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Conservation Priorities for Freshwater Biodiversity in the Upper Mississippi River Basin

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Executive Summary

The extensive network of streams, mainstem river and its floodplains, thousands of lakes, and the uplands that make up the Upper Mississippi River Basin (UMRB) provide habitat for a significant portion of the Earth's biological diversity. A considerable fraction of the world's population also depends on this area — the nation's heartland — for food, transportation and municipal water supply. Human land use in the basin has greatly altered the terrestrial and riverine ecosystems of the UMRB. This study evaluates the components and patterns of the freshwater biodiversity of the basin, and identifies the most significant places to focus conservation opportunities to maintain it.

Many aspects and portions of the UMRB are well studied. Yet, we have lacked the information to guide focused and comprehensive conservation action to sustain freshwater biodiversity throughout the whole UMRB. To address this need, NatureServe and The Nature Conservancy, with the financial support of the McKnight Foundation and Region 5 of the U.S. Environmental Protection Agency, have assembled data on the variety, distribution and condition of freshwater species and ecosystems of the basin. This report provides detailed information on three major aquatic taxonomic groups — fishes, mussels, and crayfishes. We have also classified all of the freshwater components of the basin as ecological system types based on their physical attributes and surrounding landscapes. We assessed their ecological integrity using spatial data on land use patterns which provide information on large-scale and non-point sources of impacts, as well as more site-specific information such as dams and industrial facility locations.

Through working with regional experts with these data, we have identified the set of areas of biodiversity significance (ABS), that together represent the full array of places that harbor the best remaining examples of the rare and imperiled aquatic species and the ecological systems that contain them as well as those ecological systems that contain the best examples of common and representative species and communities.

Using a suite of terrestrial areas identified in previous conservation planning exercises, we have assembled a set of fifty priority areas in the basin for both terrestrial and aquatic biodiversity. We have included a detailed description of each priority area, which includes a map and a list of the freshwater and terrestrial conservation targets found in each area

We have a high level of confidence that, if protected and/or restored, both sets of priorities (freshwater alone or freshwater combined with terrestrial) will ensure the viability of the common species and a majority of the imperiled aquatic species in the basin. Given that the basin is home to one quarter of the species of freshwater fishes in the United States and 20% of the mussel species found in the United States and Canada, successful conservation in the UMRB is critical to the conservation of a significant component of global freshwater biodiversity.

Our analysis of these data was for the specific purpose of selecting priority river systems that would be representative of the biodiversity of the basin. However, these data can be used for many additional purposes. This report explains how several data sets for fish and mussels

have been assembled into a standardized database format with spatial locations for all of the samples. We explored using these fish data to identify biological communities, to use as biological attributes of ecological systems in addition to the physical attributes we used to derive them. We used the northern glaciated watersheds of Wisconsin and Minnesota as a pilot region to explore and develop methods to identify communities. This analysis also showed the complexities involved in relating community data to the ecological classification.

We have included with this report appendices and electronic databases containing all of the data sets used to identify conservation priorities among river systems and conduct the community analysis, with the exception of point locations of sensitive species. These data can be used for conservation area planning at specific locations within the basin, to identify and set reference conditions for biological monitoring of stream health, and to design sampling frameworks for species inventories.

1. Introduction

1.1. Purpose and Scope of Work

The Upper Mississippi River Basin (UMRB) is a national, natural treasure, the crown of one of the world's major river systems in size, habitat diversity, and biological productivity. The upper basin's river and its adjacent forest and wetlands provide important refuge to thousands of species and natural communities, representing the largest area of contiguous fish and wildlife habitat in the Central United States (Wiener et al. 1998, USACE 2002). The entire basin is a globally significant for fish evolution, having served as a refuge during times of glaciation for the fish fauna of central North America and in its current role as a refuge for ancient fishes and other aquatic or semi-aquatic vertebrates (Burr and Ladonski 2000).

However, in its current state, the UMRB is also a highly regulated and degraded ecosystem: the mainstem Mississippi River bears little resemblance to the natural, free-flowing river system of the past, and the lands surrounding the tributary watersheds have been extensively changed by human settlement and commerce. Over 95% of the original native prairies, savannas, and prairie/forests of the UMRB have been converted to agricultural uses (National Audubon Society 2000), with drastic affects on both terrestrial and aquatic species and communities. Land conversion, in conjunction with widespread alteration of the natural hydrologic regime, has lead to an overall loss in native aquatic diversity and ecosystem resiliency. This high degree of alteration, and measurable downward trends in the status of aquatic species and communities creates a compelling need to examine what remains of the basin's native biodiversity and the issues that must be addressed to ensure the future health and sustainability of the Upper Mississippi River ecosystem.

With the support of the McKnight Foundation and Region V of the U.S. Environmental Protection Agency (USEPA) and help from many outside partners, scientists from NatureServe and The Nature Conservancy (TNC) have identified the UMRB's areas of freshwater biodiversity significance as well as the top "fifty" areas where aquatic and terrestrial conservation priorities overlap. Our primary purpose for the assessment was to answer the question — where are the areas of greatest freshwater biodiversity significance? This report was intended to provide a comprehensive vision that will galvanize conservation and restoration action by all stakeholders at the critical places within the UMRB.

Given the years of research on the UMRB, we started by evaluating and gathering existing data. The designation of the Upper Mississippi River as "a nationally significant ecosystem" (Water Resources Development Act of 1986), has led to coordinated research efforts and greatly increased our understanding of aquatic biodiversity patterns and natural and altered ecosystem functions. However, these federal, state and academic efforts (Appendix 1) have largely focused on only small components of the basin without considering the broader basin context. A comprehensive assessment of the status of aquatic species and system diversity across the UMRB has been lacking. The Nature Conservancy has also completed conservation plans for several ecoregions that overlap the basin. While these plans provide priority areas for terrestrial and aquatic biodiversity, ecoregions were not the most appropriate assessment units to address aquatic species and systems within the UMRB as a whole. In addition the plans vary in their completeness for aquatic targets (Table 1).

Table 1. Aquatic scope of ecoregional plans in the Upper Mississippi River basin

ECOREGION	COMPREHENSIVE FOR AQUATICS	# OF AQUATIC TARGET SPECIES	% OF AQUATIC TARGET SPECIES CAPTURED IN PORTFOLIO	# OF AQUATIC SYSTEM TARGETS	% OF AQUATIC SYSTEM TARGETS CAPTURED IN PLAN
Northern Tallgrass Prairie	No	10	0%	0	0%
Superior Mixed Forest	Yes	21	42%	37	65%
Prairie-Forest Border	Yes	23	83%	24	67%
Interior Low Plateau	No	97	87%	0	0%
Central Tallgrass Prairie	No	28	57%	0	0%
Great Lakes	Yes	31	100%	231	89%

These valuable efforts have provided us with a very good understanding of the current distribution and status of aquatic species and systems on the mainstem Mississippi River, or in selected sub-watersheds. However, the work described above does not cover the basin sufficiently to support creating a comprehensive and integrated vision for the conservation of freshwater biodiversity across the whole basin. Little has been done to establish and understand the full extent of ecological linkage between the mainstem Mississippi Rivers, its major tributaries and the smaller inland sub-watersheds. By focusing only on the mainstem, for instance, the significance of tributaries to ecosystem processes and to many species can be overlooked. From an aquatic systems perspective, the mainstem represents only a small range of ecological settings, many of which exist along a continuum, well beyond the borders of the floodplain.

This report details the NatureServe/TNC assessment of freshwater biological diversity done in the context of the whole upper basin. The report begins with an overview of the Upper Mississippi system — its physical setting, the biota and the impact of its human history. We then present the methods and results of applying the Conservancy's conservation process to identify the areas of freshwater biodiversity significance. This section includes the methods used to select targets for conservation, which include rare and imperiled species and representative aquatic ecological systems. We also present the classification framework developed to describe and map aquatic ecological systems. The next sections then describe the conservation goals set for each target and the information layers used to identify the best opportunities for conservation of these targets, which included expert interviews and spatial analysis of indicators of ecological integrity.

This information was synthesized to create a network of areas that together represent the full diversity of target species and aquatic ecological systems. This network will inform conservation work across the UMRB. Our funders were also interested in what are the top fifty areas where aquatic and terrestrial conservation priorities overlap. We used the previous ecoregional analyses completed by Nature Conservancy staff as our source for terrestrial priorities and designated forty-eight Priority Areas. We show for both networks of areas how well each met the conservation goals for our targets.

Additionally, we used the wealth of biological data to create an integrated data base of all spatially located samples (Section 9) and complete a pilot analysis of biological communities (Section 10). We were able to discern 13 fish community types and from this work and gained valuable insight about what is required to create a comprehensive biological community classification and relate the communities to the physically-defined aquatic systems. In the last section, we address the data gaps encountered during this assessment.

1.2 Background: The Upper Mississippi River Basin

The Upper Mississippi River Basin is a vast floodplain river system, emerging from its source at Lake Itasca, and flowing over 1300 miles to the confluence with the Ohio River at Cairo, IL (Figure 1). Its watershed drains an area of nearly 190,000 mi^2, equivalent to 15% of the entire Mississippi River drainage, or 6% of the area of the lower 48 United States.

The Upper Mississippi River and its tributary systems operate as an ecosystem, with biota having evolved to their current (pre-European settlement) forms over millennia, in response to large-scale geologic and climatic processes. The resident aquatic species and communities, in turn, have adapted to these processes, and rely on regular cycles of environmental conditions to fulfill their life history requirements. Many species rely on small areas or single habitat types for their needs, while others are wide-ranging, utilizing multiple habitats across large areas. Under natural conditions, the backwaters of this large temperate river system created extensive fish nursery habitat and supported fish production that made the Mississippi River fishery unparalleled in North America (Burr and Ladonski 2000).

Currently, the waters of the UMRB are home to nearly 200 native, regularly occurring fishes, roughly 25% of approximately 800 species occurring in the United States (Page and Burr 1991). The basin also holds a rich diversity of freshwater mussels, crayfish, and an as yet untold number of other aquatic invertebrates. See Section 1.3 for a more detailed discussion of the composition and status of these groups. It is a globally important flyway for 60% of all North American bird species (UMRCC 2000), and also harbors diverse amphibian, reptile, and mammal faunas. The river currently supports no less than 286 state-listed or candidate species, and 36 federally-listed or candidate species of threatened or endangered plants and animals endemic to the basin (Theiling 1996, Theiling et al. 2000).

Box 1. Upper Mississippi River acronyms.

Throughout this report and other publications on the Upper Mississippi River, several acronyms are used to describe the river system.

UMRB — Upper Mississippi River Basin (Figure 1)
Includes the entire drainage area of the Upper Mississippi River, from its source at Lake Itasca, MN, downstream to its confluence with the Ohio River at Cairo, IL. The Missouri River and its tributaries are not included.

UMR — Upper Mississippi River
Northern, navigable portion of the Mississippi River, extending approximately 850 miles from St. Anthony Falls in Minneapolis, MN, to the mouth of the Ohio River at Cairo, IL.

IR — Illinois River
Begins at the confluence of the Des Plaines and Kankakee Rivers, near Channahon, IL, flowing more than 270 miles to Grafton, IL, where it joins the UMR.

IRWW — Illinois River Waterway
Includes the entire IR, and continues approximately 60 additional miles upstream along portions of several rivers and man-made channels to Lake Michigan (USACE 1987; Appendix A, Theiling et al. 2000).

UMRS — Upper Mississippi River System
The natural floodplain between the head of navigation at Minneapolis, MN, and the confluence with the Ohio River at Cairo, IL, as defined by the Water Resources Development Act of 1986, Public Law 99-662 (Figure 2).

UMR_IRWW — Upper Mississippi River — Illinois River Waterway
Equivalent to UMRS.

Figure 1. Map of the Upper Mississippi River Basin showing state boundaries and major rivers.

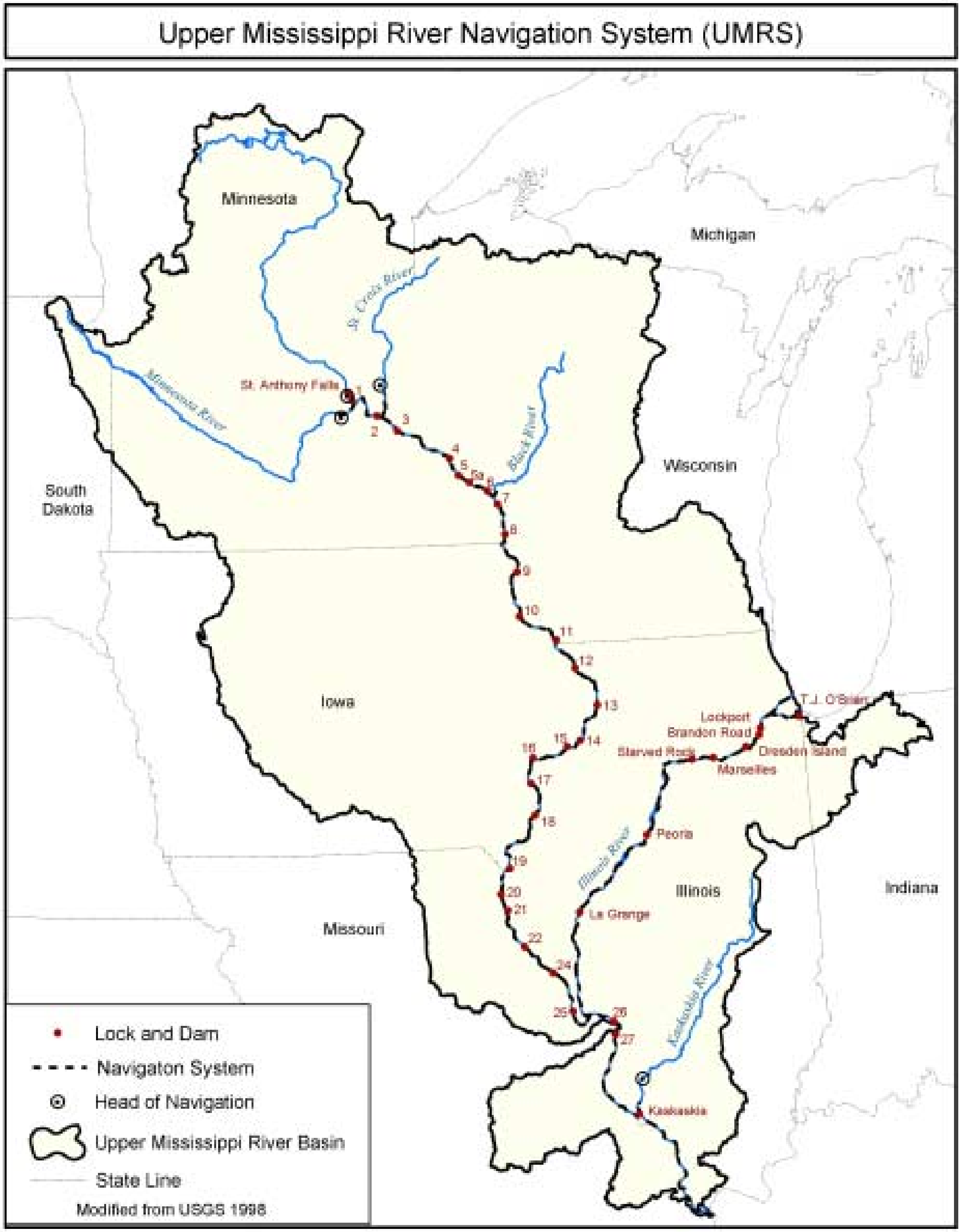

Figure 2. Upper Mississippi River System (UMRS).

The river system, its flora, and fauna have always provided diverse ecological benefits, and since its settlement, the Mississippi has supported many human uses as well. Humans have lived in the UMRB for over 11,000 years, relying upon the rich soils and waters of the basin for the cultivation of crops, and an amazing bounty of wild plants, game, and fish. The river was a transportation route for prehistoric peoples, facilitated the trade of goods from abroad, and served as a conduit for cultural exchange across long distances (Fremling and Drazkowski 2000). During most of this time, the effects of native peoples on the river was relatively minor, especially when compared to the 150 years since European "discovery", in which the river, its floodplain, and basin have been significantly influenced by the human presence (Theiling 1999). See Carlander (1954), Fremling and Drazkowski (2000), and USACE (2003) for more detailed timelines and discussion of the early exploitation of the river and its resources.

Today, the river's natural resources, scenic beauty, and cultural heritage continue to provide billions of dollars in annual revenues to local and national economies. Over 15 million people rely directly on the waters of the Mississippi River and its tributaries for drinking water (UMRCC 2000), and for many commercial and industrial uses, including pulp and paper mills, chemical and food processing, power generation, and transportation (Robinson and Marks 1994). The navigation system provides for the bulk-commodity transport of approximately 126 million tons of grain, coal, chemicals, and petroleum products per annum, and thus serves to tie Midwestern farms and industry to international markets (Robinson and Marks 1994, Theiling et al. 2000). Recreational activities including sport fishing, hunting, birding, camping, and other historical and cultural attractions draw over 12 million visitors to the basin each year, generating over 1 billion dollars in annual revenues, and supporting over 18,000 recreation related jobs (USACE 1994, Theiling 1999, Theiling et al. 2000). The river also supports a modest commercial fishery, valued at 2.4 million dollars in 1996, and a commercial mussel harvest, mostly for use in the Japanese pearl industry, valued at roughly 6 million dollars (Duyvejonk et al. 2002).

These economic benefits have, thus far, come largely at the expense of the natural ecosystem (UMRCC 2000). Development of the basin for agriculture, navigation, and industry has drastically altered the landscape, disrupting the physical and ecological processes that shape and maintain the river system, and having substantial effects on the basin's biota. Ongoing analyses have shown that certain native species and communities have declined across much of the basin, signaling deterioration in the health of the ecosystem (USGS 1999), while high public demand for use of the river's resources continues to intensify (Johnson 1992). Nevertheless, the National Research Council identified the UMRS as one of three large river floodplain systems that retain sufficient ecological integrity necessary for restoration (NRC 1992).

The following sections describe the current status of aquatic fauna in the UMRB and the major threats to aquatic biodiversity.

1.3 Aquatic Biota of the Upper Mississippi River Basin Ecosystem: an overview of diversity and imperilment.

The diversity of fauna and the patterns of its distribution across the UMRB reflect the glacial history of the basin. While at the same time the long history of glacial activity left the basin with an array of habitats, the presence of glaciers until 10,000 years ago has given the fauna little time to evolve, resulting in low levels of endemism (Robison 1986; Burr and Page 1986). Thus, while the aquatic fauna is diverse and includes nearly 300 species of fishes, mussels, and crayfishes, as well as an unknown number of other aquatic macroinvertebrates (see Appendix 2 for full species lists), the basin's fauna exhibits a relatively low degree of endemism, with possibly 18 endemic species, including 4 species of fishes (all currently awaiting formal description), 3 crayfish, 1 mussel, and 10 other aquatic macroinvertebrates. Much of the endemism is centered in the extreme southern portion of the basin in areas largely untouched by past glacial advances.

Sixty-nine aquatic species within the UMRB are currently ranked by NatureServe as globally critically imperiled (G1, 13 species), globally imperiled (G2, 14 species), or globally vulnerable (G3, 42 species) (See Appendix 3 for definitions), based on factors such as rarity, viability, trends, threats, and fragility (Master 2000). Natural resource specialists affiliated with the American Fisheries Society recognize a total of 33 fishes, mussels, and crayfish as endangered, threatened, or of special concern (Williams et al. 1989, Williams et al. 1993, Talyor et al. 1996). Nine species within the UMRB are federally listed as endangered (U. S. Endangered Species Act of 1973), with one additional fish species (Grotto Sculpin, *Cottus sp. cf. carolinae*) under consideration for future listing (Appendix 2).

Despite the relatively low endemism and diversity, the basin contains several areas recognized as nationally important areas for biodiversity. Chaplin et al. (2000) identified the Meramec River basin of Missouri, and the "driftless area" of northeast Iowa/southeast Minnesota as hotspots of rarity and species richness. The World Wildlife Fund lists an additional three sites as "important for the conservation of freshwater biodiversity in North America", including the Cache River of southern Illinois, the Fox River in Illinois, and the St. Croix River of Minnesota and Wisconsin (Abell et al. 2000).

Below, we provide a brief overview of fish, mussels and crayfish, which comprise the best known groups of freshwater organisms. For each taxa group, we briefly describe the diversity within the basin, degree of endemism, percentage of imperiled taxa within the UMRB, as well as the ecological importance, and specific major threats. Comprehensive treatment of the distribution and status of aquatic obligate herptofauna and aquatic plants was not attempted, nor have we seen it addressed in other studies.

1.3.1. Fishes

The UMRB harbors approximately 200 native, regularly occurring species of freshwater fish (Appendix 2: Table A), representing roughly one quarter of the 800 or so fish species known to occur in the United States (Lee et al. 1980, Page and Burr 1991), or about 19% of the total North American fish fauna (Burr and Mayden 1992). Seventy-eight genera of fishes in 27 families are represented in the basin, dominated by the Cyprinidae (minnows, 62 spp.), Percidae (Darters and relatives, 29 spp.), Catostomidae (suckers, 19 spp.), Centrarchidae (bass and sunfish, 19 spp.), and the Ictaluridae (bullhead catfishes, 11 spp.). The fauna also includes a number of less abundant, yet remarkable representatives of the "ancient" ichthyofaunas (Miller 1965), including the sturgeons, gars, bowfin, goldeye, and other evolutionary holdouts with origins in the pre- and early-Tertiary periods.

At the present, there are no formally described, endemic fishes in the UMRB, although there are at least four forms awaiting description that appear to be confined to the southern portion of the basin. In Missouri, there is a form of the Missouri Saddled Darter (*Etheostoma tetrazonum*), known only from the Meramec River basin (A. M. Simons, personal communication), and two forms of the Grotto sculpin (*Cottus* spp.), both associated with a single cave/stream system in the karst area of Perry County (G. Adams, personal communication). Additionally, there is an undescribed, small-eyed form of the Stonecat (*Noturus flavus*) known only from the mainstem Mississippi River between St. Louis, Missouri, and Cairo, Illinois (B. M. Burr, personal communication).

Twelve species of fish within the UMRB are currently ranked by the NatureServe as globally imperiled (G1 — G3). Two species, the Pallid Sturgeon (*Scaphirhynchus albus*) and the Topeka Shiner (*Notropis topeka*), are federally listed as endangered with a third, undescribed species, the Grotto Sculpin (*Cottus* sp.), currently being considered for listing. The American Fisheries Society (Williams et al. 1989) recognizes seven UMRB species as endangered, threatened, or of special concern, with the only consistency among the three groups being the Pallid Sturgeon. Following the NatureServe conservation ranking system (the most conservative), and including the undescribed Grotto Sculpin, roughly 6.5% of the basin's fauna are imperiled, compared with national estimates of 37% (Master et al. 2000) or 1/3 of all North American freshwater fishes (Williams et al. 1989).

Fishes have a number of direct and indirect effects on the functionality of freshwater systems. Most are predators, feeding on a variety of aquatic invertebrates as well as other fishes, directly influencing prey behavior, and controlling the abundance and species composition of aquatic assemblages. Others are grazers, consuming phytoplankton, vascular plants and algae, facilitating the transfer of nutrients from primary production. Mussels depend on fishes as hosts for their larvae, many having evolved elaborate lures to ensure the attraction of the proper host species (Mathews 1998). Fish can also serve as "ecosystem engineers", changing the physical conditions of the environment, modifying, creating, or maintaining habitats through their daily activities (Jones 1994).

The causes of decline and imperilment of freshwater fishes in the UMRB are numerous, mostly related to poor land use practices associated with agricultural and urban development, and the continued damming and severe regulation of aquatic ecosystems. The drainage of wetlands is also pervasive, responsible for direct habitat destruction and further disruption of the natural hydrologic regime. Additionally, predation and resource competition with non-indigenous species is taking an ever-increasing toll on native fishes. See Section 1.4 for a more detailed discussion of the primary threats to aquatic ecosystems in the UMRB.

1.3.2. Mussels

Sixty-two mussel species are known from within the UMRB (Appendix 2: Table B), approximately 20% of the 300 species currently known from the United States and Canada (Williams et al. 1993). Thirty-two genera are represented in two families, the vast majority in the Unionidae, and a single species, *Cumberlandia monodonta*, from the Margaritiferidae. The unionids are an ancient fauna, with evolutionary origins as early as the Middle Paleozoic, some 400 Million years ago (Smith 1976). Oesch (1995) suggests that modern day representatives of the North American fauna were most likely in place by Pleistocene times. Many populations were, undoubtedly, wiped out by advancing glaciers, but have since repopulated the upstream areas of the UMRB using fishes as host for their parasitic larvae (glochidia).

The Higgin's Eye Pearly mussel (*Lampsilis higginsi*) is the one true endemic mussel in the UMRB. Another, once widespread species, the Winged Maple Leaf (*Quadrula fragosa*), is now known from only one small area of the St. Croix River between Minnesota and Wisconsin. These two species, along with 3 others, are listed as federally endangered, representing 8% of the total UMRB fauna (62 spp.). This is in stark contrast to the 26% imperilment (16 spp.) recognized by the NatrueServe, or the 39% (24 species) of the fauna considered endangered, threatened, or of special concern by fisheries resource professionals (Williams et al. 1993). An additional 16 species appear imperiled from a basin-wide perspective, due to low average state ranks within the states constituting the UMRB, although they are not considered imperiled across their entire range. Overall, 65% of the mussel fauna in the UMRB should be considered imperiled. This is slightly lower than the national average of 69% (Master et al. 2000) or 72% (Williams et al. 1993), but underscores the status of mussels as the most imperiled of the freshwater groups. A more detailed discussion of the methodologies used to calculate mussel imperilment can be found in Section 2.1.

Mussels are sedentary filter feeders, straining plankton, organic detritus, and bacteria from the water column, and from the sediments in which they are buried. As such, they not only serve to clarify the water, but act as sinks for organic nutrients, facilitating the transfer of energy from primary producers to higher trophic levels in the ecosystem. They also create shoal habitats when in great abundance, as in historic times, and also provide substrate for algae and other organisms. They are fed upon by a wide array of terrestrial and aquatic organisms, chiefly the muskrat, but also mink, raccoons, fish, turtles, and water birds. Freshwater mussels are very sensitive to changes in water quality, and are regarded as important indicators of the health of aquatic ecosystems.

Ongoing threats to the mussel fauna of the UMRB include habitat destruction from dams, channel modification, chemical pollution, siltation, introduced species, and the loss of appropriate fish hosts. Hydrologic alterations caused by dams create unfavorable conditions for most mussels, eliminating flows, and disrupting natural nutrient, thermal, oxygen, and sediment regimes. Excessive siltation impairs respiration and feeding, and can reduce light penetration into the water column, diminishing populations of algae that mussels rely on as a food source.

Many mussels are host specific, or use only a limited range of hosts for the microscopic, dispersal stage of juveniles (gloechidia), so the distributions of mussels may be intimately linked to and influenced by the distribution of fishes (Mathews 1998). Dams block the upstream migration of fishes, and therefore limit the ability of mussels to colonize new habitats, or perpetuate existing mussel metapopulation dynamics. For instance, the blocked migration of skipjack herring, the only known host of the ebony shell mussel (*Fusconaia ebena*), has been implicated in the near eradication of the mussel species above Lock and Dam 19, at Keokuk, Iowa (Tucker and Theiling 1999). Many mussel populations in the UMRB consist only of older adults because the absence of an appropriate host species leads to recruitment failure.

1.3.3. Crayfish

Twenty-two species of crayfish can be found in the UMRB (Appendix 2: Table C), representing 6.5% of the 338 species known from the US and Canada (Taylor et al. 1996). Five genera are represented, all in the Family Cambaridae, dominated numerically by the genus *Orconectes* (11 species). Other genera represented in the basin include: Cambarus (4 spp.), Procambarus (4 spp.), Cambarellus (2 spp.), and Fallicambarus (1 sp.). UMRB crayfish inhabit a variety of flowing and standing water habitats, including subterranean and semi-aquatic systems. The highest diversity within the UMRB is evident in the southern portion of the basin, where past geological and hydrologic activities have created highly variable physical features. In this area, one finds lowland sloughs and swamps, Ozarkian uplands, prairie and big river habitats, each with its own, characteristic faunal assemblage.

Three endemic crayfish are known from the basin (*Cambarus maculatus*, *Orconectes harrisoni*, and *O. medius*), all located in the Meramec River drainage of Missouri. There are no federally listed crayfish species in the basin, and no candidates, although resource professionals consider two species, *O. illinoiensis* and *O. harrisoni*, to be of special concern (Taylor et al. 1996). The NatureServe ranks one species, *Cambarus hubrichtii*, as imperiled (G2), due to its small range and the sensitivity of its subterranean habitat, and two species, *O. illinoiensis* and the endemic *O. harrisoni* as vulnerable (G3). Considering these three species, the crayfish fauna of the UMRB exhibits a relatively low degree of imperilment (12.5%) when compared to estimates for the US imperilment of 48% (Taylor et al. 1996) and 51% (Master et al. 2000).

Crayfish are invaluable components of aquatic ecosystems, facilitating the cycling of nutrients, and serving as an important food source for many animals. They are omnivores, feeding opportunistically on a wide variety of plant and animal materials, both live and dead.

Crayfish serve as an important link in the food chain between plants and vertebrates, breaking down dead plant material (detritus) otherwise resistant to decomposition (Pflieger 1996). Organisms that rely on crayfish as a major food source, include numerous fishes, birds, reptiles, mink, and other mammals.

Threats to crayfishes in the UMRB are similar to those affecting other aquatic taxa, including degradation and destruction of habitat, chemical pollution, excess sedimentation, introduction of non-indigenous species, and the small natural range of many species (Williams et al. 1993, Warren and Burr 1994, Taylor et al. 1996). Crayfish are particularly affected by dredging and channelization of streams, as removal of gravel, boulders, woody debris, and vegetation reduces the amount and quality of available cover, increasing susceptibility to predation (Taylor et al. 1996). In the northern portion of the basin, introduction of the non-indigenous Rusty Crayfish (*Orconectes rusticus*) represents a serious threat to native species. Introduced through bait-bucket introduction, the Rusty Crayfish is a large-bodied, highly aggressive species that displaces native species through direct resource competition and hybridization (Taylor 2000).

1.3.4. Other Macroinvertebrates

The UMRB harbors a rich diversity of other aquatic macroinvertebrate groups, including, but not limited to, insects, gastropod mollusks, and non-crayfish crustaceans such as isopods and amphipods. For these groups, the total number of species inhabiting the basin is currently unknown, due largely to the patchiness of sampling across the entire basin, and instability in the nomenclature of many groups. However, over 350 macroinvertebrates have been documented from the mainstem UMRS alone (Theiling et al. 2000), suggesting the possible occurrence of one to several thousand species basin-wide. Of the species currently known to inhabit the UMRB, 42 species are currently listed by the NatureServe as globally rare (G1 — G3). Of these species, only two are federally listed as endangered, the Illinois Cave Amphipod (*Gammarus acherondytes*), and the Hine's Emerald Dragonfly (*Somatochlora hineana*).

These organisms play an extremely important role in aquatic ecosystems, serving as food for fish, grazers of algae, links in the life cycles of parasites, and processors of organic materials, including leaves and biofilms (Strayer 2000). A concerted effort to enumerate and evaluate the status of the total aquatic invertebrate fauna in the basin is necessary. A more complete discussion of data needs for aquatic invertebrates can be found in Section 10.

1.4. Major Threats to Aquatic Biodiversity in the UMRB

The aquatic ecosystems of the UMRB have been altered extensively. Declines in freshwater fauna can be attributed primarily to the intensive human use of their habitats (Master et al. 1998). Anthropogenic effects of dam construction, water withdrawals for municipal and industrial uses, incompatible land conversion, and the widespread introduction of exotic species have taken their toll, as evidenced by decreases in species abundance, an increased frequency of extreme floods, and an ever-growing list of endangered species (Mac 1995).

Since the passage of the Clean Water act of 1972, the United States has improved its regulation of pollution discharges from various industrial and municipal discharge points around the basin. These actions have caused some encouraging trends, with marginal water quality improvements accompanied by an increase of diversity in some aquatic communities. But degradation of the UMRB continues as our use of the landscape continues to alter the character of the riverine ecosystems.

The major threats to aquatic biodiversity in the Upper Mississippi today are consistent with those affecting aquatic ecosystems across all of North America: alteration of natural land cover; water quality degradation; alteration of hydrologic integrity; habitat fragmentation; and the proliferation of exotic species (Abell et al. 2000). Although it does not occur at historic levels, direct exploitation of aquatic species is an ongoing threat to some taxa. Global climate change has been hypothesized as a future concern (WEST 2000), with projected changes in rainfall and seasonal temperatures thought to pose a significant threat to the especially sensitive climatic zones of the UMRB (Bryson 1966). We will discuss three sources of these threats — land cover alteration, drainage and dams, and exotic species – in greater detail.

1.4.1. Land Cover Alteration: sediments, nutrients and altered hydrology

The most pervasive impact to aquatic systems in the UMRB is from alteration of natural land cover and associated degradation of water quality. The degree of land cover alteration in North America is strongly correlated with human population density in areas of urban growth (Abell et al. 2000), but in the UMRB, conversion of rural lands for agriculture is the larger contributor. Nearly 66% of the UMRB is managed for agricultural uses (NLCD 1992), significantly above the national average of 45% (Allen 1995, Knutson et al. 1990). Urban and suburban development in the basin is largely confined to cities along the rivers, and accounts for roughly 3% of the basin area (NLCD 1992). Only about 20% of the UMRB now remains in natural cover.

The loss of natural cover has led to dramatic increases in non-point sources of pollution, including increased water and sediment flow, and excessive chemical and nutrient inputs. Cropland is often cleared right up to the stream bank, removing vegetation that once functioned to slow the flow of water from upland areas, trapping sediments and other toxins before they could enter streams and lakes. A large proportion of the agricultural area of the upper Midwest is underlain with subsurface drainage tiles, which further speeds the delivery of excess water, sediment, and chemical pollutants to streams. Unnatural sediment inputs alter the physical character of streams, and can smother the stream bottom, destroying critical habitat for aquatic organisms. Excess nutrients are known to cause dramatic changes in energy flow in aquatic systems, increasing primary productivity and possibly shifting the composition of the biotic communities (Fajen and Layzer 1993). Other effects associated with the loss of riparian cover, such as increased light and temperature levels, and the reduced inputs of organic matter to streams, can also have detrimental effects on the ecological function of aquatic systems.

The effects of non-point source pollution resulting from urbanization are no less detrimental, although in the UMRB, they are much more localized than those of agriculture. Storm water and other runoff can carry sediments, heavy metals, oil, and large amounts of organic matter that can deplete oxygen levels in streams (Master et al. 1998), making them inhospitable to aquatic life. Other sources of pollution associated with urban areas include municipal waste, household chemicals, sediments and other contaminants from construction activities, and the large-scale use of fertilizers and pesticides on lawns, golf courses, and parklands.

In urban areas, a greater threat from land use change is altered water flows resulting from impervious surface runoff. Impervious surfaces consist of two primary components, rooftops and the transportation system, consisting of roads, driveways, and parking lots (Schueler 2000). A number of studies show that water quality is significantly degraded once the impervious cover in a watershed reaches ~10% (Booth 1991, Booth and Reinelt 1993, MWCG 1995). As the percent impervious cover increases, urban pollutant loads increase (Schueler 1987), stream temperature increases (Galli 1991), channel stability and fish habitat quality decreases (Booth 1991), as do aquatic insect diversity and abundance (Klein 1979, Jones and Clark 1987).

1.4.2. Drainage and Dams: alteration of hydrologic integrity and habitat fragmentation

The aquatic species and communities in the UMRB have evolved over thousands of years in response to the natural variability in the hydrologic regime, and are dependant on the seasonal availability of nutrients and specialized habitats to complete their life cycles. Even subtle changes in habitat availability may lead to drastic declines in the productivity or diversity of aquatic systems (Mac 1995). More than two hundred years of human activity in the basin have had profound effects on the natural hydrologic regime, greatly altering in-stream habitat, and affecting the abundance and distribution of aquatic species (Wiener et al 1998).

The highly modified drainage networks in the UMRB include millions of acres of wetland drainage, thousands of miles of field tiles, road ditches, channelized streams and stormwater sewers, all designed to convey water off of the land as quickly and efficiently as possible. This modern efficiency means that water reaches rivers more quickly, with greater velocity, and at higher stages than in the past (Bellrose et al. 1983, Gowda 1999). Thus, severe flood events are more frequent and the hydrologic integrity of the stream systems has changed dramatically. In response to higher flows, stream channels typically increase their cross-sectional area, either through widening of the stream banks, down-cutting of the stream bed, or both (Schueler 2000). The cumulative effects of these erosion processes are not confined to the stream channel, but can cause disruption of the flood regime, which changes critical river-floodplain interactions, thereby degrading adjacent floodplain ecosystems (Shankman 1999).

The presence of dams in the UMRB represents one of the most serious threats to the hydrologic and ecologic integrity of aquatic ecosystems. There are no less than 4600 major dams across the basin, i.e., those greater than 6 feet in height *and* with more than 50 acre-feet in storage (USACE 1999). The distribution of dams is biased towards large rivers, as the relatively small size of headwater streams do not lend themselves to large, flow-harnessing structures (Abell et al. 2000), although there are perhaps many thousands of additional small dams scattered throughout the smaller creek and headwater systems of the basin. These smaller dams, many unregistered and therefore innumerable, were originally built to serve a number of purposes, including small-scale flood prevention, water for livestock and irrigation, milling, and to create habitat for recreational fisheries. Due to changes in historical land use and the societal needs, many are now obsolete, even dangerous, their negative effects on aquatic ecosystems greatly outweighing their human benefits.

Dams and their associated operations have widespread and pervasive effects on freshwater life (Collier et al. 1996). Their construction alters natural flow and temperature regimes, and disrupts nutrient and sediment pathways. Reservoirs flood valuable riffle and swift-water habitat necessary for many species life cycles (Fahlund 2000). Dams pose a direct barrier to species dispersal, including the continuous downstream drift necessary for the development of eggs and larvae of many riverine species. The downstream effects of a single dam can alter the character of an entire watershed (Master et al. 1998), resulting in the destruction of native plant and animal communities, and an overall reduction of natural biodiversity. On the other hand, there are potential benefits of small dams, which can isolate upstream areas from invasion from exotic species.

Nowhere are the effects of dams and associated water control structures more prevalent than on the mainstem Mississippi and Illinois Rivers. Once free-flowing, and characterized by a mosaic of braided channels, islands, and wetlands, the Upper Mississippi River is now a severely regulated river, controlled by a series of 40 locks and/or dams from the headwaters at Lake Itasca, MN, to St. Louis, MO (Fremling et al. 1989). The series of dams upstream of Minneapolis are essentially managed for flood control, wildlife habitat, and recreation, while the downstream locks and dams are operated primarily for commercial navigation. An additional 8 dams with locks exist on the mainstem Illinois River, and together, they constitute the Upper Mississippi River Navigation System (UMRS) (Figure 2).

The federal government has extensively altered the river and its backwaters to make the river safe for large-scale commercial navigation, and make it feasible to farm the rich alluvial soils of the floodplain. Their actions, which began in 1824 and continue to this day, have included with snag and sandbar removal, removal of rock rapids and the closing of side channels, and construction of hundreds of wing and closing dams, shoreline protection areas, 29 navigation dams, and hundreds of kilometers of levees (Burr and Ladonski 2000).

The dams have formed a series of broad, shallow impoundments, creating a continuous 9-foot deep, slack-water navigation channel throughout the system. In many pools, the natural character of the river has been replaced with a repetitive longitudinal habitat structure (Lubinski 1999). The upper portion of each pool still maintains many original riverine qualities, and is relatively free-flowing, with habitat proportions similar to those that existed before impoundment. The lower end of many pools contain a significant area of open water, and are more lake-like in nature. Each area supports a species assemblage most suited to its particular conditions, and there is often a variably sized transition zone between the two ends that harbors species adapted to both (Lubinski 1999).

The inundation resulting from dam construction has caused major shifts in the availability of aquatic habitats and the land cover of the river floodplain. In general, aquatic habitats for fish and wildlife were initially increased, but at the expense of terrestrial cover classes. Any benefits for aquatic species that may have once existed have been reduced substantially by the erosion and deposition cycles associated with the reservoir aging process (Wlosinski et al. 1995). Areas just upstream of the dams are filling with sediment, resulting in the homogenization of depth across the river channel. The immediate downstream effects of the dams are equally problematic. Increased water flow below dams has resulted in channel deepening, which in turn, draws water out of side channels and backwater areas, causing these critical habitats to dry up (Sheehan and Rasmussen 1993).

Much of the mainstem Mississippi and Illinois Rivers have also been leveed for flood control, destroying the lateral connectivity between the river and its floodplain. Many aquatic species have adapted to rely on a natural, seasonal "flood pulse" to cue migrations, and provide access to areas outside the main channel important for feeding and reproduction. In natural situations the wetlands and forests of the floodplain perform valuable ecosystem services, providing storage area for flood waters, managing sediment loads, and providing critical habitat to wildlife species. Isolation of the floodplains by levees alters the natural "flood pulse", denies critical access to the floodplains for fish and wildlife, and prevents the transfer of sediments and nutrients critical to wetland and floodplain forest ecosystems. Approximately 40%, or 998,000 acres of the original floodplain area in the UMRB is currently behind levees, isolated from the river during all but the highest discharge rates (USACE 2000).

Wing dams and closing dams have further constrained the river, diverting the power of the river waters into a single channel. These structures, in conjunction with levees, have had drastic effects on river habitat by changing the relationship between discharge and water-surface elevations (Wlosinski et al. 1995). Wing dams have narrowed and deepened the main channel, while levees restrict the lateral flow of water onto the floodplain. The result has been lower water elevations at low discharge, and higher water elevations during high discharge, well outside of historical levels. This, in turn, has led to an increase in the frequency and severity of floods and increased delivery rates for sediment and nutrients to downstream areas. Overall, the hydrological characteristics of the Upper Mississippi River bear little resemblance to pre-impoundment conditions.

1.4.3. Non-indigenous Species: trophic disruption

Perhaps the most severe rising threat to native biodiversity in the UMRB is the introduction and establishment of non-indigenous species — species introduced beyond their native range by humans. Introductions in the UMRB started with the first European immigrants to the basin, and biological invasions continue today, with some species becoming established and spreading at alarming rates. The spread of non-indigenous species threatens to homogenize the basin's flora and fauna, which represent thousands of years of unique evolutionary history (Williams and Meffe 2000).

Non-indigenous species arrived in the basin from a variety of sources. Intentional stocking of fishes for sport and commercial purposes began in the late 1800's (Burr and Ladonski 2000), and continues today. Initially, this practice was viewed by many as positive enrichment of the native biota, with some introductions providing economic and recreational benefits, including enhanced sport fishing opportunities and a reliable, high-quality food source via aquaculture (Bjergo et al. 1995). Many others have proven economically and ecologically expensive (Williams and Meffe 2000). Several species have been intentionally introduced through the release of unwanted aquarium specimens, although most are unable to become established due to low winter temperatures or the lack of conspecifics with which to mate. Still others have become established as a result of inadvertent release of unused fishing bait. Whether intentional or not, the environmental consequences of the introductions are generally harmful, and can be catastrophic (Taylor et al. 1984).

Many of the most recent invasions have occurred by means of natural dispersal following release in areas outside the UMRB. In 1900, the Chicago Sanitary and Ship Canal was built to remove municipal waste removal from the Chicago-metropolitan area. The Canal connected Lake Michigan to the Des Plaines River, representing the first permanent connection between the Mississippi River and the Great Lakes. Since that time, at least one highly invasive species the Zebra Mussel (*Dreissena polymorpha*), has colonized much of the UMRB by way of the canal. Another, potentially more dangerous invader from the Great Lakes, the Round Goby (*Neogobius melanostomous*), is now common in the Upper Illinois Waterway, poised to wreak havoc in the UMRB. More highly invasive fish such as the Asian carp are moving into the basin from the south, causing profound changes in the aquatic ecosystem.

An examination of the USGS Nonindigenous Aquatic Species database (USGS 2003) reveals that no less than 55 nonindigenous aquatic animals and 12 nonindigenous plant species have been recorded from the UMRB (Appendix 4). Fifty-three percent (47 species) consist of fish species, subspecies, and hybrids native to North America, now distributed beyond their native range. Most were intentionally stocked as game- and forage-fish but many were unintentionally established through the inappropriate release of unused baitfish. There are at least 17 additional species of exotic fishes, seven mollusks (three bivalves, two gastropod snails), two crustaceans (a crayfish and an amphipod), two hydrozoans, and a single exotic cladoceran known to occur in the UMRB. Additionally, there are 12 nonindigenous plant species found in the basin. Three highly invasive species have now become established across vast areas of the basin: Eurasian Watermilfoil (*Myriophyllum spicatum*), found in 16 of 17 sub-basins within the UMRB; Curly Pondweed (*Potamogeton crispus*), 14 of 17 sub-basins; and Purple Loostrife (*Lythrurum salicaria*), 11 of 17 sub-basins.

Often, habitat degradation and the disruption of natural ecological processes allow exotics to gain a foothold. Aquatic species in the UMRB may be especially vulnerable, as the effects of nonindigenous species are magnified by widespread habitat disturbance. Once established, nonindigenous aquatic species can profoundly change biological diversity and habitat composition in ecosystems, which may result in substantially increased rates of extinction of native aquatic species (Bjergo et al. 1995). Miller et al. (1989) credit nonindigenous species with causing the extinction of 27 species and three subspecies of fish in the United States over the past 100 years.

The effects of nonindigenous species on the population structure and function of native ecosystems is well documented. Native species are often displaced through predation, or direct competition for food and habitat, causing profound disruptions in the natural trophic structure of communities. When invasive species substantially modify the existing habitat, they eliminate refugia, and interfere with natural reproductive cycles. Miller et al. (1989) document the decline of native fish species by genetic swamping through hybridization with nonindigenous species. In some cases, exotics have introduced non-native parasites and disease, decimating native populations of aquatic taxa.

The resultant alterations of water, nutrient, and energy cycles, and of the productivity and biomass of ecosystems, directly affects human society (Williams and Meffe 2000), yet the long-term extent of problems associated with non-indigenous species remains largely unknown. In most cases, biological invasions are not noticed until the situation becomes critical, and the elimination of the transgressors is all but impossible. As the world becomes more accessible to people and goods from abroad, the opportunity for future biological invasions will no doubt increase, representing a substantial future threat to the biodiversity of the UMRB.

2. Conservation targets

The biodiversity of the UMRB is comprised of numerous species and communities, making it impractical, and given data limitations, impossible, to evaluate each for conservation planning. Conservation targets are a sub-set of species and communities, and all ecological systems, which are selected to comprehensively represent the biodiversity of the basin. The conservation targets for the Upper Mississippi River Basin assessment included imperiled and rare species and aquatic ecological systems, and a few representative natural communities. The following sections describe the methods used to select these species and system targets. Representative natural communities were described by experts on an ad-hoc basis without a formal classification and hence are not listed in this report. Information on intact native assemblages was one of the factors to designate Areas of Biodiversity Significance.

2.1 Species

A total of 153 species targets were addressed in this assessment (Table 2 and Appendix 5). The initial step to identify species-level conservation targets involved generating complete lists of all fish, mussel, and crayfish taxa known to occur in the UMRB (Appendix 2). We did not attempt to compile a full list of non-crayfish macroinvertebrate fauna in the UMRB. Species were then categorized based on their conservation status, and distribution relative to the UMRB, and those species in the following categories were considered as targets.

- Imperiled Species (G1-G3 ranked species)
- Federally listed Threatened and Endangered Species
- Other species of special concern
  - declining species
  - endemic species
  - disjunct species
  - vulnerable species
  - focal species — keystone and wide-ranging species

Species of special concern were identified from a series of publications, including those from the American Fisheries Society, which listed fish, mussel, and crayfish taxa as threatened, endangered, or of special concern (Williams et al. 1989, Williams et al. 1992, Taylor et al. 1996).

For fishes, mussels, and crayfish, individual species distributions within the basin were analyzed, revealing several examples of species whose global distribution was stable, but were imperiled within the basin. This trend was especially evident in the freshwater mussels. Each mussel species was investigated state-by-state, and ten species with an average state rarity rank (S-Rank) of 2.5 or less were added to the list. Fish and crayfish targets falling in this category tended to be peripheral species, characteristic to the Ozark and Coastal Plain habitats in the southern portion of the basin. While these species were better represented in habitats outside the basin, several were added to the list to ensure that this aspect of ecosystem diversity would be captured.

Only G1-G3 macroinvertebrate (insects, snails, non-crayfish crustaceans) taxa were considered as targets. Additionally, a number of herptile species were considered as targets due to their limited distribution within the basin, and their requirements for both high quality terrestrial and aquatic habitats.

Table 2. Number of Species Targets by Taxa Group. Not all taxa known to occur in the basin have point location data available.

TAXA GROUPS	TOTAL TARGETS	TARGETS WITH SPATIAL DATA
Fish	36	31
Mussels	40	40
Crayfish	10	8
Herptiles	23	14
Insects, Snails, Amphipods	44	36
TOTAL	153	129

2.2 Aquatic Ecological Systems

Identifying aquatic ecological systems as conservation targets for this assessment involved developing and applying a hierarchical classification framework. Spatially hierarchical classification provides a specific advantage to understand freshwater ecosystems. Freshwater habitats and their biological components are shaped by a hierarchy of spatial and temporal processes (Frissell et al. 1986; Mathews 1998). Patterns of continental and regional aquatic zoogeography result from drainage connections that changed over time in response to climatic and geologic events (Bussing 1985; Hocutt and Wiley 1986). Regional patterns of climate, drainage, and physiography influence aquatic ecosystem characteristics such as morphology and hydrologic, temperature and nutrient regimes, which in turn influence biotic patterns (Swanson et al. 1988; Pflieger 1989; Poff and Allan 1995). Within regions, finer-scale patterns of stream and lake morphology, size, gradient, and drainage network position result in distinct aquatic assemblages and population dynamics (e.g., Tonn and Magnuson 1982; Angermeier and Winston 1999, Lewis and Magnuson 1999; Mathews 1998).

In this assessment, we employed the freshwater ecosystem classification framework developed by The Nature Conservancy (Higgins 2003). The framework, depicted in Figure 3, classifies environmental features of freshwater landscapes at four spatial scales, Aquatic Zoogeographic Unit, Ecological Drainage Unit, Aquatic Ecological System and Macrohabitat.

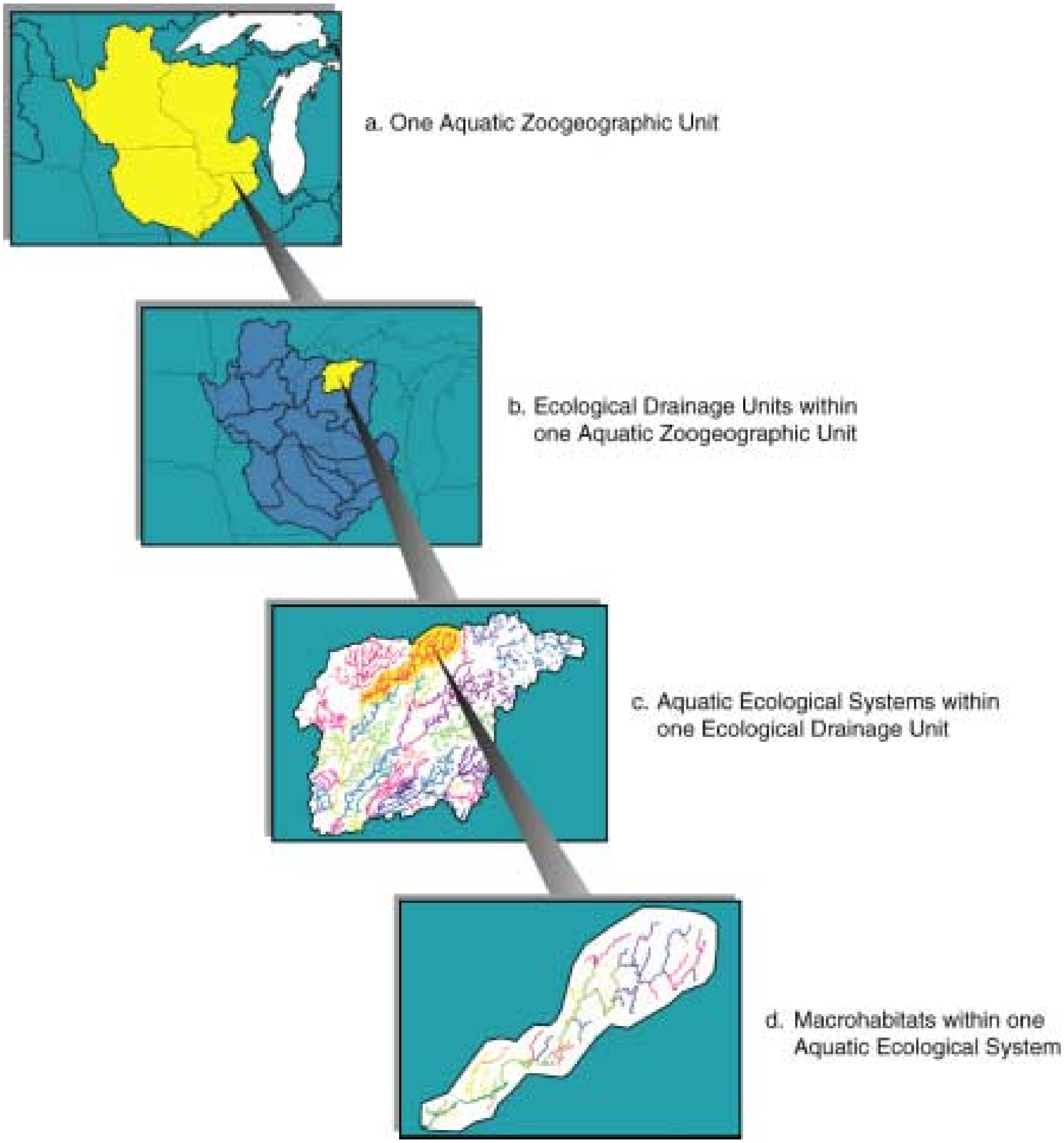

Figure 3. The Nature Conservancy's freshwater ecological classification framework.

2.2.1 Aquatic Zoogeographic Units

The broadest level of the classification is **Aquatic Zoogeographic Units,** which are large-scale drainage basins distinguished by patterns of native fish distribution. Aquatic zoogeographic units account for the geologic, climatic, and biologic history shaping present freshwater ecosystems: the fish distribution patterns are a result of large-scale geoclimatic processes (e.g., ice age glacial activity) and evolutionary history (Maxwell et al. 1995; Abell et al. 2000). In the UMRB, we defined three aquatic zoogeographic units, coinciding with portions of three aquatic subregions (Figure 4) as defined by Maxwell et al. 1995. Aquatic subregions were delineated qualitatively, after Hocutt and Wiley (1986) and various "Fishes of…" books (Clayton Edwards, USFS, personal communication). The UMRB contains the Upper and Middle Mississippi sub-regions entirely and a small portion of the Central Prairie Subregion.

The spatial patterns of aquatic fauna that we see in the UMRB today reflect the unique geomorphic history of the area. Repeated glacial advance and retreat during the Pleistocene forced the dispersal and isolation of fish and other aquatic species, allowing unique faunal elements to develop. The final glacial retreat, created new drainage patterns and subsequent mixing of faunas that has resulted in the present patterns of subregions in the Upper Mississippi River Basin (Maxwell et al. 1995). For a detailed discussion of drainage evolution in the UMRB and its implications for the aquatic fauna, see Burr and Page (1986), Cross et al. (1986), and Robison (1986).

The most distinctive aquatic subregion, in terms of both zoogeographic and physiographic characteristics, is the Central Prairie subregion portion of the southwest UMRB. This area, consisting of the Meramec River basin of Missouri, is part of the Interior Highlands physiographic province (Cross et al. 1986), and remained unglaciated through the Pleistocene. Nevertheless, the series of glacial advances had pronounced effects on the fauna, creating a large and complex assemblage of fishes, with a higher level of fish diversity and endemism than elsewhere in the basin. Pflieger (1971) cites numerous examples of the apparent southward dispersal of northern fishes through connections that developed with glaciation, and varying patterns of dispersal and isolation subsequent to glacial retreat. Similar patterns have been documented in boreal caddisflies and stoneflies (Ross 1965), amphibians (Smith 1957), and crayfish (Pflieger 1996).

The zoogeographic distinctions between the Upper and Middle Mississippi sub-regions are not as clear. Maxwell et al. (1995) provide no accounting for the specific zoogeographic characteristics used in their delineation of the two. Overall, the fish faunas of these two sub-regions are relatively uniform, with neither exhibiting any real degree of endemism. One notable exception is an undescribed form of the Stonecat, *Noturus flavus*, known only from the mainstem Mississippi River between the mouths of the Missouri and Ohio river (B.M. Burr, personal communication).

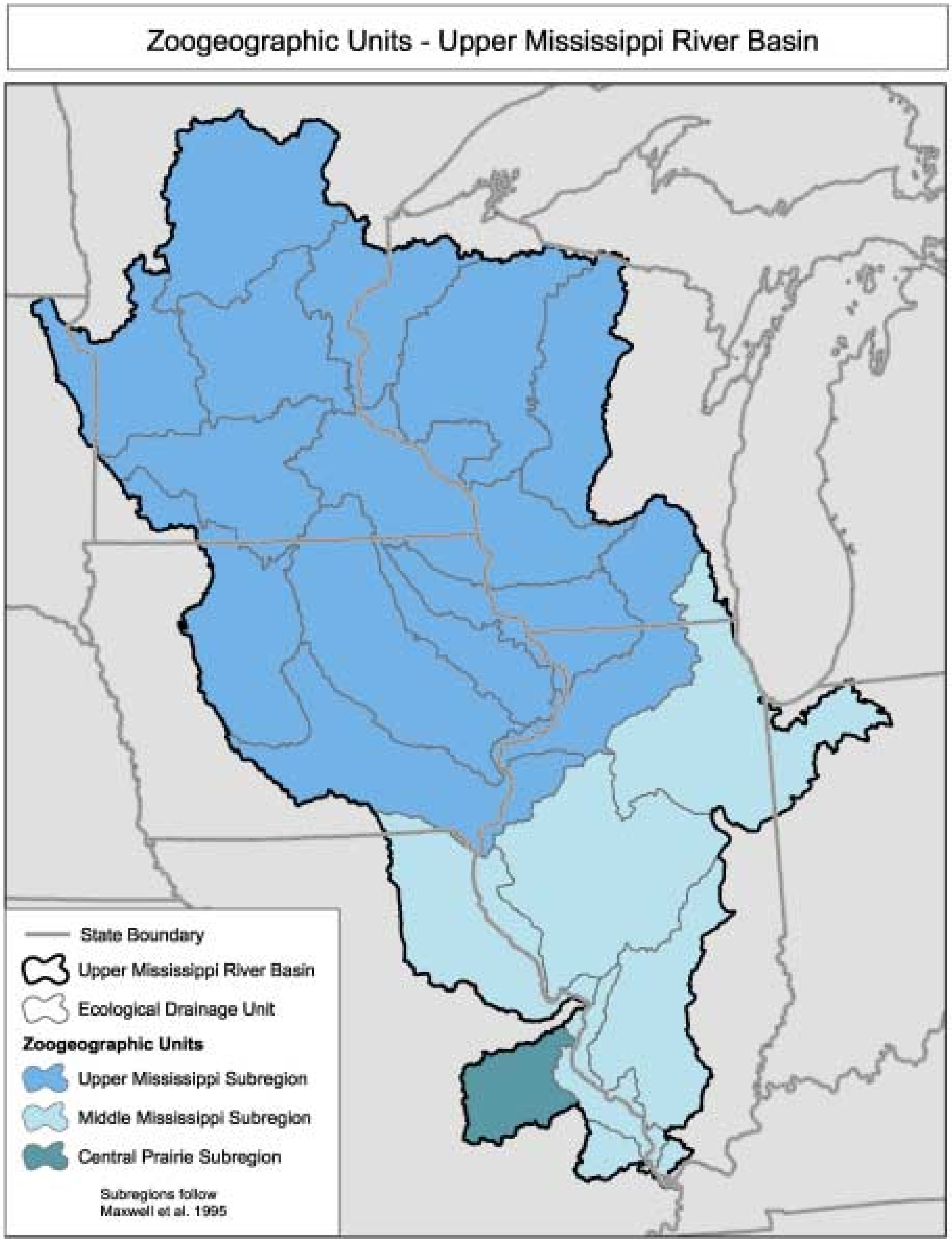

Figure 4. Aquatic Zoogeographic Units in the UMRB.

In an analysis of 19 major drainages within the Lower Ohio-Upper Mississippi River Basin, Burr and Page (1986) identified two phenetic basin groupings based on percent shared fish taxa: (1) the Ohio River Fauna and (2) the Mississippi River fauna. Within the Mississippi River fauna, they observed an additional two major clusters: a southern and central cluster of four drainage units (Cache, Kaskaskia, Illinois, and Kankakee rivers) and a northern cluster of eight drainage units (Des Moines, Iowa-Cedar, Rock, Wapsipinicon, Wisconsin, Chippewa, St. Croix, and Minnesota rivers). These two clusters agree with Maxwell et al. (1995), and provide to recognize to two separate Mississippi subregions.

There are examples of unique habitat and fauna within each of the sub-regions, due to the differential geomorphological history of each area and/or patterns in post-Pleistocene dispersal from adjacent subregions. For instance, the extreme southern portion of the Middle Mississippi Subregion in Illinois includes a thin band of unglaciated, Ozarkian streams and associated taxa in the Shawnee Hills, and a number of lowland habitats and taxa associated with the northern boundary of the Mississippi Embayment. Nevertheless, with the exception of the Cache River basin of Southern Illinois, naturally an Ohio River tributary (now directly connected to the Mississippi River through a flood control channel), no two watersheds within the two sub-regions exhibit less than 62 % similarity in their fish faunas (Burr and Page 1986).

2.2.2. Ecological Drainage Units

Where Aquatic Zoogeographic Units reflect major patterns in endemism and fish community structure, Ecological Drainage Units (EDUs) account for the variability within zoogeographic units due to finer-scale drainage basin boundaries and physiography. EDUs are groups of watersheds that not only share a common zoogeographic history but also share physiographic and climatic characteristics. EDUs likely have a distinct set of species assemblages and habitats and provide ecologically-meaningful stratification units that insure that we are protecting conservation targets across key environmental gradients. Sources of mapped physiographic and climatic data include ecoregion descriptions, surficial geology and lithology maps and hydrography data (Figure 5). We used the three zoogeographic subregions to guide the development of the EDUs.

Additional sources of information used in the delineation of EDUs for the UMRB included: zoogeography (Hocutt and Wiley 1986, Maxwell et al. 1995); ecoregional sections and subsections (Albert 1995, Bailey et al. 1995, Keys et al. 1995, Omernik 1987 and 1988); and numerous state fish books and peer-reviewed publications. To gain further insight into zoogeographic patterns in the basin we performed a cluster analysis (PC-ORD version 4.x) of fish distributional data by 8-digit hydrologic catalog unit (NatureServe 2001). While not definitive, repeating spatial patterns in fish distributions were observed, allowing greater confidence in many of the EDU designations. A complete list and brief description of each EDU can be found in Appendix 6.

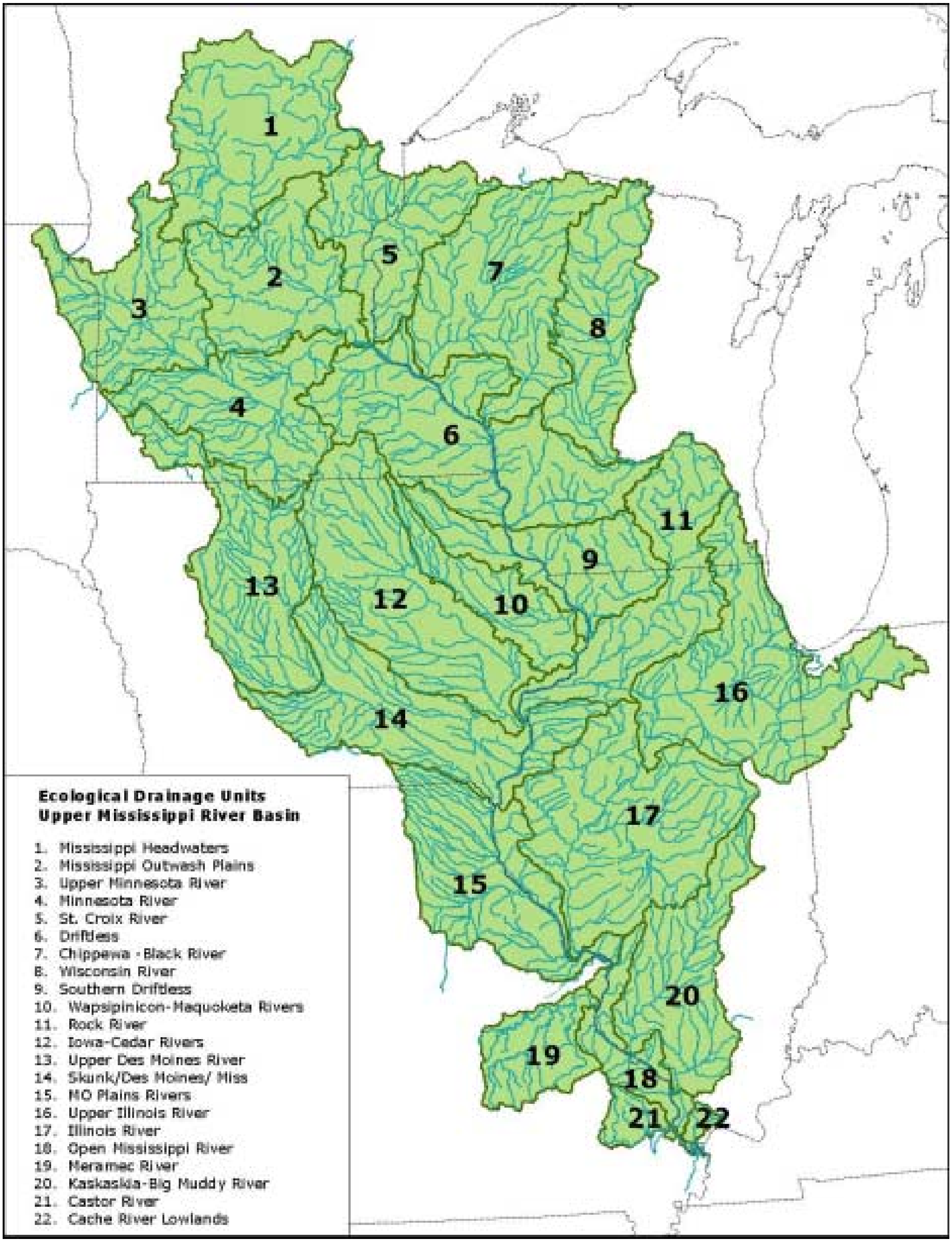

Figure 5. Ecological Drainage Units in the UMRB.

2.2.3 Aquatic Ecological Systems

The next finer level of the classification framework is the Aquatic Ecological System. Given that sufficient biological information to classify or describe freshwater communities or freshwater ecosystems seldom exists, we rely on models to classify and map environmental patterns in freshwater ecosystems that are known to influence the distribution and abundance of freshwater biodiversity. Aquatic ecological systems are ecological units that represent stream, lake and wetland networks that are distinct in terms of the nutrient flow, energy exchange and have distinct characteristics that have been shown to influence the types and distributions of communities and individual species. Aquatic ecological systems are characterized by distinct combinations of key ecological factors. These factors may vary by region. We defined aquatic ecological systems based on the distribution of finer-scale units we call Macrohabitats, which are discussed in detail below along with the specific factors used to define distinct ecological settings (Tables 3 and 4). The aquatic ecological systems are essentially aggregations of macrohabitats that show a repeating pattern. The following sections describe how this basic method was applied to classify headwater, creek, medium river, large river and big river systems, and lake systems. A total of 238 unique stream and river system types and 28 lake types were identified across the UMRB. The aquatic systems types are defined in Appendix 7.

The first step to define aquatic ecological systems was to define size classes of streams that correspond to significant changes in habitat characteristics (see Table 5). We then delineated watersheds for each of the five sizes of streams. The second step was to assign a system type to each watershed. For the smallest three size classes we assigned the system type based on the macrohabitat types found within each drainage. We used cluster analysis, which grouped the watersheds into types based on how similar each was in terms of its macrohabitats, measured as total length of stream of each type occurring within the watershed. Treating the cluster types as a draft classification, we then overlayed the clusters on maps of geology, hydrography, and elevation to determine if the clusters made ecological sense. For the 27 large rivers in the UMRB, we classified each as a unique system type either because of the landscape setting or because it occurred in a different ecological drainage unit.

The big river systems types were defined using a classification framework parallel to but distinct from that described above. The federal and state agencies (USGS, USFWS, State DNR's) accountable for the mainstem Mississippi River recognize three hierarchical management units, the Floodplain Reach, Geomorphic Reach, and Navigation Pool (Figure 6), USGS 1999, Thieling et al. 2000, WEST 2000). While these management units are constrained by the presence of man-made structures (locks and dams), their boundaries were designed to coincide as closely as possible with the natural breaks in environmental gradients and habitats that existed prior to impoundment. This framework creates 18 unique, mainstem Big River system types (Appendix 7), with a total of 32 occurrences.

The Floodplain Reach (FPR) level of classification was delineated based on physiography and land use characteristics, including width, habitat composition, vegetation coverage, presence of dams or levees, and geomorphological characteristics (USGS 1999). This level of classification is similar in scale to that of the EDU, and stratifies the mainstem Mississippi River into meaningful assessment and management units.

Units at the Geomorphic Reach (GMR) level are fully nested within the Floodplain Reaches and are based on valley and floodplain morphology, geologic controls, gradient properties, and sediment transport characteristics (WEST 2000). These factors create the template upon which plant and animal communities and habitats develop (Theiling et al. 2000). We used the 18 Geomorphic Reaches defined by the US Army Corps of Engineers (WEST 2000) as the spatial unit on the mainstem UMR-IWW that would best approximate the Aquatic Ecological System level of the classification hierarchy.

The Navigation Pools are bounded on each end by lock and dam structures. Each Navigation Pool within a particular Geomorphic Reach is an occurrence of that system type. The pools vary in terms of hydrologic regime and number of aquatic/geomorphic habitats (USGS 1999), which are controlled by the flow regime and structure of the navigation channel imposed on the pool to maintain adequate navigation. There is some degree of biological exchange between pools, but essentially, each pool can be thought of as a separate ecosystem, within which the resident organisms must account for all aspects of their life-history. Within the pools the lateral connectivity to the original floodplain varies, depending on the extent of levees and other modifications existing along a particular reach. Overall, roughly 50% of the original floodplain area of the two rivers remains unleveed (Mills et al. 1966, Starrett 1972, Delaney and Craig 1997).

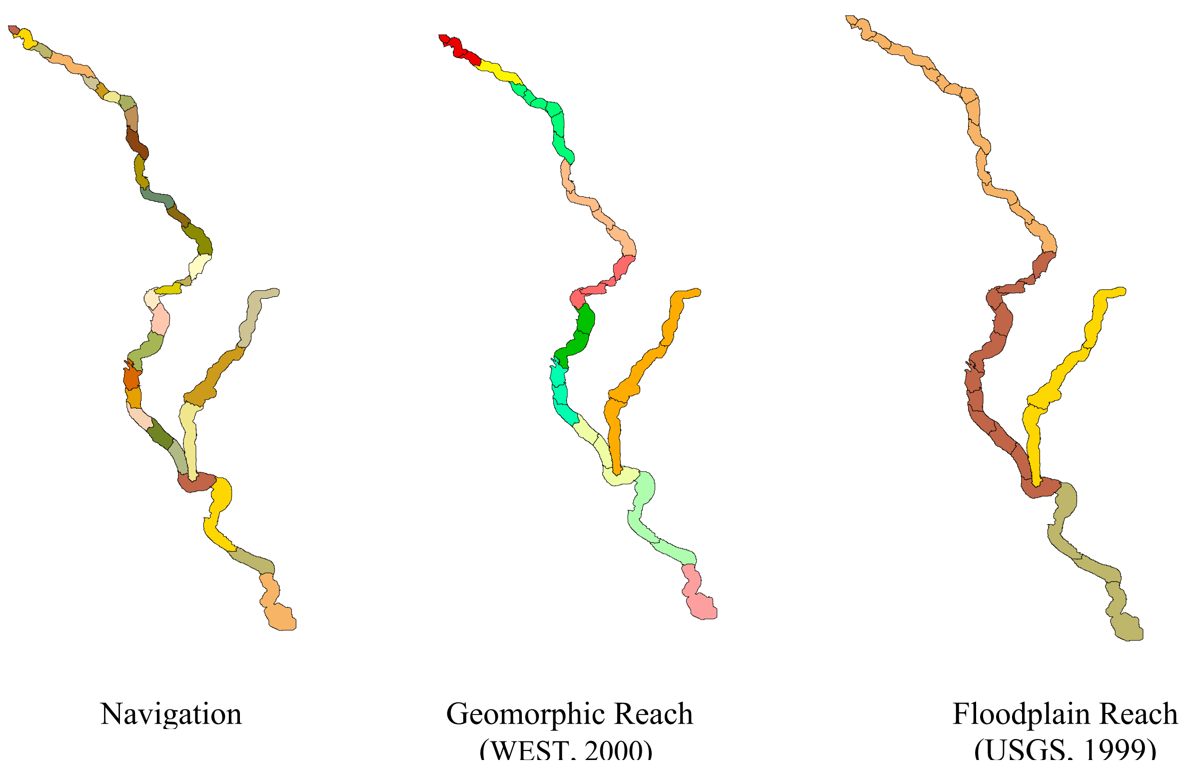

Figure 6. Management units on the mainstem Upper Mississippi River.

2.2.4. Stream Macrohabitats

Macrohabitats are small to medium-sized lakes and valley segments of streams defined by hydrology and map-based criteria (stream size, gradient, connectivity) to represent local environmental patterns and processes. Macrohabitats are river valley segments (typically 1 to 10 km in length) and small- to medium-sized lakes or lake basins (typically < 1000 hectares) that are relatively homogeneous with respect to hydrologic regime, temperature, chemistry and morphology. We hypothesize that macrohabitats have potentially distinct biological assemblages, i.e., they represent the community-level diversity of freshwater ecosystems. This approach to classifying and mapping stream macrohabitats is based on work by Seelbach et al. (1997) describing stream valley segments in Michigan, and the description of valley types in Washington by Cupp (1989). Macrohabitats also correspond to the valley segment types defined by Paustian (1992), and lake classification methods are similar to those reviewed by Busch and Sly (1992).

A set of attributes for each river and lake reach within the basin was generated in a GIS using three primary layers of spatial data: hydrography (EPA rf3), surficial geology, and a digital elevation model (DEM). We stitched together surficial geology maps from each state to develop a comprehensive surficial geology map for the region (see Box 2). A framework of abiotic variables known to influence the distributions of freshwater organisms was developed, and applied to each river and lake reach in the UMRB (Tables 3 and 4). Each reach was then assigned a numerical code, based upon the combination of values for each of the framework variables. A total of 159,733 river and lake reaches were classified. Each unique numerical code represents a distinct macrohabitat type. A total of 610 stream macrohabitat types were delineated across the basin (1728 unique combinations of variables were possible). These macrohabitat types represent the finest scale unit in the spatial hierarchy of our classification system and were used to differentiate the range of aquatic ecological systems found within the basin.

2.2.5. Lake system types (non-mainstem)

Lake classification poses many challenges because the information most critical to distinguishing lake types requires direct measurement. Although efforts have been made to predict lake characteristics from spatial data, studies show that the variability that shapes lake faunal assemblages is not sufficiently accounted for with spatial data only (Tonn 1990). However, given the density of lakes in the northern region of the UMRB, we wanted to include what information we could about their variety and distribution. Thus we applied a simple macrohabitat classification to about 32,500 lakes using key factors that distinguish lakes and that can be mapped (Table 4). This classification created 71 types. We then overlayed the stream system boundaries and used multivariate cluster analysis to group the stream systems into types based on the composition of lakes within their drainages. This process defined 28 lake system types (Appendix 7b). Headwater and creek stream systems, for example, have one grouping of lakes that includes a low number of lakes whose dominant geology is fine, calcareous rock as well as several large lakes. Another lake grouping associated with headwater and creek systems includes many large riverine lakes with complex shorelines and coarse calcareous geology and small lakes in coarse calcareous and neutral/acidic geology.

There is great variety within many of the lake types and these types are found associated with multiple stream types. We recommend that the lake system type be used as an attribute that can distinguish further occurrences of the same stream type.

Box 2. Surficial geology classification.

A digital coverage of surficial geology is one of three basic input layers necessary for the classification of macrohabitat types following the methods of Higgins et al. 1998. At the outset of the project, no comprehensive coverage of surficial geology existed in digital format for the entire UMRB. For many of the states overlapping the basin, there exist very detailed digital coverages for surficial geology, although they exhibit differences in scale and geologic nomenclature that limit their comparability.

A complete, digital map of surficial geology for the UMRB was assembled by combining those coverages readily available from the individual states across the basin (IL, IN, MI, MN, MO, WI: see surficial geology metadata for sources). For South Dakota and Iowa, no digital maps were available, necessitating the hand digitization of surficial features from several different sources (Goebel et al. 1983, Fullerton et al. 1995, and Halberg et al. 1991, Giglierano and Howes 1992, Soller and Packard 1998). Once assembled into a common coverage, the degree of resolution of the geologic features and the differing nomenclature for geologic classes were both standardized (Appendix 4) following the appropriate 4° x 6° quadrangle maps from the USGS Quarternary Geologic Atlas of the United States (Goebel et al. 1983, Lineback et al. 1983, Whitfield et al. 1993, Farrand et al 1984, Fullerton et al. 1995, Gray et al. 1991, and Halberg et al. 1991). A total of 39 unique geological classes were defined across the UMRB.

Due to the large number of variable classes in our classification framework (Tables 3 and 4) and data limitations of the software program (Microsoft Excel) used to attribute the macrohabitat information to river and lake reaches, the 39 original geology classes were re-classified into eight (8) broad geologic classes based three characteristics: texture, chemistry, and relative permeability (Tables 3 and 4), characters believed to influence the distribution and structure of biological communities in aquatic ecosystems.

Table 3. UMRB stream macrohabitat classification framework.

VARIABLE	DESCRIPTION	CLASSES	CODE	JUSTIFICATION
Size	Link# = the number of first order streams upstream of the classified segment.	Link# 1-10 (Headwater) Link# 11-50 (Creek) Link# 51-200 (Small River) Link# 201-700 (Medium River) Link# 701-2500 (Large River) Link# >2500 (Big River)	1 2 3 4 5 6	Stream size is a critical factor for determining biological assemblages (Vannote et al. 1980, Mathews 1998, S. Sowa, personal communication)
Gradient	A unit-less measurement of rise over run.	Gradient < 0.003 (Low) Gradient 0.003 — 0.013 (Medium) Gradient > 0.013 (High)	1 2 3	Stream gradient is correlated with flow velocity, substrate material, and types of cannel units (e.g., pools and riffles) and their patterns (Rosgen 1994). A gradient of 0.003 generally separates streams with a well-developed pool-riffle-run habitat structure from flat streams (Wang et al. 1998). The presence of riffles is a key factor determining the types of fish and invertebrate assemblages present (Lyons 1996).
Flow	USGS designation in digital line graph.	Intermittent (Ln2at2 = 610) Perennial (Ln2at2 ≠ 610)	1 2	Hydrologic regime is a dominant characteristic of freshwater ecosystems and influences the types and distributions of freshwater assemblages (Poff and Ward 1989, Poff and Allan 1995, Lyons 1996).
Network Position	Dlink# - the link number of the next downstream segment.	Dlink# 1-50 (Stream) Dlink# 51-700 (River) Dlink# >700 (Large River)	1 2 3	Drainage network position has been shown to correspond to patterns in freshwater community structure (Vannote et al. 1980, Mathews 1998, Lewis and Magnuson 1999, Newall and Magnuson 1999). Network position refers to the size of the next downstream stream segment. Osborne and Wiley (1992) showed that for warmwater streams in Illinois, the downstream-connected habitat (downstream link) was the most influential factor in determining stream fish community structure.

Table 3. Continued.

Dominant Geology	Numerical code identifying the dominant geologic type within the catchment area of the classified segment. Each code contains information on texture, chemistry, and relative permeability of the substrate.	Coarse, neutral-acidic, high permeability. Coarse, calcareous, high permeability. Fine, calcareous, low permeability. Fine, neutral-acidic, low permeability. Peat and muck, neutral-acidic, low permeability. Bedrock: calcareous, limestone, dolomite. Bedrock: non-calcareous (volcanic, igneous, crystalline). Man-made: strip mines, quarries, made land, artificial till.	1 2 3 4 5 6 7 8	Geology contributes to substrate characteristics, chemistry and hydrologic regime.
Temperature	Based on state Trout Stream coverages.	Coldwater Warmwater	1 2	Stream temperature sets the physiological limits for where stream organisms can persist (Allan 1995).

Table 4. UMRB lake macrohabitat classification framework.

VARIABLE	DESCRIPTION	CLASSES	CODE
Size	Surface area of the lake	Small (Area ≤ 1,000,000 m^2) Medium (1,000,000 m^2 < Area ≤ 10,000,000 m^2) Large (10,000,000 m^2 < Area ≤ 100,000,000 m^2) Very Large (Area > 100,000,000 m^2)	1 2 3 4
Connectivity	Number of surface connections	Unconnected [seepage] (0 connections) Catchment [drainage] (1 connection) Riverine (≥2 connections)	1 2 3
Shoreline Complexity (development)	Function of area and perimeter (D_L)*	Round ($D_L < 2$) Complex ($D_L \geq 2$)	1 2
Geology	Numerical code identifying the dominant geologic type within the catchment area of the classified segment. Each code contains information on texture, chemistry, and relative permeability of the substrate.	Coarse, neutral-acidic, high permeability. Coarse, calcareous, high permeability. Fine, calcareous, low permeability. Fine, neutral-acidic, low permeability. Peat and muck, neutral-acidic, low permeability. Bedrock: calcareous, limestone, dolomite. Bedrock: non-calcareous (volcanic, igneous, crystalline). Man-made: strip mines, quarries, made land, artificial till.	1 2 3 4 5 6 7 8

* Shoreline Development (Wetzel 1983, p. 32) = the ratio of the length of the shoreline [L] to the circumference of a circle of area [A] equal to that of the lake.

$$D_L = \frac{L}{2\sqrt{\pi A_0}}$$

Box 3. Effects of temperature.

Temperature unquestionably sets limits on where a species presently can live (Allan 1995). From the literature, it is well documented that thermal regime has diverse effects on the life-histories of aquatic organisms. Seasonal changes in water temperature often cue development or migration, influence growth rates of eggs and juveniles, and can affect the body size, and therefore the fecundity of adults. Many aquatic species have adapted over millennia to very specific temperature regimes, and are intolerant of even slight changes in average water temperatures.

In addition to limiting effects on biological productivity, temperature extremes may directly preclude certain taxa from inhabiting a water body. Lyons et al. (1996) found that high quality coldwater streams in Wisconsin have lower fish species richness than comparable high quality warmwater streams, and that many of the taxonomic groups that are important in the warmwater streams are rare or absent in the coldwater streams. They also found that the fish assemblages of the two stream type responded differently to environmental degradation, necessitating alternative management strategies to protect natural levels of biological diversity.

The temperature of running waters usually varies on seasonal and daily time scales, and among locations due to climate, elevation, extent of streamside vegetation, and the relative importance of groundwater inputs (Allan 1995). Elevation is not a serious consideration in the UMRB, as the topography is relatively level across most of the basin. Climate and riparian cover can be relatively easily accounted for using readily available spatial data in a GIS. At the present, no comprehensive method exists for modeling groundwater input at the appropriate scale (stream reach) across the entire UMRB.

In order to account for the importance of stream temperature in structuring biological communities, we developed a spatial coverage of coldwater streams using several trout stream classifications (WI DNR, MNDNR 2001) and coldwater stream designations (IADNR 1994) completed for the region. Additional trout streams in the Kankakee River basin of Indiana were identified and hand-digitized from a state list of stocked trout streams (INDNR 2003). No trout stream or other coldwater stream designations are maintained by Illinois or South Dakota, and so were not included in the coverage, although several of the streams draining the eastern Prairie Coteau support introduced trout populations.

3. Conservation Goals for the UMRB

Establishing a set of numerical goals for species targets creates benchmarks against which to measure the success of a particular set of conservation areas in capturing biodiversity. The goals are created with the aim of ensuring the long-term viability of species and ecosystems. Viable species can be defined as those with a high probability of continued existence over time (90% certainty of surviving 100 years and/or 10 generations). In other words, goals are meant to ensure that, if met, each species targeted will possess sufficient genetic variability across their range to adapt naturally in the face of continually changing environmental conditions. Viable systems are those that function within an historic range of variation, and demonstrate a high level of ecological integrity. Depending on the context of the region in question, viable occurrences of all species and system types may not exist, in which case, the deficit in viable occurrences represents a set of restoration goals.

3.1 Species Goals

The distribution and general life history requirements of each species target within the UMRB was assessed. Numerical goals for each species target (Appendix 5) were calculated individually, based on the following factors:

- Proportional range representation - the target's range-wide distribution relative to the basin.
- Spatial pattern - the geographic scale of spatial patterns exhibited by the species (Poiani et al. 2000, Figure 7).

Localized, endemic species were considered the most susceptible to extirpation and were assigned the highest conservation goals. Peripheral species, most with far better representation outside the basin, were assigned the lowest goals. Regional species are to be considered on a case-by-case basis, depending on habitat requirements and issues of connectivity.

The exact number of individual occurrences or populations needed to ensure the long-term viability of most species is uncertain. We simply do not have the knowledge and data available to set concrete goals with any degree of confidence. Out of a total of 1100 individual occurrences of species targets from the natural heritage program databases, we have viability information for 341. The data points from non-Heritage sources do not have a viability rank. The conservation goals for target species within the UMRB should be considered provisional, and should be adapted over time as new information on each species and its life requirements are made available.

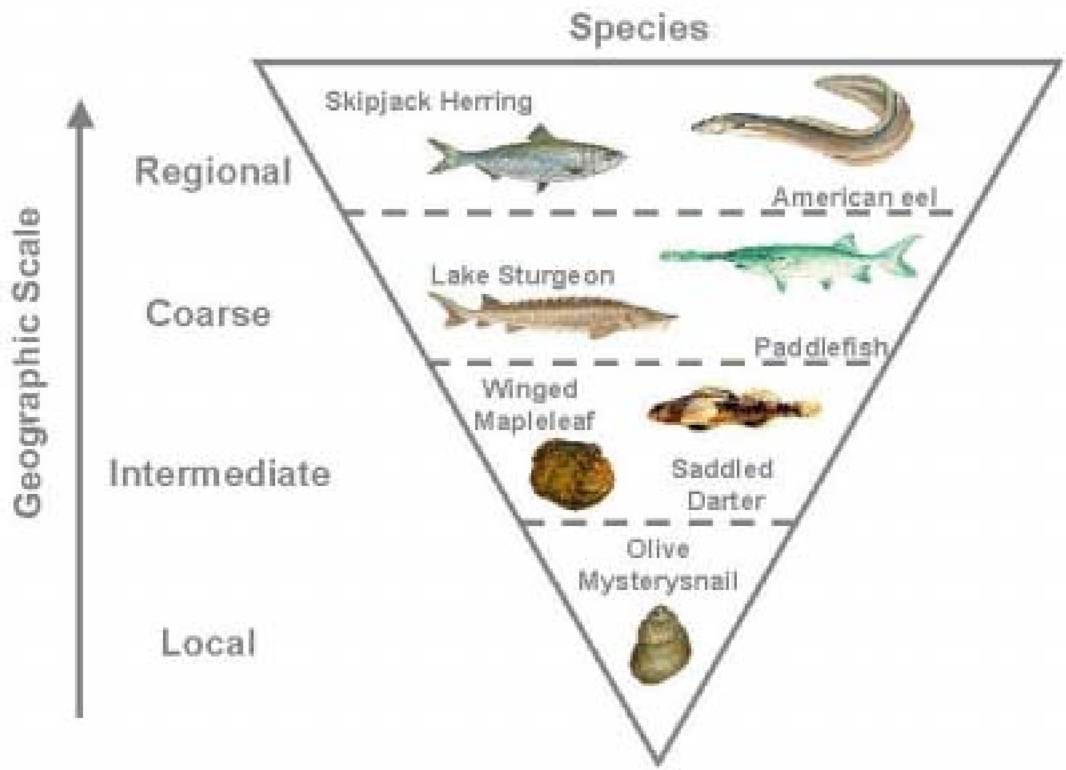

Figure 7. Freshwater biodiversity at four geographic scales including local, intermediate, coarse and regional. After Poiani et al. 2000.

3.2. Systems Goals

The minimum goal for aquatic systems was to conserve one example of each unique system type across the basin. Ideally, each occurrence captured will be functioning within a historic range of natural variation, and will demonstrate a high level of ecological integrity. In the case that no high quality examples of a particular type yet exist, the example with the greatest potential for successful restoration will be identified. See the section below on "Identifying Freshwater Areas of Biodiversity Significance" for further details regarding the criteria for selecting representative systems occurrences.

4. Integrity Assessment

A critical step in prioritizing conservation areas is to determine the condition and suitability of potential conservation targets (Groves et al. 2002). Key to developing an accurate assessment of condition and suitability is understanding the intensity and spatial arrangement of a range of stressors to aquatic ecosystems, including dams, agricultural areas, point sources of pollution, and invasive species. Such information greatly enhances efforts to identify potential aquatic conservation areas with high ecological integrity, low conservation cost, and a high likelihood of conservation success. Additionally, data describing the location and intensity of anthropogenic stressors can indicate potential locations of high integrity systems in locations where biological data and expert information to guide conservation site selection are absent or limited.

To evaluate the relative integrity of freshwater system occurrences across the UMRB, we analyzed threats to biodiversity using several basin-wide spatial data sources (Table 5). Many of the leading stressors to aquatic ecosystem integrity have been mapped digitally, including hydrologic alterations, and point and non-point sources of pollution, and therefore lend themselves well to GIS analysis. For each system occurrence we calculated a series of potential habitat integrity indicators known to influence the biological integrity of streams (Bryan and Rutherford 1993). These data are available in the Conservation Planning Tool (CPT) database on the accompanying CD-ROM.

Table 5. Indicators of ecological integrity and their sources.

CLASS	DATA SOURCE	UNITS	COMMENTS
Land Cover /Land Use	National Land Cover Data (USGS 1992)	Area percentage	Cultivated Lands, Urban Area, Natural Vegetation, and Wetlands.*
Impervious Cover	National Land Cover Data (USGS 1992)	Area percentage	Low Density Residential, High Density Residential, Commercial/Industrial/Transportation.†
Road Density	1999 TIGER Roads (USDOC 1999)	road length/area	Includes all road classes
Road/Stream Crossing Density	1999 TIGER Roads (USDOC 1999)	# crossings/ total km streams	
Dams	National Inventory of Dams. (USACE 1999)	# dams/area	
Point Sources	BASINS 3.0 (USEPA 2001)	# point sources/area	Superfund Sites (CERLIS), Industrial Facility Discharges (IFD), and Toxic Release Inventory (TRI).
Mines	BASINS 3.0 (USEPA 2001), MINES97 (IADNR 1997)	# mines/area	Includes both active and abandoned mines.
303d Streams	EPA BASINS 3.0	km 303d streams/ total km streams	

* Land Cover/Land Use classes in this study include the following NLCD categories:
Cultivated Lands = Pasture/Hay, Row Crops, and Small Grains.
Urban Area = Low Density Residential, High Density Residential, Commercial/Industrial/Transportation.
Natural Vegetation = Deciduous Forest, Evergreen Forest, Mixed Forest, Shrubland.
Wetlands = Woody Wetlands, Emergent Herbaceous Wetlands.

† Impervious Cover = (Low Density Residential x 0.55) + (High Density Residential x 0.90) + (Commercial/Industrial/Transportation x 0.75)

Indicators for headwater through large river systems were calculated using a set of GIS tools (FitzHugh 2002) that characterize the watershed upstream of every stream reach. For big river systems (size 5), values were calculated for the area immediately adjacent to the river. Given that the contributing areas of these rivers are extremely large, we concluded that entire-watershed indicators might not be meaningful at that scale. Integrity indicators were calculated for an area extending five kilometers beyond the floodplain laterally and longitudinally from one pool boundary to the next. This buffer was designed to capture the small, bluff tributaries, the lower parts of the larger tributaries, and also the entire floodplain including the main channel, and all the backwaters and lateral channels. The entire contributing area of a mainstem can be derived from totaling the values for each tributary system. For the non-mainstem Mississippi River big river systems (e.g. Des Moines River, Wisconsin River, etc.), the contributing area was defined as extending five kilometers to either side of the river.

The values assigned for most quality indicators are straight calculations of percent area coverage or simple counts of features (e.g., percent of total system area in cultivated land cover, or the number of dams), with no weighting of the variables. The impervious cover value for each system, however, represents the sum of the three urban land use classes, each multiplied by a factor representing its relative degree of imperviousness (Table 5). We compared values of individual indicators within each system type to identify high quality system occurrences, and in selecting the Areas of Biodiversity Significance. This information was particularly useful where we had no other means to distinguish among system occurrences.

The indicator values vary across the Ecological Drainage Units, reflecting land use patterns and the underlying landscape features. Agricultural cultivation is highest in the EDUs in Iowa and southeastern Minnesota (Upper Des Moines, Upper Minnesota, Iowa-Cedar). The highest concentrations of wetlands are found in the Mississippi River Headwaters and the St. Croix EDUs. With the exception of mines, point sources appear to be most concentrated in Illinois, particularly industrial facility dischargers. However, the variability in values is also a result of inconsistencies in data collection across states. Road density and road crossings are even across the whole region.

Land use measures varied little among size classes of streams. The most striking difference in land use among size classes is in urban land use. For all sizes of streams except the mainstem rivers, the average percent urban land use is approximately 2%. Urban development is more concentrated in the buffer of the mainstem — where it constitutes 9% of the land use type.

The frequency of point sources increased with drainage area. However, because the big river values were based on a buffered area, the large river and medium rivers consistently had the highest values for point sources such numbers of dams, numbers of industrial dischargers, number of mines. Big rivers had the highest average percentage of stream miles that do not meet their designated uses.

5. Experts meetings

Expert recommendations for areas important to freshwater biodiversity conservation constituted one of the more important sources of information used in setting conservation priorities across the UMRB. With most experts actively working in the field, they have unparalleled knowledge of condition and extent of species and systems, and represent potential partners to develop and implement conservation strategies for the region.

Expert recommendations came from two sources for this analysis. First, we consulted the Conservancy's ecoregional plans to identify streams and rivers highlighted by experts in those previous planning efforts. Where the information from the ecoregional plans needed to be augmented, we held new expert workshops, which took place in Iowa, Missouri and Minnesota. Experts either participated in these meetings or phone interviews, and provided up-to-date knowledge of the aquatic species and systems of the UMRB, including information on distribution and status, and threats to their viability.

Each of the state or river-basin focused meetings, included representatives of major resource management agencies, academic institutions, and non-profit organizations working in each region. Experts provided feedback on the initial selection of conservation targets, shared new records for target species, and provided information on current trends, distribution, and threats for each target. Also provided were innumerable helpful publications, data sets, and contacts for further experts around the region.

Products of the workshops and phone interviews included refined lists of species targets and specific streams, rivers or lakes recommended based on the presence of viable target species occurrences, high overall species and/or habitat diversity, high water quality and intact ecosystem processes, and exceptional occurrences of common species or native assemblages.

In total experts recommended 186 sites covering 77 species targets. Eighty-one of these sites are captured in the final set of freshwater areas of biodiversity significance. The expert recommended areas and their attributes are listed in Appendix 9.

6. Freshwater Areas of Biodiversity Significance:

6.1. Creating the network of ABS

The freshwater Areas of Biodiversity Significance (ABS) (Figure 8) were selected to represent all aquatic ecological systems types found in the UMRB and capture examples in sufficient number of the globally rare and imperiled aquatic species targets in the basin. This analysis involved synthesizing several layers of information including the systems classification, quality assessment, species target locations, expert workshop recommendations, and ecoregional planning data (see Appendix 10 for the attributes of each ABS). This represents the recommendation for the suite of areas that comprise the remaining best examples of aquatic biodiversity representative of the UMRB.

The small river systems provided the initial set of systems on which the network of ABS was built. We chose to start with the small rivers as it was more practical to select among 350+ small river than 3200+ headwaters and creeks. Comparisons of the small river systems within system type were made, with the goal of selecting at least one example of each system type. Priority was given to those systems that captured target species occurrences, were expert recommended, were ecoregional priorities in prior plans, represented the best quality example based on a suit of quality indicators, or was simply the only example available. Clear priorities were given a value of 1. If the quality of the “best” or only example was in question or poor, the ABS was assigned a value of 2. The map of the ABS shows these lower confidence choices in a lighter shade. Land use quality shown for agriculture, urban and natural vegetation on average is higher for ABS with a rank of 1 (Table 6).

Table 6. Values for three land use types summarized by system size and ABS confidence rank.

SYSTEM SIZE	ABS	%AG	%URBAN	%NATVEG
1	1	58	1	33
1	2	74	2	19
2	1	55	1	31
2	2	68	2	24
3	1	64	2	25
3	2	83	2	10
4	1	66	2	24
5	1	49	10	26

Following the selection of the 74 small river ABS, we selected all of their headwater and creek systems for inclusion as ABS. Again, if we had concern about quality or a question, a value of 2 was assigned to that system. We selected these connected headwaters because we reasoned that these areas would need to be addressed in protecting the small rivers and should be included. This initial selection captured about three-fourths of the headwater and creek system types, so a few additional headwater systems were selected to meet representation goals.

The medium rivers immediately downstream of the selected small rivers were also automatically included, to emphasize the importance of connectivity. Other examples were added as necessary to meet the goal of representing each system type. Finally, all the large river and big river systems, including the entire mainstem UMR_IWW were selected as ABS. Due to their position in the drainage network and the characteristics of their tributaries, each of these rivers are unique, and as such need to be included to meet the goal of representing all the system types at least once.

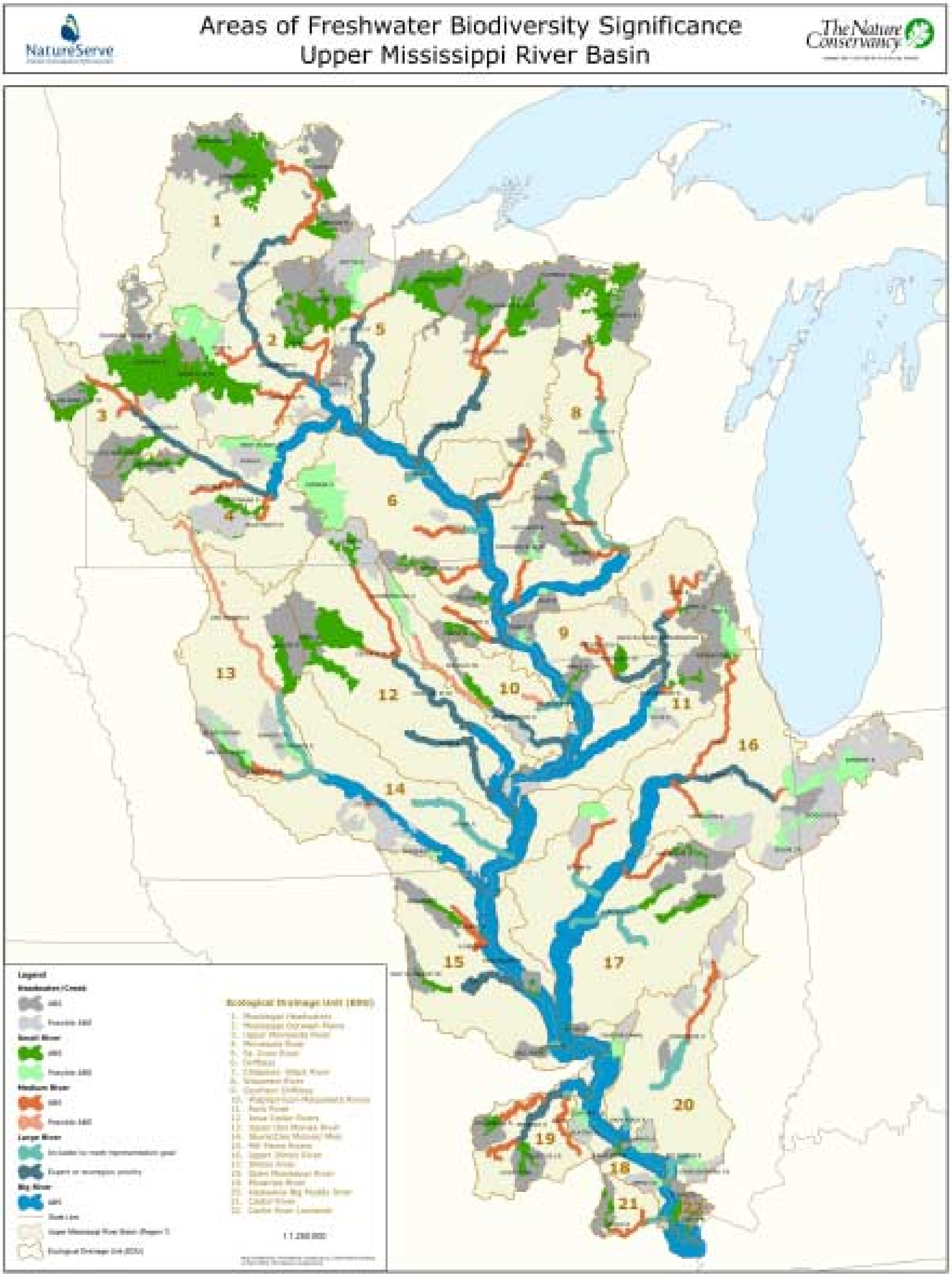

Figure 8. Freshwater Areas of Biodiversity Significance in the UMRB.

6.2. Goals Met by Freshwater ABS network

We used the goals for species and systems to evaluate the conservation impact of the freshwater ABS network. The network of ABS captures of the aquatic ecological systems and a high proportion of the target species. We evaluated both the number of occurrence captured within the entire UMRB as well as by Ecological Drainage Unit. The system results are summarized in Table 7. The species results are summarized in Table 8. Given the lack of viability data for individual species occurrences, we used the systems selected as ABS to select the species occurrences. We presumed these were the most viable as we selected ABS that are the most viable.

6.2.1. System goals met

As described in Section 6.1, the ABS network was constructed to represent all of the systems types within each EDU. Goals were met at 100% for all targets. Once we had the set of systems to represent each type, we then assessed how well this network of aquatic systems would capture the target species. As the two scale score for the ABS suggests, not all of these systems are viable in their current condition. For example, the lack of longitudinal connectivity on the mainstem Mississippi River jeopardizes the long-term viability of regional or wide-ranging species, and some coarse-scale species. The ABS are the places to maintain or improve ecological integrity, where one should measure the success of conservation actions in the UMRB.

Table 7. Systems goals met by ABS network.

SYSTEM SIZE	TOTAL NUMBER OF SYSTEM TYPES	NUMBER OF SYSTEMS CAPTURED	% OF TYPES CAPTURED
Headwater/Creeks	89	447	100
Small Rivers	54	78	100
Medium Rivers	40	43	100
Large Rivers	27	27	100
Big River	11	11	100

6.2.2. Evaluating species goals met: data sources and how species were counted

For all taxa we used species occurrences from the natural heritage programs in the basin. In addition, for fish and mussels, we compiled species occurrences from several additional data sets. The data used to meet conservation goals is no older than 1988. Details regarding these additional data sources are described in Section 8. For both the mussel and fish data, sampling points do not necessarily represent actual occurrences of species — for example, some points represent single individuals while some represent repeated sampling at the same location over a series of years. In order to standardize the count of species occurrences, we created what we have termed functional occurrences based on separation distances specified by NatureServe and the spatial scale over which a given taxa ranges (Figure 7). The species table (Appendix 5) includes the categorization of the species as local, intermediate, course and regional species.

All mussels were classified as intermediate and we used a separation distance of 15 km to group together sampling points into single occurrences. The original data set has 3365 points, which has been reduced to 906 functional occurrence based on application of this rule.

For the fish, the separation distance varied from 3 km for such local species as Western sand darter (*Ammocrypta clara*) to 200 km for such wide-ranging species as Lake sturgeon (*Acipenser fulvescens*). The original fish data set for the target species has 2522 points, now reduced to 422 functional occurrences.

A few of the invertebrate taxa data points were also grouped into functional occurrences based on a 5 km separation distance.

We identified a total of 153 target species. We lack spatial data for three undescribed sub-species of fish found in Missouri, two of which are cave obligates, and for one dragonfly thought to occur in the UMRB. Ten species have not been found in the basin since 1987. Nine more have occurrences in the basin, but were not captured in the ABS network.

Out of 131 species for which we have spatial occurrences, 102 are captured in this network of stream systems. Those not captured include taxa that historically occurred in the basin, have very limited occurrences, whose status is in question, or are simply under sampled. The most complete data are available for fishes and mussels. Of those, 71 percent of the fish and 55 percent of the mussel species are captured at or above the goals set for each species. Overall, 77% of the species for which we have location data within the UMRB were captured by the ABS network, with approximately 45% of these meeting their conservation goal.

Table 8. Species targets captured by ABS network.

TAXA	TOTAL NUMBER OF TARGET SPECIES*	# CAPTURED (AT LEAST ONE EXAMPLE)	# MEETING GOAL	% MET GOAL
Fish	34	30	22	71
Mussels	40	32	22	55
Insects, Snails and Amphipods	34	25	5	15
Crayfish	9	7	4	44
Herptiles	14	8	5	36
Total	131	102	58	45

*includes only taxa for which we have occurrences

7. Selection of Priority Areas

7.1. Identification of Priority Areas for Biodiversity Conservation

The Priority Areas (Figure 9) are intended to highlight the top fifty areas of general biological diversity significance. The areas selected are locations where freshwater areas of biodiversity significance overlap extensively with terrestrial priority areas identified in the Conservancy's ecoregional plans, with a couple of exceptions. We identified at least one Priority Area in each ecological drainage areas. This led to the identification of aquatic-only Priority Areas in a few cases. We also created Priority Areas to capture significant lake and subterranean complexes. Appendix 11 provides maps and a detailed description of each Priority Area .

The Priority Areas were not selected to represent the full array of aquatic species or aquatic system types found in the basin. However, we analyzed these areas to see what level of protection this set of forty-seven places provides for the aquatic conservation targets.

Table 9. Systems captured by priority areas.

SYSTEM SIZE	TOTAL SYSTEM TYPES CAPTURED	% CAPTURED	TOTAL SYSTEM TYPES
Headwater/Creek	65	73	89
Small River	34	63	54
Medium River	25	63	40
Large River	24	89	27
Big River	11	100	11
Total	159	72	221

Table 10. Conservation target species capture by Priority Areas.

TAXA	TOTAL NUMBER OF TARGET SPECIES*	# CAPTURED (AT LEAST ONE EXAMPLE)	# GOAL MET	% MET GOAL
Fish	34	30	20	65
Mussels	40	32	21	53
Insects, Snails and Amphipods	34	17	6	18
Crayfish	9	5	3	33
Herptiles	14	10	4	29
Total	131	94	54	42

*includes only taxa for which we have occurrences

Although less than the ABS network, the Priority Areas capture significant biological diversity in the basin. The Priority Areas capture 72% of the aquatic system types (Table 9) and 94 of the species for which we have spatial locations (72%, Table 10). The ABS and Priority Areas both achieve approximately 42% of the conservation goals for the species that occur within them.

The consistency between results for target species represented is in part due to the fact that both the ABS network and the set of Priority Areas include the entire mainstem Mississippi River and the mouths of its major tributaries (the big river habitat). The mainstem Mississippi has occurrences of all but 21 of the target species. However, the mainstem Mississippi represents only 11 of the 237 aquatic system types (<5%). Thus, both the mainstem Mississippi and the upstream systems are important. The big rivers contain most of the imperiled taxa and large numbers of common taxa. The upstream areas also harbor widespread and common species, as well as many that are highly localized. While at a local scale declines are of concern (many taxa are listed as state imperiled that we did not include as targets), when viewed from a basin perspective, these taxa appear secure. Taking the approach that we have here of proposing representative aquatic systems for conservation is a means to prevent the declines in the more common assemblages of aquatic fauna across the basin.

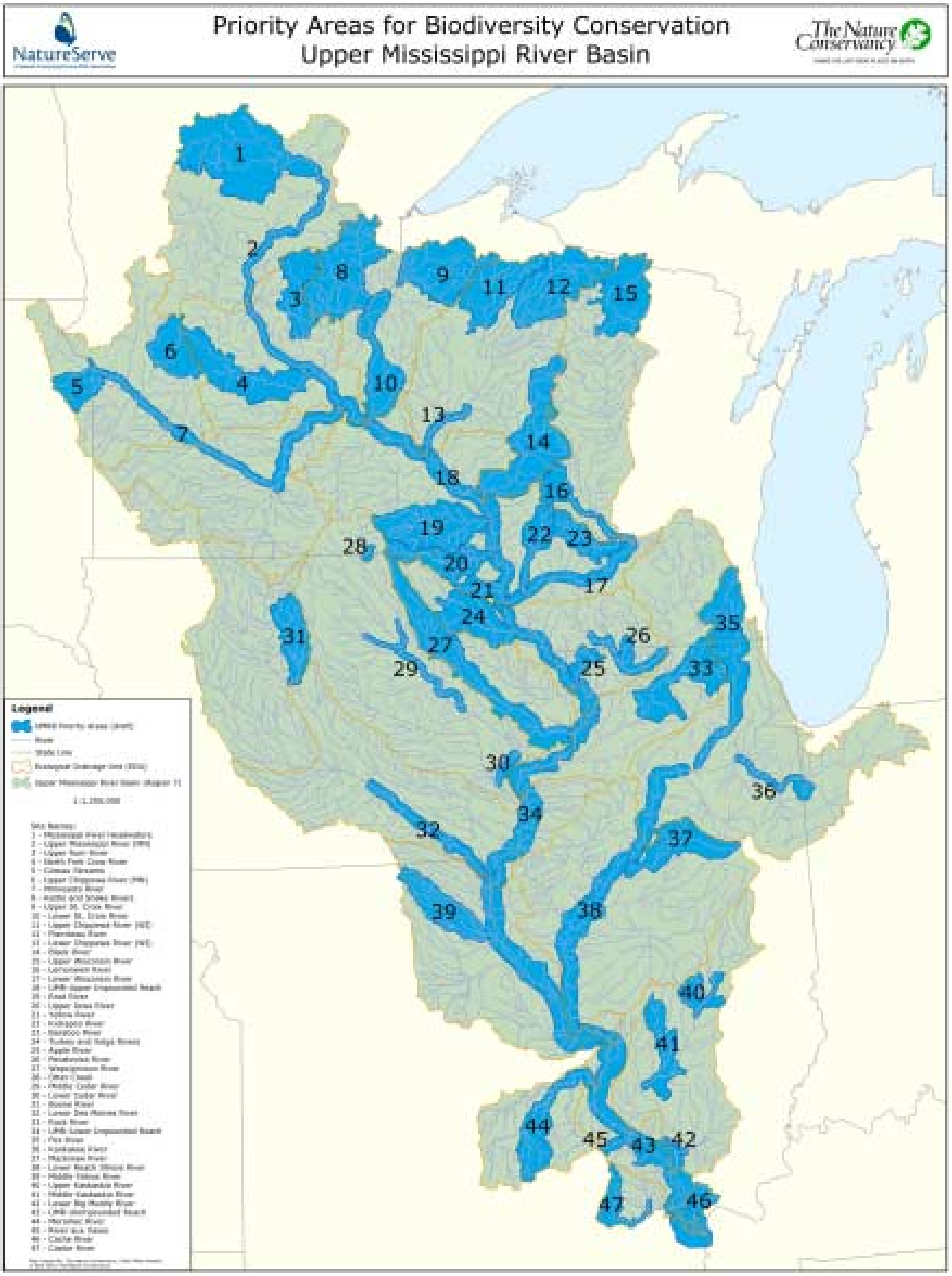

Figure 9. Priority areas for freshwater and terrestrial biodiversity.

7.2. Special note on the UMR-IRWW

You will recall from the discussion of the selection of ABS on the mainstem that the entire extent of the UMR-IRWW was identified as significant for aquatic biodiversity. When we compared the ABS with ecoregional planning data, the overlap of ABS and terrestrial portfolio sites was nearly complete. Therefore, the entire mainstem system qualifies as a Priority Area following the criteria listed above.

While it makes sense that the whole UMR-IRWW would be a priority site from an ecological standpoint, the vast scale of the ecosystem, not to mention the complexities associated with the large number of political and resource management entities at work on the river, make it unrealistic to attempt to manage the system as a single unit. The challenge, therefore, is to devise a way to subdivide the river into smaller, more manageable units that still make sense ecologically.

Again, as with the ABS, we chose to work within the bounds of the existing management structure on the UMR-IRWW. We divided the mainstem river system into four Priority Areas, corresponding with the Floodplain Reach sub-units as outlined above. Each of these reaches can be distinguished from another by its unique geomorphological, biological , and anthropogenic characteristics, requiring that the ecological health of each be evaluated separately (USGS 1999). Concentrating conservation efforts separately on each of these reaches will allow practitioners to focus on abating the threats specific to each reach.

8. UMRB Freshwater Species Database

8.1. Purpose of Database

Analysis and planning for conservation must be grounded in a firm understanding of the distribution of elements of biodiversity ranging from species to landscapes. Often, such information is limited or lacking, hampering efforts to achieve a sound conservation plan. In the Upper Mississippi Basin, researchers ranging from academics to federal, state and local agency personnel have compiled abundant data on freshwater species occurrences, including records that date from the late 19th century. These datasets are dispersed across all of the states of the UMRB, and are variously maintained, accessible, and quality-controlled. For the purposes of conservation planning and analysis, we sought to gather these datasets, record available metadata regarding collection methods, and structure them in a standardized format.

Freshwater species occurrence data collected through this effort were used to inform the selection of conservation areas (see Section 6 for further details), assess the strength of the systems classification framework for the UMRB, identify characteristic fish assemblages in the UMRB (see section 9 for details), and test landscape metrics of aquatic system integrity. They may also be used in local site conservation area planning efforts and future analyses of UMRB aquatic species and communities such as developing lists of aquatic biota found within specific ecological systems and system types.

8.2. Biological Data Search

The search for freshwater biological datasets was limited to fish, mussel, crayfish and macroinvertebrate occurrence records. Survey and collection methods were not restricted; data ranged from incidental-take notes to community and relative abundance surveys collected using standardized methods. The date of data collection was also not restricted, however data were required to have relatively precise locality information, such as latitude/longitude coordinates. Primary sources of available data included academics and federal, state and local government agency personal. A small number of individuals not associated with research institutions or government agencies were also contacted regarding available datasets.

8.3. Data Acquisition and Standardization

Freshwater biological datasets were acquired from approximately 60 sources, between March, 2001 and January, 2003; 30 of these datasets were included in the final database (Table 11: Data Sources). Collections ranged in age from the late 1800's to 2002. All sources were questioned for minimal metadata information, including research notes, collection methods, and accompanying reports and publications. From the datasets provided, selected data were queried, transferred into a standardized format, and merged into a relational database consisting of four primary tables: "species," "sites," "samples," and "projects" (Table 12: Relational Database Structure). All locations of species occurrences were to converted to a common projection, and stored in a GIS.

At the time of publication, data processing has been completed for fish and mussel datasets only. The final dataset includes approximately 885,000 records of species occurrences from over 60,000 survey locations in all states of the UMRB (Figures 10 and 11).

Table 11. Data sources for the UMRB Freshwater Biological Database.

Source Code	Taxon	Title	Source/Contact	Coverage	Site ID Range
IA02	Fish	Iowa Baseline Fish Survey (Paragamian Study)	Clay Pierce — Iowa State University	61 sites within the UMRB	7120-7188
IA03	Mussels	Iowa Mussels Dataset	John Downing — Iowa State University	211 sites in UMRB, 118 sampled twice	36908-37107
IA05	Fish and Inverts	IA DNR (1/2 of the Iowa Contemporary Dataset)	Tom Wilton — Iowa Department of Natural Resources	200 reference sites across Iowa	58057-58167 (fish sites only)
IA06	Fish	Manchester dataset (1/2 of the "Iowa Contemporary	Greg Gellwicks - Iowa State University	60 sites in Iowa	4259-4299
IL01	Fish	IL DNR Streams Data	Dave Day — Illinois Department of Natural Resources	305 sites across the UMRB of Illinois	1-305
IL02	Fish		Frank Hutto - Illinois Natural Heritage Biodiversity Section	34,128 samples across the UMRB of IL	1000-3429
IL03	Mussels		Frank Hutto - Illinois Natural Heritage Biodiversity Section	10,952 samples across the UMRB of IL	37108-37874
IL06	Fish		Bill Bertrand — Illinois Department of Natural Resources	2467 records from 243 stations along Mississippi mainstem of IL	306-548
IL07	Fish	Illinois River Electrofishing Dataset	Mark Pegg - Illinois Department of Natural Resources - Havana	6 pools on the Illinois River	30646-30651
IL10	Mussels	IL River Starett Mussel Data	Kevin Irons		

IN02	Fish	IDEM 1990-1994 IBI	Stacey Sobat — Indiana Department of Environmental Management	Indiana statewide; 155+ sites within the UMRB	3500-4258
IN03	Fish	IDEM 1995 REMAP	Stacey Sobat — Indiana Department of Environmental Management	Indiana statewide	7773-7961
IN04	Fish	IDEM 1996-2000 IBI	Stacey Sobat — Indiana Department of Environmental Management	Indiana statewide; 86 sites within the UMRB	30652-30986
MN01	Fish	PCA Fish	Scott Nimela — Minnesota Pollution Control Agency	9692 records at 831 stations throughout Minnesota	7198-7772
MN02	Mussels	MN Mussel Data (DNR)	Mike Davis — Minnesota Department of Natural Resources	5337 records from 672 sites in Minnesota	37990-38928
MN03	Fish	Konrad's Personal Dataset	Konrad Schmidt — Minnesota Department of Natural Resources	33139 records from sites in Mississippi, St. Croix, Minnesota and Des Moines River drainages	4300-7113
MN08	Fish	MN Lake Surveys	Konrad Schmidt — Minnesota Department of Natural Resources	65,536 records from MNDNR Lakes database	30987-34844
MN14	Fish	Konrad's MS River Pool 1-9	Konrad Schmidt — Minnesota Department of Natural Resources	1437 records from pools 1-9 on Mississippi River	37875-37989
MO01	Fish	MoRAP Dataset (Fish)	Scott Sowa - MoRAP	14355 records from UMRB of MO	34845-36907
MO04	Fish	MDC-Fish_Winston	Matt Winston — Missouri Department of Conservation	15927 records from UMRB of MO	MO04a= 710-792; MO04b=793-970; MO04c=8031-8455
MO05	Mussels	MoRAP Dataset	Scott Sowa — Missouri	7423 records from UMRB of MO	38929-39552

		(Mussels)	Resource Assessment Partnership		
SD01	Fish	Backlund Dataset	Chad Kopplin — South Dakota Aquatic GAP	51 records from UMRB of SD	39553-39901
SD02	Fish	Dietermann Dataset	Chad Kopplin - South Dakota Aquatic GAP	Records from 19 sites in UMRB of SD	600-618
SD03	Fish	Bailey and Allum Dataset	Chad Kopplin - South Dakota Aquatic GAP	Records from 10 sites in UMRB of SD	620-702
UMR01	Fish	LTRMP-Fish	Upper Midwest Environmental Sciences Center	739197 sampling points in six study reaches in the	39902-53619
UMR03	Fish	NAWQA-UMR	Kathy Lee - USGS	1850 records from Upper Mississippi Drainage in MN and WI	549-596
UMR12	Fish, Mussel, Crayfish, Reptiles, Amphibi ans, Aqua	Natureserve Aquatic Element Occurrences for IA, IL, IN, MN, MO, SD, and WI	Roy Weitzell - NatureServe	IA, IL, IN, MN, MO, SD and WI	58168-62969
UMR13	Mussels	Natureserve Aquatic Element Occurrences for IA, IL, IN, MN, MO, SD, and WI	Roy Weitzell - NatureServe	IA, IL, IN, MN, MO, SD and WI	63446-65340
WI01	Fish	Fago Master Fish Database	Don Fago — Wisconsin Department of Natural Resources	1135906 records from 15607 collections in the UMRB	8456-30645
WI03	Fish and Crayfish	Wisconsin Wadeable Streams data	Li Wang, John Lyons - Wisconsin Department of Natural Resources	2985 records from WI; about 250 sites	7962-8008

Table 12. Contents and structure of UMRB Freshwater Biological Database.

Table	Field Name	Field Definition and Codes	Field Type
Sites	*Site ID	Unique number assigned to each survey site in UMRB database	Numeric
	*Source Code	Unique identifier assigned to source dataset	Text
	*EDU ID	Ecological Drainage Unit	Text
	System Type	Watershed group type	Text
	*System ID	Watershed identification number	Text
Samples	*Site ID	Unique number assigned to each survey site in UMRB database	Numeric
	Year	Year of Survey	Text
	Source Scientific Name	Scientific species name, as identified by the source	Text
	Corrected Scientific Name	Scientific species name, corrected for misspellings, nomenclature updates, etc.	Text
	*GEL Code	Natural Heritage Element Code	Text
	Sample Method	Notes on gear or survey method, if available	Text
	EO Code	Element occurrence code, for natural heritage data	Text
	*Source Code	Unique identifier assigned to source dataset	Text
Species	*GEL Code	NatureServe Element Code	Text
	Scientific Name	Scientific name of species	Text
	Common Name	Common name of species	Text
	Grank	NatureServe Global Rank	
	USESA	Federal Conservation Status	Text
Projects	*Source Code	Unique identifier assigned to source dataset	Text
	Taxon	Focal taxonomic group of survey (Fish, Mussel, Crayfish, etc.)	Text
	Title	Name of dataset	Text
	Source/Contact	Person from whom dataset was acquired	Text
	Coverage	Spatial extent of survey data	Text
	Time Span	Approximate range of survey dates	Text
	Methodology	Notes on survey methodology, if available	Text
	Site ID Range	Site ID numbers assigned to dataset	Text

- Indicates fields by which data tables can be linked.

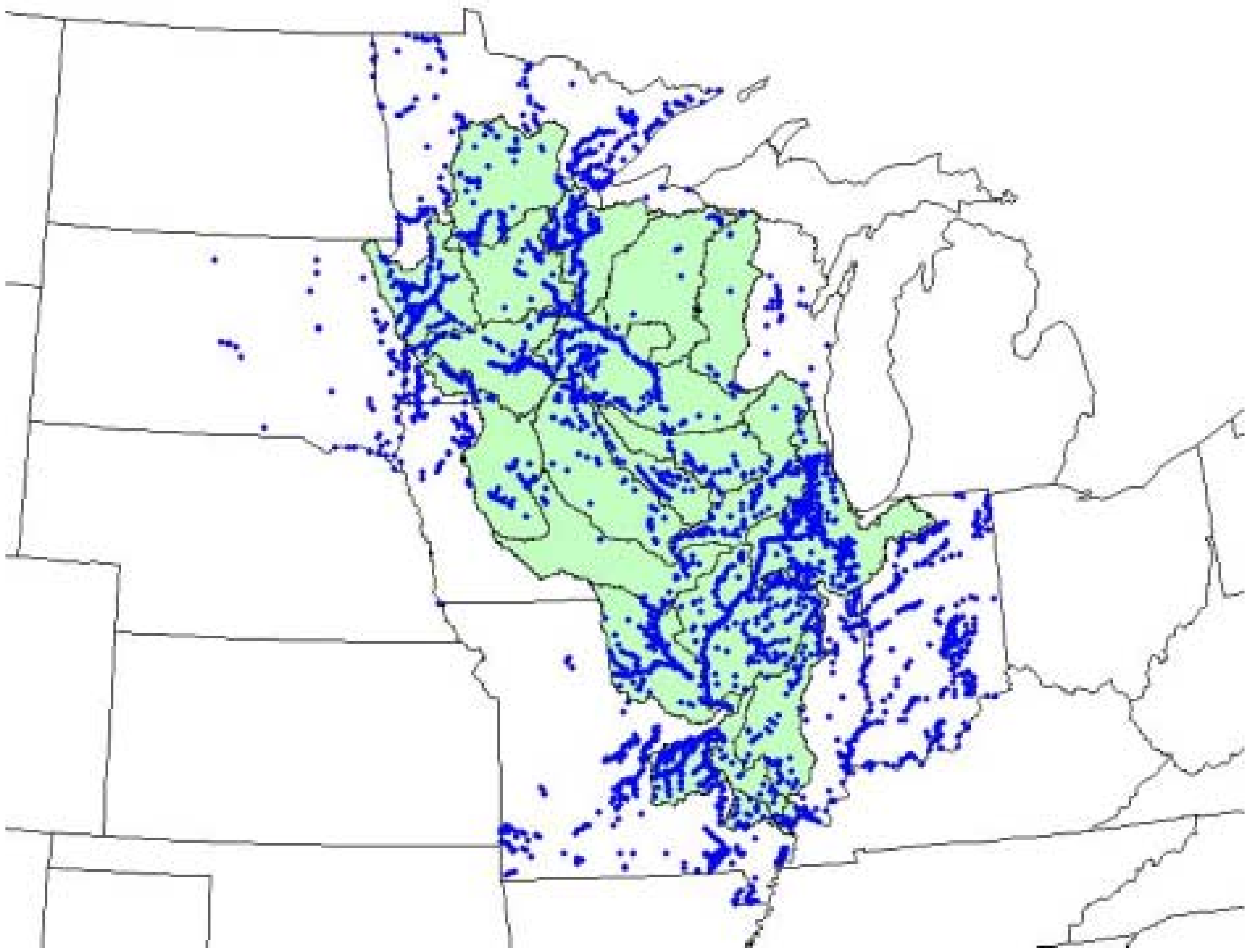

Figure 10. Location of mussel survey information in the UMRB Freshwater Biological Database. Blue dots represent survey locations. Green polygons represent EDUs in the UMRB.

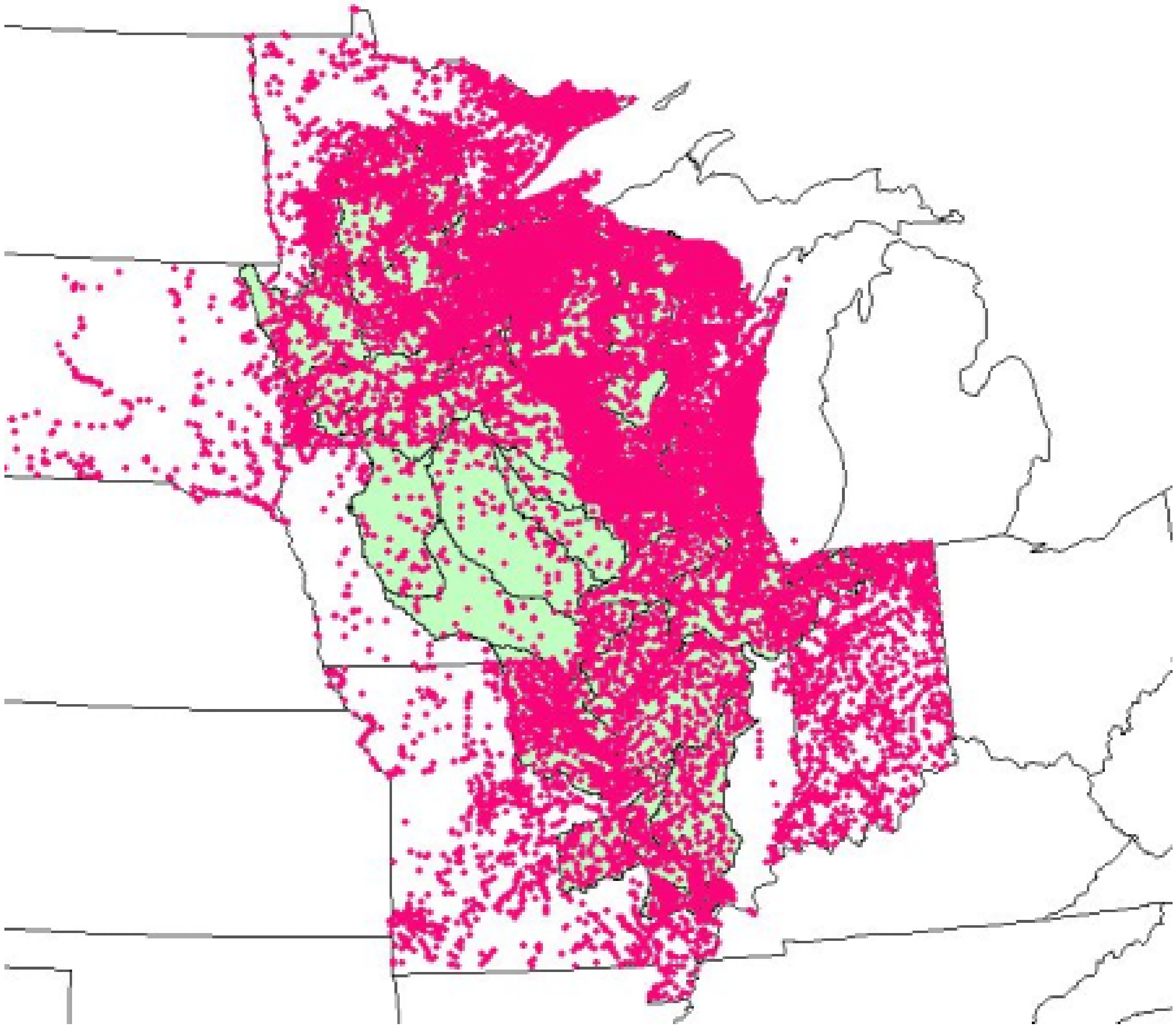

Figure 11. Locations of fish survey information in the UMRB Freshwater Biological Database. Green polygons represent EDUs in the UMRB.

9. Assessment of Fish Communities across Aquatic Systems of the Northern Glaciated Zone

9.1. Introduction and Objective

As coarse-filter targets for conservation, aquatic ecological systems must serve to capture elements of biological diversity at finer levels of organization, including communities and species which are common and representative of a region. Rarely do we have the opportunity to describe the full range of biological diversity captured by individual aquatic ecological system types or assess the degree to which they are successful in capturing all subsequent elements of biodiversity. Most frequently, aquatic systems are defined primarily in terms of physical factors, and we are left to infer the types and distribution of biological elements occurring within them based on experimental knowledge of species habitat preferences and distribution patterns.

This study presented a rare opportunity to better describe the biological elements associated with aquatic system types. The fish fauna of the northern glaciated portion of the UMRB has been examined extensively. The availability of high quality fish community data from hundreds of locations, and the relative diversity of stream habitats in this zone, makes this an ideal place for more detailed biological descriptions of aquatic system types of the UMRB (Figure 12).

Our objective to identify groups of fish species (“assemblage types”) occurring within the northern glaciated portion of the UMRB and describe the distribution of these groups within the aquatic systems that occur there. Furthermore, we sought to describe the strength of the association between fish assemblage types and system types.

9.2. Methods

9.2.1. Study Area

The northern glaciated portion of the UMRB includes five ecological drainage units: the Upper Mississippi Headwaters, Mississippi Outwash Plains, St. Croix River, Chippewa-Black Rivers and Wisconsin River EDUs (Figure 12). The primary land cover is forest, and streams are generally low-gradient and underlain by glacial deposits ranging from coarse to fine in texture. Streams are also characterized by mixed chemistry, including calcareous and non-calcareous. Fishes ranged from coldwater to warmwater species and from lake-dwellers to stream and riverine forms. Sixty system types were identified for the region. Systems ranged from low-gradient headwater-creeks to low-gradient large rivers. For a description of all of the system types that occur in the study area, see Appendix 7A.

9.2.2. Data Selection and Acquisition

Fish community survey data from the northern glaciated zone of the UMRB were sought from local sources, including academic institutions and federal, state and local governmental agencies (Table 11). Data were required to have been collected since 1979 and include community survey information (i.e., the incidence or abundance of *all* fish species at a survey site, to the extent practicable through standard survey methods). Our search resulted in six datasets appropriate for this analysis (Table 13).

9.2.3. Data Preparation

To avoid the use of assemblage data from locations with high anthropogenic impacts or insufficient sampling, all sites containing fewer than four species or draining catchments with less than 20 percent natural cover were omitted. To narrow the analysis to native communities only, all non-native and hybrid species occurrence records were deleted. All records of fishes not identified to the species level were also omitted.

9.2.4. Analysis Methods

Two hierarchical agglomerative cluster analyses were conducted to identify fish assemblages from the presence/absence information provided by site survey data. Both cluster analyses used PCOrd 4.17 (McCune and Mefford 2002) with the Sorenson/Bray-Curtis distance measure and Ward's linkage method (McCune and Grace 2002). The first cluster analysis included only common species; rare species (taxa occurring at fewer than 5% of survey sites) were eliminated from the dataset to prevent them from unduly weighting the analysis. The second analysis was conducted using the full complement of species found in the basin. Results of the two analyses were compared for consistency. Species groups were considered valid fish assemblage types if member species had similar instream habitat requirements (Page and Burr 1991; Becker 1983; Lyons 1989, 1996; Niemela and Fiest 2000, 2002), if they occupied similar waterbody types (i.e., large river vs. headwater creek vs. lake), or if the assemblage type seemed to be limited to a particular area in the northern glaciated zone.

We also assessed the validity of the cluster groupings using non-metric multidimensional scaling (NMDS). This analysis allowed us to visually inspect ordinations of fish species (labeled with cluster group membership) to determine their relative proximity to species within the same group and species in other cluster groups. Greater clustering and isolation of a particular assemblage's species in the ordination diagram was interpreted as stronger assemblage validity.

To assess the distribution of fish assemblage types among EDUs and system types, we calculated the ratio of assemblage sites (defined as a location with at least 49% of assemblage-type species) occurring within each classification unit to the number of assemblage sites across the whole study area. The degree of assemblage fidelity and constancy for specific classification units was also determined (Boesch 1977). Constancy was calculated by summing the number of sites in which each assemblage occurred for each classification unit, and dividing by the total number of sites in that unit. Fidelity of an assemblage for a classification unit was the ratio of its constancy for that classification unit to its constancy for all sites. Finally, we mapped the locations of sites where species of each assemblage type were found, and visually inspected these figures to identify assemblage associations with particular system types, system sizes and EDUs.

9.3. Results

9.3.1. Fish Assemblages

Our initial database of sites and species included 10,931 survey locations and 253 taxa (including hybrids and non-native species). After eliminating potentially disturbed sites and non-native and hybrid species occurrences, the final dataset included 2207 sites (Figure 12) and 111 species, of which 65 were considered rare (taxa occurred at fewer than 5% of survey sites).

Cluster analysis resulted in 10 fish assemblage groups in the reduced (common species) dataset, and 16 groups in the full-species dataset (Table 14). Finer cluster groupings (i.e., more groups with fewer taxa) could not be explained by patterns in species ecological requirements. Larger groupings resulted in clusters with little ecological affinity; they appeared to be formed mostly on the basis of rarity and very broad trends in fish assemblage structure. Cluster analyses of the reduced and full-species datasets showed considerable similarity in group structure and composition; common species in the full dataset were broken into groups that were very close to group divisions in the reduced dataset (Appendix 11 Table 3). Because of the close similarity, we chose to focus on the cluster groups derived from the full dataset, in order to include rare species in our assemblage groups.

Of the 16 groups in the full-species dataset, 13 cluster groups were considered valid fish assemblage types (Appendix 11 Table 3), because species habitat requirements of component species were similar within each group. Three groups were determined to be invalid groups (groups 1, 69 and 85), because they consisted only of rare species with dissimilar habitat requirements. Our assessment of the structure, ecological affinity and validity of the groups was based on published reports of fish habitat requirements, NMDS of fishes in the study area, and figures of the occurrences of each assemblage type (Appendix 12 Figures 1-13). A summary of these assessments is provided in the final three columns of Table 14. Also provided in the table (in the column entitled "confidence of cluster") is a rating of the degree to which we felt confident that the assemblage type was valid, based on the previous assessment.

NMDS analysis provided moderate support for the fish group structure identified in the cluster analysis. In particular, the NMDS of common species distinguished the 10 cluster units identified in the cluster analysis (Figure 13). In the ordination diagram, species of the same assemblage type were generally tightly clustered, although multiple assemblage groups overlapped slightly.

9.3.2. Relating Fish Assemblages to Aquatic Systems

The strength or weakness of assemblage type association with each classification unit is assessed using the distribution (Appendix 11 Table 1), constancy (Appendix 11 Table 2), and fidelity (Appendix 11 Table 3) scores. High values in each of these tables are an indication that the assemblage is closely tied to a specific unit type. Assemblage groups were distributed unevenly among the classification units: system types, EDUs and system size classes (Appendix 11 Table 1). Units contained a range of 0 to 100 percent of all assemblage type occurrences (defined as the presence of 50 percent or more of the assemblage type species at a given location). Several groups showed close affiliation with specific EDUs (e.g., Assemblage M; Appendix 12 Figure 12), and other groups were closely aligned with specific systems and system size classes (e.g., Assemblages B and C; Appendix 11 Table 1; Appendix 12: Figures 2 and 3). One group was strongly associated with a wide range of system types and EDUs (Assemblage G; Appendix 12 Figure 8; Appendix 11 Table 1) while another demonstrated little association with any system type, EDU, or system size class (e.g., Assemblage I; Appendix Figure 9; Appendix 11 Table 1).

Constancy scores ranged from 0 to 0.50 and fidelity scores ranged from 0 to 61 (Appendix 11 Tables 2 and 3). Again, assemblages showed varying levels of constancy and fidelity for specific system types, EDUs and size classes, demonstrating considerable variation in the spatial patterns of the biological communities inhabiting each of the classification units.

9.4. Discussion

Characterizing aquatic system types using biological community information poses multiple challenges. Primary among these is the selection of the appropriate grain of ecological information with which to characterize the systems. To be effective, the biologic community characteristic must be ecologically meaningful, relatively easy to measure across broad spatial scales, and representative of a larger range of ecologic features. They must also must strike a balance between providing sufficient information to distinguish system types, and limiting that information appropriately to offer broad generalities.

In this assessment, we chose to describe the biological nature of aquatic system types by quantifying the distribution, constancy and fidelity of fish assemblage types (defined by a cluster analysis of basin taxa) among these systems. Fish assemblages provide sufficient biological information to characterize a system, are indicative of functional and trophic processes within a system, and are thought to be sensitive to changes in habitat structure at the system scale (Poff and Allan 1994). Furthermore, component taxa are widely understood and familiar to many scientists and conservation practitioners. The primary concern we had with this approach was that the presence and absence of particular assemblage types would not vary sufficiently among similar systems to demonstrate the ecological distinctions represented by the systems.

9.4.1. Clustering of Fish Assemblages

We arrived at 13 fish assemblage types, which utilize a broad diversity of freshwater habitats across the range of the northern glaciated zone. Fish assemblage types generally appear to be accurate representations of fish community structure throughout the study area, but our confidence in the validity of this analysis is mediated by several factors.

First, species within Assemblages E and I appear to be very weakly associated by ecological characteristics and may not be considered valid assemblage types. We are also concerned about the validity of groups that appear to have considerable ecological overlap with other assemblage types, and may, in fact represent nested fish groups rather than distinct assemblage types. For example, assemblages C and J are very closely affiliated riverine fish communities. Group C appears to consist of more common species, while J is generally comprised of more rare and sensitive taxa. These assemblages may have overlapping distributions, with the latter group species simply co-occurring with assemblage C species where habitats are less disturbed. Rather than draw a distinction between these groups based on their relative rarity in rivers, it may be more appropriate to combine them into one assemblage type. Potentially nested assemblages and groups with questionable ecological association require more investigation, and may need to be reclassified.

Also problematic is the fact that a few species appear to be misclassified. In particular, the central stoneroller, which is classified in Assemblage E, is not a species of lakes, ponds and backwaters, but rather one of rocky riffles and runs in streams. In addition, the southern brook lamprey appears to be misclassified in Assemblage I, a large-river taxa group. These errors may be due to misidentifications in one or more of the datasets (Wang et al. 1997), which were not corrected before this analysis was conducted.

In reviewing the results of this analysis, we realize that our study design may have introduced some error. For example, by eliminating sites with fewer than four species we may have omitted high quality small trout streams. In eliminating sites with less than 20% natural land cover in the catchment area, we may have omitted other high-quality sites and retained highly impaired sites. For example, sites with good riparian buffers may have been excluded and conversely, those with large amounts of urban impacts may have been included. We also did not purposefully eliminate impoundments and other unnatural habitats, which are likely to be represented in the datasets. Finally, we have concerns about the use of multiple datasets for this analysis, and inconsistencies in sample design and effort among these data. Further analysis should be directed at testing whether these problems unduly influence the fish cluster analysis and the resulting assemblage types.

Overall, our confidence in the fish assemblage groups is bolstered by the large sample database, which should provide sufficient coverage to ensure accurate representation of most system types. In addition, there is general concurrence between the cluster analyses and the common-species NMDS, indicating that we have captured broad patterns of assemblage structure.

We purposefully excluded non-native taxa from the analysis in order to characterize system types as they might historically have occurred. We would expect considerable changes in the assemblage groups developed for this analysis had we included all non-native taxa. However, this analysis may benefit from an approach that includes these taxa, because it would allow us to identify assemblage types that have been most reconfigured due to species invasions, as well as system types most characterized by non-native taxa. Finally, the inclusion of non-indigenous species would probably provide a more accurate representation of current assemblage composition related to system types.

9.4.2. Fish Assemblages and Aquatic Systems

Fish assemblages showed varying degrees of specificity to aquatic system types in the UMRB. In a few cases, systems and assemblages show a very tight correspondence. More often, subtle differences in the distribution, fidelity and constancy of multiple assemblage types among different classification units demonstrate the biological differences among system types and provide the information needed to fully characterize the fish community found within a particular system. For example, four of the five northern glaciated EDUs include system types described as "low density, perennial creek systems with low gradient with low to moderate gradient headwaters, in coarse ground moraines with local areas of outwash, peat and muck" (system types: *1* 1A 18, *2* 1A 18, *5* 1A 18 and *7* 1A 18). Each of these systems would seem to be probable locations where Assemblage A species (taxa typical to rocky, riffle habitats) could be found. However, this assemblage type is not distributed evenly across all of these system types, despite their relative similarity in habitats. The distribution, constancy and fidelity scores for Assemblage A in system 7 1A 18 are 0.32, 0.027 and 2.37, respectively (Appendix 11 Tables 1, 2, and 3). In contrast, Assemblage A scores are 0 for distribution, constancy and fidelity in the 1A 18 system types in the other three EDUs. Assemblage A appears to be much more specific to system 7 1A 18 than any other similar system type in the northern glaciated region. Other assemblage types (e.g., Assemblages F and K) appear to favor system 1 1A 18 over other similar systems (e.g., *2* 1A 18, *5* 1A 18 and *7* 1A 18) in the study area, based on Appendix 11 Tables 1, 2, and 3. In summary, the biological distinctiveness of aquatic systems lies in the relative affinities of different fish assemblage types for each system type. This affinity is described in the distribution, constancy and fidelity scores.

Several factors challenge our ability to characterize the relationship between fish assemblages and aquatic system types. First, among Upper Mississippi aquatic systems, the northern glaciated zone contains diverse habitats and a considerable diversity of system types. Despite the relative diversity of habitats, fish assemblages are comparatively depauperate and quite uniform across the region. Many taxa are generalists, and reside in a range of habitat conditions. Because there are a limited number of fish assemblage types (13) and an abundance of different system types (60), there is considerable overlap in fish assemblage composition across multiple system types. Had we clustered fish assemblages into smaller groups, defined them using more detailed information (e.g., relative abundance data) or chosen a different characteristic of the biological community to measure (e.g., the relative abundances of different species), we may have been more successful in documenting a finer level of correspondence between biological elements and aquatic ecological systems. Finally, our analysis demonstrated that fish assemblages may be associated with different spatial units, ranging in scale from EDUs to ecological systems. Although we did not test this possibility, some assemblages may be tied to even finer spatial levels of classification units, such as macrohabitats.

Despite relatively low endemism and taxonomic diversity, fish communities of the northern glaciated portion of the UMRB may be effectively used to describe the biological nature and distinctiveness of aquatic systems of this region. Patterns in fish assemblage distribution offer insight into the suite of biological communities inhabiting the diversity of aquatic system types that occur there. Because fish assemblages vary in their specificity to aquatic system types, factors such as assemblage distribution, fidelity and constancy allow us to draw modest conclusions about the biological characteristics that differentiate system types. Future analyses should evaluate the degree to which aquatic system types and selected conservation areas capture the diversity of fish assemblage types in the region.

Table 13. Data sources for the biological community analysis.

Source Code	Taxon	Title	Source/Contact	Coverage
MN01	Fish	PCA Fish	Scott Niemela — Minnesota Pollution Control Agency	9692 records at 831 stations throughout Minnesota
MN03	Fish	Konrad's Personal Dataset	Konrad Schmidt — Minnesota Department of Natural Resources	33139 records from sites in Mississippi, St. Croix, Minnesota and Des Moines River drainages
UMR01	Fish	LTRMP-Fish	USGS -Upper Midwest Environmental Sciences Center	739197 sampling points in six study reaches in the UMRB
UMR03	Fish	NAWQA-UMR	Bob Goldstein and Kathy Lee — USGS Mounds View, MN	1850 records from Upper Mississippi Drainage in MN and WI
WI01	Fish	Fago Master Fish Database	Don Fago — Wisconsin Department of Natural Resources	1135906 records from 15607 collections in the UMRB
WI03	Fish	Wisconsin Wadeable Streams data	Li Wang, John Lyons - Wisconsin Department of Natural Resources	2985 records from WI; about 250 sites

Table 14. Cluster analysis results and final assemblage groupings in the northern glaciated portion of the UMRB. All fishes included in the analysis are listed. Those identified as common species are listed in italics.

Assemblage Type Letter	Species Code	SCIENTIFIC NAME	Common Name	Group affiliation in common species dataset (10 groups)	Group affiliation in full dataset (16 groups)	Confi-dence of Cluster	Habitat	Geographic Distribution	Waterbody type
Assemblage A	LSS	CAMPOSTOMA OLIGOLEPIS	LARGESCALE STONEROLLER		2	high	rocky riffle	concentrated in central reaches of Wisconsin and Chippewa-Black Basins	streams and small rivers
	RAD	ETHEOSTOMA CAERULEUM	RAINBOW DARTER		2				
	FAD	ETHEOSTOMA FLABELLARE	FANTAIL DARTER		2				
	BAD	ETHEOSTOMA ZONALE	BANDED DARTER		2				
	NBL	ICHTHYOMYZON FOSSOR	NORTHERN BROOK LAMPREY		2				
	ROS	NOTROPIS RUBELLUS	ROSYFACE SHINER		2				
Assemblage B	LED	ETHEOSTOMA MICROPERCA	LEAST DARTER		3	high	shallow, quiet margins of vegetated lakes, ponds and and streams; pools and slow runs in streams; usually over sand or mud	lake-dominated systems (headwaters of most EDUs, particularly Wisconsin and Upper Mississippi EDUs)	lakes and low gradient streams
	BAK	FUNDULUS DIAPHANUS	BANDED KILLIFISH		3				
	LES	LEPOMIS MEGALOTIS	LONGEAR SUNFISH		3				
	PUS	NOTROPIS ANOGENUS	PUGNOSE SHINER		3				
	BCS	*NOTROPIS HETERODON*	*BLACKCHIN SHINER*	1	3				
	BNS	*NOTROPIS HETEROLEPIS*	*BLACKNOSE SHINER*	1	3				
Assemblage C	GIS	DOROSOMA CEPEDIANUM	GIZZARD SHAD		5	high	main channels, pools, backwaters; over sand, silt or gravel	major mainstems of all EDUs	medium to big rivers
	GOE	HIODON ALOSOIDES	GOLDEYE		5				
	SIC	MACRHYBOPSIS STORERIANA	SILVER CHUB		5				
	WHB	MORONE CHRYSOPS	WHITE BASS		5				
	BUM	PIMEPHALES VIGILAX	BULLHEAD MINNOW		5				
	FHC	PYLODICTIS OLIVARIS	FLATHEAD CATFISH		5				
	SAR	STIZOSTEDION CANADENSE	SAUGER		5				
	BIB	*ICTIOBUS CYPRINELLUS*	*BIGMOUTH BUFFALO*	2	5				
	NOP	*ESOX LUCIUS*	*NORTHERN PIKE*	3	6	high	clear, cool-water streams associated with lake habitat or rivers with slow-moving backwater habitats; vegetated areas;	widespread across all EDUs	streams and rivers
	PUD	*LEPOMIS GIBBOSUS*	*PUMPKINSEED*	3	6				
	BLL	*LEPOMIS MACROCHIRUS*	*BLUEGILL*	3	6				
	LAB	*MICROPTERUS SALMOIDES*	*LARGEMOUTH BASS*	3	6				
	YEP	*PERCA FLAVESCENS*	*YELLOW PERCH*	3	6				
	BKC	*POMOXIS NIGROMACULATUS*	*BLACK CRAPPIE*	3	6				

Assemblage Type Letter	Species Code	SCIENTIFIC NAME	Common Name	Group affiliation in common species dataset (10 groups)	Group affiliation in full dataset (16 groups)	Confidence of Cluster	Habitat	Geographic Distribution	Waterbody type
	ROB	*AMBLOPLITES RUPESTRIS*	*ROCK BASS*	28	6				
	MUE	*ESOX MASQUINONGY*	*MUSKELLUNGE*	28	6				
	SMB	*MICROPTERUS DOLOMIEU*	*SMALLMOUTH BASS*	28	6				
	WAE	*STIZOSTEDION VITREUM*	*WALLEYE*	28	6				
Assemblage E	BON	AMIA CALVA	BOWFIN		7	medium-low	lakes, ponds, pools and backwaters	concentrated in St. Croix and Mississippi headwaters and Mississippi outwash EDUs	
	CES	CAMPOSTOMA ANOMALUM	CENTRAL STONEROLLER		7				
	ORS	LEPOMIS HUMILIS	ORANGESPOTTED SUNFISH		7				
	BMS	NOTROPIS DORSALIS	BIGMOUTH SHINER		7				
	TRH	PERCOPSIS OMISCOMAYCUS	TROUT-PERCH		7				
	BKS	*LABIDESTHES SICCULUS*	*BROOK SILVERSIDE*	4	7				
	SOS	*NOTROPIS HUDSONIUS*	*SPOTTAIL SHINER*	4	7				
Assemblage F	BLB	*AMEIURUS MELAS*	*BLACK BULLHEAD*	5	8	high	slow water (pools, backwaters and sluggish areas); soft substrates	pretty widespread in western portions of Northern Glaciated zones	creeks, streams, rivers, ponds and impoundments
	YBH	*AMEIURUS NATALIS*	*YELLOW BULLHEAD*	5	8				
	BRB	*AMEIURUS NEBULOSUS*	*BROWN BULLHEAD*	5	8				
	IOD	*ETHEOSTOMA EXILE*	*IOWA DARTER*	5	8				
	GRS	*LEPOMIS CYANELLUS*	*GREEN SUNFISH*	5	8				
	GOS	*NOTEMIGONUS CRYSOLEUCAS*	*GOLDEN SHINER*	5	8				
	TAM	*NOTURUS GYRINUS*	*TADPOLE MADTOM*	5	8				
Assemblage G	WHS	*CATOSTOMUS COMMERSONI*	*WHITE SUCKER*	6	9	high			streams and lakes
	JOD	*ETHEOSTOMA NIGRUM*	*JOHNNY DARTER*	6	9				
	COS	*LUXILUS CORNUTUS*	*COMMON SHINER*	6	9				
	BLD	*RHINICHTHYS ATRATULUS*	*BLACKNOSE DACE*	6	9				
	CRC	*SEMOTILUS ATROMACULATUS*	*CREEK CHUB*	6	9				
	CEM	*UMBRA LIMI*	*CENTRAL MUDMINNOW*	6	9				
	GRR	MOXOSTOMA VALENCIENNESI	GREATER REDHORSE		11	medium-high	clear, rocky runs		small-medium rivers
	SPS	*CYPRINELLA SPILOPTERA*	*SPOTFIN SHINER*	8	11				
	MIS	*NOTROPIS VOLUCELLUS*	*MIMIC SHINER*	8	11				
	BLM	*PIMEPHALES NOTATUS*	*BLUNTNOSE MINNOW*	8	11				
	NHS	*HYPENTELIUM NIGRICANS*	*NORTHERN HOG SUCKER*	11	11				

Assemblage Type Letter	Species Code	SCIENTIFIC NAME	Common Name	Group affiliation in common species dataset (10 groups)	Group affiliation in full dataset (16 groups)	Confi-dence of Cluster	Habitat	Geographic Distribution	Waterbody type
	BUT	*LOTA LOTA*	*BURBOT*	11	11				
	SIR	*MOXOSTOMA ANISURUM*	*SILVER REDHORSE*	11	11				
	GOR	*MOXOSTOMA ERYTHRURUM*	*GOLDEN REDHORSE*	11	11				
	SHR	*MOXOSTOMA MACROLEPIDOTUM*	*SHORTHEAD REDHORSE*	11	11				
	HOC	*NOCOMIS BIGUTTATUS*	*HORNYHEAD CHUB*	11	11				
	LOH	*PERCINA CAPRODES*	*LOGPERCH*	11	11				
	BSD	*PERCINA MACULATA*	*BLACKSIDE DARTER*	11	11				
	LOD	*RHINICHTHYS CATARACTAE*	*LONGNOSE DACE*	11	11				
	STT	NOTURUS FLAVUS	STONECAT		11				
	GID	PERCINA EVIDES	GILT DARTER		11				
	SHD	PERCINA PHOXOCEPHALA	SLENDERHEAD DARTER		11				
	CHL	*ICHTHYOMYZON CASTANEUS*	*CHESTNUT LAMPREY*	11	11				
Assemblage I	MUD	ETHEOSTOMA ASPRIGENE	MUD DARTER		12	medium -low		mostly confined to St. Croix, Chippewa and Wisconsin EDUs	large rivers
	WAH	LEPOMIS GULOSUS	WARMOUTH		12				
	BLR	MOXOSTOMA DUQUESNEI	BLACK REDHORSE		12				
	WES	NOTROPIS TEXANUS	WEED SHINER		12				
	PAH	POLYODON SPATHULA	PADDLEFISH		12				
	WHC	POMOXIS ANNULARIS	WHITE CRAPPIE		12				
	LAS	ACIPENSER FULVESCENS	LAKE STURGEON		12				
	SBL	ICHTHYOMYZON GAGEI	SOUTHERN BROOK LAMPREY		12				
	SIL	ICHTHYOMYZON UNICUSPIS	SILVER LAMPREY		12				
	WSD	AMMOCRYPTA CLARA	WESTERN SAND DARTER		13	high		Mississippi and lower reaches of the largest tributaries	large rivers
	RIC	CARPIODES CARPIO	RIVER CARPSUCKER		13				
	HIC	CARPIODES VELIFER	HIGHFIN CARPSUCKER		13				
	BLS	CYCLEPTUS ELONGATUS	BLUE SUCKER		13				
	MOE	HIODON TERGISUS	MOONEYE		13				
	SAB	ICTIOBUS BUBALUS	SMALLMOUTH BUFFALO		13				
	LOG	LEPISOSTEUS OSSEUS	LONGNOSE GAR		13				
	RRS	NOTROPIS BLENNIUS	RIVER SHINER		13				

Assemblage Type Letter	Species Code	SCIENTIFIC NAME	Common Name	Group affiliation in common species dataset (10 groups)	Group affiliation in full dataset (16 groups)	Confi-dence of Cluster	Habitat	Geographic Distribution	Waterbody type
	CRD	CRYSTALLARIA ASPRELLA	CRYSTAL DARTER		13				
	SHS	SCAPHIRHYNCHUS PLATORYNCHUS	SHOVELNOSE STURGEON		13				
	RID	PERCINA SHUMARDI	RIVER DARTER		13				
Assemblage K	FID	PHOXINUS NEOGAEUS	FINESCALE DACE		18	high	small streams; beaver ponds, small lakes		
	BRS	*CULAEA INCONSTANS*	*BROOK STICKLEBACK*	10	18				
	BSM	*HYBOGNATHUS HANKINSONI*	*BRASSY MINNOW*	10	18				
	PED	*MARGARISCUS MARGARITA*	*PEARL DACE*	10	18				
	NRD	*PHOXINUS EOS*	*NORTHERN REDBELLY DACE*	10	18				
	FAM	*PIMEPHALES PROMELAS*	*FATHEAD MINNOW*	10	18				
Assemblage L	FWD	APLODINOTUS GRUNNIENS	FRESHWATER DRUM		26	high		occur in mainstem of Mississippi outwash and lower reaches of Chippewa, Black and WI rivers;	Uncommon or occasional in large rivers and small streams and creeks;
	QUB	CARPIODES CYPRINUS	QUILLBACK		26				
	CHC	ICTALURUS PUNCTATUS	CHANNEL CATFISH		26				
	RIR	MOXOSTOMA CARINATUM	RIVER REDHORSE		26				
	EMS	NOTROPIS ATHERINOIDES	EMERALD SHINER		26				
	SAS	NOTROPIS LUDIBUNDUS	SAND SHINER		26				
Assemblage M	SLS	COTTUS COGNATUS	SLIMY SCULPIN		19	medium-high	cool, coldwater assemblage		
	BRT	SALVELINUS FONTINALIS	BROOK TROUT		19				
	RED	CLINOSTOMUS ELONGATUS	REDSIDE DACE		19				
	SRD	PHOXINUS ERYTHROGASTER	SOUTHERN REDBELLY DACE		19				
not valid	PIP	APHREDODERUS SAYANUS	PIRATE PERCH		1	low	fishes inhabiting moderate-gradient streams flowing into large rivers (Wisconsin)		
	ABL	LAMPETRA APPENDIX	AMERICAN BROOK LAMPREY		1				
	RGP	ESOX AMERICANUS	REDFIN OR GRASS PICKEREL		1				
	YEB	MORONE MISSISSIPPIENSIS	YELLOW BASS		1				
not valid	SDS	MINYTREMA MELANOPS	SPOTTED SUCKER		69	low	rare		
	PUM	OPSOPOEODUS EMILIAE	PUGNOSE MINNOW		69				
Not valid	SHG	LEPISOSTEUS PLATOSTOMUS	SHORTNOSE GAR		85	low	rare		
	SDC	MACRHYBOPSIS AESTIVALIS	SPECKLED CHUB		85				

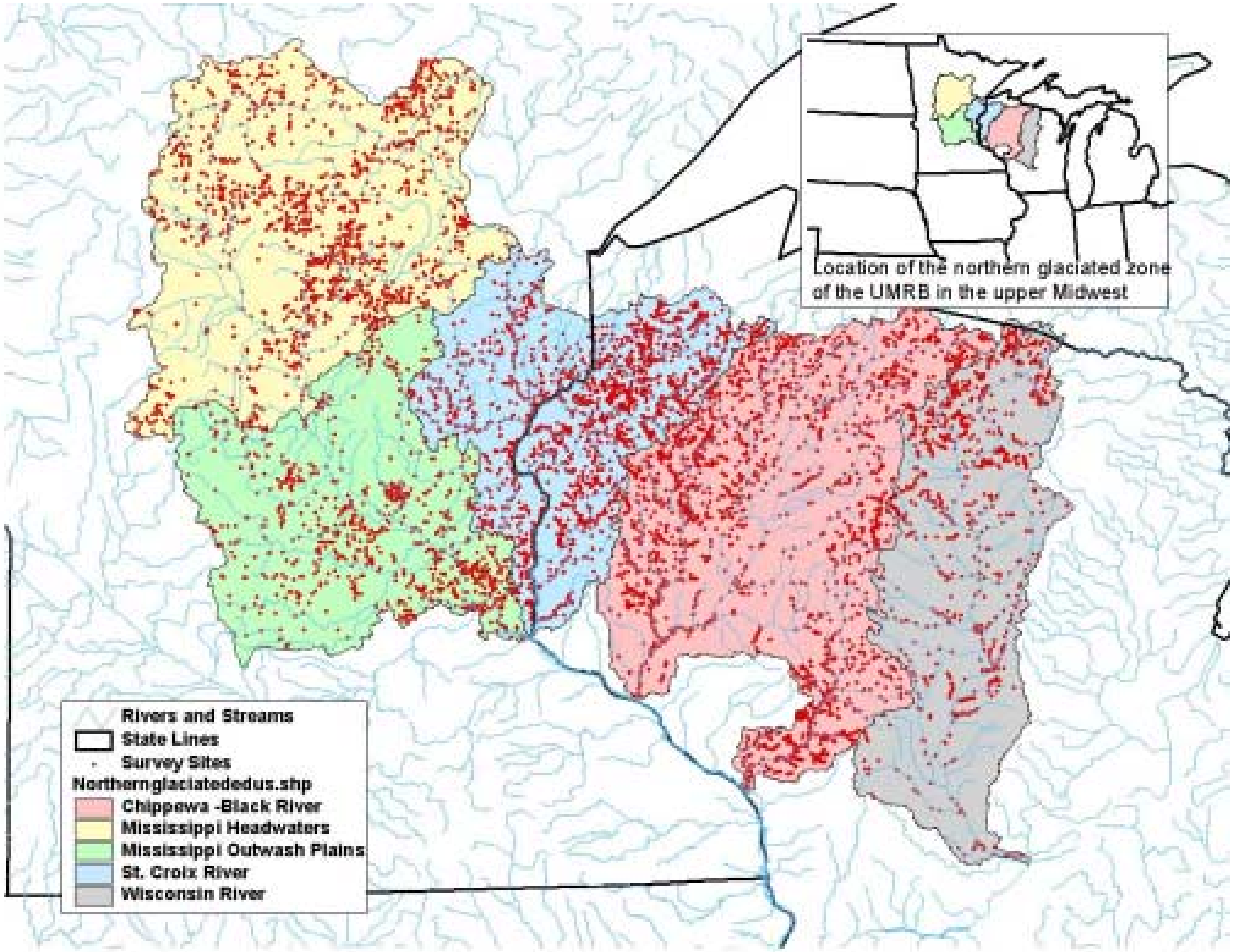

Figure 12. Northern Glaciated portion of the UMRB with locations of all survey data included in this study (red dots).

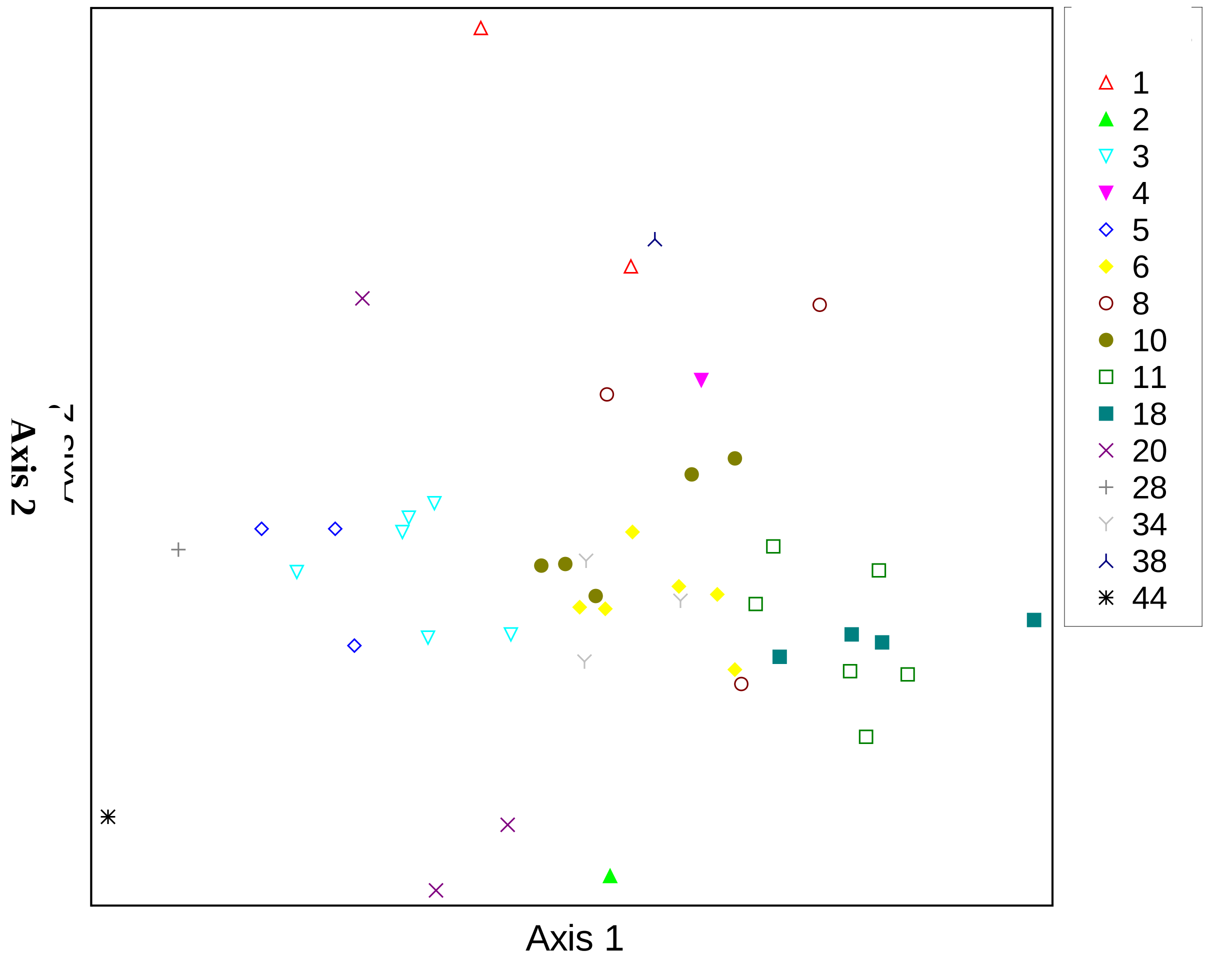

Figure 13. Non-metric multidimensional scaling ordination of common species in the northern glaciated zone of the UMRB. Cluster group numbers correspond to group numbers in Table 14, column 5, entitled “Group affiliation in common species dataset.”

10. Future Needs and Information Gaps

Future Needs and Information Gaps

The information gathered, analyzed, and generated for this project has significantly advanced our understanding of the Upper Mississippi River ecosystem, yet there are several issues relating to freshwater biodiversity yet to be adequately addressed. Some revolve around the physical aspects of aquatic ecosystems, such as methods to adequately model stream temperatures or map surficial geology across larger geographic areas (both discussed in the section on defining conservation targets), but the majority center on the biological and ecological aspects of these ecosystems. Further consultation with regional experts may be sufficient to address several of these needs, but many can only be addressed through the concerted efforts of resource professionals across the basin, and beyond.

Major informational needs for the UMRB, and aquatic ecosystems as a whole, include:

Species inventory:
There is a strong need for further sampling and taxonomic work in many aquatic groups, especially for the lesser-studied groups of invertebrates. Existing datasets are not consistent in their level of taxonomic resolution, with the lack of taxonomic experts and published keys for the more obscure groups serving as the limiting factors. Given the spotty and incomplete knowledge of the distributions of many freshwater invertebrates, it is impossible to know whether populations are declining or endangered, and to precisely identify the major threats to their existence.

Electronic data development:
A concerted effort is needed to computerize historic datasets. There exists a wealth of distributional information for many aquatic groups, inaccessible to researchers because it is hidden in private files, obscure papers, or sometimes only in the brains of researchers. The addition of this information to computerized databases would add to our knowledge of past distributions of aquatic taxa, and help to identify long-term trends in population numbers, providing historical context to discussions of the current status of species.

Ecological Research:
A better understanding of the life-histories, habitat needs, and community relationships for many aquatic taxa is necessary to account for the effects of environmental change, and to develop more refined and defensible conservation goals (the number and distribution of occurrences) for target species. This information is also critical to rank the viability of species occurrences. Currently, very few species occurrences have viability information.

Thresholds of Biological Response:
Specific thresholds of biological response to various landscape-scale alterations are not known, yet are essential in creating more meaningful measures of ecosystem integrity.

In future aquatic conservation assessments, every effort should be made to include the full array of aquatic ecosystem types, including rivers, lakes, wetlands, and subterranean habitats. These habitat types are interconnected, hydrologically and ecologically, with many species relying on two or more of these distinct habitats to complete their life-history. Alternatively, numerous species are restricted to a single habitat type, and the failure to include all types therefore paints an incomplete picture of the aquatic diversity in an area. Unfortunately, adequate and comparable classification methodologies for each habitat type have not been developed.

Lakes

Lake ecosystems dominate large areas of the upper Midwest, USA, and southern Ontario, Canada. Despite decades of monitoring and research, our knowledge of the biodiversity of these systems is cursory, as most data comes from the management of lakes for recreational and commercial fisheries. While this reports provides information on the distribution of lake types across the landscape, it is mainly focused on the riverine aquatic systems. Our intention was to address lakes in greater detail, but we found it was beyond the scope of this document to develop a robust classification and assessment of current lake conditions. However, the need for such work is great and it would create a more complete picture of freshwater biodiversity in the UMRB.

Minnesota and Wisconsin have the largest concentrations of inland lakes, with more than 22,000 located within the bounds of the UMRB (Figure 27). These glacial lakes are among the most endangered of aquatic systems, currently threatened with a multitude of anthropogenic disturbances. Drainage of shallow lakes and wetlands for agriculture has altered local and regional surface and groundwater flows, while the widespread conversion of land for lakeshore properties has led to the wholesale destruction of riparian, emergent, and submergent plant communities. Subsequent nutrification and other pollution from lawn fertilizers and septic systems, increased runoff from impervious surfaces, and the widespread introduction of exotic species are having serious negative effects on the structure and function of these ecosystems.

An accurate assessment of lake types and their associated physical and biological components, will allow us to monitor how human manipulations are affecting the biodiversity of lake ecosystems. We recommend that a systematic methodology for classifying inland lake ecosystems be developed and applied. The products of this work would provide:

- a complete description of lake ecosystem types, based on physical, chemical, and biological variables.
- insight into the variables limiting the distribution of aquatic plants and animals.
- detailed reference conditions on ecosystem integrity with which to monitor future changes.
- the basis for predictive distribution models for aquatic organisms.
- critical information for the design of sampling regimes that would appropriately characterize lake community assemblages and physical habitat attributes.

- a flexible framework that could be adapted and applied to other regions of the U.S. and Canada.

Caves

The UMRB also contains a number of subterranean aquatic ecosystems, with the highest density occurring in the karst areas of southern basin, along the border between Missouri and Illinois (Figure 28). The caves and springs of this region are inhabited by a highly specialized, and very diverse biota, including many species of snails, fishes, salamanders, crustaceans, and many other obscure invertebrate groups. Relative to our knowledge of the surface fauna, we know little about the full diversity and distribution of cave species and communities in the basin, due in large part to a lack of accessibility of underground habitats. Where data on the distribution of cave species does exist, it is often very hard to obtain due to concerns over the possible exploitation of the caves and their biota by rogue cavers and collectors.

Subterranean aquatic systems and their faunas are relatively fragile and highly susceptible to perturbation. High degrees of endemism, limited distributions, small populations sizes, and highly specialized morphological, physiological, and ecological adaptations all contribute to the highly sensitive nature of cave biota (Walsh 2000). Ongoing threats to subterranean biodiversity stem from a variety of incompatible human activities, including habitat destruction and the alteration of hydrologic regimes from mining and urbanization, environmental pollution from agricultural and industrial runoff, and the introduction of exotic or pest species and their associated pathogens (Elliot 1998).

Karst systems are generally linked to both local and regional groundwater systems, and are not confined by surficial drainage boundaries, thus, groundwater species may be affected by disturbance events over long distances. In fact, a single, catastrophic event has the potential of eliminating entire species or communities. Given the vulnerability of cave systems, and our inadequate knowledge of the distribution and life history requirements of much of the fauna, urgent attention is warranted. More baseline faunal and ecological surveys are clearly needed, as well as a more clear understanding of the connectivity of surficial and subterranean systems in the region.

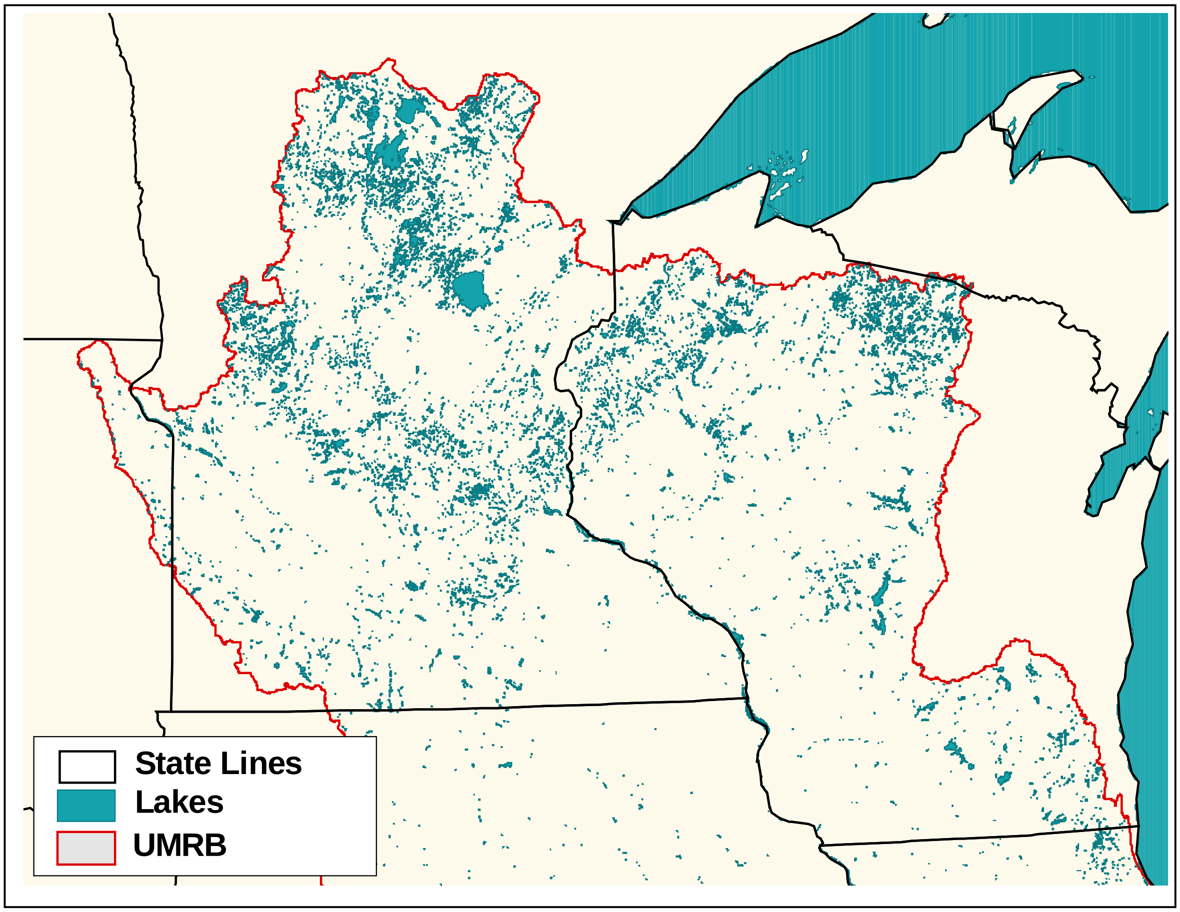

Figure 14. Distribution of lakes in the northern UMRB. (Inland lakes outside the basin were omitted for clarity.)

Figure 15. Priority karst region of the southern UMRB.

11. How to use the information in this report.

This report includes all of the underlying data sets used in the analysis of Areas of Biodiversity Significance and Priority Areas. There are several tables included in the appendix as well as databases available only with electronic versions of this report.

The following data sets are included as tables in the main text of the report or in the appendices:

- Species information:
  APPENDIX 2: Species Lists for the UMRB.
  Table A: Fish, Table B: Mussels, Table C: Crayfish
  APPENDIX 4: List of non-indigenous aquatic animals and plants in the UMRB.
  APPENDIX 5: Species conservation targets.
- Community information:
  Table 14. Cluster analysis results and final assemblage groupings in the northern glaciated portion of the UMRB.
- Aquatic Ecological System information:
  APPENDIX 6: Descriptions of the EDUs.
  APPENDIX 7: Aquatic systems descriptions. A: stream systems, B: lake systems.
  APPENDIX 8: Standardization of surficial geology
- Priority areas information
  APPENDIX 10: Areas of biodiversity significance attributes
  APPENDIX 11: Priority Areas maps and reports.
- Expert recommended site information:
  APPENDIX 9: Expert recommended streams and lakes
  APPENDIX 11: Priority areas maps and reports.

The CD also contains several electronic files that are separate from the report. These include the following:

- UMRB fishes and mussels database
  This database is described in detail in Section 8 of the report. It is in Microsoft Access 2000. The fields are listed and described in Table 12.
- Conservation Planning Tool (public version: species location information is not included). This database is in the standard format created by The Nature Conservancy to manage ecoregional and basin planning data. This relational database is in MS Access 2000. Each field is defined in the table definitions. There are standard tables and user defined tables that include attributes not standard across The Nature Conservancy. The following types of tables are included:
  - Conservation Targets descriptions (species and ecological systems)
  - Conservation Target occurrences (species and ecological systems)
  - Additional attributes of system occurrences
  - Expert site information
  - Expert contact information
  - Priority areas

The tables are cross-referenced so that, for example, species can be linked to systems or Priority Areas, or aquatic systems can be linked to the Priority Areas.

- Spatial data: The following files are also included on the CD. Shapefiles are in the following projection:

  Albers
  NAD 1927
  Units: meters
  Parameters:
    Central Meridian: -96
    Central Latitude: 23
    1st parallel: 29.5
    2nd parallel: 45.5
    False Easting: 0
    False Northing: 0

  - Shapefiles for each size class of aquatic ecological systems
  - (Note: attributes for these shapefiles can be exported from the conservation planning tool.)
  - Geologic layer for the UMRB
  - Stream Hydrography with sequenced arcs (ReachFile3 — 1:100,000)
  - Ecological Drainage Units
  - Aquatic Zoogeographic Units
  - Priority Area polygons

For further information regarding these data, contact Mary Lammert Khoury, The Nature Conservancy, mkhoury@tnc.org, (312) 759-8017.

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