Overview of the Michigan Rivers Inventory (MRI) Project

Paul W. Seelbach
and
Michael J. Wiley
OVERVIEW OF THE MICHIGAN RIVERS INVENTORY (MRI) PROJECT

Paul W. Seelbach
and
Michael J. Wiley
Overview of the Michigan Rivers Inventory (MRI) Project

Paul W. Seelbach

Institute for Fisheries Research
Michigan Department of Natural Resources
212 Museums Annex
Ann Arbor, Michigan 48109

and

Michael J. Wiley

School of Natural Resources and Environment
The University of Michigan
Ann Arbor, Michigan 48109

Abstract.—The sound, scientific management of lower Michigan’s expansive river systems will require a sophisticated understanding of their ecological structures and processes, and a careful evaluation of the state of these rivers as they currently exist—i.e. a comprehensive inventory. To this end we developed a partnership in 1988 between scientists at the Michigan Department of Natural Resources—Institute for Fisheries Research, and the University of Michigan—School of Natural Resources and Environment, known as the Michigan Rivers Inventory (MRI) project. Our strategy for studying the comparative ecology of Michigan rivers has four primary components: conducting an Inventory, developing Descriptions and Predictive Models, developing an Ecological Classification System, and developing Management Applications. The foundation of the inventory was a large Geographic Information System (GIS); i.e. a collection of maps and a relational, geo-referenced database containing key physical and biological characteristics for a large number (~675) of river sites representative of rivers draining the Lower Peninsula of Michigan. Data incorporated in the MRI came from a variety of sources and included (1) field measurements made by project personnel; (2) numerous existing datasets that were compiled by other State and University research groups; (3) mapped data of various origins that could be processed and related to MRI study sites by manipulation in a GIS; and (4) "synthetic" data produced by modeling site-scale variables (for example stream flows) from summaries of catchment landscape characteristics for a subset of sites. To explore linkages between different-scale habitat variables and fishes, we emphasized data development at 3 distinct spatial scales of influence: (1) the catchment landscape; (2) the local channel reach; and (3) the immediate sampling site. The temporal extent of the data covered the past 2.5 decades, providing a reasonable summary of the current nature of Michigan’s rivers. We used the GIS to develop several graphical summaries and statistical models of habitat and fish community characteristics. These helped to identify broad patterns within the data, explore the underlying relationships between local ecological conditions and the larger-scale processes that drive them, and to provide predictive capabilities. We likewise developed an ecological classification for the river valley segments of Michigan’s Lower Peninsula, incorporating both physical and biotic characteristics.
segment attributes. The multi-scale framework of the MRI approach provides a toolbox for addressing many local river management issues. Viewing a system in its larger-scale (landscape) context helps managers to define key variables and constraints that shape site-scale problems. MRI models provide the complimentary ability to predict specific site-scale attributes for developing management expectations and targets. Comprehensive regional assessments like the MRI ultimately should provide a platform for more-informed, broader-scale thinking and communication about river ecosystems. The MRI is an ongoing project; current work includes extending geographical coverage to Michigan’s Upper Peninsula and further refinement of the valley segment ecological classification system.

Hundreds of permanently-flowing streams drain Michigan’s Lower Peninsula. These form about 20 major river ecosystems, and scores of smaller, coastal systems. Managed wisely these fluvial resources can provide a rich suite of ecological, water supply, recreational, and aesthetic benefits for years to come. Sound scientific management of these expansive systems will require a sophisticated understanding of their ecological structures and processes, and a careful evaluation of the state of these rivers as they currently exist-- i.e. a comprehensive inventory. Extensive historical data sets on many aspects of Michigan’s rivers already exist. In Appendix 1 we provide a guide to key references that illustrate both the disciplinary breadth and the impressive histories of earlier Michigan river survey efforts. But as is commonly observed (Chamberlin 1984), most of these studies have been carried out by separate agencies, were purposefully narrow in focus, and the results of many are difficult to locate and utilize. Despite the fact that large amounts of detailed information have been collected (often through routine government monitoring), available data are not well integrated, nor have they been examined from a holistic perspective. There is a pressing need to gather and synthesize the wealth of relevant information on Michigan’s rivers.

To this end we developed a partnership in 1988 between scientists at the Michigan Department of Natural Resources--Institute for Fisheries Research, and the University of Michigan--School of Natural Resources and Environment, known as the Michigan Rivers Inventory (MRI) project. This collaboration has been largely informal, built initially around the project “Inventory and classification of Michigan rivers” (funded primarily by Federal Sportfish Restoration monies and several small university grants). The combined platform of the state agency and the university has consistently provided many logistic and technical resources. More recently, MRI work has been developed further through a series of more specifically-focused, externally-funded research projects (Table 1).

The overall purpose of the MRI has been to study the comparative ecology of Michigan rivers. Though interested in the full spectrum of rivers found in Michigan, we felt the Lower Peninsula represented a natural study unit of a scale consistent with our logistical abilities to conduct field sampling from our operating base in Ann Arbor (located in southeast MI). Lower Peninsula rivers also represent an interesting, very hydrologically-diverse set; some rivers are nearly entirely runoff-driven, while others are nearly entirely groundwater-driven.

Conceptually, we view rivers as large-scale hydrologic, geomorphic, and biological systems, rather than as aggregations of distinct sites (Wiley and Seelbach 1997). As rivers are expansive, landscape-scale systems, we have also drawn upon the fundamental principles of the discipline of Landscape Ecology (Risser et al. 1983; Ricklefs 1987; Levin 1992; Pickett and Cadenasso 1995). For example: (1) River system dynamics involve the transfer of water and sediment downslope across complex mosaics of landscape units; in the MRI we focused on hydrology as a key discipline linking landscape, channel, and ecological processes. (2) Large-scale patterns in ecosystem structure and dynamics exist within and among rivers; in the MRI, we searched for patterns in ecological characteristics of rivers that could be quantified.
both within and across systems, and for relationships among variables that might suggest mechanisms behind the observed patterns (Levin 1992). And finally, (3) human-modified landscapes are integral to the study of rivers; in the MRI we studied river systems as they presently exist, often radically-modified by human activities. Landuse variables were explicitly included in many of our descriptions and models.

The goals of the MRI project were:

- To assemble selected data on important aspects of Michigan's watershed landscapes, river channels, and associated fishes.
- To describe the broad-scale spatial variation and patterns observed in these river ecosystems and their fish assemblages.
- To develop a set of models that suggest mechanisms behind the patterns observed in river ecosystems; both for comparison with existing theories of river organization and to provide predictive capabilities to river managers.
- To develop a system for the classification of ecological units within Michigan rivers.
- To develop decision-making tools for river management.

This report is the underlying reference document for the MRI project. In it we document both our conceptual approach and some of the fundamental methods. Hopefully it can also serve as a guide to others involved in developing regional inventory programs.

The objectives of this report were:

- To provide an overview of the conceptual and functional approach used in the MRI.
- To describe the MRI GIS (map and database system) structure.
- To describe development of primary datasets.
- To provide a guide to current and expected products.

Overview of the MRI

Our strategy for studying the comparative ecology of Michigan rivers had four primary components (Figure 1):

1) We conducted an Inventory to assemble data (existing and new) on characteristics of river sites, their catchments, and associated fishes.
2) We used these data and appropriate hydrologic, geomorphic, and ecologic theory to develop Descriptions and Predictive Models of both physical habitats and fish communities; these both describe patterns and help clarify causal hypotheses. Model outputs were incorporated into the inventory database as site attributes.
3) We developed an Ecological Classification System to allow generalization of the complexity found in river ecosystems. Again, classification attributes were incorporated into the inventory database.
4) We developed Management Applications for specific projects to demonstrate how MRI tools could be used to aid local decision-making.

Inventory

We developed a rivers inventory by building a large Geographic Information System (GIS); i.e. a collection of maps and a relational, geo-referenced database containing key physical and biological characteristics for a large number (~675) of river sites representative of rivers draining the Lower Peninsula of Michigan. This GIS provided us with extensive capabilities for both map- and table-based storage, query, display, and analysis of data. Data incorporated in the MRI came from a variety of sources (Figure 1) and included: (1) field measurements made by project personnel; (2) numerous existing datasets that were compiled by other state and university research groups; (3) mapped data of various origins that could be processed and related to MRI study sites by manipulation in a GIS; and (4) "synthetic" data produced by modeling site-scale variables (for example, flow duration curves, see Modeling below ) from
summaries of catchment landscape characteristics for a subset of sites.

Spatial coverage

About 675 MRI study sites have been established in the Lower Peninsula to date. These sites constitute the sampling framework upon which the MRI GIS has been built and their unique site numbers act as the shared “common field” in the relational database. Data from these sites were used to construct an overall picture of the spatial structure and organization of Michigan’s river ecosystems. Because site selection was based in part on a desire to incorporate existing data collections, it is important to emphasize that this group of sampling sites does not constitute a true random sample of Michigan streams. However, we believe that the MRI sampling sites as a group are: (1) representative of the major types of fluvial ecosystems that occur in lower Michigan (Figure 2; though this shows that MRI sites likely under-represent the smallest streams [tabulated by site and segment numbers, not by stream miles]); and (2) sufficiently dispersed to provide a basis for large-scale description of spatial patterns across the Lower Peninsula (Figure 3).

Spatial Scales

Linking the multi-scale dynamics of geoclimatic, catchment-level driving variables, local river channel habitats, and fish populations has often been identified as an important goal of fishery scientists (Dewberry 1980; Imhof et al. 1996; Rabeni and Sowa 1996). To explore these linkages we emphasized data development at 3 distinct spatial scales of influence: (1) the catchment landscape; (2) the local channel reach bracketing each site (about 5-10 km long); and (3) the immediate sampling site (about 100-300 m long). First, catchment landscapes determine the extent and timing of water, sediment, and nutrient deliveries to a local site (Dunne and Leopold 1978; Newson 1994). The nature of these deliveries defines much of the ecological character of a site. We therefore focused on the development of catchment-landscape data sets which could be used to describe and model hydrology at each site. Catchment-specific climatic, geologic, soil, and landcover data (measured from GIS maps) comprise the basic MRI data sets at this larger scale (Wiley and Seelbach 1997).

Second, some ecological conditions of a site are determined or constrained by the unique geology and morphology of the valley through which a reach runs (Cupp 1989; Rosgen 1994). For example, a reach that lies in a clayey, former glacial lake bed might have a low gradient, high sinuosity, fine substrates, high turbidity, and broad floodplain wetlands regardless of hydrologic sources upriver. As another example--channel meanders and floodplain morphology will typically be restricted, gradients will be higher, and substrates rockier, when a stream flows within a fairly narrow valley through a resistant, rocky morainal area.

Third, local ecological conditions may be even further shaped by unusual site-specific characteristics. The presence of a bedrock outcrop, waterfall, or glacial gravel deposit; as well as local variations in channel gradient all influence the development of substrates, pools, and riffles. Similarly, local water temperatures are affected by the presence of upstream impoundment or lake.

An important assumption of the MRI approach was that factors shaping riverine biology operate at some larger-than-site or -reach scale (such as river segment or perhaps multiple segments). Throughout their life cycles, many riverine biota undergo extensive movements among multiple, distinct habitats (for example fishes; Schlosser 1991; Gowan et al. 1994); suggesting that some mid-scale unit (at least) is needed for population-level studies (Bayley and Li 1992). So we conceptually viewed site data as samples of some larger ecological units (Seelbach et al. 1997).

Temporal extent

Our inventory has incorporated data on the status of Michigan rivers from the past 2.5 decades (roughly 1970 to present). Data for many parameters of interest are available for this
index period and they provide a reasonable summary of the current nature of Michigan’s rivers.

Climatic and landscape variables controlling river geomorphology change slowly, on the order of 100-10,000 year time scales (Knighton 1989). On the other hand, hydrologic variables are characterized by exceptionally-high, short-term (daily, seasonal) temporal variance (Poff and Ward 1989). We believe that index periods of several decades provide both a current view of stable, geomorphic controls and a sufficient period for statistical summarization of higher-frequency, hydrologic and biological variables (Hakanson 1996). In the MRI project, we have focused on an intermediate time-scale set by the scale of variation seen in biological communities. Although the abundance of component fish populations certainly varies both seasonally and annually; in most river species, persistence and rough community composition are fairly stable over a longer time frame of multiple generations (Vannote et al. 1980; Imhof et al. 1996; Maxwell et al. 1995; Wiley et al. 1996); generally comparable to the decadal scale of the MRI.

MRI databases include data in two formats: data-series and data summaries. In both data are referenced to specific MRI site locations. Data series files contain measurements at individual MRI sites repeated over some period of time. Data summaries typically contain but one value for each MRI site (e.g., one measure for late summer discharge, channel width, or abundance of smallmouth bass). Some data summaries (such as temperature or discharge values) are statistical summaries of data series. When necessary data (such as late summer fish abundance) were single collections. Recognizing that annual variation occurs and adds considerable "noise" to our data, we nonetheless used such single values to represent the average condition at a site over the study time period. In landscape-scale studies the scale of observation is always limited at some point by technical or logistical constraints (Levin 1992). Noisy data are, however, often entirely adequate to answer many important questions. We proceeded under the assumption that such data were appropriate to examine, at the least, the larger-scale spatial variation in the structure of Michigan’s river ecosystems.

The MRI Geographic Information System (GIS)

The MRI GIS provides a powerful analytical environment. It contains a collection of maps and a relational, geo-referenced database. Its capabilities include data storage, spatial or tabular queries, and spatial display and analyses. This GIS is a flexible system that can be refined and expanded upon. Study regions, sampling sites, data types, or temporal components can be added as they are needed or available (geographic expansion into Michigan’s Upper Peninsula is already underway). The MRI GIS consists of three general components, presently residing in two separate hardware environments:

1. A collection of digital map data layers for Michigan’s Lower Peninsula. These include (a) map layers representing numerous landscape characteristics useful for catchment description (e.g., surficial geology and land use), and (b) map layers containing locations of study sites and their catchment and major watershed boundaries. These map data are maintained in a Unix environment, and were developed and managed using ARC/INFO and ArcView (ESRI, Inc.) and IMAGINE (ERDAS, Inc.) GIS software.

2. A collection of data files containing data summaries for a wide variety of pertinent physical and biological variables (Figure 4). Each data summary is referenced by a common “site number” datafield, allowing both relational use of the multiple files and geo-referencing of these data to mapped site locations.

3. A series of data files that contain data collected on multiple dates (series data) and are similarly geo-referenced to the site locations. Data file types 2 and 3 are stored in a Windows NT environment and managed using Microsoft Excel and Microsoft Access (Microsoft Corporation) database software. Copies of the type-2 datafiles are also maintained on the Unix platform for use within the Unix GIS environment. Users
often access this Unix environment from a remote Windows-based PC terminal, using an x-windows client software (that emulates the Unix operating system). And some users are operating the GIS solely within a Windows PC environment, using Arcview software.

Map layers and geographic analyses

The MRI GIS currently contains numerous maps that describe the landscapes of lower Michigan (Table 2). Most maps were obtained from other agencies, and some were developed or modified within the MRI project. Maps are in both raster and vector formats, and generally represent the best-available (statewide) scale of resolution. Raster-format maps are at either the 1-km$^2$ or 1-ha$^2$ scale. Vector-format maps are generally at either 1:100,000 or 1:24,000 scale; and data include catchment boundaries for each major river basin, location and catchment boundaries for each site, and statewide coverages of stream channel networks. All maps were georeferenced to the following coordinate systems: UTM Zone 16, Clarkeson 1866 spheroid, rad 27 datum.

We characterized the catchment landscape for each of the 675 MRI study sites using the GIS. The entire boundary for the catchment upstream of each site was digitized to create a digital map layer for each site-specific catchment. Surficial catchment boundaries were delineated as the divides between stream channels based initially on subwatershed boundaries developed by MDNR from 1:24,000 maps and locally modified according to the 3 arc-second USGS Digital Elevation Map. A digital map layer depicting major watershed boundaries was also created. Buffer outlines of radius 1 km, 2 km, and 4 km were made for each site; and of 1 km for the stream network upstream of each site. We used the catchment, major watershed, site buffer, and stream buffer boundaries to "clip" and summarize descriptive data from various map layers (e.g. soil textures or land covers) for each site and major watershed. Catchment summaries were either of the form "percent coverage" (e.g. categories of soil textures) or "mean value" (e.g. mean annual rainfall). Summaries were saved in the MRI relational database.

Data files

We compiled data from sources including MRI field measurements (Appendix 2), existing agency and university datasets, summaries of map information, and site-specific model outputs. Databases were stored in database format (as "*.dbf" files) and were relational according to a "site number" variable common to all databases. Table 3 provides a general overview of the MRI databases.

Descriptions and Predictive Models

We developed a number of graphical summaries and statistical models of habitat and fish community characteristics. These helped to identify broad patterns within the data, explore the underlying relationships between local ecological conditions and the larger-scale processes that drive them, and to provide predictive capabilities. Simple graphical summaries provided a first-cut description of particular ecological resources and of some relationships between variables; as illustrated in Figures 6 and 7.

Our general approach to modeling these processes was to search for statistical relationships among datasets (an empirical and inferential approach). This was appropriate given (1) some inherent randomness in river systems, (2) the considerable sampling error inherent in our datasets, and (3) a need for simplification and abstraction in modeling complex river ecosystems (Schumm 1977; Knighton 1989; Levin 1992; Hakanson 1996). But we also consciously tried to incorporate logical causal structure (a deductive approach) whenever possible (Hakanson 1996). For example, linear regression equations predicting various discharge exceedence frequencies were based on the commonly-accepted hydraulic geometry relationship:

$$Q = a D^b A^c P^d M^{e} \ldots$$  EQ. 1.
where \( Q \) = discharge; \( DA \) = drainage area; \( P \) = precipitation; \( M \) = hydrologic modifiers such as slope or urban land use; "a", "b", "c", "s", "t", and "u" are derived coefficients (Dunne and Leopold 1978; Holthag and Crosky 1984). As another example, models of the July water temperature regime included independent variables that represented important elements of a heat-balance model; eg. travel time, water volume, local groundwater inputs, and upstream shading (Wehrly et al. 1997).

**Ecological Classification System**

Like modeling, developing a classification is another way to simplify, and generalize about, complex information sets. The classification process of grouping and separating is a valuable one, helping us refine our understanding of interrelationships among entities and of hierarchical systems organization.

River classification schemes have been proposed using many different kinds of variables (e.g. aquatic plants, fish fauna, chemistry, or geomorphology) across scales of examination ranging from whole watersheds; through valley segments, reaches, and channel units, down to microhabitats (e.g Frissel et al. 1986; Hawkins et al. 1993; Maxwell et al. 1995). To balance the goal of simplification with the retention of information, we chose to focus our classification work on an intermediate spatial scale, the valley segment.

We developed an ecological classification for the river valley segments of Michigan’s Lower Peninsula, incorporating both physical and biotic segment attributes (Seelbach et al. 1997). Using MRI data; and model-derived knowledge of the relationships among catchment landscapes, local geomorphology, and local riverine conditions, we interpreted from GIS maps:

1) The boundaries of ecologically-distinct river valley segments. Segment boundaries are usually associated with abrupt changes in geomorphology or major river confluences. The biota and physical character within each ecological valley segment are relatively homogeneous and segments are often fairly large, roughly 2-40 miles in length.

2) a number of component ecological attributes for each segment, including discharge regime, July temperature regime, nutrient chemistry, slope, valley character, and fish assemblage.

**Management Applications**

The multi-scale framework of the MRI approach provides a toolbox for both 1) providing statewide perspectives on aspects of the riverine resource, and 2) addressing many local river management issues. Viewing a system in its larger-scale (landscape) context helps managers to define key variables and constraints that shape site-scale problems. MRI models provide a complimentary ability to predict specific site-scale attributes for developing management expectations and evaluating current status (Biggs et al. 1990).

For example, MRI models are currently being used to assess ecological status and potentials for rehabilitation on several Michigan rivers. We first use the regional models to develop predicted (or expected or reference) ecological conditions specific to selected sites and catchments. Current ecological status is assessed by comparing these expected conditions with historical and current observed conditions. Mechanisms controlling current status are suggested by the model structures. This compilation of site-specific data provides a basis for interpreting how a particular system is currently working and how it may have changed over time; and provides an ecological basis for the identification of management opportunities and priorities. Very similar comparative, modeling approaches to ecological assessment have been recently developed for other aquatic systems (Wright 1995; Ladle and Westlake 1996; Hakanson 1996; Imhof et al. 1996). Preliminary results have been encouraging, in that information derived at moderate-to-fairly large scales, seems to be appropriate for answering both segment-specific and regional management questions.

Specifically, we have developed rehabilitation targets for fish communities, discharge regimes, and
water temperatures for specific segments of the heavily-degraded, Rouge River near Detroit. The MRI models have provided regionally- and catchment-appropriate summaries of what a similar-sized, unurbanized river in southeast Michigan, with similar discharge patterns, would be like ecologically. These summaries are being used by the Rouge River National Wetweather Demonstration Project as a vision for developing a rehabilitation strategy for the river.

Similar landscape-based modeling results are helping local watershed councils to assess stream conditions and develop management strategies for habitat and fisheries restoration. On Mill Creek (Huron River system): we assessed the potentials for fishery developments resulting from the proposed removal of a barrier dam and riparian wetland enhancements. On the Pigeon River, models were used to assess the potential for development of a coldwater fishery, following resolution of water quality problems.

A product of the models, the MRI valley segment ecological classification (VSEC) system provides a basis for the development of additional management tools. We are building an ecologically-supported, segment-based inventory of the coldwater (or trout-supporting) streams of lower Michigan; this will be an important foundation for both state trout and water-quality management programs. Water quality regulations are more stringent for coldwater streams. We are likewise beginning the development of a set of statewide, segment-specific standards for environmental integrity. This involves an expansion of the modeling done for the Rouge River, Mill Creek, and the Pigeon River; to provide a range of expected values of ecological (physical and biotic) traits for each unique river segment. The Nature Conservancy is building upon this classification framework to develop a segment-based system for prioritizing regional and national aquatic conservation programs. And the U.S. Forest Service is considering using ecological segments as the basis for their aquatic habitat protection programs within Michigan.

Finally, a comprehensive, regional GIS-based inventory like the MRI should ultimately serve as a platform for broader, more-informed communications among those interested in river ecosystems. Many such regional river assessments are being conducted—some at state or multi-state scales (Rankin et al. 1996, Beard et al. 1998), some for large watersheds (Lammert et al. 1997; Myers and Finnegan 1995; Bain 1996), and even for nations (Biggs et al. 1990; Wright 1995). These are typically done using somewhat different approaches but improving computer technologies should allow for increasing sharing of information and broad-scale comparative study.

Products and future directions

A number of theses and reports have been, or are currently being, completed (Table 4); those that are Michigan Department of Natural Resources, Fisheries Division reports will be available as Adobe Acrobat documents through the web site of the Institute for Fisheries Research: http://www.dnr.state.mi.us/www/ifr/ifrlibra/ifrlibra.htm.

We expect the MRI project to be ongoing. Current work includes:

- Extending the GIS, modeling, and classification work to Michigan’s Upper Peninsula (in cooperation with E. Baker, Michigan Department of Natural Resources, Marquette, MI; The Nature Conservancy, Chicago Regional Office; and the U.S. Forest Service, Region 5 Office, Milwaukee, WI)
- Additional sampling of streams within the Lower Peninsula (in cooperation with The Nature Conservancy, Chicago Regional Office; and The U.S. Environmental Protection Agency, Chicago Regional Office; and others).
- Testing, refining, and expanding the valley segment ecological classification system throughout Michigan (in cooperation with The Nature Conservancy, Chicago Regional Office; and The U.S. Forest Service, North Central Forest Experiment Station, Rhinelander, WI).
- Developing an inventory and ecological classification for riparian ecosystems, and exploring the linkages between terrestrial and stream classification systems (in cooperation with The Michigan Natural Features Inventory).
• Exploring the uses of catchment modeling or valley segment classifications for development of reach- or valley-specific ecological (e.g., biological, hydrologic, and thermal) standards (this is as an alternative to regionalization; in cooperation with the U.S. Environmental Protection Agency, Chicago Regional Office, The U.S. Fish and Wildlife Service, The Wisconsin Department of Natural Resources, and the Minnesota Department of Natural Resources).

• Applying MRI concepts and models to local case studies; specifically developing ecological stream assessments for local watershed councils that describe ecological history and status, and management options for specific stream segments (in cooperation with The Rouge River National Wet–weather Demonstration Project, Wayne Co., MI; the Huron River Watershed Council, Washtenaw Co., MI; and the Timberlands Resource Conservation and Development Area Council, Sparta, MI).

Acknowledgments

The Michigan Department of Natural Resources, Fisheries Division, Institute for Fisheries Research; and the University of Michigan, School of Natural Resources and Environment have provided commitment to, and continuous facilities support for, this long-term effort.

Funding for component projects has come from Federal Sportfish Restoration Funds, small grants administered by The University of Michigan, School of Natural Resources and Environment, The Michigan Coastal Zone Management Program, The Nature Conservancy–Great Lakes Office, and the Environmental Protection Agency–Region 5 Office.

Our GIS was built and managed with the assistance and considerable efforts of John Fay, Jennifer Kotanchik, Bill Whipps, Dave Zaber, and Sarah Zorn (GIS Lab, School of Natural Resources and Environment, University of Michigan, Ann Arbor); Dr. John Bartholic and Yung-Sung Kang (Institute of Water Research, Michigan State University, East Lansing); Gary Taylor and others (Michigan Department of Natural Resources, Michigan Resource Information System, Real Estate Division), and Matt Krogulecki (Database Graphics, East Lansing, MI). GIS maps for Indiana waters of the St. Joseph basin were provided by Dr. J.C. Randolf (School of Public and Environmental Affairs, Indiana University, Bloomington).

Influential early insights and guidance regarding large-scale patterning and processes in Michigan rivers were drawn from an unpublished manuscript – Classification of midwestern rivers-- by T.C. Dewberry (Pacific Rivers Council, Eugene, OR); and discussions with L.L. Osborne and S.L. Kohler (Illinois Natural History Survey, Champaign, IL).

Assistance in developing hydrologic databases was received from Dave Hamilton, Jerry Fulcher and Richard Popp (Land and Water Management Division, Michigan Department of Environmental Quality, Lansing) and Steve Blumer (U.S. Geological Service, Lansing, MI). Michigan Department of Natural Resources, District Fisheries staff have collaborated extensively on collections of field data on water temperatures, site habitats, and fish communities.

And the horsepower driving the MRI has been, of course, the many University of Michigan, School of Natural Resources, graduate students who have taken the lead on component research projects: Matthew Baker, Steven Bowler, Leon Hinz, Richard Kleiman, Jennifer Kotanchik, Kathrine Reising, Kevin Wehrly, David Zaber, and Troy Zorn.

We appreciate the critiques of reviewers Dave Fielder and Jim Diana towards the preparation of this document.
Figure 1.—Strategic components of the MRI project.
Figure 2.—Comparison of size-class frequencies (as indicated by link numbers) between MRI study sites and the total number of lower Michigan river valley segments (Seelbach et al. 1997; M. Lammert, personal communication, The Nature Conservancy, Great Lakes Regional Office, Chicago, IL). The link number at a point on a stream is the sum of the upstream first-order streams.

Figure 3.—Spatial distribution of 672 MRI study sites, within major watershed boundaries.
Figure 4.—General model of the MRI relational database, showing multiple database files and some examples of component data fields; files are linked by the common “SITENUM” field.
Figure 5.—Response surface of July weekly mean water temperature versus baseflow yield and drainage area for lower Michigan streams and rivers.

Figure 6.—Relationships between brown trout and smallmouth bass densities, and predicted mean July water temperatures.
Table 1.–Funded research projects developed collaboratively through the MRI partnership. Abbreviations are UM/SNRE, University of Michigan, School of Natural Resources and Environment; US EPA, U.S. Environmental Protection Agency; MDEQ-SWQD, Michigan Department of Environmental Quality, Surface Water Quality Division.

<table>
<thead>
<tr>
<th>Years</th>
<th>Project title/principal investigators</th>
<th>Funding sources and (additional partners)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988-98</td>
<td>Inventory and classification of Michigan rivers/ Seelbach and Wiley</td>
<td>Federal Aid to Sportfish Restoration, UM/SNRE grants</td>
</tr>
<tr>
<td>1993-98</td>
<td>Structure and function of trout-stream food webs/ Wiley and Kohler</td>
<td>National Science Foundation (with U. of Illinois)</td>
</tr>
<tr>
<td>1995-97</td>
<td>Ecological classification of Michigan rivers/ Seelbach and Wiley</td>
<td>MI Coastal Zone Management Program (with MI Natural Features Inventory)</td>
</tr>
<tr>
<td>1996-97</td>
<td>Ecological targets for rehabilitation of the Rouge River/ Seelbach and Wiley</td>
<td>Wayne Co., Rouge Program Office</td>
</tr>
<tr>
<td>1996-98</td>
<td>Decision tools for river management/ Seelbach</td>
<td>Federal Aid to Sportfish Restoration</td>
</tr>
<tr>
<td>1996-98</td>
<td>Nutrient effects on the organization of stream algal and invertebrate communities/ Wiley, Stevenson, and Holomuski</td>
<td>NSF--US EPA, Watershed Initiative (with University. of Louisville and Ohio State University.)</td>
</tr>
<tr>
<td>1997-98</td>
<td>Ecological valley segment classification/ Wiley and Seelbach</td>
<td>The Nature Conservancy, Great Lakes Regional Office</td>
</tr>
<tr>
<td>1997-99</td>
<td>Biological criteria for Michigan rivers/ Seelbach and Wiley</td>
<td>US EPA, Region 5 (with MDEQ, SWQD)</td>
</tr>
<tr>
<td>1997-00</td>
<td>Bio-indicators for the Northern Lakes and Forests Eco-region/ Seelbach and Wiley</td>
<td>US EPA, R-EMAP Program</td>
</tr>
</tbody>
</table>
Table 2.—Primary map layers currently used in the MRI GIS. Abbreviations are: MRI—Michigan Rivers Inventory; MDNR—Michigan Department of Natural Resources; USGS—U.S. Geological Survey; MIRIS—Michigan Resource Information System; MSU-CRS—Michigan State University, Center for Remote Sensing; MDA-MWS—Michigan Department of Agriculture, Michigan Weather Service; CRIES—Comprehensive Resource Inventory Evaluation System; MNFI—Michigan Natural Features Inventory; NOAA—National Oceanic and Atmospheric Administration; CES—Cooperative Extension Service; AES—Agricultural Experiment Station; USDA-NRCS—U.S. Department of Agriculture-Natural Resource Conservation Service; STATSGO—State Soil Geographic Database.

<table>
<thead>
<tr>
<th>Maps</th>
<th>Map source, date, format</th>
<th>Data source, scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>• statewide MRI site locations,</td>
<td>• MRI, 1995, vector</td>
<td>• MDNR catchment boundaries,</td>
</tr>
<tr>
<td>site catchment and major</td>
<td>• MRI, 1995, raster</td>
<td>1:2,000 (modified by MRI using 1:250,000 DEM)</td>
</tr>
<tr>
<td>watershed boundaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• statewide stream channels</td>
<td>• MRI, 1995, vector</td>
<td>• USGS Digital Line Graphs,</td>
</tr>
<tr>
<td></td>
<td>• MRI, 1995, raster</td>
<td>1:100,000</td>
</tr>
<tr>
<td></td>
<td>• MDNR-MIRIS, 1987, vector</td>
<td>• USGS topographic maps, 1:24,000</td>
</tr>
<tr>
<td>• annual and monthly mean precipitation,</td>
<td>• MSU-CRS, 1974, 1-km raster</td>
<td>• MDA-MWS data 1940-69</td>
</tr>
<tr>
<td>annual and monthly mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>monthly mean air temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• quaternary geology</td>
<td>• MSU-CRIES, 1981, 1-km raster</td>
<td>• Farrand and Bell (1984) map,</td>
</tr>
<tr>
<td></td>
<td>• MRI, 1996, 1-ha raster</td>
<td>1:500,000</td>
</tr>
<tr>
<td></td>
<td>• MNFI, 1996, vector</td>
<td>• Indiana portion of St. Joseph watershed digitized by MRI from Goebel et al. (1983) map, 1:1,000,000.</td>
</tr>
<tr>
<td>• statewide digital elevation</td>
<td>• USGS/NOAA, 1984, 1-km raster</td>
<td>• USGS Digital Elevation Model from 3 arc-second data, 1:250,000</td>
</tr>
<tr>
<td></td>
<td>• MRI, 1996, 1-ha raster</td>
<td></td>
</tr>
<tr>
<td>• soil texture</td>
<td>• MSU-CRS/CRIES, 1981, 1-km raster</td>
<td>• MSU-CES &amp; AES and USDA-NRCS from Soil Association Map of Michigan</td>
</tr>
<tr>
<td></td>
<td>• USDA-NRCS, STATSGO Soil</td>
<td>• statewide Michigan and Indiana portion of St. Joseph watershed from STATSGO Soil Association Map, 1:250,000.</td>
</tr>
<tr>
<td></td>
<td>Association Map, vector</td>
<td></td>
</tr>
<tr>
<td>• statewide 1978 land cover</td>
<td>• MSU-CRS, 1981, 1-km raster</td>
<td>• MDNR-MIRIS vector-format map from 1981-86 aerial photos, 1:24,000; Indiana portion of St. Joseph watershed from USGS Land Use/Cover Map, 1:250,000.</td>
</tr>
<tr>
<td></td>
<td>• MRI, 1996, 1-ha raster</td>
<td></td>
</tr>
<tr>
<td>• groundwater movement</td>
<td>• MRI, 1997, 1-ha raster</td>
<td>• modeled from 1-ha raster quaternary geology and digital slope maps</td>
</tr>
</tbody>
</table>
Table 3.—General overview of the MRI relational database.

<table>
<thead>
<tr>
<th>Database name</th>
<th>Description of fields</th>
<th>Sample size</th>
<th>Temporal extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sites</td>
<td>• site number, location, data types</td>
<td>672</td>
<td>NA</td>
</tr>
<tr>
<td>Landcovers</td>
<td>• site number&lt;br&gt;• catchment size from GIS analysis&lt;br&gt;• catchment means for precipitation, air temperature, evapotranspiration, topography from GIS analysis&lt;br&gt;• catchment percent coverage for surficial geology, soils, landuse from GIS analysis</td>
<td>672</td>
<td>climate: means for period 1940-69&lt;br&gt;landuse for 1979-82</td>
</tr>
<tr>
<td>Hydrology</td>
<td>• site number&lt;br&gt;• site USGS gage data: mean monthly and period discharges, and exceedence frequencies&lt;br&gt;• site USGS miscellaneous measures: mean late summer low discharge&lt;br&gt;• predicted monthly and period exceedence frequencies</td>
<td>672&lt;br&gt;138&lt;br&gt;93&lt;br&gt;672</td>
<td>for period of record for period of record</td>
</tr>
<tr>
<td>Chemistry</td>
<td>• site number&lt;br&gt;• site alkalinity, nutrients, suspended solids at high and low discharges?</td>
<td>~200&lt;br&gt;~50</td>
<td>variable</td>
</tr>
<tr>
<td>Temperature</td>
<td>• site number&lt;br&gt;• site July water temperatures&lt;br&gt;• site annual water temperatures</td>
<td>218&lt;br&gt;~50</td>
<td>1+ years beginning late 1980s</td>
</tr>
<tr>
<td>Habitat</td>
<td>• site number&lt;br&gt;• segment slope, sinuosity, stream network structure from 1:24,000 maps&lt;br&gt;• site channel geometry from USGS measures&lt;br&gt;• site channel geometry, substrates, riparian cover, slope from MRI field measures&lt;br&gt;• MRI-VSEC segment ID</td>
<td>672&lt;br&gt;~110&lt;br&gt;188&lt;br&gt;672</td>
<td>multiple measures&lt;br&gt;1-time measures</td>
</tr>
<tr>
<td>Fishes</td>
<td>• site number&lt;br&gt;• site species presence&lt;br&gt;• site species abundance by number and weight&lt;br&gt;• site trout abundance only</td>
<td>340&lt;br&gt;257&lt;br&gt;78</td>
<td>1-time samples</td>
</tr>
<tr>
<td>Benthic invertebrates</td>
<td>• site number&lt;br&gt;• site species presence/abundance</td>
<td>~100</td>
<td>single- and multiple-season samples</td>
</tr>
<tr>
<td>Other biota</td>
<td>• site/segment number&lt;br&gt;• river otter trapping records&lt;br&gt;• breeding bird distributions (Brewer et al. 1991)</td>
<td>271&lt;br&gt;672</td>
<td>past 10 years&lt;br&gt;period 1983-88</td>
</tr>
</tbody>
</table>
Table 4.—Manuscripts produced through the MRI (status either completed or in preparation). Michigan Department of Natural Resources, Fisheries Division reports are (soon to be) available on the Institute for Fisheries Research Internet homepage (shown below by an “*”), at http://www.dnr.state.mi.us/www/ifr/ifrlibra/ifrlibra.htm.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Year</th>
<th>Institution/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berry, T.</td>
<td>Land use and stream discharge in Michigan's cold water streams</td>
<td>1992</td>
<td>University of Michigan, Ann Arbor</td>
</tr>
<tr>
<td>Cornejo, C.R.T.</td>
<td>Regional characteristics of longitudinal patterns in stream fish biodiversity</td>
<td>1992</td>
<td>University of Michigan, Ann Arbor</td>
</tr>
<tr>
<td>Prasad, S.</td>
<td>GIS-based watershed integrated water quality modeling</td>
<td>1994</td>
<td>University of Michigan, Ann Arbor</td>
</tr>
<tr>
<td>Gooding, M.</td>
<td>Large-scale classification of Michigan watersheds</td>
<td>1995</td>
<td>University of Michigan, Ann Arbor</td>
</tr>
<tr>
<td>Kleiman, R.</td>
<td>Modeling water quality in Michigan rivers from landscape variables</td>
<td>1995</td>
<td>University of Michigan</td>
</tr>
<tr>
<td>Kotanchik, J.C.</td>
<td>Large-scale distribution of river otters in Michigan’s Lower Peninsula</td>
<td>1997</td>
<td>University of Michigan, Ann Arbor</td>
</tr>
<tr>
<td>Zaber, D.</td>
<td>Multi-scale analysis of the correspondence between spacial patterns of avian and fish community diversity</td>
<td>1997</td>
<td>PhD Dissertation, University of Michigan, Ann Arbor.</td>
</tr>
</tbody>
</table>
References


Appendix 1. Selected bibliography of major inventory work on Michigan rivers; arranged by discipline and chronology. This is not intended to be comprehensive, but rather to illustrate the historical scope of inventories. Reports that are examples of an existing series are indicated as "(S)".

**Hydrology**

*Streamflow gaging, statewide*


*Summaries and modeling of streamflows, statewide*


**Water quality**

*Point source water quality, select streams*


Summaries of water quality, statewide


Anonymous. 1977. Water quality inventory and environmental/water quality relationships. East Central Michigan Planning and Development Region, areawide waste treatment management plan. The Chester Engineers. (S)


Goudy, G. W. 1986. Water quality and pollution control in Michigan. Michigan Department of Natural Resources, Surface Water Quality Division, Lansing. (S)

Nonpoint source water quality, select basins and statewide


Consumptive water uses, statewide and select basins


Hydropower impacts on flows and water quality, select streams


Basin morphometry and landscapes

Stream network and basin morphometry, statewide

Brown, C.J.D. 1944. Michigan streams-their lengths, distribution, and drainage areas. Michigan Department of Natural Resources,


GIS landscape data, statewide


Channel geomorphology and habitat

Streambank erosion and sand sediment loads, select coldwater streams


Habitat measures and modeling, select streams


River corridor protection—Statewide


Fishes and mussels

Distributions of fishes and mussels, statewide and select rivers


Hubbs and Cooper. 1936. Minnows of Michigan. Cranbrook Institute of Science, Bulletin 8, Bloomfield Hills, MI.


Distributions of gamefishes, statewide and select warmwater rivers

Estimates of fish community composition, statewide and select rivers

Anonymous. 1996. Qualitative biological and habitat survey protocols for wadable streams and rivers. Michigan Department of Environmental Quality, Surface Water Quality Division, GLEAS Procedure #51, Lansing. (S)


Integrated watershed assessments

Water resource assessments, select basins


Fishery resource assessments, select basins


Ecosystem studies, select basins


Watershed management projects, select basins


Appendix 2.—Methods for developing physical and biological site databases

Hydrology

Discharge data for all historical and current USGS stream discharge gaging stations (N=138; these were all included as MRI sampling sites) in the Lower Peninsula were obtained from the Michigan Department of Environmental Quality, Land and Water Management Division--Hydrology Section. Data were summaries for the period of record: mean annual and mean monthly discharges; and annual, April (period of saturated soils), and August (period of unsaturated soils) percent exceedence frequencies (for the percent series: 5, 10, 25, 50, 75, 90, 95). We also computed the mean of any MDEQ miscellaneous discharge measures taken at an MRI site during the low-flow months of July, August, and September. Discharges were converted to catchment yields with units cfs/km². Discharges at the above range of exceedence frequencies were also predicted for all 672 sampling sites using MRI models (unpublished).

Water chemistry

Most data on water chemistry were obtained by collections at selected MRI sites during 1992-1997. Alkalinity and conductivity were analyzed in situ; while concentrations of phosphorus, nitrogen, ammonia, and suspended solids were analyzed in the lab using standard and automated methods (Kleiman 1995). Some additional chemistry data for MRI sites were obtained from the STORET database.

Water temperature

Water temperature regimes were characterized for selected sites during July 1989-90 using weekly-readings of maximum-minimum thermometers, and at some over a year’s time using continuous recorders deployed for 1-2 years per site, beginning in 1988 (Wehrly et al. 1997). Data were summaries of mean July weekly minimum, median, and maximum temperatures.

Channel habitat

Data on channel characteristics and habitats were collected at both segment and site scales. For each MRI study site, we measured (digitized or counted) slope, sinuosity, and stream network structure (link number and derivations) for the encompassing stream reach from 1:24,000 maps. We characterized channel geometry (mean width and depth) and hydraulics (mean velocity) at high and low flows for as many sites as possible, using both measures available from USGS gaging activities and field measurements. Some additional channel characteristics, such as percent composition of riparian vegetation and substrates, were assessed by eye during field sampling.

Fishes

Data on fish community characteristics at selected MRI sites were gathered from existing Michigan Department of Natural Resources and USDA Forest Service records and from field surveys. For most sites data described the abundance of fish species, as estimated from either rotenone sampling or 3-pass-removal electrofishing. For sites where 1-pass electrofishing was used, our data described either species presence and absence, or presence only (depending on thoroughness of effort). We incorporated population estimates of selected gamefishes, such as trout, at sites where such estimates were available. When the fish community at a site had been sampled more than once, we used the most recent or most exhaustive collection to characterize the site. Consequently, the data represent the most recent, complete “snapshots” of fish communities at MRI sites. The collections were categorized according to sampling method used and the quality of data.

To date, rotenone surveys have been conducted at 160 sites, mostly in medium to large (3rd to 5th order) warmwater streams, in the lower half of the Lower Peninsula, from
1978-93 by MDNR Fisheries Division field crews. Collection methods used were described by Seelbach et al. (1988). With the exception of non-game species collected during the 1978 Grand River surveys, lengths of individuals and total numbers caught were recorded for all species sampled. We consider the quality of the fish identification as good since early samples were being sent to the University of Michigan to confirm species identity, and later sampling crews included persons skilled at species identification. Seelbach et al. (1994) suggest that these samples provide fair estimates of total standing crop of a stream site (about 75% of actual), but are not as useful for describing numerical abundance unless corrected for biases in species- and site-specific recapture efficiency. Rotenone survey data in the MRI databases were not corrected for such biases.

Multiple-pass depletion sampling using electrofishing has been done at 97 sites, mostly in small (1st or 2nd order) streams, from 1990-95. Sampling was done by MDNR Fisheries Division, University of Michigan, and USDA Forest Service crews. We considered the quality of species identification by crews as very good for MDNR and UM surveys, but only fair for USDA Forest Service surveys as these were conducted by part-time workers and there appeared to be some identification errors. Blocking nets were used in most (if not all) surveys, and the number of passes in each survey ranged from two to five. To allow estimates to be calculated for each species at a site, we initially made a depletion estimate for all species combined (Zippen 1958). We estimated population size for each species as: 

\[ N_i = \frac{N_t}{C} \] 

where \( N_i \) is the estimated abundance (number or weight) of species \( i \); \( N_t \) is the total catch (number or weight) of species \( i \); \( C \) is the estimated numerical abundance of all species combined; and \( C_t \) is the total numerical catch of all species.

Length and weight data for each species were typically collected for rotenone and depletion surveys, and lengths were measured for mark-recapture estimates. When weight for a species was not measured in the field, we estimated it using length-weight regressions developed for Michigan fishes (Schneider et al. 1991; and from unpublished data for lampreys). When length-weight regressions were unavailable for a species, we used equations from Schneider et al. (1996) for fishes with similar body shapes (Table A1). To compensate for differences in the accuracy of the balances used on various surveys, we re-estimated weights for all species whose total weights at a site were minimal (< 0.03 pounds). Occasionally, neither length nor weight data were available for small individuals (such as minnows and young of the year fishes) when only a few were collected at a site. When this occurred, we used lengths in August for fishes collected in Wisconsin (Becker 1983), Ohio (Trautman 1981), or Ontario (Scott and Crossman 1979).

Mark-recapture population estimates, using the Bailey modification (Cooper and Ryckman, 1981), were obtained (primarily for salmonids) at 82 sites between 1960-95. All surveys were conducted by MDNR Fisheries Division field crews, and fish identifications are considered excellent.

Two types of single-pass electrofishing data were obtained. Thorough single-pass electrofishing runs were completed at 190 sites between 1951-95. These data reflect several hours of electrofishing at the site, with the collection and identification of all species present. They provide reliable information on species presence and absence at sites, and where effort has been recorded, can be used in calculating catch per unit effort.

Cursory single-pass electrofishing and seine survey data were collected at 82 sites from 1926-95. These surveys typically involved less than an hour of electrofishing effort by crews, and represent a less-exhaustive attempt at collecting all individuals at sites. We refer to these data as “presence only” (pr) because they provide reliable information only on species presence at sites, but cannot be used to confirm absence.

We constructed several databases (RAWWTS, RAWNUM, ONEPASS, and HABITAT) from these collection records. RAWWTS and RAWNUM contain total weights and numbers for each species collected at sites along with sample area dimensions for computing fish densities. ONEPASS contains catch information for the first pass of electrofishing runs, along with sample area
dimensions and the number of minutes electrofished, for use in generating catch per unit effort data. Several missing value codes were used to complete the databases: “-1” indicated species present at site, but abundance unknown; “-99” indicated site sampled, but species’ status at site unknown; and “-111” indicated fishes not sampled at site.

Numerical and weight estimates were standardized by surface area (acres) of the sampling site, producing databases on density (NUMACRE) and standing crop (WTACRE), respectively. A standardized transformation, calculating the Z-score (mean of distribution = 0) for each species produced 2 additional databases, ZNUM and ZWTS. This transformation allowed us to evaluate the relative abundance of one or more species across sites, without the confounding effect of differential fish absolute abundance or size. Z-scores would therefore be comparable between fish like common carp (typically few in number but very large in total weight) and bluntnose minnows (typically very numerous but small in total weight).
Table A1.—Sources of length-weight regression equations for Michigan fishes from Schneider et al. (1991) used in estimating weights for fishes without species-specific length-weight regressions.

<table>
<thead>
<tr>
<th>Equation applied to</th>
<th>Equation source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redside dace</td>
<td>Finescale dace</td>
</tr>
<tr>
<td>Pirate perch</td>
<td>Creek chub</td>
</tr>
<tr>
<td>Hybrid sunfish</td>
<td>Bluegill</td>
</tr>
<tr>
<td>Black redhorse</td>
<td>Golden redhorse</td>
</tr>
<tr>
<td>River redhorse</td>
<td>Golden redhorse</td>
</tr>
<tr>
<td>Greater redhorse</td>
<td>Golden redhorse</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>Rainbow trout</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>Rainbow trout</td>
</tr>
<tr>
<td>Spotted sucker</td>
<td>Golden redhorse</td>
</tr>
<tr>
<td>Pugnose shiner</td>
<td>Spottail shiner</td>
</tr>
<tr>
<td>Troutperch</td>
<td>Rainbow trout</td>
</tr>
<tr>
<td>Silverjaw minnow</td>
<td>Bluntnose minnow</td>
</tr>
<tr>
<td>Least darter</td>
<td>Johnny darter</td>
</tr>
<tr>
<td>Banded killifish</td>
<td>Blackstripe topminnow</td>
</tr>
<tr>
<td>Lake chub</td>
<td>Creek chub</td>
</tr>
</tbody>
</table>