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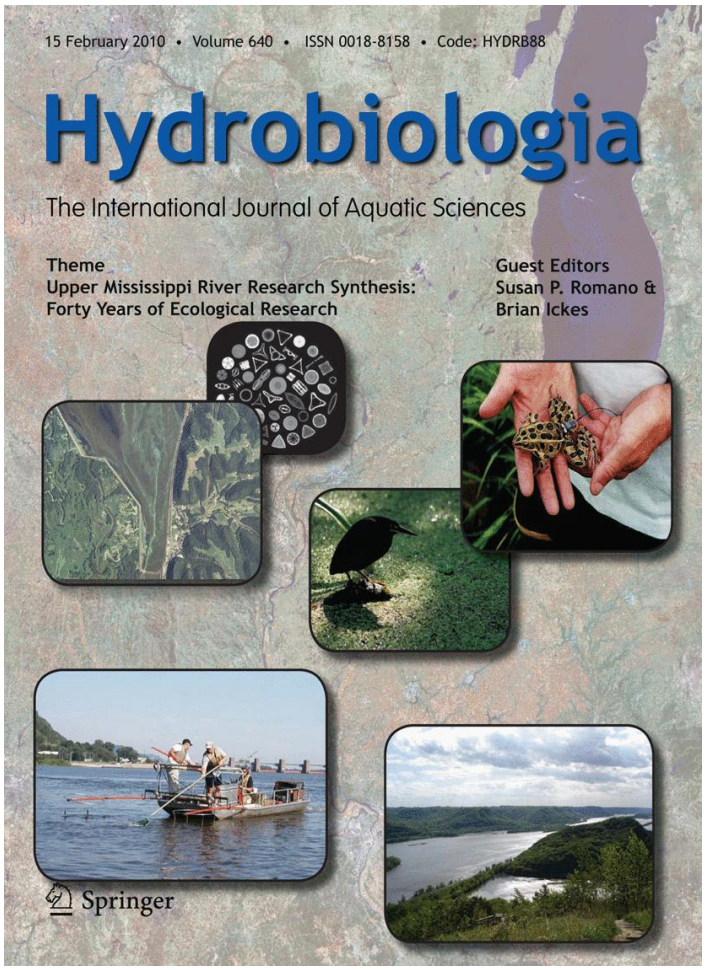

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Challenges in merging fisheries research and management: the Upper Mississippi River experience

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Abstract The Upper Mississippi River System (UMRS) is a geographically diverse basin extending 10° north temperate latitude that has produced fishes for humans for millennia. During European colonization through the present, the UMRS has been modified to meet multiple demands such as navigation and flood control. Invasive species, notably the common carp, have dominated fisheries in both positive and negative ways. Through time, environmental decline plus reduced economic incentives have degraded opportunities for fishery production. A renewed focus on fisheries in the UMRS may be dawning. Commercial harvest and corresponding economic value of native and non-native species along the river corridor fluctuates but appears to be increasing. Recreational use will depend on access and societal perceptions of the river. Interactions (e.g., disease and invasive species transmission) among fish assemblages within the UMRS, the Great Lakes, and other lakes and rivers are rising. Data collection for fisheries has varied in intensity and contiguousness through time, although resources for research and management may be growing. As fisheries production likely relies on the interconnectivity of fish populations and associated ecosystem processes among river reaches (e.g., between the pooled and unpooled UMRS), species-level processes such as genetics, life-history interactions, and migratory behavior need to be placed in the context of broad ecosystem- and landscape-scale restoration. Formal communication among a diverse group of researchers, managers, and public stakeholders crossing geographic and disciplinary boundaries is necessary through peer-reviewed publications, moderated interactions, and the embrace of emerging information technologies.

Keywords River fisheries · Fish communities · Fisheries restoration · Spatial patterns · Temporal trends · Upper Mississippi River

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Introduction

The Upper Mississippi River System (UMRS) including both the mainstem and its myriad tributaries is vast, intersecting many natural and human-made landscape features (see Theiling & Nestler, this

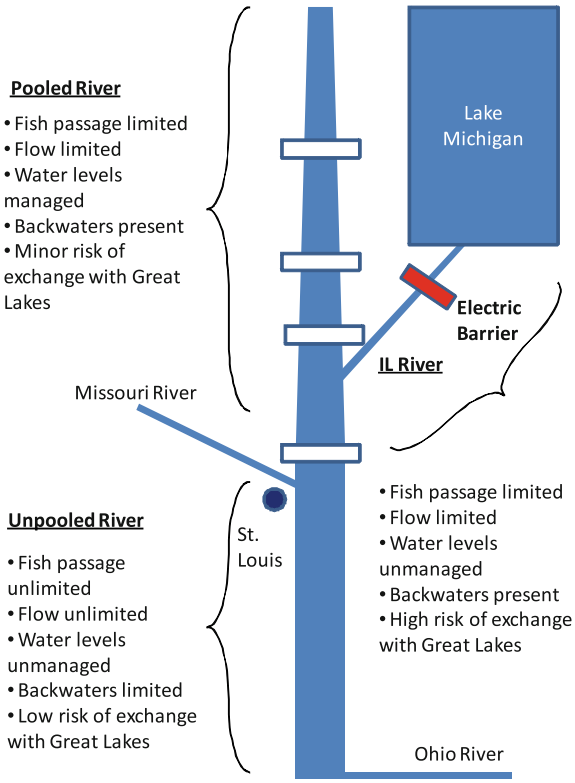

Fig. 1 Schematic diagram of the Upper Mississippi River System and related fisheries issues from north (*top*) to south (*bottom*) at the confluence of the Ohio River. *Open bars* are examples of locks and dams. The bar on the Illinois River is the electric barrier separating the Illinois River basin from Lake Michigan. Locks and dams are also present on the Illinois River, but not depicted. Exchange with Great Lakes includes movement of fish species, exotic invertebrates, contaminants, and vegetation

volume; Fig. 1). A diverse array of fish assemblages are distributed throughout this system and many species provide commercial and recreational opportunities for fishers. As we illustrate herein, although consistent monitoring has occurred in some reaches during the past 15 years, surprisingly little is known mechanistically about factors influencing species composition and, most importantly from a fisheries perspective, production of fishes in the UMRS. Current statistical models using long-term data do not explain much variability in economically valued fish assemblages (Barko et al., 2005; Ickes et al., 2005). Similarly, the economic and social factors affecting the behavior and participation of the fishing public in the fishery are not well understood. The growing importance of this system to the production of fishes, some of which are quite valuable, and its proximity to other aquatic systems (e.g., the Great Lakes) with well-developed and valuable fisheries makes it a critical target for research and management. In this article, we first outline the general historical relationship between large rivers such as the UMRS and their fisheries resources. We then introduce the UMRS presenting some of its major fisheries challenges (e.g., identifying research gaps and major management needs) and provide some specific case studies to illustrate the complexities involved. We end by making some specific recommendations by which current and future fisheries research and management may be merged in the UMRS as well as other large river systems facing similar complex issues.

Fisheries history in the UMRS

Fisheries within large rivers provide protein for growing human populations, particularly for localities with limited economic resources (Borgstrum, 1978; Junk et al., 2007). This included human settlements around the UMRS before European colonization as well as towns and cities during the first century after European colonization (Carlander, 1954; Nielsen, 1999; Fremling, 2005). Due to growing demands of expanding human populations, overfishing probably occurred in the nineteenth century, as it likely does in rivers in developing areas today. In fact, concerns about declining fish production were so great in the nineteenth century that fish rescue teams were organized to return stranded fish from the floodplain to the river (Fremling, 2005). The growing fisheries pressure in the Amazon River basin is a poignant recent example (Winemiller & Jepsen, 1998; DeJesus & Kohler, 2004; Junk et al., 2007). By the mid-twentieth century, however, the fishery of the UMRS was likely not overexploited (Risotto & Turner, 1985), perhaps because economic incentives were no longer present (see below).

As regions develop economically, fisheries may face conflicting issues. Rivers including the UMRS continue to be modified for alternative uses for society such as irrigation, hydropower, commerce, and transportation, with subsequent losses of fisheries production (Karr et al., 1985; Sheehan & Rasmussen, 1999; Janvrin, 2005). Indeed, this happened in the

United States by the early twentieth century in the UMRS (Karr et al., 1985; Johnson et al., 1995). Fishing in the UMRS as a way of life declined as economic incentives dwindled and other pursuits became more fiscally lucrative (Carlander, 1954; Nielsen, 1999; Fremling, 2005). Although large river fish populations may be released from harvest pressure once regions develop economically, environmental degradation prevents strong recovery (Karr et al., 1985). This appears to be occurring in Asia currently, most notably in the Yangtze River system (Turvey et al., 2007; Xie et al., 2007) and has been an issue in the UMRS for more than a century (see Bertrand, 1997; Fremling, 2005).

Ironically, as protein sources from marine and terrestrial ecosystems are played out and global human population grows (Hilborn et al., 2003), pressure is sure to grow on fish protein derived from riverine systems, including the UMRS. In fact, economic value of the fishery has increased slightly over the past 50 years, although total yield appears to fluctuate (Schramm, 2004). Facing this renewed pressure is a host of problems, both real and perceived. Given that rivers integrate pollutants leaving pipes and the landscape, some river fish species become contaminated and risky to consume (Upper Mississippi River Basin Association, 2005; Wiener & Sandheinrich, this volume). In reality, contaminant concentrations within river fishes vary among species depending on their position in the food web. Contaminant loads also can vary among individuals within populations (Koch et al., 2006) depending on factors such as size, age, and origin, suggesting that yields of safe fish are possible. If harvest increases in large rivers such as the UMRS, reduced fish production due to habitat alteration or loss may make overfishing at large geographic scales a simple task. Although a long-term, multi-species data set is growing for specific reaches of the UMRS and the multi-jurisdictional Upper Mississippi River Conservation Commission (UMRCC) collects available harvest data from the states, sound fisheries production models (e.g., yield models, population viability models) for predicting responses to harvest in the UMRS are lacking. Thus, planning and assessment in the face of changing harvest patterns are veritable shots in the dark.

Fisheries issues in the UMRS extend beyond native species and harvest for meat. With human population growth and globalization of commerce comes increased species invasions (Rahel, 2000, 2002), notable examples being common carp (*Cyprinus carpio* Linnaeus), grass carp (*Ctenopharyngodon idella* Valenciennes), bighead carp (*Hypopthalmichthys nobilis* Richardson), silver carp (*H. molitrix* Valenciennes), and round gobies (*Neogobius melanostomus* Pallas). Often, invaders are more successful (i.e., by percent biomass) than natives and may provide the primary focus of fisheries in the UMRS. Common carp and its two contemporary counterparts, bighead and silver carp, in the Mississippi River are cogent illustrations of fish that produce high biomass, are prized in some markets (e.g., common carp generated $270,000 USD annually between 1953 and 1977, Lubinski et al., 1986), and have a future in others (Kolar et al., 2007). Other market forces unrelated to protein demand such as egg harvest for caviar from shovelnose sturgeon and paddlefish also appear to influence fishery dynamics in the Mississippi River (Colombo et al., 2007).

The only growing sector in fisheries globally is aquaculture, with more than 40% of fish production being derived from cultured sources (FAO, 2007). Although aquaculture is only a very minor economic enterprise in the UMRS region (about $18 million USD in 2007; US Department of Agriculture, 2009), aquaculture in the UMRS basin is likely to increase with global demand. Aquaculture growth is assisted by regional agencies such as the North Central Regional Aquaculture Center (NCRAC), which is supported by the US Department of Agriculture. The NCRAC is currently committed to increasing marketing opportunities for regionally grown aquacultured products. Although aquaculture may reduce fishing pressure on wild stocks in the UMRS, other issues associated with large-scale production such as reduced water quality, increased disease transmission, and exotic species introduction must be considered (Cole et al., 2009). The recent detection of viral hemorrhagic septicemia (VHS) in the Great Lakes Region and its potential to spread throughout the UMRS via hatchery fish transfers is one poignant example of the risk of a growing aquaculture industry in the basin (APHIS, 2006).

Recreational fishing in large rivers is not a recent phenomenon, having occurred for millennia in some fashion (Policansky, 2002). In the UMRS and other regional rivers, recreational fishing occurs but it is

minor compared to fishing within natural lakes, reservoirs, and the Great Lakes. About 32% of angling hours are spent in rivers nationwide; given limited access to fishing such as boat ramps and fishing piers, particularly in the southern reaches, much less recreational fishing likely occurs in the UMRS (US Department of the Interior, 2006). It is difficult to forecast how recreational fishing patterns will change in the UMRS in the future. Unless more boat ramps are built and perceptions about the river change (e.g., boaters view the swift-flowing, barge-dominated lower UMRS as safe to navigate), recreational fishing will likely not increase. If recreational fishing does increase, which may occur in some of the more populated reaches in the upper UMRS, then conflicts between commercial and recreational interests may arise, requiring intensive management. A primary source of monetary support for most state natural resource agencies is through the Federal Aid in Sportfish Restoration Program, which partially depends on the number of participants actively engaged in recreational fishing. Thus, if more recreational fishing occurs in the UMRS, then individual states would receive more federal funds to conduct research and management (and perhaps provide more access via boat ramps) in this system. Presumably, this increased attention would benefit fish resources in the UMRS through better informed management.

UMRS description

Managing fisheries in the UMRS requires an understanding of its spatial diversity. The UMRS extends along a north–south gradient from its headwaters in Lake Itasca in Minnesota, US, to the confluence of the Ohio River at Cairo, Illinois, US, at a length of 2,320 river kilometers (Fig. 1). For this article, we focus primarily on fisheries issues in the UMRS extending from St. Anthony Falls, Minneapolis, Minnesota to its southernmost extent at the Ohio River confluence. The headwaters region above St. Anthony Falls does not experience commercial fishing (Schramm, 2004), and thus is subject to more conventional inland management issues under the single control of the state of Minnesota (i.e., size regulations, ensuring angler access) associated with a mix of warm and cool water recreational fisheries.

Due to its wide range, the UMRS has many unique characteristics that vary across geographic scales (Delong, 2005), making it difficult to effectively categorize from a fisheries perspective. The UMRS crosses 10° temperate latitude, which affects the duration of growing seasons and reproductive cycles of fishes. As with most broadly distributed fishes, the growing seasons for many UMRS fishes are longer and spawning dates earlier in southern reaches (Shuter & Post, 1990; Garvey & Marschall, 2003). Thus, management such as length and seasonal harvest regulations that are based on information about growth and maturation schedules must account for population differences among latitudes.

The UMRS intersects Boreal Forest, Temperate Deciduous, and Temperate Grassland biomes. Given that the landscape affects the catchment, fisheries dynamics such as production are shaped by the biome in which the river reach is located. The river varies substantively in discharge and gradient, with the Illinois and Missouri River "tributaries" contributing to its size, water quality, and likely its potential fisheries production. Geologic and geographic differences exist along the UMRS as well, integrating glacial effects through time (Delong, 2005). Most notably, a large proportion of the UMRS drains through glacial till, consisting of highly eroded silt-, sand-, and gravel-sediment. However, a portion of the river intersects an unglaciated, Driftless Area in parts of Minnesota, Wisconsin, Iowa, and Illinois characterized by high bluffs and predominantly sandy sediment. Differences in bedform and landscapes in this unique region shape fisheries diversity and production in ways that deviate from the remainder of the UMRS (Lyons, 1996).

Human population and subsequent land use varies along the UMRS, affecting water quality and fisheries responses. Urban areas are sources of point-source pollution that enrich the water with nutrients and introduce contaminants (Wiener & Sandheinrich, this volume). The reach of the UMRS below St. Louis was so degraded during the mid-twentieth century that anoxia was a frequent problem (Kittrell, 1958). Following the clean water legislation in the late 1900s, point-source pollution has declined in the reaches below major urban areas. However, non-point pollution from both urban and agricultural landscapes continues to be a concern for local fisheries as well as those downstream, most notably

causing the decline of fisheries in the Gulf of Mexico due to hypoxia via nitrogen enrichment (Rabalais et al., 2002). Mercury deposition primarily from atmospheric deposition and organic contaminants trapped in river sediments also are major issues in the UMRS region (NADP, 2005). Concerns about contaminant accumulation in fishes have led to consumption advisories in all UMRS states. For example, consumption of channel catfish in the Illinois waters of the UMRS are limited to one meal per week for small (<18 in.) catfish and one meal per month for large individuals due to risk of organochlorine exposure.

The UMRS has long been viewed by society as an asset for transportation as well as a threat due to its ability to exceed its banks and flood human settlements and farmland. The economic benefit of navigation is about $1 billion USD annually, whereas fisheries are valued at about $3 million USD (Black et al., 1999). These differing economic realities have influenced the value of the UMRS to fisheries. To facilitate transportation of goods and people, the US government, primarily through the machinations of the US Army Corps of Engineers (USACE), began modifying the UMRS in profound ways by the nineteenth century. Large woody debris was removed to prevent snagging of boats. By the early twentieth century, the US Congress authorized a network of locks and dams in the upper UMRS to maintain a 3-m navigation channel. The river has been further modified by a program of water-training structures, revetments, submerged weirs, and dredging that continually forces the river into a single, simplified channel. To prevent flooding of land, an extensive system of levees has restricted access of the UMRS to its floodplain. As a consequence of these alterations, habitat for fish populations has declined (Bertrand, 1997), although long-term records (>50 years) on the extent of the decline and its implications for fish diversity and production are rare (Janvrin, 2005; Theiling & Nestler, this volume).

Engineering of the UMRS and its potential for fisheries impacts can roughly be divided into two categories: pooled and unpooled river (Fig. 1). In the UMRS above the confluence of the Missouri River, discharge is insufficient to maintain a 3-m channel year round. Thus, water levels in this portion of the river, including the Illinois River, are maintained by lock and dam complexes, with temporally variable impoundments between them. These pools have lotic characteristics upstream in the dam tailwaters and lentic qualities downstream near the next dam (Flinn et al., 2008). Some of these pools are maintained on a "hinge point," whereby the downstream portion of the pool is lowered more than the upstream portion and the mid-point of the pool is kept at a relatively constant water level. This arrangement allows water managers to dewater downstream shoreline areas during spring, facilitating the growth of vegetation (Wlonski & Hill, 1995; Woltemade, 1997; Garvey et al., 2003). This vegetation is subsequently flooded by late summer and early fall as water levels are restored. This water-level management creates habitat heterogeneity within pools, enhancing the diversity and perhaps production of fishes (Gutreuter et al., 1999; Garvey et al., 2003; Adams, 2004; Theiling & Nestler, this volume). In particular, flooded vegetation is used by young of year fishes including the rare blue sucker (Adams et al., 2006), suggesting that this management action facilitates recruitment.

Even though water-level management may somewhat emulate a historical hydrograph, dams, and resulting pools can have multiple negative impacts on fishes and their habitat. Given that water is held back by the closed gates of dams when discharge is low, dams likely hinder movement of fishes more during months of low flow such as the summer and winter than during spring (Wilcox et al., 2004). A hydroelectric dam near Keokuk, Iowa is typically closed year round, creating a semi-permanent barrier to fish movement. Sedimentation of backwater areas that are continually inundated by water is a serious concern (Knights et al., 1995; Raibley et al., 1997; Johnson et al., 1998). These areas provide rearing habitat for young fish as well as overwintering sites for many species. Degradation of this habitat and reduced water quality such as hypoxia may compromise fisheries integrity, although the concept that backwater access and quality is the primary factor limiting fish production in parts of the UMRS has been challenged (Gutreuter, 2004).

Below the Missouri River, discharge in the UMRS has been sufficient to provide a navigable channel all year (Delong, 2005), under the condition that the UMRS channel is kept confined and deep. As such, this reach is not pooled and considered "open" (Fig. 1). The river does have one potential fish barrier at the Chain of Rocks adjacent to the St. Louis,

Missouri metropolitan area. The 6-m low-head dam at this area is exposed during low flow and may prevent fish from passing over it under these conditions. For this same reason, the Chain of Rocks area is not navigable, and is circumvented by a lateral navigation canal (Lock and Dam 27). Thus, this area is the only major mainstem section of the UMRS not directly affected by towed barges. The unique physical characteristics of this area including turbulent water, scoured bed, and heterogeneous bedform appear to facilitate fisheries production. For example, catch rates of shovelnose and pallid sturgeon are high below the lowhead dam at this locale (Killgore et al., 2007). An alternate view is that this lowhead dam may be inhibiting upstream movement of these fishes and causing them to "pile up." A future research and management goal would be to understand the impact of this unique river area on fish population dynamics throughout the UMRS.

The entire open river reach of the UMRS maintains some semblance of its historical hydrograph, although fluctuations of water level are elevated due to confinement of the channel between levees as well as possibly by the presence of artificial instream structures (Pinter & Heine, 2005). Further, off-channel habitat is limited, likely preventing fish from accessing low-velocity refuges. Given that swimming ability of many fishes is compromised by cold temperatures during temperate winters (Bodensteiner & Lewis, 1992, 1994), access to offshore areas is necessary for their persistence in the river (Sheehan et al., 1990, 2004; Johnson et al., 1998).

Issues complicating the UMRS fishery

Large rivers are complex entities that pose challenges for fisheries research and management. This is not a new concept for the UMRS. In 1949, Lloyd Smith wrote about the UMRS fishery: "…conservation administrators realize that comprehensive and thorough research is the only possible basis for the solution of fishery problems." However, Smith (1949) also noted that this goal for research is difficult to achieve in the UMRS because of the large number of research and management entities involved. Then, as it is now in the US, fisheries issues are typically addressed by individual states rather than the federal government as mandated by the 10th Amendment of the US Constitution. The UMRS crosses the borders of many states and in fact forms state borders; about 96 fishes are recognized by the states as inter-jurisdictional. Thus, similar to marine systems and the Great Lakes, management of fisheries requires inter-jurisdictional policies and management. One simple example of inter-jurisdictional management occurs when a licensed fisher launching their boat from one state finds herself fishing in another state. To avoid the problem of possibly having constituents being penalized for fishing without a license in another state, state agencies communicate and have developed fishing agreements that allow fishers to fish in both waters.

As management of the navigable waterway is under the parlance of the USACE, federal involvement in fisheries issues is mandated, particularly when the restoration of federally endangered species such as the pallid sturgeon become involved. The primary agency responsible for managing fisheries issues across state borders and interacting with the USACE is the US Fish and Wildlife Service (USFWS), usually in cooperation with state agencies, university researchers, non-profit organizations, and other federal agencies. In addition, fisheries issues are addressed through various organizations including the Mississippi Interstate Cooperative Resource Association (MICRA), which is comprised of 28 state natural resource agencies, Indian nations, and federal agencies (Table 1). To place this in perspective, Smith (1949) was only juggling research activities among six separate conservation agencies. Research, management, and policy are also orchestrated through partnerships between government and stakeholder organizations such as the fisheries technical committee of the UMRCC.

Research information used for management may derive from sources such as individual state natural resource agencies, the federal US Geological Survey, public and private universities, and private consulting agencies. Funding for research varies and typically is directed toward habitat rehabilitation through the USACE. The Missouri Department of Conservation is a notable because it receives fisheries conservation funds through a mandatory state sales tax of one-eighth cents. Funds through the State Wildlife Grant program administered by the USFWS and the burgeoning (but not yet passed by Congress) National

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Table 1 Major interagency partnerships with aquatic and fisheries interests in the Upper Mississippi River System

Partnership	Date formed	Partners	Mission	Example issues addressed
Upper Mississippi River Conservation Committee (UMRCC)	1943	IA, IL, MN, MO, WI; federal and non-government partners are non-voting	Promote the preservation and wise utilization of the natural and recreational resources of the Upper Mississippi River and to formulate policies, plans and programs for conducting cooperative studies. Note: Originally formed as the UMR Conservation Survey Committee by a consortium of fishery biologists to focus on fishery issues	Commercial and sport fisheries, wildlife, sedimentation, water quality, recreational use, law enforcement
Upper Mississippi River Basin Association (UMRBA)	1981	IA, IL, MN, MO, WI; six federal agencies are non-voting partners	To facilitate dialog and cooperative action regarding water and related land resource issues. Note: Formed by agreement by the states as the successor to the former federally authorized Upper Mississippi Basin Commission	Non-point pollution, water quality planning, and management, sediment and erosion, hazardous spills, toxic pollution, habitat restoration, navigation capacity, channel maintenance, floodplain, and wetland protection
Mississippi River Research Consortium (MRRC)	1968	Individual scientists, river managers, teachers, students, and private persons from business and the general public	To encourage both pure and applied research on the water and land resources of the Mississippi River and its watershed including cooperation among institutions, functioning as an advisory group, and disseminating information among scientists, river managers, teachers, students, and individuals from private business and the general public	Communication of research and management findings
Mississippi Interstate Cooperative Resource Association (MICRA)	1991	AL, AR, CO, GA, IL, IN, IA, KS, KY, LA, MN, MS, MO, MT, NE, NY, NC, ND, PA, OH, OK, SD, TN, TX, VA, WV, WI, and WY; four federal agencies and two native American tribes	To improve the conservation, development, management and utilization of interjurisdictional fishery resources (both recreational and commercial) in the Mississippi River Basin through improved coordination and communication among the responsible management entities	Interjurisdictional fisheries; exotic species, paddlefish and sturgeon; native mussels
Middle Mississippi River Partnership (MMRP)	2004	IL, MO; five federal and seven private agencies	To restore and enhance the natural resources of the Middle Mississippi River corridor through public and private resource management, compatible economic development, private lands conservation, and education and outreach to the citizens of the region. Note: the partnership covers the 314 km reach of the UMR from St. Louis, MO to Cairo, IL	Wetlands, wildlife habitat, invasive species, aquatic habitat, floodplain management, water quality, agricultural viability

Table 1 continued

Partnership	Date formed	Partners	Mission	Example issues addressed
Environmental Management Program (EMP)	1986	IA, IL, MN, MO, WI; five federal agencies	To ensure the coordinated development and enhancement of the ecology of the Upper Mississippi River system. Note: the EMP was federally authorized through the Water Resources Development Act (reauthorized in 1999) with two active elements, Habitat Rehabilitation and Enhancement Projects, and the Long-Term Resource Monitoring Program	Monitoring of fish, water quality, and aquatic vegetation; aquatic and floodplain habitat
Navigation and Ecosystem Sustainability Program (NESP)	2007	Development of institutional arrangements is ongoing	Federal legislation to give navigation and ecosystem interests equal consideration, but the program is not fully developed and funds have not yet been appropriated	Ecosystem management

Mission statements and examples of issues addressed were excerpted from organizational documents and web sites

Fish Conservation Habitat Initiative could potentially be directed toward UMRS fisheries issues. The largest source of funding for research and management in the UMRS has been provided through the Environmental Management Program (EMP) of the 1986 US Water Resources Development Act (WRDA; Table 1). Habitat rehabilitation and enhancement projects authorized through EMP have been large and expensive (>$10 million) that typically benefit fisheries resources in addition to other river ecosystem components (O'Hara et al., 2008). The EMP also has supported a 15-year Long-Term Monitoring Program (LTRMP) which includes sampling fish of economic value (Ickes et al., 2005). This multi-species program, however, does not specifically target economically important fish in its monitoring protocol, so some species (e.g., Asian carps, paddlefish, and sturgeon) that are not efficiently caught with mandatory research gear (e.g., electrofishing, fyke nets, and seining) used by LTRMP (Gutreuter et al., 1995) may not be effectively tracked through time without using additional gear (e.g., trot lines) and effort (cost).

Further complicating the tangled web of stakeholder relationships in the UMRS is the differing economic needs of the diverse constituents around the river. Transportation of goods such as grain and coal via towed barges is one of the most important economic roles of the river, leading to continual maintenance of the waterway by the USACE. Farming continues in the productive land behind the levees generating about $5 billion annually (Black et al., 1999). Developers seek to build housing, office, and industrial space on the floodplain. The UMRS and other rivers continue to be important dumping areas for residential and industrial wastewater. Along the economic continuum, the health of fisheries resources is valued less. However, if society turns back toward this and other large river systems with a renewed need for food and perhaps an increased outlet for recreational opportunities, then economic opportunities via fisheries production may be lost.

To many, conserving the river's fish diversity is an important aesthetic goal that should not be discounted, although it is difficult to valuate. Outdoor recreational activities which include fishing probably generate $200 million USD annually (Black et al., 1999). Fishes including those of apparent economic interest probably play a critical role in maintaining the integrity and thus the recreational value of the

UMRS. However, the ecological roles of specific species in the UMRS are not well understood. Recently, economically important catfish have been found to be seed dispersers in the UMRS flood plain, thus linking fish behavior and abundance of fish in the floodplain to the dynamics of vegetation (Chick et al., 2003a). Certain fishes may play important roles as keystone consumers or specific hosts for threatened, endangered, or commercially harvested freshwater mussels (Havlick & Sauer, 2006). Thus, the reduction or changes in behaviors (e.g., successful passage between pools) of specific fish species through inadequate management and conservation may have unanticipated effects on the UMRS ecosystem.

The complex intersection of policy and economics is further challenged by the ecological complexity of the UMRS and our lack of mechanistic knowledge about even its most fundamental ecological processes. All river ecosystems are open and dynamic; we know that at least three competing principles, the river-continuum (Vannote et al., 1980), flood-pulse (Junk, 1999), and serial-discontinuity (Stanford & Ward, 2001) concepts, may apply. But to what degree these concepts affect fisheries production and diversity and how they interact in a hierarchical sense (Johnson et al., 1995) are largely unknown (see Delong, this volume). The 2007 incarnation of the federal US WRDA, passed by the US Congress, vetoed by President Bush, and then overridden by the US Congress into law, contains provisions for navigational development that minimize ecological effects (Navigation and Ecosystem Sustainability Program, NESP; Table 1). This is intended to be the next generation of the EMP and could restore substantial amounts of habitat in the UMRS, with benefits to fisheries. Authorization does not mean that a program in a law will receive appropriations. If this program receives funding (e.g., $35 million USD requested for 2009) via the US Congress, habitat restoration projects will have to be closely monitored to understand more about the ecological function of the UMRS as it pertains to fish resources and diversity. In our view, these results must be disseminated in the peer-reviewed literature and simultaneously distributed in a clear and concise fashion to the public and other stakeholders to have a maximum impact on the development of effective management in the UMRS and other large rivers.

Case studies

To illustrate the complex issues confronting fisheries in the UMRS, we provide a few contemporary examples already touched upon earlier. It should be clear that these issues require well-designed and relevant research. For sound management to occur, we also require clear communication and stakeholder support at all stages of the research process.

Harvest

Although commercial fishing has been a minor ecosystem service of the UMRS in the recent past dominated by taxa such as catfish (*Ictalurus* spp.), buffalo (*Ictiobus* spp.), and common carp (Black et al., 1999; Schramm, 2004), its economic value is growing. During the past decade, economic demand for shovelnose sturgeon and paddlefish (*Polydon spathula* Walbaum) roe has increased as fisheries for sturgeon caviar collapsed in the Caspian Sea region (Pala, 2005; Fig. 2). Shovelnose sturgeon populations appear to be sensitive to this subsequent increase in fishing pressure targeted on reproductive females (Boreman, 1997; Quist et al., 2002). Historical patterns of shovelnose sturgeon recruitment strength are negatively correlated with harvest intensity (Colombo et al., 2007). Annual mortality rates of shovelnose sturgeon in commercially harvested reaches are currently about four times greater than in unfished reaches (Colombo et al., 2007; Tripp et al., 2009). Effects of fishing in addition to poor

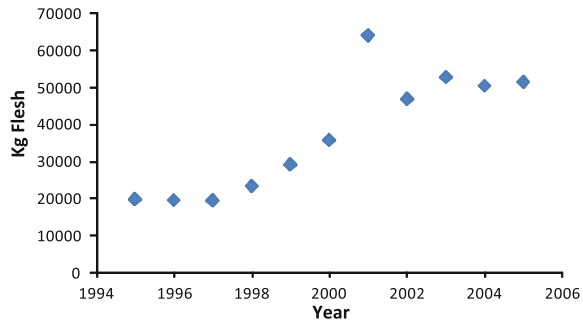

Fig. 2 Total harvest of shovelnose sturgeon flesh as compiled by commercial fishers of the state of Illinois, Iowa, and Missouri in the UMRS. Historical roe harvest data are limited and are only recently being collected by most states. Thus, we assume that flesh harvest and roe harvest are positively related (also see Colombo et al., 2007). Data courtesy of the UMRCC fish technical committee

environmental conditions for recruitment may be compromising the shovelnose sturgeon population, leading to declining adult stocks and eventually reduced yield (Tripp et al., 2009). These concerns caused the state agencies that currently allow commercial harvest in the UMRS to implement size regulations and a seasonal limit on harvest. However, some research suggests that these current regulations are insufficient to curb recruitment and growth overfishing of this population (Colombo et al., 2007).

Complicating the harvest of shovelnose sturgeon is the potential for exploitation of its morphologically similar congener, the US federally endangered pallid sturgeon, in the open river portion of the UMRS. This issue appears to be isolated to the open river because pallid sturgeon have not been documented in the pooled UMRS in recent history. Confirming concerns about incidental or intentional harvest, pallid sturgeon have appeared in the commercial creel (Bettoli et al., 2009), even with the efforts of resource agencies to educate fishers and attempts of conservation officers to enforce federal law in this large system. Mortality rates of pallid sturgeon are currently similar to those of shovelnose sturgeon in the harvested reach of the UMRS and greatly exceed those of sturgeon in unharvested reaches in the UMRS and the Missouri River (Colombo et al., 2007; Killgore et al., 2007). The USFWS is currently considering prohibiting fishing of shovelnose sturgeon based on the Similarity of Appearance Section of the Endangered Species Act (Federal Register, 2009), which will likely generate a diverse array of reactions among the stakeholders. If this ruling is upheld, then it will be implemented and monitoring must occur to gage the response of the two congeners. Of course, lawsuits and political debate may delay or prevent the implementation of this proposed rule and harvest will continue until these issues are resolved.

Relative to marine and Great Lakes counterparts, state agencies have insufficient resources to collect robust, long-term fisheries data on commercially important stocks in the UMRS (e.g., most catch data are self-reported by fishers but should be independently gathered). Thus, it is difficult to ascertain the dynamics of both the fishers and the fish populations on which they depend. Evidence of overharvest in the UMRS is not restricted to sturgeon, catfish also have responded negatively to harvest, with positive responses occurring once harvest regulations were implemented (Pitlo, 1997). Concerns about paddlefish also have arisen, with some regulations suggested (Scarnecchia et al., 1989). Given the complex political climate in which management must be determined in the UMRS (Table 1), aggressive and rapid responses to pressing fisheries needs are probably unexpected even though they are required. Providing additional federal resources to the states and their research partners (e.g., universities and allied federal agencies) for monitoring, assessment, and policy through an established consortium like MICRA is likely the best way to address increased fishing pressure in the UMRS. The recently formed Great Rivers Cooperative Ecosystem Study Unit (CESU) is an ideal way to form partnerships among multiple academic institutions, states, and federal entities and rapidly provide these groups the resources needed to evaluate fisheries issues for making informed management decisions.

Fish passage

As the UMRS has been modified by a series of locks and dams in its northern reach (Fig. 1), the potential for altered or impeded fish movement is a possibility (Wilcox et al., 2004). This should be particularly important for fish species with migratory behavior or early life stages that depend on long distances of contiguous river to develop. Candidates include skipjack herring (*Alosa chrysochloris* Rafinesque), which has very small populations in the upper portion of the UMRS, and paddlefish. How locks and dams are operated relative to hydraulic conditions in the river will affect the performance of resident fish species (DeGrandchamp et al., 2007; Lohmeyer & Garvey, 2009). Many fishes in the UMRS are expected to move most frequently and likely upstream during spring, purportedly to reach spawning areas (Wilcox et al., 2004; although see DeGrandchamp et al., 2008). If discharge is sufficiently ample during this season, the gates of most dams are left open and fish movement may not be impeded. However, for fishes that attempt to move or migrate during times of low discharge when dams are partially or fully closed, then movement will likely be curtailed. How this affects the integrity of fish populations in the UMRS is not well understood.

Fish passage in the UMRS is currently being improved by the construction of fish passage devices

at locks and dams via NESP funding that has been authorized, but not yet fully funded by the 2007 WRDA. Monitoring of fish behavior and construction are currently underway at Locks and Dams 22 and 26 of the UMRS at considerable societal cost (at least $50 million USD per project). These efforts include quantifying movement of adults of potentially migratory species using remote telemetry, monitoring location of fishes around the lock and dam complexes via echosounding, and exploring detailed behavior of fishes near lock and dam structures (e.g., the water-control gates) using high definition, dual-frequency identification sonar (DIDSON). Management of the fishways, once in place, will be adaptive. As more is learned about fish behavior around these structures and movement through them, managers will be able to adapt the fishways to improve their performance. Dissemination of this information is important to the stakeholders and the public. Thus, some of these results are regularly provided in a geospatial context via the internet at http://fishdata.siu.edu/passage.

Non-native species

Many invading species have found their way into the UMRS and either have an impact on natives or themselves support fisheries efforts. From a fisheries perspective, the introduction and expansion of the common carp starting in the nineteenth century may be one of the most notable examples, which has likely degraded water quality and reduced native fishes (Nielsen, 1999; Wolfe et al., 2009), but also has supported commercial fishing (Lubinski et al., 1986). In the last three decades, two additional carp species, the bighead and silver carps of the genus *Hypopthalmichthys*, have risen to dominance in the UMRS fish assemblage (Chick & Pegg, 2001). Black carp (*Mylopharyngodon piceus*) also was recently discovered in the UMRS (Chick et al., 2003b). Round gobies that entered from Lake Michigan are currently moving downstream through the Illinois River (Irons et al., 2006).

Both carp and gobies may dramatically affect resident fishes via competition or predation. The bighead and silver carp consume plankton and small particles including phytoplankton, bacteria, and particulate organic matter (Kolar et al., 2007). Diet overlap does occur between the silver carp and some native species of commercial importance (Sampson et al., 2009). Bighead carp have been shown experimentally to reduce growth of paddlefish (Schrank et al., 2003). Long-term monitoring data suggest that some fish species have declined as the Asian carps have increased in the Illinois River (Irons et al., 2007). These fish also are nuisances, causing public problems when mass die-offs occur and endangering boaters due to their propensity for jumping out of the water. Whether an established population of black carp exists is unknown. If one does become established, this fish is a molluscivore and may threaten native mussels in the UMRS. A management plan has been recently developed for these carp species (Conover et al., 2007), which includes directed harvest as a mechanism for control. Effects of round gobies in the UMRS are uncertain, although they do interfere with nesting centrarchids in the Great Lakes via nest predation (Steinhart et al., 2004, 2005) and likely have similar effects in rivers.

In the US, considerable funds have been expended to curb the potential movement of Asian carp and other nuisance fishes between the UMRS and the Great Lakes via the Chicago Sanitary and Ship Canal (USACE, 2008; Fig. 1). This canal maintains an artificial conduit between these historically disconnected basins, thereby allowing fish assemblages to interact that previously had no contact. Thus, the USACE orchestrated the design and implementation of a set of electric fish barriers to prevent fish movement. The cost of operation and maintenance was $6.25 million USD in 2007–2008 (USACE, 2008). The importance of this barrier is paramount, given that recent advances in detection techniques using DNA in water samples have detected silver carp only 16 km downstream (USACE, 2008). Of course, techniques such as using DNA need to be validated; contamination of samples may create false positives. Thus, concerted sampling for individuals and linking this with other detection techniques (e.g., DNA, sonar, and telemetry) is still needed to assess potential threats.

Although management has focused on preventing interchange, little management has been directed toward reducing established populations in the UMRS (see Conover et al., 2007). This is likely due again to the complex political issues associated with the river and assigning responsibility for invasive species control (see Conover et al., 2007). If funds become available, control options may include

market development for Asian carp, probably through government-subsidized fishing, processing, and consumer education. In fact, both houses of the Illinois State General Assembly unanimously passed legislation in 2009 to start a pilot research program on the feasibility of control through harvest (Illinois Public Act 096-0452, signed into law 14 August 2009). Again, the value of this law to management will depend on the level of funding it authorizes. Funding is unlikely at this juncture due to economic woes in the state.

Management of these species and their harvest should be directed with as much mechanistic information as possible. Lohmeyer & Garvey (2009) found that reproduction of Asian carp varied more across years in the pooled portion of the UMRS relative to unimpounded reaches and predicted that isolating this portion of the river from the lower, unpooled river may cause the pooled populations (including those in the Illinois River) to be more susceptible to poor recruitment and control from directed fishing (also see DeGrandchamp et al., 2007). Installing species-specific barriers at locks and dams to isolate and perhaps diminish populations of Asian carps within pools may prevent further movement and establishment (Pegg & Chick, 2002).

Communication

Communication and cooperation among scientists, managers, and the public: the multi-use, interjurisdictional nature of most large rivers presents resource managers and scientists with substantial challenges to communicate information and coordinate management actions. Communication between scientists and managers is difficult even under the simplest of management scenarios (Cullen, 1990; Table 2). Much of this difficulty stems from differences in the "currency" of academia (i.e., peer-reviewed publications, tenure, textbooks, and students) versus management (i.e., reports, enhanced production, and species recovery; Cullen et al., 1999; Table 2). From a fisheries perspective, an efficient framework that encourages formal and informal cooperation among individual researchers and agencies is essential for developing a collective understanding and prioritization of conservation issues as well as managing them at appropriate scales.

Table 2 Differing forums, incentives, and latitude for engagement for river scientists and managers may make it difficult for them to effectively integrate the "state of the art" knowledge into management decisions

Issue	Academic scientists	Government agency scientists	River managers
Forum for engagement	Peer-reviewed journals, national/international science conferences	Peer-reviewed journals, peer-reviewed agency reports, regional/national/inter-national science conferences	Peer- and non-peer-reviewed reports, regional meetings
Access to peer-reviewed literature and other "high quality" information	High, access to very specialized laboratory results	High, access to large data sets	Variable
Incentive to engage in management	Low, self-motivated	High, motivated by agency, policy makers	High, motivated by agency, policy makers
Influence on policy[a]	Direct communication of research findings to policy makers	Indirect, provide research information to policy makers through reports or solicited recommendations	Indirect, manage based on information from scientists and guidance from policy makers

[a] Ability for individuals to directly comment on policy (e.g., through editorials, policy recommendations)

In the UMRS, several successful partnerships have evolved over time for addressing natural resource issues including fisheries interests (Table 1). Although there is considerable divergence in the missions of these organizations, overlapping focus on key aquatic resource issues, common participants, and a stated desire to manage the river in an ecosystem context has fostered crosspollination and cooperative endeavors including shared political support for some federal legislation on river management such as EMP and NESP (Table 1). The main challenge is getting the right "mix" of researchers and managers together in an efficient and effective manner.

Many methods are available for facilitating interactions and smoothly translating research into management. Anyone working in the UMRS knows that there are many (perhaps too many) forums available for sharing information and translating research to management (Table 1). In a formal sense, a recent effort to identify how to better direct research and management toward recovery of the pallid sturgeon is a good example of how to tackle a formidable problem (Bergman et al., 2008). In general, a management agency needs to identify the specific fisheries issue, making sure to clearly define the desired outcome (Fig. 3a). It is at this point in the process that the agency must clearly establish whether public support and understanding is present. If the agency decides to proceed, then it should contact a group of experts that are both directly involved in the fisheries research as well as those from outside the UMRS, but with similar experiences in other rivers (Fig. 3b). After all the available information about the fishery issue is distributed to the experts, a moderated, working conference should be held, allowing stakeholders to interact. It is at this point that research, not policy, should be discussed (Fig. 3b). The very best research approaches should be outlined and prioritized. During the meeting, the appropriate experts should be matched with the facets of the management problem of which they are most familiar. In the timeframe allotted, some consensus needs to be reached, with issues that failed to generate a common opinion clearly documented. A comprehensive report should be compiled, reviewed, and revised until all researchers and managers have provided input (Fig. 3c). Again, areas of disagreement need to be documented. This report then can be used to guide management and provide a starting point for future research management interactions on some regular time scale (e.g., 5-year reviews), focusing on the recommendations that worked in practice as well as those that failed.

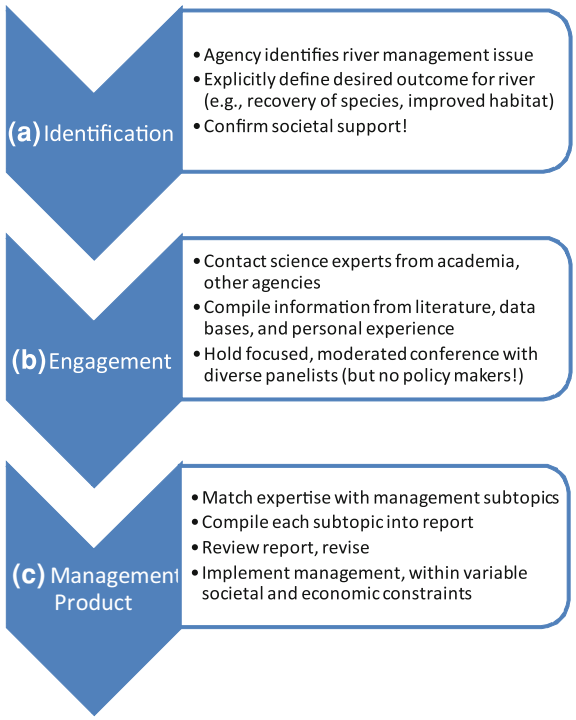

Fig. 3 Hypothetical process of addressing an Upper Mississippi River System fisheries management issue

It is imperative that all of the primary players both in fisheries research and management in the UMRS have sound training in river science and management. Fisheries programs are limited in the US (U.S. Department of Commerce, 2008) and more so those that focus on riverine fisheries. In addition to receiving cutting-edge education in river-related disciplines of ecosystem science, geographic information systems, and fluvial processes, training in "traditional" fisheries issues such as stock assessment, fish biology, statistics, and taxonomy must also occur. Programs in higher education should provide these diverse training opportunities. Federal agencies such as the National Science Foundation and US Environmental Protection Agency provide support for developing training programs catered toward these major interdisciplinary issues (e.g., through Integrative Graduate Education and Research Traineeships,

IGERTs and Science to Achieve Results Program, STAR Fellowships). Programs that extend beyond university boundaries (e.g., through continuing distance learning and mandatory continuing education requirements in agencies) also need to be developed for keeping researchers and managers at the cutting edge of fisheries issues in large rivers.

Successful long-term management of fishery resources in large rivers will not only require strong partnerships between scientists and managers, but also strong engagement of the public (Barbour et al., 2008) at all stages of the research and management process (Fig. 3). Rogers (2006) argues that the widespread view of the role of river scientists and managers as experts that will solve environmental problems without society's input is unhelpful. Rather, a partnership framework that integrates input from scientists, managers, and the public in an adaptive management context may result in broad societal responses that are more likely to succeed. Thus, scientists and managers will need to better engage society to develop an understanding of the function of river ecosystems, a shared vision of desirable future fisheries conditions, and the costs and benefits of ongoing management actions to address fishery issues in rivers (Kates et al., 2001; Wohl et al., 2005; Rogers, 2006).

The rapid advancement of information technology will undoubtedly change how scientists and managers communicate scientific information about fisheries (Friedlander & Bessette, 2003). Journal publication has historically been the linchpin of communication among fisheries scientists. Although presenting research in the peer-reviewed literature is not necessary for knowledge about fisheries and their resident ecosystems to grow, it is through this process that ecological conceptual development may most effectively proceed and then guide management (but see DeVries et al., 2009 for a critique of the process). It is also the most likely way to get academic scientists to engage in management because it appeals to their internal reward system (Table 2). Some drawbacks of publishing in journals are that poor access and backlogs to printing often limit use by managers and access to the public (see Table 2).

Alternatives to peer-review do exist and must be pursued in tandem. Dissemination of scientific information through the internet and world-wide web has become an increasingly common and effective method of communication among scientists, managers, and the public. Of course, quality assurance must be ensured to avoid misinformation being distributed. Both universities and agencies are exploring ways to effectively and efficiently provide research information through open-access portals. Fisheries agencies are exploring gathering data in real time, for example, by having fishers text message catch information from the field to a central database (Baker & Oeschger, 2009). Programs like the LTRMP (Table 1) serve fisheries and other environmental monitoring data through the internet both in raw form and through a user-friendly interface for data summary. Such efforts encourage the use of expensive, publically funded data, whereas past efforts to use poorly available data and gray literature in synthetic analyses were sometimes hampered by access (e.g., Murchie et al., 2008). If in-depth knowledge of many river restoration projects only resides with individual project managers, this will substantially reduce its broader use for advancing river restoration science and adaptive management (O'Donnell & Galat, 2007).

Declining ecosystem function may be first perceived through declines in fisheries production. However, such declines must be considered in light of physical, chemical, and biological processes that are interconnected across a hierarchy of spatial and temporal scales. As river restoration efforts may be more likely to succeed if objectives focus on restoration of these processes, often in the context of entire watersheds or riversheds, multidisciplinary cooperation will be key to advance river restoration science and conserve or enhance fisheries (Wohl et al., 2005). Advancement of river fisheries science would benefit from comparisons of rivers at regional, continental, and global scales, especially to understand and respond to common problems like the effects of flow regulation on fishes and larger scale phenomena like climate change. New paradigms in river science and management will require fishery scientists and managers to extend cooperation across geographic boundaries as well as scientific ones (Cullen et al., 1999). Also it would be helpful to engage economists and sociologists using the framework in Fig. 3 to help provide information about the complex behavior of humans in the fishery and surrounding landscape.

Lessons learned

Over a decade has passed since Johnson et al. (1995) suggested that the UMRS and other large rivers require a hierarchical approach for directing ecological questions and more than half a century since Smith (1949) recognized the importance of research. Interestingly, our recent search of the combined terms "fisheries," "Mississippi," and "River" in the powerful ISI Web of Science search engine revealed less than 50 articles published on this topic in the UMRS during this time period. Conceptual development regarding the ecological basis of fisheries production and diversity (and their interaction) is arguably in its infancy in the UMRS. For example, Dettmers et al. (2001) were among the first investigators to provide information about the fish assemblage in the main river channel using a relatively unbiased technique (i.e., trawling). Before then, information about fish species composition and abundance (ultimately production) in the mainstem of the UMRS was limited. In addition to novel sampling techniques, other monitoring technology to quantify absolute abundance, size distributions, and movements of fishes such as sonar and telemetry need to be explored. Another important research gap is placing the status of fish populations in the context of their life-history needs, recruitment, and evolution (Conover & Munch, 2002). We currently do not understand the degree of genetic differentiation within most fish species in the UMRS, with the exception of a few species including the shovelnose sturgeon (Schrey et al., 2009) and smallmouth bass (Stark & Echelle, 1998); the spatial and temporal scale of relevant evolutionary processes is currently unknown. For example, we do not understand how factors such as harvest and lock and dam "barriers" of the UMRS affect genetic structure of fish populations. For closely related species, how hybridization is influenced by conditions in the UMRS also need to be explored. Intersexuality in shovelnose sturgeon and likely other species is alarmingly common in the UMRS (Koch et al., 2006). The linkages among contaminant accumulation, other environmental factors, intersexuality, and population viability need to be explored.

Although focusing on population and community dynamics is useful for fisheries management, placing fisheries diversity and production in the context of the surrounding UMRS ecosystem and landscape is imperative. However, we must find the correct categories by which we may define the UMRS ecosystem in a meaningful way. One significant challenge is determining the spatial extent of the ecosystem relative to the population or community. Obviously, this is difficult given that native and invasive river species are capable of rapidly moving considerable distances (>1,000 km) and that the life stage (e.g., larva or adult) that moves or drifts among reaches and rivers differs among species. Assuming that the populations within each major geographic region are somewhat unique, we might first consider dividing the UMRS into the pooled region including the Illinois River and compare it to the lower, open river extending south to the Ohio River confluence, realizing that these two reaches are certainly interacting (Fig. 1). We also must not ignore the contribution of other major rivers such as the Missouri and the Ohio (Fig. 1).

In the pools of the UMRS including the Illinois River, fisheries success within each impounded area is likely related to access of populations to both adjacent pools as well as off-channel areas within each pool (Fig. 1). Obviously, fish passage through lock and dam complexes is limited to specific hydraulic circumstances and patterns of water-level management. These limitations may negatively affect basic life history processes of fishes such as reproduction and also inhibit food web interactions by limiting foraging opportunities to isolated pools. Backwater areas are declining in the pools of the UMRS through constant inundation and resulting sedimentation (Heitmeyer & Westphall, 2007). Given that fish must move from the main channel to seek low-velocity habitats during winter, these backwater habitats may be critical for survival. However, the lack of fisheries data across multiple scales, including across pools, makes it difficult to assess the magnitude of this effect. At Swan Lake, a major restored backwater of the Illinois River through the EMP, quantifying movement of fishes revealed that this area was more important for the production of young fishes in spring (Csoboth & Garvey, 2008) than for overwinter use by adult fish (Schultz et al., 2007). However, the shallow depth of this backwater may not have provided sufficient overwintering areas relative to deeper areas (Sheehan et al., 1990). This failure of the EMP in this sense can be used as

lessons learned for future restoration and management of backwater fisheries in the UMRS.

In the open reach of the UMRS below the Missouri River (Fig. 1), fisheries issues differ from the pools in some ways that are subtle and, in other ways, less subtle. In the open river, fish access to the floodplain is less restricted by sedimentation and more so by an extensive network of flood-control levees (Heitmeyer, 2008). In a sense, the problem is similar to that in the pools, although the causal mechanism is different. As the open river still maintains some semblance of contiguous river with a series of flood pulses, fishes such as sturgeon, paddlefish, freshwater drum, and the invasive Asian carps that require large expanses of unimpeded river for embryos and larvae to develop should be more successful reproductively (Galat & Zweimuller, 2001; Braaten et al., 2008; Lohmeyer & Garvey, 2009). Within-channel habitat heterogeneity (e.g., islands and associated sloughs) in the open river is scarce compared to the pooled river, probably reducing velocity refuges, nursery habitats, and foraging opportunities for many fish species (Galat & Zweimuller, 2001). Connectivity between the pooled reach upstream and the open river has been undeniably altered, potentially preventing upstream migrations of open-river residents and also reducing downstream transport of ecosystem subsidies (organic matter) produced in the upper river. Further, sediment loading from the Missouri River into the open UMRS has been substantially reduced relative to historic levels because the Missouri River has been isolated from its floodplain and dammed at Gavin's Point (Davinroy, 2006). These reductions in Missouri-derived sediment surely have altered the fish assemblage in the open UMRS in ways that are not well understood. Another potential issue affecting fisheries in this reach may be the installation of expansive fields of hydropower turbines on the river bottom (e.g., Freeflow Power; http://free-flow-power.com). Although considered to have a low impact on the river, their influence on flow, bedform, sediment transport, macroinvertebrate drift, actively moving fish, and drifting larvae is not known.

Conclusions

In conclusion, we suggest that fisheries within the UMRS are at a historically critical juncture. Abundant resources in terms of expertise and funding are available and likely will increase in future. To take full advantage of current and future opportunities, all the innovations in communication that have been flourishing in the early twenty-first century need to be understood and embraced to facilitate joint partnerships among all stakeholders and rally public support. All fisheries professionals should consider themselves students and continue to develop their skills through enhanced learning opportunities and actively seek collaborations across disciplines. Research efforts (e.g., monitoring) throughout the UMRS should be standardized as much as possible so that large-scale patterns can be assessed. The LTRMP partnerships between the USGS and states funded through the EMP provide an example of such a well-coordinated effort (Table 1). These long-term monitoring efforts should be as inclusive as possible, including data generated by all researchers vested in the UMRS not just those incurring direct funding through the program. Finally, fisheries professionals must acknowledge that ecosystem approaches are important. However, it is important for these individuals to hold onto their roots, understanding that underlying life histories, population dynamics, and associated genetics are key to conserving and enhancing fisheries in the UMRS for generations to come.

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References

Adams, S. R., 2004. Fish community dynamics in off-channel habitats of the Mississippi River: patterns across space, time, and hydrologic gradients. PhD Dissertation, Southern Illinois University, Carbondale, IL.

Adams, S. R., M. B. Flinn, B. M. Burr, M. R. Whiles & J. E. Garvey, 2006. Ecology of larval blue sucker (*Cycleptus elongatus*) in the Mississippi River. Ecology of Freshwater Fish 15: 291–300.

Animal and Plant Inspection Service, 2006. Viral Hemorrhagic Septicemia in the Great Lakes Region. US Department of Agriculture Industry Alert.

Baker, M. S. Jr., & I. Oeschger, 2009. Description and initial evaluation of a text message based reporting method for marine recreational anglers. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1: 143–154.

Barbour, M. T., N. L. Poff, R. H. Norris & J. D. Allan, 2008. Perspective: communicating our science to influence public policy. Journal of the North American Benthological Society 27: 562–569.

Barko, V. A., B. S. Ickes, D. P. Herzog, R. A. Hrabik, J. H. Chick & M. A. Pegg, 2005. Spatial, Temporal, and Environmental Trends of Fish Assemblages Within Six Reaches of the Upper Mississippi River System. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, LaCrosse, WI, February 2005. Technical Report LTRMP 2005-T002.

Bergman, H. L., A. M. Boelter, K. Paraday, C. Fleming, T. Keevin, D. C. Latka, C. Korshgen, D. L. Galat, T. Hill. G. Jordan, S. Krentz, W. Nelson-Statsny, M. Olson, G. E. Metsl, K. Rouse & J. Berkley, 2008. Research needs and management strategies for pallid sturgeon recovery. Proceedings of a Workshop Held July 31–August 2, 2007, St. Louis, Missouri. Final Report to the U.S. Army Corps of Engineers. William D. Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie.

Bertrand, B. A., 1997. Changes in the Mississippi River fishery along Illinois, 1976–1996. Journal of Freshwater Ecology 12: 585–597.

Bettoli, P. W., M. Casto-Yerty, G. D. Scholten & E. J. Heist, 2009. Bycatch of the endangered pallid sturgeon (*Scaphirhynchus albus*) in a commercial fishery for shovelnose sturgeon (*S. platorynchus*). Journal of Applied Ichthyology 25: 1–4.

Black, R., B. McKenney, A. O'Connor, E. Gray & R. Unsworth, 1999. Economic Profile of the Upper Mississippi River Region. Industrial Economics Incorporated, Cambridge, MA.

Bodensteiner, L. R. & 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.

Bodensteiner, L. R. & W. M. Lewis, 1994. Downstream drift of fishes in the upper Mississippi River during winter. Journal of Freshwater Ecology 9: 45–56.

Boreman, J., 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. Environmental Biology of Fishes 48: 399–406.

Borgstrum, G., 1978. The contribution of freshwater fish to human food. In Gerking, S. D. (ed.), Ecology of Freshwater Fish Production. John Wiley and Sons, New York, NY: 469–491.

Braaten, P. J., D. B. Fuller, L. D. Holte, R. D. Lott, W. Viste, T. F. Brandt & R. G. Legare, 2008. Drift dynamics of larval pallid sturgeon and shovelnose sturgeon in a natural side channel of the upper Missouri River, Montana. North American Journal of Fisheries Management 28: 808–826.

Carlander, H. B., 1954. History of Fish and Fishing on the Upper Mississippi River (UMR). Upper Mississippi River Conservation Committee, Dubuque, IA.

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

Chick, J. H., R. J. Cosgriff & L. S. Gittinger, 2003a. Fish as potential dispersal agents for floodplain plants: first evidence in North America. Canadian Journal of Fisheries and Aquatic Sciences 60: 1437–1439.

Chick, J. H., R. J. Maher, B. M. Burr & M. R. Thomas, 2003b. First black carp captured in US. Science 300: 1876–1877.

Cole, D. W., R. Cole, S. J. Gaydos, J. Gray, G. Hyland, M. L. Jacques, N. Powell-Dunford, C. Sawhney & W. W. Au, 2009. Aquaculture: environmental, toxicological, and health issues. International Journal of Hygiene and Environmental Health 212: 369–377.

Colombo, R. E., J. E. Garvey, N. D. Jackson, R. Brooks, D. P. Herzog, R. A. Hrabik & T. W. Spier, 2007. Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse? Journal of Applied Ichthyology 23: 444–451.

Conover, D. O. & S. B. Munch, 2002. Sustaining fisheries yields over evolutionary time scales. Science 297: 94–96.

Conover, G., R. Simmonds & M. Whalen (eds), 2007. Management and Control Plan for Bighead, Black, Grass, and Silver Carps in the United States. Asian Carp Working Group, Aquatic Nuisance Species Task Force, Washington, DC.

Csoboth, L. A. & J. E. Garvey, 2008. Lateral exchange of larval fish between a restored backwater and a large river in the east-central U.S. Transactions of the American Fisheries Society 137: 45–56.

Cullen, P., 1990. The turbulent boundary between water science and water management. Freshwater Biology 24: 201–209.

Cullen, P. W., R. H. Norris, V. H. Resh, T. B. Reynoldson, D. M. Rosenberg & M. T. Barbour, 1999. Collaboration in scientific research: a critical need for freshwater ecology. Freshwater Biology 42: 131–142.

Davinroy, R. D., 2006. Sedimentation in the Upper Mississippi River Basin. US Army Corps of Engineers Applied River Engineering Center, St. Louis District.

DeGrandchamp, K. L., J. E. Garvey & L. A. Csoboth, 2007. Linking adult reproduction and larval density of invasive carp in a large river. Transactions of the American Fisheries Society 136: 1327–1334.

DeGrandchamp, K. L., J. E. Garvey & R. E. Colombo, 2008. Movement and habitat selection by invasive Asian carps in a large river. Transactions of the American Fisheries Society 137: 45–56.

DeJesus, M. J. & C. C. Kohler, 2004. The commercial fishery of the Peruvian Amazon. Fisheries 29: 10–16.

Delong, M. D., 2005. Upper Mississippi River basin. In Benke, A. C. & C. E. Cushing (eds), Rivers of North America. Elsevier Academic Press, New York: 327–373.

Delong, M. D., this volume. Food webs and the upper Mississippi River: contributions to our understanding of ecosystem function in large rivers. doi:10.1007/s10750-009-0065-6.

Dettmers, J. M., D. H. Wahl, D. A. Soluk & S. Gutreuter, 2001. Life in the fast lane: fish and foodweb structure in the main channel of large rivers. Journal of the North American Benthological Society 20: 255–265.

DeVries, D. R., E. A. Marschall & R. A. Stein, 2009. Exploring the peer review process: what is it, does it work, and can it be improved? Fisheries 34: 270–279.

Federal Register, 2009. Proposed Rule to List the Shovelnose Sturgeon as Threatened Due to Similarity of Appearance, 54 Fed. Reg. 48215-48220 (September 1, 2009) (to be codified at 50 CFR Part 17).

Flinn, M. B., M. R. Whiles, S. R. Adams & J. E. Garvey, 2008. Biological responses to contrasting hydrology in

backwaters of Upper Mississippi River Navigation Pool 25. Environmental Management 41: 468–486.

Food and Agriculture Organization, 2007. The state of the world fisheries and aquaculture 2006. FAO Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations, Rome

Fremling, C. R., 2005. Immortal River: The Upper Mississippi River in Ancient and Modern Times. The University of Wisconsin Press, Madison, WI.

Friedlander, A. & R. S. Bessette, 2003. The Implications of Information Technology for Scientific Journal Publishing: A Literature Review. National Science Foundation, Division of Science Resources Statistics, Arlington, VA, Report NSF 03-323. http://www.nsf.gov/statistics/nsf03323/start.htm.

Galat, D. L. & I. Zweimuller, 2001. Conserving large-river fishes: is the highway analogy an appropriate paradigm? Journal of the North American Benthological Society 20: 266–279.

Garvey, J. E. & E. A. Marschall, 2003. Understanding latitudinal trends in fish body size through models of optimal seasonal energy allocation. Canadian Journal of Fisheries and Aquatic Sciences 60: 938–948.

Garvey, J. E., B. D. Dugger, M. R. Whiles, S. R. Adams, M. B. Flinn, B. M. Burr & R. J. Sheehan, 2003. Responses of Fish, Waterbirds, Invertebrates, Vegetation, and Water Quality to Environmental Pool Management: Mississippi River Pool 25. U.S. Army Corps of Engineers: 181 pages.

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 & K. Lubinski, 1995. Long Term Resource Monitoring Program Procedures: Fish Monitoring. National Biological Service, Environmental Management Technical Center, Onalaska, WI, July 1995. LTRMP 95-P002-1: 42 pp. + Appendixes A–J.

Gutreuter, S., A. D. Bartels, K. Irons & 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.

Havlick, M. E. & J. S. Sauer, 2006. Native Freshwater Mussels of the Upper Mississippi River System. Project Status Report, Upper Midwest Environmental Sciences Center, La Crosse, WI.

Heitmeyer, M. E., 2008. An Evaluation of Ecosystem Restoration Options for the Middle Mississippi River Regional Corridor. US Army Corps of Engineers, St. Louis District, Report 08-02.

Heitmeyer, M. E. & K. Westphall, 2007. An Evaluation of Ecosystem Restoration and Management Options for the Calhoun and Gilbert Lake Divisions of Two Rivers National Wildlife Refuge. US Army Corps of Engineers, St. Louis District.

Hilborn, R., T. A. Branch, B. Ernst, A. Magnussson, C. V. Minte-Vera, M. D. Scheuerell & J. L. Valero, 2003. State of the world's fisheries. Annual Review of Environment and Resources 28: 359–399.

Ickes, B. S., M. C. Bowler, A. D. Bartels, D. J. Kirby, S. DeLain, J. H. Chick, V. A. Barko, K. S. Irons & 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, WI. LTRMP 2005 T005: 60 pp. + Appendixes A–E.

Irons, K. S., M. A. McClelland & M. A. Pegg, 2006. Expansion of round goby in the Illinois waterway. American Midland Naturalist 156: 198–200.

Irons, K. S., G. G. Sass, M. A. McClelland & J. D. Stafford, 2007. Reduced condition factor of two native fish species coincident with invasion of non-native Asian carps in the Illinois River, USA – is this evidence for competition and reduced fitness? Journal of Fish Biology 71: 258–273.

Janvrin, J. A., 2005. A comparison of the pre- and post-impoundment fish assemblage of the Upper Mississippi River (Pools 4–13) with an emphasis on centrarchids. American Fisheries Society Symposium 45: 323–343.

Johnson, B. L., W. B. Richardson & T. J. Naimo, 1995. Past, present, and future concepts in large river ecology. BioScience 45: 134–141.

Johnson, B. L., B. C. Knights, J. W. Barko, R. F. Gaugush, D. M. Soballe & W. F. James, 1998. Estimating flow rates to optimize winter habitat for centrarchid fish in Mississippi River (USA) backwaters. Regulated Rivers-Research & Management 14: 499–510.

Junk, W. J., 1999. The flood pulse concept of large rivers: learning from the tropics. Archiv Fur Hydrobiologie 115: 261–280.

Junk, W. J., M. G. M. Soares & P. B. Bayley, 2007. Freshwater fishes of the Amazon River basin: their biodiversity, fisheries, and habitats. Aquatic Ecosystem Health & Management 10: 153–173.

Karr, J. K., L. A. Toth & D. R. Didley, 1985. Fish communities of Midwestern rivers: a history of degradation. BioScience 35: 90–95.

Kates, R. W., W. Clark, R. Corell, J. Hall, C. Jaeger, I. Lowe, J. McCarthy, H. Schellnhuber, B. Bolin, N. Dickson, S. Faucheux, G. Gallopin, A. Grubler, B. Huntley, J. Jager, N. Jodha, R. Kasperson, A. Mabogunje, R. Matson, H. Mooney, B. Moore, T. O'Riordan & U. Svedin, 2001. Environment and development: sustainability science. Science 292: 641–642.

Killgore, K. J., J. J. Hoover, J. P. Kirk, S. G. George, B. R. Lewis & C. E. Murphy, 2007. Age and growth of pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23: 452–456.

Kittrell, F. W., 1958. Pollution of Interstate Waters of the Mississippi River in the St. Louis Metropolitan Area. PB-216 902. Robert A. Taft Sanitary Engineering Center, Cincinnati, OH.

Knights, B. C., B. L. Johnson & M. B. Sandheinrich, 1995. Responses of bluegills and black crappies to dissolved oxygen, temperature, and current in backwater lakes of the Upper Mississippi River during winter. North American Journal of Fisheries Management 15: 390–399.

Koch, B. T., J. E. Garvey, J. You & M. J. Lydy, 2006. Elevated organochlorines in the brain-hypothalamic-pituitary complex of intersexual shovelnose sturgeon. Environmental Toxicology and Chemistry 25: 1689–1697.

Kolar, C. S., D. C. Chapman, J. W. R. Courtenay, C. M. Housel, J. D. Williams & D. P. Jennings, 2007. Bigheaded

Carps: A Biological Synopsis and Environmental Risk Assessment, Vol. 33. American Fisheries Society Special Publication, Bethesda, MD.

Lohmeyer, A. M. & J. E. Garvey, 2009. Placing the North American invasion of Asian carp in a spatially explicit context. Biological Invasions 11: 905–916.

Lubinski, K. S., A. Vanvooren, G. Farabee, J. Janecek & S. D. Jackson, 1986. Common carp in the Upper Mississippi River. Hydrobiologia 136: 141–153.

Lyons, J., 1996. Patterns in the species composition of fish assemblages among Wisconsin streams. Environmental Biology of Fishes 45: 329–341.

Murchie, K. J., K. P. Hair, C. E. Pullen, T. D. Redpath, H. R. Steven & S. J. Cooke, 2008. Fish response to modified flow regimes in regulated rivers: research methods, effects and opportunities. River Research and Applications 24: 197–217.

National Atmospheric Deposition Program, 2005. Monitoring Mercury Deposition: A Key Tool to Understanding the Link Between Emissions and Effects. Illinois State Water Survey, Champaign, IL.

Nielsen, L. A., 1999. History of inland fisheries management in North America. In Kohler, C. C. & W. A. Hubert (eds), Inland Fisheries Management in North America, 2nd ed. American Fisheries Society, Bethesda, MD: 3–30.

O'Donnell, T. K. & D. L. Galat, 2007. Evaluating success criteria and project monitoring in river enhancement within an adaptive management framework. Environmental Management 41: 90–105.

O'Hara, T. M., M. A. McClelland, K. S. Irons, T. R. Cook & G. G. Sass, 2008. Effect of a Recently Completed Habitat Rehabilitation and Enhancement Project on Fish Abundances in La Grange Pool of the Illinois River Using Long Term Resource Monitoring Program Data. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, LaCrosse, WI. LTRMP Technical Report, 2008-T001.

Pala, C., 2005. Ban on beluga sturgeon caviar points to sturgeon's worldwide decline. Science 310: 37.

Pegg, M. A. & J. H. Chick, 2002. Aquatic Nuisance Species: An Evaluation of Barriers for Preventing the Spread of Bighead and Silver Carp to the Great Lakes. Final Report, Illinois-Indiana Sea Grant (A/SE (ANS)-01-01).

Pinter, N. & R. A. Heine, 2005. Hydrodynamic and morphodynamic response to river engineering documented by fixed-discharge analysis, Lower Missouri River, USA. Journal of Hydrology 302: 70–91.

Pitlo, J. Jr., 1997. Response of upper Mississippi River channel catfish populations to changes in commercial harvest regulations. North American Journal of Fisheries Management 17: 848–859.

Policansky, D., 2002. Catch-and-release recreational fishing: a historical perspective. In Pitcher, T. J. & C. E. Hollinsworth (eds), Recreational Fisheries: Ecological, Economic, and Social Evaluation. Blackwell Science Limited, NJ: 74–94.

Quist, M. C., C. S. Guy, M. A. Pegg, P. J. Braaten, C. L. Pierce & V. H. Travnichek, 2002. Potential influence of harvest on shovelnose sturgeon populations the Missouri River system. North American Journal of Fisheries Management 22: 537–549.

Rabalais, N. N., R. E. Turner & W. J. Wiseman, 2002. Gulf of Mexico hypoxia, aka "The dead zone". Annual Review of Ecology and Systematics 33: 235–263.

Rahel, F. J., 2000. Homogenization of fish faunas across the United States. Science 288: 854–856.

Rahel, F. J., 2002. Homogenization of freshwater faunas. Annual Review of Ecology and Systematics 33: 291–315.

Raibley, P. T., K. S. Irons, T. M. O. Hara, K. D. Blodgett & 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 17: 401–412.

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

Rogers, K. H., 2006. The real river management challenge: integrating scientists, stakeholders and service agencies. River Research and Applications 22: 269–280.

Sampson, S. J., J. H. Chick & M. A. Pegg, 2009. Diet overlap among two Asian carp and three native fishes in backwater lakes on the Illinois and Mississippi rivers. Biological Invasions 11: 483–496.

Scarnecchia, D. L., T. W. Gengerke & C. T. Moen, 1989. Rationale for a harvest slot limit for paddlefish in the Upper Mississippi River. North American Journal of Fisheries Management 9: 477–487.

Schramm, H. L. Jr., 2004. Status and management of Mississippi River fisheries. In Welcomme, R. L. & T. Petr (eds), Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries. Food and Agriculture Organization of the United Nations.

Schrank, S. J., C. S. Guy & J. F. Fairchild, 2003. Competitive interactions between age-0 bighead carp and paddlefish. Transactions of the American Fisheries Society 132: 1222–1228.

Schrey, A., R. Colombo, J. Garvey & E. Heist, 2009. Stock structure of shovelnose sturgeon analyzed with microsatellite DNA and morphological characters. Journal of Applied Ichthyology. doi:10.1111/j.1439-0426.2009.01330.x.

Schultz, D., J. E. Garvey & R. Brooks, 2007. Backwater immigration by fishes through a water control structure: implications for connectivity and restoration. North American Journal of Fisheries Management 27: 172–180.

Sheehan, R. J. & J. L. Rasmussen, 1999. Large rivers. In Kohler, C. C. & W. A. Hubert (eds), Inland Fisheries Management in North America, 2nd ed. American Fisheries Society, Bethesda, MD: 529–560.

Sheehan, R. J., W. M. Lewis & L. R. Bodensteiner, 1990. Winter Habitat Requirements and Overwintering of Riverine Fishes. Final Report, Federal Aid in Sportfish Restoration Program, F-79-R.

Sheehan, R. J., P. S. Wills, M. A. Schmidt & J. E. Hennessy, 2004. Determinations of the Fate of Fish Displaced from Low-Velocity Habitats at Low Temperatures. U.S. Army Corps of Engineers Districts, Rock Island, St. Louis, and St. Paul. ENV 32.

Shuter, B. J. & J. R. Post, 1990. Climate, population viability, and the zoogeography of temperate fishes. Transactions of the American Fisheries Society 119: 314–336.

Smith, L. L., 1949. Cooperative fishery survey of the Upper Mississippi River. Transactions of the American Fisheries Society 76: 279–282.

Stanford, J. A. & J. V. Ward, 2001. Revisiting the serial discontinuity concept. Regulated Rivers-Research & Management 17: 303–310.

Stark, W. J. & A. A. Echelle, 1998. Genetic structure and systematics of smallmouth bass, with emphasis on interior highlands populations. Transactions of the American Fisheries Society 127: 393–416.

Steinhart, G. B., R. A. Stein & E. A. Marschall, 2004. High growth rate of young-of-the-year smallmouth bass in Lake Erie: a result of the round goby invasion? Journal of Great Lakes Research 30: 381–389.

Steinhart, G. B., M. E. Sandrene, S. Weaver, R. A. Stein & E. A. Marschall, 2005. Increased parental care cost for nest-guarding fish in a lake with hyperabundant nest predators. Behavioral Ecology 16: 427–434.

Theiling, C. H. & J. M. Nestler, this volume. River stage response to alteration of upper Mississippi River channels, floodplains, and watersheds. doi:10.1007/s10750-009-0066-5.

Tripp, S. J., R. E. Colombo & J. E. Garvey, 2009. Declining recruitment and growth of shovelnose sturgeon in the Middle Mississippi River: implications for conservation. Transactions of the American Fisheries Society 138: 422–426.

Turvey, S. T., R. L. Pitman, B. L. Taylor, J. Barlow, T. Akamatsu, L. A. Barrett, X. J. Zhao, R. R. Reeves, B. S. Stewart, K. X. Wang, Z. Wei, X. F. Zhang, L. T. Pusser, M. Richlen, J. R. Brandon & D. Wang, 2007. First human-caused extinction of a cetacean species? Biology Letters 3: 537–540.

United States Army Corps of Engineers, 2008. Chicago Sanitary and Ship Canal Fish Barrier System. http://www.lrc.usace.army.mil/projects/fish_barrier/.

United States Department of Agriculture, National Agricultural Statistics Service, 2009. 2007 Census of Agriculture: Statistics and Summary Data.

Upper Mississippi River Basin Association, 2005. Upper Mississippi River Fish Consumption Advisories: State Approaches to Issuing and Using Fish Consumption Advisories on the Upper Mississippi River. St. Paul, MN, USA.

U.S. Department of the Interior, Fish and Wildlife Service & U.S. Department of Commerce, U.S. Census Bureau, 2006. National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

U.S. Department of Commerce and U.S. Department of Education, 2008. The Shortage in the Number of Individuals with Post-Baccalaureate Degrees in Subjects Related to Fishery Science. NOAA Tech. Memo. NMFS-F/SPO-91: 84 pp.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130–137.

Wiener, J. G. & M. B. Sanheinrich, this volume. Contaminants in the upper Mississippi River: historic trends, present status, and emerging concerns. doi:10.1007/s10750-009-0064-7.

Wilcox, D. B., E. L. Stefanik, D. E. Kelner, M. A. Cornish, D. J. Johnson, I. J. Hodgins, S. J. Zigler & B. L. Johnson, 2004. Improving Fish Passage Through Navigation Dams on the Upper Mississippi River System. Upper Mississippi River-Illinois Waterway System Navigation Study ENV 54.

Winemiller, K. O. & D. B. Jepsen, 1998. Effects of seasonality and fish movement on tropical river food webs. Journal of Fish Biology 53: 267–296.

Wlonski, J. H. & L. Hill, 1995. Analysis of water level management on the Upper Mississippi River (1980–1990). Regulated Rivers: Research and Management 11: 239–248.

Wohl, E., P. L. Angermeier, B. Bledsoe, G. M. Kondolf, L. MacDonnel, D. Merrit, M. Palmer, N. L. Poff & D. Tarboton, 2005. River restoration. Water Resources Research 41: W10301.

Wolfe, M. D., V. J. Santucci, L. M. Einfalt & D. H. Wahl, 2009. Effects of common carp on reproduction, growth, and survival of largemouth bass and bluegills. Transactions of the American Fisheries Society 138: 975–983.

Woltemade, C. J., 1997. Water level management opportunities for ecological benefit, Pool 5 Mississippi River. Journal of the American Water Resources Association 33: 443–454.

Xie, S., Z. Li, J. Liu, H. Wang & B. R. Murphy, 2007. Fisheries of the Yangtze River show immediate impacts of the Three Gorges Dam. Fisheries 32: 343–344.