. and
- Dabbling Duck Models.

For additional information about these and other UMRS DSS tools, go to http://www.umesc.usgs.gov/dss.html.

3.2.3 Ecosystem Rehabilitation and Management

Environmental Management Program Habitat Rehabilitation and Enhancement Projects

Land cover data are used for nearly all EMP HREPs. The LTRMP component data (e.g., water quality and fisheries) have been used in a few select response studies, such as Swan Lake, Peoria, Chautauqua, Pool 8 islands, and Brown's Lake. When a project is in a Resource Trend Analysis Pool or reach, the data are regularly used for resource condition analysis and project planning. Since 2007, the LTRMP has engaged in specific efforts to link LTRMP data and expertise to design and evaluation of rehabilitation projects throughout the system.

HREP Design Handbook

The HREP Design Manual (USACE 2006b) was developed to share lessons learned from 20 years of designing and building UMRS ecosystem rehabilitation projects. Each chapter of the handbook is devoted to different habitat project features, such as shoreline protection, backwater dredging, or islands. Each chapter also generally follows the same format including a discussion of the resource problem, design methodology, case studies, references, and lessons learned. LTRMP data (e.g., bathymetry, land cover, and water quality) are used in this document help describe resources issues, develop appropriate project design, and assess project performance.

UMRS Habitat Rehabilitation

Several Federal and state agencies and private organizations are making use of LTRMP data in their rehabilitation efforts on the UMRS. State natural resource agencies, U.S. Fish and Wildlife refuges, and The Nature Conservancy are using land cover, water quality, and fisheries information to help plan, construct, and manage Mississippi and Illinois River floodplains, wetlands, islands, side channels, and backwater rehabilitation projects. In addition to EMP rehabilitation projects, the Corps is also using LTRMP information to support ecosystem rehabilitation occurring as part of the Illinois River Basin Restoration Program (519) and Continuing Authorities Program (Section 1135, 206, 204), and planned as part of NESP.

3.3 Future Efforts

3.3.1 Enhancing Assessment of Status and Trends

The LTRMP data provide an excellent baseline for comparison with both past and future data. For each indicator, the data provide information about the status in specific years or seasons, and change among years. The data have been analyzed to determine both directional trends over multiple years and patterns and relations among components, seasons, or habitats. For systems such as large rivers, which exhibit substantial variation both within and among years, 10 years is probably the minimum period needed to provide an acceptable baseline. A better picture of long-term dynamics, including identifying trends and cycles will develop as more years of data are collected.

Trends represent responses to longer term changes in underlying system conditions and drivers. For detecting trends, each year represents one data point. The ability to detect trends will be greatest for indicators that have relatively high levels of underlying change and relatively low levels of variation due to local conditions or sampling methods. This can be illustrated using the LTRMP data on suspended solids. In Pool 13, about 90% of the variation in summer averages for suspended solids in the main channel results from actual year-to-year variation rather than from sampling variations or responses to local conditions. If there were an underlying change of 3% per year in suspended solids concentration, it would require about 16 years to detect that trend with statistical power of 80%. However, if the underlying annual change is 5%, only about 11 years of data are required to detect a trend. In both instances, halving or doubling the annual effort for data collection would result in only 1 year difference to detect the trend. Thus, for detecting trends, the underlying rate of change and the number of years of data are more critical than the amount of effort expended in each year. For some indicators, trends may be occurring at rates too slow to be detected within the 10-year frame of this report. More information about trend detection with LTRMP data is available at http://www.umesc.usgs.gov/ltrmp/power_plots.html.

Annual changes typically represent responses to short-term changes in environmental conditions or interactions among biota. Analyses of how annual changes are related among different indicators provide hypotheses about what might be causing some of the changes observed. Yearly differences in factors such as flows, temperatures, reproductive success of biota, and sediment inputs can increase interannual variation in indicators. More effort within a year typically reduces variability in estimates of indicator means making analyses more statistically powerful. Thus, for analyses of relations among components, the amount of effort expended within each year is more critical than for trend analyses. A previous report by Lubinski et al. (2001) assessed the ability to detect annual change using LTRMP data. Results from these types of analyses generate hypotheses and specific questions that can be evaluated more rigorously through focused research.

As currently configured, the LTRMP is a broadly based program providing data for analyses of both trends and annual change. It is difficult for any one program to be efficient at both these types of data collection, but any analysis of change is best achieved when consistent and comparable information is provided over time. Changes in the LTRMP design or methods that may improve the efficiency of data collection should be considered. However, any change should also consider the existing data and, when possible, try to maintain the continuity of information they provide.

3.3.2 Improving Indicator Selection

The information presented in this report represents a first attempt to define indicators based on LTRMP data. Generally, the most useful indicators will be those that relate directly to program goals. The more specifically those goals are defined, the easier it is to identify an indicator that relates directly to that goal. The goals of the EMP are currently only broadly defined and many of the indicators presented in this report were chosen because they can relate to these broad perceived goals. Thus, refining and quantifying EMP goals and objectives will result in the development of more accurate and meaningful indicators.

Indicators that change slowly, exhibit high variability, or are subject to time lags will require many years of information to assess the underlying trends. Yet those trends are derived from changes in processes and function within the system. Thus, it may also be useful to define surrogate indicators that identify changes in processes (e.g., nutrient processing, feeding relations, growth rates) that foreshadow changes in abundances. Determining these surrogate indicators will require further analyses and focal studies, which will also help contribute to the broader EMP goal of improving our understanding of how the UMRS functions. In addition, for fishes in particular, further analyses are suggested to compare the usefulness of community metrics, representative species, or functional guilds as indicators.

Endpoints are the values or set of conditions that define the desired system condition. When these endpoints are achieved, the management program has, by definition, been successful. Endpoints can be defined using specific units of measurement, level of resolution, desired ranges, degree of statistical certainty, and target dates that enable quantitative assessment of progress. Indicators should be expressed using the same metrics that apply to endpoints. For most of the current indicators for the UMRS, endpoints or target ranges have not yet been determined. An active process should be used by the EMP partnership to define and refine endpoints as understanding of the UMRS is increased.

3.3.3 Conclusions

A well-designed, adaptable monitoring system is the first step in documenting efforts toward sustaining and, where possible, improving the ecological integrity of the UMRS floodplain reaches. Historical observations and current LTRMP data clearly indicate that the reaches have been changed by human activity in ways that have diminished the original integrity of the river. The scientific evidence provided in this report from the LTRMP suggests that floodplain river reaches of the UMRS require further rehabilitation and continued monitoring. The next step is to assist the river stakeholders with the creation of an objective, functional evaluation system to measure the acceptability of ecological conditions within each reach and clarify what management actions are the most urgent. This 10-year review of status and trends on the river system provides the first opportunity to renew this process.

As river management becomes more collaborative and adaptive, attention will become more focused on the appropriate scale at which to monitor and manage. The LTRMP data indicate the reach level is most appropriate for assessing many biota, but that materials, such as sediments and nutrients, may be better served at larger scales (e.g., system level). Finally, the LTRMP has aggressively pursued innovative, useful ways to serve program data. The Program stands as a national leader in developing and implementing a successful multipartner collaboration that transcends traditional geo-political boundaries that often hamper environmental programs.

Ultimately, society's investment in monitoring programs must be justified by the relevance and utility of the information the program provides to its users. The relevance of a monitoring program increases over time, as changes in status and trends of important resources can be more reliably detected and this information can be directly incorporated into management actions and question-driven scientific investigations. The continuing role of the LTRMP will be to provide the data needed to assess the results of management actions and how these changes should be viewed in the context of the ecological integrity of the river system.

References

Anderson, K. B., R. E. Sparks, and A. A. Paparo. 1978. Rapid assessment of water quality using the fingernail clam, *Musculium transversum*. University of Illinois, Water Resources Center, Urbana, Illinois, U-WRC-78-0133, Research Report (133). 115 pp.

Anfinson, J. O. 2003. The river we have wrought: A history of the Upper Mississippi. University of Minnesota Press. Minneapolis, Minnesota. 365 pp.

Barko, J. W., M. S. Adams, and N. L. Cleseri. 1986. Environmental factors and their consideration in the management of submersed aquatic vegetation: a review. Journal of Aquatic Plant Management 24:1–10.

Barko, J. W., D. G. Hardin, and M. S. Matthews. 1982. Growth and morphology of submersed macrophytes in relation to light and temperature. Canadian Journal of Botony 60:877–887.

Barko, V. A., M. W. Palmer, D. P. Herzog, and B. Ickes. 2004. Influential environmental gradients and spatiotemporal patterns of fish assemblages in the unimpounded Upper Mississippi River. American Midland Naturalist 151:369–385.

Belanger, K. D., D. J. Dieterman, and T. W. Deyo. 1990. Pre- and post-construction water quality monitoring for habitat rehabilitation and evaluation projects at Big Lake Bay, Finger Lakes, Lake Onalaska, and the Pool 8 Islands area of the Upper Mississippi River. U.S. Fish and Wildlife Service Environmental Management Technical Center. Onalaska, Wisconsin. EMTC 90–94. 17 pp.

Bellrose, F. C., F. L. Paveglio, and D. W. Steffeck. 1979. Waterfowl populations and the changing environment of the Illinois River valley. Illinois Natural History Survey Bulletin Volume 32, Article 1. Urbana, Illinois. 54 pp.

Best, E. P. H., A. H. Teeter, and S. K. Nair. 2004a. Modeling the impacts of suspended sediment concentration and current velocity on submersed vegetation in an Illinois River pool, USA. Aquatic Plant Control Research Program Technical Notes Collection (ERDC TN-APCRP-EA-07), U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Best, E. P. H., G. A. Kiker, and W. A. Boyd. 2004b. A simulation model on the competition for light of meadow-forming and canopy-forming aquatic macrophytes at high and low nutrient availability. Aquatic Plant Control Research Program ERDC/EL TR-04-14, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Bhowmik, N. G., and J. R. Adams. 1989. Successional changes in habitat caused by sedimentation in navigation pools. Hydrobiologia 176/177:17–27.

Bhowmik, N. G., T. W. Soong, W. F. Reichelt, and N. M. L. Seddik. 1992. Waves generated by recreational traffic on the Upper Mississippi River System. Report by the Illinois State Water Survey, Champaign, Illinois, for the U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, in fulfillment of Project Number FWS14-16-0003-80-973, November 1992. EMTC 92-S003. 68 pp. (NTIS PB92-161868)

Bodensteiner, L. R., and W. M. Lewis. 1992. Role of temperature, dissolved oxygen, and backwaters in the winter survival of freshwater drum (*Aplodinotus grunniens*) in the Mississippi River. Canadian Journal of Fisheries and Aquatic Sciences 49:173–184.

Brauer, E. J., D. R. Busse, C. Strauser, R. D. Davinroy, D. C. Gordon, J. L. Brown, J. E. Myers, A. M. Rhoads, and D. Lamm. 2005. Geomorphology study of the middle Mississippi River. U.S Army Corps of Engineers, St. Louis District, Engineering Division, Final Report.

Carlander, K. D., C. A. Carlson, V. Gooch, and T. L. Wenke. 1967. Populations of *Hexagenia* naiads in Pool 19, Mississippi River, 1959–1963. Ecology 48:873–878.

Carlson, D. M. 1992. Importance of wintering refugia to the largemouth bass fishery in the Hudson River estuary. Journal of Freshwater Ecology 7:173–180.

Chamberlin, F. 1994. Wind-generated waves in navigation pools. Report by the U.S. Army Corps of Engineers, St. Paul, Minnesota, for the National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, December 1994. LTRMP 94-S001. 16 pp. (NTIS PB95-209532)

Chen, Y. H. and D. B. Simmons. 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River System. Hydrobiologia 136:5–20.

Chick, J. H., B. S. Ickes, M. A. Pegg, V. A. Barko, R. A. Hrabik, and D. P. Herzog. 2005. Spatial structure and temporal variation of fish communities in the Upper Mississippi River System. U.S. Geological Survey, UMESC, La Crosse, Wisconsin, May 2005. LTRMP Technical Report 2005-T004. 15 pp.

Chick, J. H., and M. A. Pegg. 2001. Invasive carp in the Mississippi River Basin. Science 292 (5525): 2250–2251.

Chick, J. H., M. A. Pegg, and T. M. Koel. 2006. Spatial patterns of fish communities in the Upper Mississippi River System: Assessing fragmentation by low-head dams. River Research and Applications 22:413–427.

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

Coker, R. E. 1929. Studies of common fishes of the Mississippi River at Keokuk. U.S. Department of Commerce, Bureau of Fisheries, Document 1072.

Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53(Supplement 1):267–282.

DeHaan, H. C., N. M. McVay, C. H. Theiling, and R. S. Soileau. 2003. Upper Mississippi River-Illinois System environmental objectives planning workshops, Interim Report. Prepared for the U.S. Army Engineer District, Rock Island, St. Louis, and St. Paul. 37 pp.

Descy, J. P. 1992. Eutrophication in the River Meuse. *In* D. W. Sutcliffe, and J. G. Jones, editors. Eutrophication: Research and Application to Water Supply. Freshwater Biological Association.

Dettmers, J. M., S. Gutreuter, D. H. Wahl, and D. A. Soluk. 2001. Patterns in abundance of fishes in main channels of the upper Mississippi River. Canadian Journal of Fisheries and Aquatic Sciences 58:933–942.

Dodds, W. K., J. R. Jones, and E. B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen and phosphorus. Water Research 32:1455–1462.

Donner, S. D., C. J. Kucharik, and J. A. Foley. 2004. Impact of changing land use practices on nitrate export by the Mississippi River. Global Biogeochemical Cycles 18: Art. No. GB1028.

Eldridge, J. 1988. Aquatic invertebrates important for waterfowl production. U.S. Fish and Wildlife Service, Fish and Wildlife Leaflet 13.3.3, Waterfowl Management Handbook, U.S. Department of the Interior. 6 pp.

Engstrom, D. R., J. E. Almendinger, D. W. Kelly, and E. A. Nater. 2000. Historical changes in sediment and phosphorus loading to the Upper Mississippi River: Mass-balance reconstructions from the sediments of Lake Pepin. Final Research Report Prepared for the Metropolitan Council Environmental Services. Minneapolis, Minnesota. 50 pp.

Fischer, J. R., J. N. Houser, K. L. Hoff, and E. Harms. 2005. Spatial and temporal variation of dissolved oxygen. Pages 28–38 *in* Houser, J. N., editor. Multiyear synthesis of limnological data from 1993 to 2001 for the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP Technical Report 2005-T003. 59 pp.

Fremling, C. R. 1964. Mayfly distribution indicates water quality on the Upper Mississippi River. Science 146:1164–1166.

Fremling, C. R. 1989. *Hexagenia* mayflies: Biological monitors of water quality in the Upper Mississippi River. Journal Minnesota Academy of Science 55:139–143.

Fremling, C.R. 2005. Immortal river: The Upper Mississippi in ancient and modern times. University of Wisconsin Press. Madison, Wisconsin. 429 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, Honey Harbour, Ontario, Canada, Canadian Special Publication of Fisheries and Aquatic Sciences.

Goolsby, D. A., and W. A. Battaglin. 2001. Long-term changes in concentrations and flux of nitrogen in the Mississippi River Basin, USA. Hydrological Processes 15:1209–1226.

Gray, B. R., R. J. Haro, J. T. Rogala, and J. S. Sauer. 2005. Modeling fingernail clam (Family: Sphaeriidae) abundance-habitat associations at two spatial scales using hierarchical count models. Journal of Freshwater Biology 50: 715–729.

Green, W. E. 1984. The great river refuge. Pages 431–439 *in* A. S. Hawkins, R. C. Hanson, H. K. Nelson, and H. M. Reeves, editors. Flyways: pioneering waterfowl management in North America. Supplement of documents, U.S. Government Printing Office, Washington D. C., May 1984.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology. 8:27–38.

Gutreuter, S. 2004. Challenging the assumption of habitat limitation: An example from centrarchid fishes over an intermediate spatial scale. River Research and Applications 20:413–425.

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., 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., J. M. Dettmers, and D. H. Wahl. 2003. Estimating mortality rates of adult fishes from entrainment through the propellers of river towboats. Transactions of the American Fisheries Society 132:646–661.

Hoopes, D. T. 1960. Utilization of mayflies and caddisflies by some Mississippi River fishes. Transactions of the American Fisheries Society 89:32–34.

Houser, J. N., editor. 2005. Multiyear synthesis of limnological data from 1993 to 2001 for the Long Term Resource Monitoring Program. Final report submitted to the U.S. Army Corps of Engineers from the U.S. Geological Survey, Upper Midwest Environment Sciences Center, La Crosse, Wisconsin, March 2005. LTRMP Technical Report 2005-T003. 59 pp. (NTIS PB2005-105228)

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: A method for assessing stream potentials. Environmental Management 10:629–635.

Ickes, B. S. 2005. A research framework for aquatic over-wintering issues in the Upper Mississippi River Basin. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. 26 pp. + Appendixes A–B.

Ickes, B. S., M. C. Bowler, A. D. Bartels, D. J. Kirby, S. DeLain, J. H. Chick, V. A. Barko, K. S. Irons, and M. A. Pegg. 2005. Multiyear synthesis of the fish component from 1993 to 2002 for the Long Term Resource Monitoring

Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. LTRMP 2005-T005. 60 pp. + CD-ROM (Appendixes A–E).

Johnson, J. H. 1976. Effects of tow traffic on the resuspension of sediments and on dissolved oxygen concentration in the Illinois and Upper Mississippi Rivers under normal pool conditions. Technical Report Y-76-1. U.S. Army Corps of Engineers. St. Louis, Missouri. 129 pp.

Johnson, M. G., and W. H. Charlton. 1960. Some effects of temperature on the metabolism and activity of largemouth bass. Progressive Fish-Culturist 22:155–163.

Johnston, D. K., and P. W. Aasen. 1989. The metropolitan wastewater treatment plant and the Mississippi River: 50 years of improving water quality. Journal of the Minnesota Academy of Science. 55(1):134–138.

Jude, D. J. 1968. Bottom fauna utilization and distribution of ten species of fish in Pool 19, Mississippi River. M.S. Thesis, Iowa State University, Ames. 238 pp.

Knight, S. K., and T. M. Parchure. 2004. Hydraulic effects of recreation boat traffic on the Upper Mississippi River System, Vol. 1. ENV Report 3. U.S. Army Corps of Engineer Research and Devlopment Center, Vicksburg, Mississippi. 91 pp.

Knox, J. 2000. Geomorphic reaches of the Upper Mississippi River System. Chapter 5 in: WEST Consultants Inc. 2000. Volume 1. Geomorphic Assessment. Upper Mississippi River and Illinois Waterway cumulative effects study. Report prepared for the U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois.

Knox, J. C., P. J. Bartlein, K. K. Hirschboeck, and R. J. Muckenhirn. 1975. The response of floods and sediment yields to climate variation and land use in the Upper Mississippi Valley. University of Wisconsin, Institute for Environmental Studies Report No. 52. 76 pp.

Knox, J. C. and D. J. Faulkner. 1994. Post-settlement erosion in the lower Buffalo River watershed. Final report to the Western District, Wisconsin Department of Natural Resources, Eau Claire, Wisconsin. 83 pp.

Koel, T. M. 2001. Classification of Upper Mississippi River pools based on contiguous aquatic/geomorphic habitats. Journal of Freshwater Ecology, 16:159–170.

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.

Korschgen, C. E. 1990. Feasibility study: Impacts of turbidity on growth and production of submersed plants. Report by the U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, La Crosse, Wisconsin, for the U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, November 1990. EMTC 90-07. 11 pp. (NTIS PB91135475)

Kreiger, K. A., D. W. Schloesser, B. A. Manny, C. E. Trisler, S. E. Heady, J. H. Ciborowski, and K. N. Muth. 1996. Evidence of the recovery of burrowing mayflies (Ephemeroptera: Ephemeridae: *Hexagenia*) in western Lake Erie. Journal of Great Lakes Research 22:254–263.

Kreiling, R. M., Y. Yin, and D.T. Gerber. 2007. Abiotic influences on the biomass of *Vallisneria americana* Michx. in the Upper Mississippi River: River Research and Applications, 23:343–349.

Kundzewicz, Z. W., L. J. Mata, N. W. Arnell, P. Döll, P. Kabat, B. Jiménez, K. A. Miller, T. Oki, Z. Sen, and I. A. Shiklomanov. 2007. Freshwater resources and their management. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, editors, Cambridge University Press, Cambridge, UK, 173–210.

Kushlan, J. A. 1978. Feeding ecology of wading birds. Pages 249–297 *in* A. Sprunt, IV, J. C. Ogden, and S. Winckler, editors. Wading birds. National Audubon Society Research Report No. 7, National Audubon Society, New York.

Landwehr, K. J., C. H. Theiling, T. R. Gambucci, D. R. Busse, J. M. Stemler, D. B. Wilcox. 2005. Water level management opportunities for ecosystem restoration on the Upper Mississippi River and Illinois Waterway. U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. Upper Mississippi River- Illinois Waterway System Navigation Study ENV Report 53. 139 pp.

Langrehr, H. A., B. R. Gray, and J. A. Janvrin. 2007. Evaluation of aquatic macrophyte community response to island construction in the Upper Mississippi River. Lake and Reservoir Management 23:313–320.

Lubinski, K. S., and J. W. Barko. 2003. Upper Mississippi River System Navigation and Ecosystem Sustainability Program: Environmental Science Panel Report. U.S. Army Corps of Engineers, Env Report 52.

Lubinski, K, R. Burkhardt, J. Sauer, D. Soballe, and Y. Yin. 2001. Initial analyses of change detection capabilities and data redundancies in the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, September 2001. LTRMP 2001-T001. 23 pp. + Appendixes A-E. (NTIS PB2002-100123)

Lubinski, K. S., and S. Gutrueter 1994. Ecological information and habitat rehabilitation on the Upper Mississippi River. Pages 87–100 *in* L. W. Hesse, C. B. Stalnaker, N. G. Benson, and J. R. Zuboy, editors. 1994. Proceedings of the Symposium, Restoration Planning for the Rivers of the Mississippi River Ecosystem, National Biological Survey, Washington, D.C. Biological Report 19. Reprinted by the National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin. December 1994. LTRMP 94-R010. 14 pp.

McCabe, G. J., and D. M. Wolock. 2002. A step increase in streamflow in the conterminous United States. Geophysical Research Letters 29(24), 2185, doi:10.1029/2002GL015999, 2002.

Meade, R. W., editor. 1995. Contaminants in the Mississippi River, 1987–92. U.S. Geological Survey Circular 1133, Reston, Virginia. 140 pp.

Mills, B. H., W. C. Starett, and F. C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Natural History Survey Biological Notes No. 57. Urbana, Illinois. 24 pp.

Mitsch, W. J., J. W. Day, Jr., J. W. Gilliam, P. M. Groffman, D. L. Hey, G. W. Randall, and N. Wang. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent ecological problem. BioScience 51:373–388.

Myslinski, E., and W. Ginsburg. 1977. Macroinvertebrates as indicators of pollution. American Water Works Association Journal 69:538–544.

Nelson, J. C., A. Redmond, and R. E. Sparks. 1994. Impacts of settlement on floodplain vegetation at the confluence of the Illinois and Mississippi Rivers. Transactions of the Illinois State Academy of Science 87(3&4):117–133.

Patrick, P. 1998. Rivers of the United States, Vol. IV. Part A: the Mississippi River and tributaries north of St. Louis. John Wiley & Sons, Inc., New York. 408 pp.

Pegg, M. A., and M. A. McClelland. 2004. Spatial and temporal patterns in fish communities along the Illinois River. Ecology of Freshwater Fish 13:125–135.

Pinter, N. 2005a. Policy forum: Floodplain encroachment since the 1993 flood. Science 308:207–208.

Pinter, N. 2005b. One step forward, two steps back on U.S. floodplains, Science 308:201–208.

Pinter, N., B. S. Ickes, J. H. Wlosinski, and R. van der Ploeg. 2006. Trends in flood stages: Contrasting results from the Mississippi and Rhine River systems. Journal of Hydrology 331: 554–566.

Pinter, N., and R. Thomas, 2003. Engineering modifications and changes in flood behavior of the Middle Mississippi River. Pages 96–114 *in* R. Criss and D. Wilson, editors. At the confluence: Rivers, floods, and water quality in the St. Louis Region.

Pinter, N., R. Thomas, and J. H. Wlosinski. 2001. Assessing flood hazard on dynamic rivers. Transactions of the American Geophysical Union 82:333,338–339.

Rabalais, N. N., R. E. Turner, and D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. BioScience 52:129–142.

Raibley, P. T., K. S. Irons, T. M. O'Hara, K. D. Blodgett, and R. E. Sparks. 1997. Winter habitats used by largemouth bass in the Illinois River, a large river-floodplain ecosystem. North American Journal of Fisheries Management 15:390–399.

Ranthum, R. G. 1969. Distribution and food habits of several species of fish in Pool 19, Mississippi River. M.S. Thesis, Iowa State University, Ames. 207 pp.

Richardson, L. A. H., and T. L. Clemment. 1993. A summary of water quality characteristics at selected habitat sites in Navigation Pool 8 of the Mississippi River from July 17, 1988, to December 31, 1990. Report by the Wisconsin Department of Natural Resources, Onalaska, Wisconsin, for the U.S. Fish and Wildlife Service, Environmental Management Technical Center, Onalaska, Wisconsin, June 1993. EMTC 93-S009. 21 pp. (NTIS PB94-108255).

Richardson, W. B., E. A. Strauss, L. A. Bartsch, E. M. Monroe, J. C. Cavanaugh, L. Vingum, and D. M. Soballe. 2004. Denitrification in the Upper Mississippi River: Rates, controls, and contribution to nitrate flux. Canadian Journal of Fisheries and Aquatic Sciences 61:1102–1112.

Rogala, J. T., J. H. Wlosinski, and K. J. Landwehr. 1999. Pool 13 drawdown: Predicting success rates and affected areas. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, April 1999. LTRMP 99-T002. 27 pp. + Appendix. (NTIS PB99-145393)

Rogala, J. T., P. J. Boma, and B. R. Gray. 2003. Rates and patterns of net sedimentation in backwaters of Pools 4, 8, and 13 of the Upper Mississippi River. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. An LTRMP Web-based report available online at http://www.umesc.usgs.gov/data_library/sedimentation/documents/rates_patterns/page1.html.

Rogers, S., T. Blackburn, H. Langrehr, J. Nelson, and A. Spink. 1998. 1994 annual monitoring at selected locations in Pools 4, 8, 13, and 26 and La Grange Pool of the Upper Mississippi River System. U.S. Geological Survey, Environmental Management Technical Center, Onalask, Wisconsin, July 1998, LTRMP 98-P009, 22 pp. + Appendixes A–B

Rosenberg, D. M., and V. H. Resh. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York. 488 pp.

Sandusky, M. J., and R. E. Sparks. 1979. Investigations of declines in fingernail clam (*Musculium transversum*) populations in the Illinois River and Pool 19 of the Mississippi River. The Bulletin of the American Malacological Union, Inc. 1979:11–15.

Sauer, J. 2004. Multiyear synthesis of the macroinvertebrate component from 1992 to 2002 for the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environment Sciences Center, La Crosse, Wisconsin, Technical Report LTRMP 2004-T005. 31 pp. + Appendixes A–C.

Sheehan, R. J., P. S. Wills, M. A. Schmidt, and J. E. Hennessy. 2004. Determinations of the fate of fish displaced from low-velocity habitats at low temperatures. U.S. Army Corps of Engineers, Upper Mississippi River- Illinois Waterway System Navigation Study, ENV Report 32, Rock Island, Illinois. 11 pp.

Simon, T. P. 1999. Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Roton, Florida. 671 pp.

Simons, D. B., S. A. Schumm, and M. A. Stevens. 1974. Geomorphology of the Middle Mississippi River. Report DACW39-73-C-0026, U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 110 pp.

Smith, R. A., R. B. Alexander, and G. E. Schwarz. 2003. Natural background concentrations of nutrients in streams and rivers of the coterminous United States. Environmental Science and Technology 37:3039–3047.

Smith, V. H., B. G. Tilman, and J. C. Nekola. 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100:179–196.

Soballe, D. M., and J. R. Fischer. 2004. Long Term Resource Monitoring Program procedures: Water quality monitoring. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, March 2004. Technical Report LTRMP 2004-T002-1 (Ref. 95-P002-5). 73 pp. + Appendixes A–J.

Sparks, R. E. 1980. Response of fingernail clam populations in the Keokuk Pool (Pool 19) to the 1976–1977 drought. Pages 43–71 *in* J. L. Rasmussen, editor. Proceedings of the UMRCC symposium on the Upper Mississippi River bivalve mollusks. Rock Island, Illinois.

Sparks, R. E. 1984. The role of contaminants in the decline of the Illinois River: Implications for the Mississippi: Pages 25–66 *in* J. G. Wiener, R. V. Anderson, and D. R. McConville, editors. Contaminants in the Upper Mississippi River. Butterworth Publishers, Stoneham, Massachusetts.

Sparks, R. 1992. The Illinois River-Floodplain ecosystem. Pages 412–432 *in* National Research Council (U.S.) Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy (editors). Restoration of Aquatic Ecosystems. National Academy of Sciences, USA.

Sparks, R. E. 1995. Need for esosystem management of large rivers and their floodplains. Bioscience 45:168–182.

Sparks, R. E., J. C. Nelson, and Y. Yin. 1998. Naturalization of the flood regime in regulated rivers. BioScience 48:706–720.

Starrett, W. C. 1972. Man and the Illinois River. Pages 131–167 *in* R. T. Oglesby, C. A. Carlson, and J. A. McCann, eds. River Ecology and Man. Academic Press, New York. 465 pp.

Steingraber, M. T., and J. G. Wiener. 1995. Bioassessment of contaminant transport and distribution in aquatic ecosystems by chemical analysis of burrowing mayflies (*Hexagenia*). Regulated Rivers: Research & Management 11:201–209.

Stoddard J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16:1267–1276.

Strauss, E. A., W. B. Richardson, L. A., Bartsch, J. C. Cavanaugh, D. A. Bruesewitz, H. Imker, J. A Heinz, and D.M. Soballe. 2004. Nitrification in the Upper Mississippi River: patterns, controls, and contribution to the NO3- budget. Journal of the North American Benthological Society 23:1–14.

The Nature Conservancy. 1998. Illinois River site conservation plan. The Nature Conservancy of Illinois. Illinois Project Office, Lewiston, Illinois.

The Wetlands Initiative. 1997. Farming the floodplain. The potential for flood tolerant floodplain uses. Proceedings of a workshop, Moline, Illinois, September 1997. 66 pp + attachments.

Thiel, P. A., and J. S. Sauer. 1999. Long Term Resource Monitoring Program Procedures: Macroinvertebrate monitoring. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, Revised May 1999. LTRMP 95-P002-2 (Revised 1999). 7 pp + Appendixes A–H.

Theiling, C. H. 1995. Habitat rehabilitation on the upper Mississippi River: Regulated Rivers Research & Management 11:227–238.

Theiling, C. H., C. Korschgen, H. DeHaan, T. Fox, J. Rohweder, and L. Robinson. 2000. Habitat needs assessment for the Upper Mississippi River System: Technical Report. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Contract report prepared for the U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 248 pp + Appendixes A to AA.

Thompson, D. 1973. Feeding ecology of diving ducks on Keokuk Pool, Mississippi River. Journal of Wildlife Management 37:367–381.

Tucker, J. K., C. H. Theiling, K. D. Blodgett, and P. A. Thiel. 1993. Initial occurrences of zebra mussels (*Dreissena polymorpha*) on freshwater mussels (Family Unionidae) in the Upper Mississippi River System. Journal of Freshwater Ecology 8(3):245–251.

Turner, R. E., and N. N. Rabalais. 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. BioScience 53:563–572.

Tyson, J. T. and R. L. Knight. 2001. Response of yellow perch to changes in the benthic invertebrate community of western Lake Erie. Transactions of the American Fisheries Society 130:766–782.

Upper Mississippi River Basin Association (UMRBA). 2004. Upper Mississippi River water quality: The states approaches to Clean Water Act monitoring, assessment, and impairment decisions. Upper Mississippi River Basin Association Report. St. Paul, Minnesota. Available online at www.umrba.org/wq/wq2002rpt.pdf.

Upper Mississippi River Conservation Committee (UMRCC). 2000. A river that works and a working river. Upper Mississippi River Conservation Committee. Rock Island, Illinois. 36 pp.

Upper Mississippi River Conservation Committee (UMRCC). 2003. Proposed water quality criteria necessary to sustain submersed aquatic vegetation in the Upper Mississippi River. Upper Mississippi River Conservation Committee. Rock Island, Illinois. 6 pp.

U.S. Army Corps of Engineers (USACE). 2000. Upper Mississippi River System Habitat Needs Assessment: Summary report 2000. U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 53 pp.

U.S. Army Corps of Engineers (USACE). 2004. Upper Mississippi River-Illinois Waterway System navigation feasibility study, feasibility report. Rock Island District, St. Paul District, and St. Louis District.

U.S. Army Corps of Engineers (USACE). 2006a. Illinois River Basin restoration conprehensive plan. U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. 551 pp.

U.S. Army Corps of Engineers (USACE). 2006b. Upper Mississippi River System, Environmental Management Program, Environmental Design Handbook. U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois. 462 pp.

U.S. Environmental Protection Agency (USEPA). 2000a. Nutrient criteria: Technical guidance manual: Rivers and Streams. EPA 822B-00-002. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 2000b. Progress in water quality: An evaluation of the national investment in municipal wastewater treatment. EPA-832-R-00-008. U.S. Environmental Protection Agency. Washington, D.C. Available online at http://www.epa.gov/owmitnet/wquality/benefits.html.

U.S. Fish and Wildlife Service (USFWS). 2006. Comprehensive conservation plan for the Upper Mississippi River National Wildlife and Fish Refuge. U.S. Fish and Wildlife Service. 228 pp.

U.S. Geological Survey (USGS). 1997. Annual work plan, fiscal year 1997, for the Upper Mississippi River System Long Term Resource Monitoring Program. USGS Environmental Management Technical Center. Onalaska, Wisconsin. LTRMP 1997-P005. 67 pp + Appendixes A–D.

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.

Wasley, D. 2000. Concentration and movement of nitrogen and other materials in selected reaches and tributaries of the Upper Mississippi River System. M.S. Thesis. University of Wisconsin, La Crosse, Wisconsin.

Welch, E. B., J. M. Jacoby, and C. W. May. 1998. Stream quality. *In* R. J. Naiman and R. E. Bilby, editors. River Ecology and Management. Springer. New York.

WEST Consultants, Inc. 2000. Final report: Upper Mississippi River and Illinois Waterway cumulative effects study, Volume 1: Geomorphic Assessment. ENV Report 40-1. 228 pp.

Wilcox, D. B., E. L. Stefanik, D. E. Kelner, M. A. Cornish, D. J. Johnson, I. J. Hodgins, S. J. Zigler, and B. L. Johnson. 2004. Improving fish passage through navigation dams on the Upper Mississippi River System. Interim report of the Upper Mississippi River- Illinois Waterway System navigation study, U.S. Army Corps of Engineers, Rock Island District. ENV Report 54. 110 pp + Appendixes A–D.

Wilson, D. M., T. J. Naimo, J. G. Wiener, R. V. Anderson, M. B. Sandheinrich, and R. E. Sparks. 1995. Declining populations of the fingernail clam *Musculium transversum* in the Upper Mississippi River. Hydrobiologia 304:209–220.

Wlosinski, J. 1999. Hydrology. Pages 6-1 to 6-10 *in* U.S. Geological Survey. 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.

Yin Y. and H. A. Langrehr. 2005. Multiyear synthesis of the aquatic vegetation component from 1991 to 2002 for the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Technical Report LTRMP 2005-T001. 29 pp. + Appendixes A–F.

Yin, Y., and J. C. Nelson. 1995. Modifications to the Upper Mississippi River and their effects on floodplain forests. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, February 1995. LTRMP 95-T003. 17 pp. (NTIS PB95-201208).

Yin, Y, J. C. Nelson, and K. S. Lubinski. 1997. Bottomland hardwood forests along the Upper Mississippi River. Natural Areas Journal 17:164–173.

Yin, Y., J. S. Winkelman, and H. A. Langrehr. 2000. Long Term Resource Monitoring Program procedures: Aquatic vegetation monitoring. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. April 2000. LTRMP 95-P002-7. 8 pp. + Appendixes A–C.

Appendix A

Glossary of terms used in this report

adaptive management: An approach to natural resources management that acknowledges the risk and uncertainty of ecosystem restoration and allows for modification of restoration measures to optimize performance. The process of implementing policy decisions as scientifically driven management experiments that test predictions and assumptions in management plans, and using the resulting information to improve the plans. A mechanism for integrating scientific knowledge and experience for the purpose of understanding and managing natural systems. Adaptive management is a continuous, iterative process by which the consequences of management actions and policies are systematically evaluated, and the actions and policies modified in response to the resulting new information.

backwater: Small, generally shallow body of water attached to the main channel, with little or no current of its own; shallow, slow-moving water associated with a river but outside the river's main channel.

basin: The entire geographical area drained by a river and its tributaries, such as the Illinois River basin.

bathymetry: The measurement of water depth across a water body.

benthic: Refers to the bottom layer of any body of water and the organisms therein.

biodiversity: The variety of living organisms considered at all levels of organization, from genetics through species, to higher taxonomic levels, and including the variety of habitats and ecosystems, as well as the process occurring therein. Biodiversity occurs at four levels: genetic diversity, species richness, ecosystem diversity, and landscape diversity.

biotic: Living; as applied to the components of an ecosystem.

catchment: Watershed; the area drained by a stream, lake, or other body of water. Frequently used to refer to areas that feed into dams; may also refer to areas served by a sewerage or stormwater system.

channel training structure: A human-made flow obstruction (e.g., wing dam, closing dam, or revetment) used to divert river flow to a desired location, usually toward the center of the main channel to increase flow and limit sedimentation or to protect the riverbank from eroding.

community: A grouping of populations of different species found living together in a particular environment.

conservation: Active management to ensure the survival of the maximum diversity of species, and the maintenance of genetic diversity within species; implies the maintenance of ecosystem functions; embraces the concept of long-term sustainability; a careful preservation and protection of something; especially planned management of a natural resource to prevent exploitation, destruction, or neglect.

corridor: A relatively narrow strip of habitat that crosses an area of nonhabitat land and serves to connect larger areas of habitat.

desired future conditions: A description of management goals for an area to achieve optimal conditions; the descriptions should be constructed with the input of all interested parties in the region and should include clear goals for species, communities, and ecosystem composition, structure, and functions across the landscape. For this system study, the desired future condition was based on coordination with resource managers and became the system objectives.

drawdown: Lowering the level of water in a selected portion of an aquatic system; conducted for habitat management purposes with dams or pumps.

ecological (or biological) integrity: A system's wholeness or "health," including presence of all appropriate elements, biotic and abiotic, and occurrence of all processes that generate and maintain those elements at the appropriate rates. The capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and a functional organization comparable to that of natural, unimpacted habitat of the region.

ecosystem: Dynamic and interrelating complex of plant and animal communities and their associated nonliving environment; a biological community together with the physical and chemical environment with which it interacts.

ecosystem function: Processes that drive the ecosystem; any performance attribute or rate function at some level of biological organization (e.g., energy flow, sedimentation, detritus processing, nutrient spiraling).

ecosystem health: A condition when a system's inherent potential is realized, its condition is stable, its capacity for self-repair, when perturbed, is preserved, and minimal external support for management is needed.

ecosystem management: Protecting, conserving or restoring the function, structure, and species composition of an ecosystem, recognizing that all components are interrelated.

ecosystem or **ecological processes:** The aggregate of all interactions among the various biotic components of an ecosystem (e.g., migration, pollination, predation), between the abiotic and biotic components of an ecosystem (e.g., nutrient uptake, erosion, respiration) and natural events and cycles (e.g., fire regimes, hydrologic cycles) that operate over different scales of time and space.

ecosystem restoration: Management actions that attempt to accomplish a return of natural areas or ecosystems to a close approximation of their conditions prior to human disturbance, or to less degraded, more natural conditions in terms of structure and function.

ecosystem services: All of the goods and services provided to humanity by natural ecosystems; examples include wood products, fertile soils, genetic variation, clean water, and clean air.

ecosystem sustainability: The ability of aquatic, wetland, and terrestrial complexes to maintain themselves as self-regulating, functioning systems.

fish passage: Modification or removal of human-made barriers that would otherwise restrict or prevent movement or migration of fish.

floodplain: Lowlands bordering a river that are subject to flooding, thereby providing flood storage. Floodplains are composed of sediments carried by rivers and deposited on land during flooding and contain a mosaic of habitat types.

geomorphology: The science that deals with land and submerged relief features (landforms) of the earth's surface; the physical structure of the river floodplain environment.

habitat: The living place of an organism or community, characterized by its physical or biotic properties; habitats can be described on many scales from microhabitat to ecosystems to biomes.

hydrologic: Pertaining to the cyclic phenomena of waters of the earth; successively as precipitation, runoff, storage and evaporation, and quantitatively as to distribution and concentration.

hydrology: A science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

hypoxia: The condition in which dissolved oxygen concentrations are less than two parts per million of water (e.g., zones in the Gulf of Mexico and other estuaries).

impoundment: The volume of standing water that is maintained behind a dam.

indicator: A measurable surrogate for environmental endpoints, such as biodiversity, that are assumed to be of value to the public; are sensitive to changes in the environment; and can warn that environmental changes are taking place.

invasive species: Any species that has the tendency to invade or enter a new location or niche; an introduced species that out competes native species for space and resources; an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.

landscape: A heterogeneous land area composed of interacting ecosystems that are repeated in similar form throughout; landscapes are variable in size; usually overlaps governmental jurisdictions, thus requiring collaboration from a broad range of participants.

levee district: Cooperative quasi-governmental organizations that protect areas from floodwaters, primarily for agricultural areas, but may also serve as wildlife areas.

life history: An organism's patterns of growth, reproduction, and longevity that are related to specific demands for survival in a particular place at a particular time.

macroinvertebrates: Small, but visible with the naked eye, animals without backbones (insects, worms, larvae, etc). Water bodies have communities of aquatic macroinvertebrates. The species composition, species diversity and abundance of the macroinvertebrates in a given water body can provide valuable information on the relative health and water quality of a waterway.

management action: A structural or non-structural measure that modifies or adjusts the condition of the ecosystem.

moist soil unit: An area where water levels are controlled to provide a desired mix of moist soil vegetation, generally for use by waterfowl.

nonnative species: Species of plants and animals that are imported or unintentionally transported to a new location where they do not naturally occur.

nonpoint source pollution: Water pollution produced by diffuse watershed land-use activities.

point source pollution: pollution into bodies of water from specific discharge points, such as sewer outfalls or industrial-waste pipes.

pool: The area of water that is impounded and maintained at a higher level behind a navigation dam; generally refers to the length of river between sequential dams.

population: A group of individuals of the same species occupying an area small enough to permit interbreeding among all members of the group.

prairie: An area of land of low topographic relief that principally supports grasses and herbs, with few trees, and is generally of a mesic (moderate) climate. Most of the Great Plains; most of Ohio, Indiana, Illinois, and Iowa; and much of Missouri and Minnesota is considered prairie. Almost all of this area has been converted into farmland. Fire is an important part of prairie ecology; naturally occurring and human-induced fires were common in prairie areas. Grazing by animals, such as the American bison and prairie dogs, also helped maintain the original prairie environment.

reach: A continuous stretch or expanse. In reference to rivers, it can be used to define portions of rivers at different scales (i.e., pool reach, reach between two river bends).

reference condition: The range of factors (e.g., hydrology, sediment movement, animal and plant communities, and channel geometry) that is representative of an area or ecosystem prior to significant alteration of its environment.

rehabilitation: Improvements to a natural resource; putting back into good condition or working order.

restoration: Reestablishing degraded ecosystem structure, function, and dynamic processes to a less degraded, more natural condition. In its broadest usage, restoration encompasses the following concepts: conservation, enhancement, naturalization, preservation, protection, rehabilitation, restoration, and stabilization.

riparian: Areas that are contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent water bodies (e.g., rivers, streams, lakes, or drainage ways); pertaining to the boundary between water and land; normally represents the streamside zone and the area of influence of the stream.

river stage: The elevation of the water surface (usually in feet) above an arbitrary datum.

savanna: Area with a well-developed herbaceous ground cover composed principally of prairie species with scattered trees at densities ranging form 1 per acre to roughly 50% canopy closures. The frequency of fire maintains this habitat type by influencing the amount and density of woody vegetation encroaching into the prairie environment.

sediment resuspension: The movement of sediment from the river bed into the water column due to a disturbance (e.g., wave action).

sediment transport: The movement of sediment (usually by water).

sedimentation: The process of sediment being deposited in a given location.

side channel: Aquatic channel connected to the main channel and separated from the main channel by an island; usually has flowing water.

species: One or more populations of individuals that can interbreed, but cannot successfully breed with other organisms.

species diversity: The richness, abundance, and variability of plant and animal species and communities.

species richness: A simple count of the number of species in an area.

stakeholder: Those organizations and/or individuals having a vested interest in the outcome of a decision making process.

stressor: A substance or action that has the potential to cause an adverse effect on an ecosystem.

structure: The horizontal and vertical spatial arrangement, or configuration, of a habitat, community or ecosystem; includes biotic and abiotic diversity.

succession: Sequential change in the vegetation at a particular location over time.

sustainable/sustainability: A level and method of resource use that does not destroy the health and integrity of the systems that provide the resource; thus the long-term resource availability does not diminish due to such use.

temporal: Of, relating to, or limited by time.

threatened and endangered species: Those species that are listed as threatened or endangered under the Federal Endangered Species Act (ESA) of 1973, and those species that are candidates or proposed as candidates for listing under the ESA; listing can occur at the Federal or state level or both.

tributary: A stream or river whose water flows into a larger stream or river.

turbidity: Measure of the "lack of clearness" of water; an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample; the measure of relative sample clarity.

watershed: The geographic area that naturally drains into a given watercourse, such as a stream or river.

Appendix B

Acronyms used in this report

CCP	Comprehensive Conservation Plan
CPUE	Catch Per Unit Effort
DO	Dissolved Oxygen
DSS	Decision Support System
EMP	Environmental Management Program
GIS	Geographic Information System
HNA	Habitat Needs Assessment
HREP	Habitat Rehabilitation and Enhancement Project
IWW	Illinois Waterway
LTRMP	Long Term Resource Monitoring Program
NESP	Navigation and Ecosystem Sustainability
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UMESC	Upper Midwest Environmental Sciences Center
UMR	Upper Mississippi River
UMRCC	Upper Mississippi River Conservation Committee
UMRS	Upper Mississippi River System
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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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.