FEATURE

Combining Statewide Surveys and Classification to Support Management of Streams

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Michigan Department of Natural Resources Fisheries Division technicians Dan Traynor (left) and Lydia Doerr (right) probe submerged woody habitat during an electrofishing survey of the Pilgrim River, a small coldwater stream in Michigan's Upper Peninsula. Standardized fish community surveys provide the basis for characterizing fish assemblage and habitat conditions in the array of rivers throughout the state. Photo credit: Troy Zorn.

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Data from agency-based inventory programs could be very useful for local fishery management if appropriately summarized and served, but data are often accessible to few. Fundamental management questions at regional and local scales center around resource status and trends, highlighting the need for decision support tools operating at multiple scales. As stream classifications are developed for regions, survey programs become standardized, and innovations for serving spatially and temporally extensive data publicly become common, opportunities arise for developing locally relevant management decision support tools. We describe simple public-facing tools that use information from a statewide stream inventory program to increase understanding of local and regional trends in important fish populations, describe benchmark conditions for all stream types at various spatial scales, and provide empirical support for local and broader scale management of stream fishes and habitat. We provide examples demonstrating their utility to encourage development of similar tools elsewhere.

INTRODUCTION

Agency-based inventory programs seeking to better understand status or trends in aquatic resources across regions often accumulate extensive survey data potentially useful to many. After achieving broadscale project goals, survey data routinely reside in large databases accessible to few people outside (or even within) the agency. Such information could be useful for local fishery management if appropriately summarized and served, especially when data are collected for waters seldom surveyed.

Local-scale fishery management by agencies and conservation groups could benefit from finer-scale analysis of survey information from regional assessment programs. Local fishery managers often represent a government agency that are geographically dispersed, focusing on their "home waters"; lakes and streams within the fishery management unit they are responsible for. They face an array of questions and desire relevant data-driven tools to support understanding and management of their home waters. Even questions that seem basic, such as, "What are typical stream habitat, fish assemblage, and fish population characteristics for this type of stream?"; "Are observed conditions out of the ordinary for this stream reach?"; or "Is specific management action needed?" are difficult to address without rigorous, spatially and temporally extensive data. Sometimes more complex questions are posed, such as, "How do regional climatic or hydrologic processes that affect other populations in the region shape local populations?" Using survey data to gain insight into such questions is often beyond the spatial responsibility of an individual biologist or local management unit, and requires a long-term, regionally coordinated sampling approach, appropriate syntheses of survey data across larger spatial and temporal scales to describe spatiotemporal variation, and a technology framework to serve the information.

The broader perspective from a regional survey program can provide important context for managers trying to interpret data from an individual survey. Fundamental management questions are often similar at regional and local scales, centering on status of the resource (e.g., current conditions, differences across space, or potential management needs) and trends or changes in resource condition over time. Well-designed inventory programs can provide data for addressing regional and local issues, though summarizing and serving the information from large data sets to answer basic management questions at different spatial scales can be challenging. Nevertheless, data from properly designed, large-scale assessment efforts can readily support needs of local fishery managers and others if data are accessible, analyzed in an appropriate ecological context, and served using relevant summary and query tools.

As stream classifications are developed for regions, survey programs become regionally standardized (Adams et al. 2011), and technological innovations for serving spatially and temporally extensive data through open-access Web tools become more common, opportunities arise to leverage such advances towards development of locally relevant management decision support tools. Classifications have long been used to identify similar aquatic systems and better understand key processes driving them (Frissell et al. 1986; Maxwell et al. 1995; Seelbach et al. 2006; Rypel et al. 2019). Relevant attributes of classified stream segments, combined with standardized field survey data, can provide a spatial and ecological framework for quantifying benchmark values of biological and habitat parameters in stream segments. Such values can then be compared with survey data from a site on a stream segment sharing those type and region attributes, in essence providing context for interpreting survey data and functioning as an empirical decision support tool.

We describe simple public-facing tools that use information from a statewide stream inventory program to inform users and support local fisheries management. The tools increase understanding of local and regional trends in important fish populations, describe benchmark conditions for all stream types at various spatial scales, and provide empirical support for local management of stream fishes and habitat. The tools are flexible, enabling users to tailor summaries to accommodate their specific needs (e.g., statewide, regional, or local) and the availability of survey data. Our objectives are to (1) provide an overview of the statewide inventory program that provides the data; (2) describe how program data are packaged and publicly served to address broadscale and local-scale questions that anglers, conservation groups, the public, and other biologists often ask fishery managers; and (3) show examples of how the tools can be used to address a variety of common management questions. Our goal is to demonstrate the simplicity, flexibility, and utility of these stream decision support tools, and to provide an impetus and template for development of similar tools elsewhere.

DATA SOURCES

Project data came from the Michigan Department of Natural Resources (MDNR) Fisheries Division statewide Stream Status and Trends Program (SSTP). The SSTP was initiated in 2002 to characterize differences among a diverse array of stream systems and to describe trends in key fish populations over time (Hayes et al. 2003). The SSTP grew from recognition of existing knowledge gaps and understanding acquired from earlier stream fish ecology studies in Michigan and elsewhere. Analyses of long-term index site data on Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta* populations in the Au Sable River and other Michigan waters highlighted the importance of long-term population index data to trout ecology and management (e.g., Clark et al. 1980; Zorn and Nuhfer 2007a, 2007b; Zorn et al. 2020). An appreciation

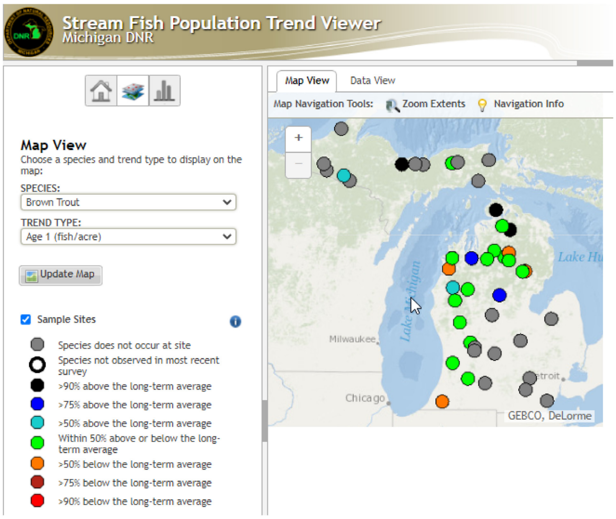

Figure 1. Stream Fish Population Trend Viewer output showing numerical density (fish/acre) of age-1 Brown Trout from most recent surveys at electrofishing index (Stream Status and Trends Program fixed) sites in Michigan. Color of dots indicates how the value from the most recent survey compares to the long-term average value for all surveys at that site since 2002 (i.e., percent above or below long-term average).

of the diversity of Michigan streams and the need to better understand stream-specific influences on fish populations was evident from several studies completed in Michigan during the past three decades (e.g., Wiley et al. 1997; Wiley and Seelbach 1997; Zorn et al. 2002; Wehrly et al. 2003; Seelbach et al. 2006). Collectively, these efforts highlighted a fundamental need to structure the SSTP to enable further understanding of factors driving spatial and temporal patterns in fish populations and habitat conditions in Michigan streams.

The SSTP initiated use of standardized data collection protocols for stream surveys statewide and entry of survey data into MDNR Fisheries Division's centralized Fish Collection System (FCS) database. Centralized coordination of surveys occurs, but actual field work is accomplished and data entered by local management unit field staff dispersed throughout the state. After the SSTP was initiated, several years were needed for data to accumulate in the FCS to reach a critical mass for use in development of decision support tools.

The SSTP was charged to provide information needed to describe spatial and temporal variation in stream fish populations at regional and statewide scales. This created the challenge of conveying the importance of processes operating on stream fish populations at larger temporal and spatial scales to interest groups and a public typically less exposed to this perspective. The design of the SSTP incorporates two different, yet complementary, types of sampling. Each type of sampling and the tool associated with it are discussed below. Both tools employ English units of measurement rather than metric, because they are designed for use by the public in the United States.

FIXED SITE SAMPLING AND THE FISH POPULATION TREND VIEWER TOOL

Fixed (index) site sampling is used for documenting trends in wild trout or Smallmouth Bass *Micropterus dolomieu* populations in representive stream reaches across Michigan. Populations in wadeable index stations are sampled via electrofishing in late-summer using a 3-years-on, 3-years-off rotation to provide broad geographic coverage while enabling periodic estimates of year-to-year survival of trout at sites. Parameters measured during each fixed site survey include: Chapman–Peterson mark–recapture population estimates (Ricker 1975) by size- and age-group for commonly occurring salmonids (Brook Trout, Brown Trout, Rainbow Trout *Oncorhynchus mykiss*, and Coho Salmon *O. kisutch*), and single pass catch rates for Smallmouth Bass; length-at-age; and annual survival of trout. Additional details on fish population estimation and data summary were described by Zorn et al. (2020). Instream, riparian, and woody habitat conditions and fish community composition of electrofishing reaches are measured once per 3-year-on cycle to enable assessment of effects of river- and site-level attributes on fish populations (Wills et al. 2008). Overall, this approach facilitates trend detection, with the regional network of sites providing information on the spatial extent of trends and synchrony among populations (Zorn and Nuhfer 2007b).

The Trend Viewer (TV) tool (https://bit.ly/3Hgm4T3, or enter "stream fish population trend viewer" in an Internet search engine) provides annual estimates of total biomass and numerical density (pounds and numbers per acre), density by age- or size-class, mean length-at-age, and annual survival for Brook Trout, Brown Trout, Rainbow Trout, Coho Salmon, and Smallmouth Bass age-classes at fixed sites. These data are annually extracted and summarized from the tables underlying the FCS for use in the TV via Microsoft Access Open Database Connectivity (OBDC) queries. The TV provides map, graphical, and tabular outputs for users. Map-based outputs enable users to explore spatial patterns in population attributes. For map-based depictions, average values for each parameter at each fixed site are calculated from all surveys conducted there since 2002 and represent "long-term" mean values at the site.

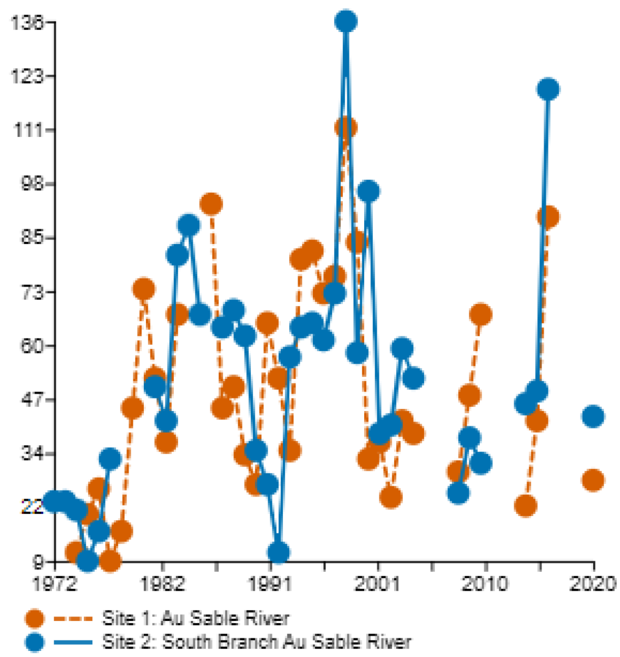

Figure 2. Stream Fish Population Trend Viewer output showing numerical density (number/acre on *y*-axis) of age-1 Brook Trout from surveys conducted since 1972 at fixed sites on the mainstem Au Sable River (orange) and South Branch Au Sable River (blue).

This allows TV users to map current status (percent departure of the most recent value from "long-term" average) of their chosen abundance, growth, or survival parameter (e.g., numerical density of age-1 Brown Trout) at all fixed sites and assess the extent to which populations in the region share a similar status (i.e., the spatial extent of the trend; Figure 1). Map-based outputs and interpretation are analogous to Daily Streamflow Condition maps provided by the U.S. Geological Survey (e.g., https://bit.ly/3Xlo5CY). Map-based outputs of the TV make it easy to assess population trends at a site, and to compare conditions among sites. For example, recent data on age-1 Brown Trout densities show values for most fixed sites are within 50% of their long-term averages, suggesting average reproductive success across much of the state, with a few sites showing recent densities more than 50% above or below their long-term mean (Figure 1).

Through the TV, the most recent data documenting trends in abundance, growth, and survival of wild salmonids and Smallmouth Bass are efficiently summarized and made publicly available for fixed sites on 16 wild trout streams with Great Lakes access, 19 wild trout streams without Great Lakes access, and 9 Smallmouth Bass streams, with survey data at some locations going back as far as 1947. For any site, users can access data on several fish abundance metrics (total biomass or numerical density, or numerical density by age or size-class) and mean length-at-age or annual survival for fish up to age-3. Data are viewable in graph (Figure 2) and tabular formats for any site (or pair of sites), with numeric values downloadable as .pdf or .xls files. Historic (pre-2002) data are available at several fixed sites.

Graphic and tabular outputs from the TV allow detailed exploration of long-term trends in abundance, growth, and survival of wild trout populations and assessment of similarity of trends among populations. Outputs enable users to see the typical range in variance of each parameter (from year-to-year and over longer periods) and how patterns of variance compare between populations at fixed sites of their choosing. For example, long-term data from the mainstem Au Sable River and South Branch Au Sable River show similar temporal patterns in density of age-1 Brook Trout, suggesting population dynamics may be influenced by larger-scale processes acting similarly on trout populations across the region (Figure 2). Previous work identified spatial synchrony in age-class density trends for trout populations in northern Michigan streams, describing the roles of streamflow conditions at fry emergence and water temperature patterns in synchronizing trout recruitment among streams (Zorn and Nuhfer 2007b). The TV builds on this initial work, enabling users to explore temporal trends in abundance, growth, and survival of trout at broader spatial scales using all fixed sites, or to focus in-detail on relationships between populations in any pair of fixed sites they choose.

RANDOM SITE SAMPLING AND THE STREAM EVALUATOR TOOL

The SSTP uses a stratified random sampling approach for resource inventory, with the intent of quantifying fish assemblages and habitat conditions in each type of stream segment in Michigan (only wadeable reaches are covered in this report). The primary sampling unit is the river valley segment (Seelbach et al. 2006), each segment being characterized by relatively uniform hydrology, water quality, channel morphology, riparian land cover, and fish community conditions along its length. Valley segments were mapped to the 1:24,000 of the National Hydrology Data Set hydrography layer, with attributes including catchment area, July mean water temperature, channel gradient, Great Lakes accessibility, and MDNR fisheries management unit. Associated categories and breakpoints (Table 1) were assigned to each attribute for data summarization (Zorn et al. 2008). Standardized surveys at random sites involve sampling the fish assemblage in the sample reach via single-pass electrofishing and collection of data describing instream, riparian, and woody habitat conditions within the sample reach (Wills et al. 2008). Seeing the value of standardized sampling and thorough data collection procedures, MDNR Fisheries Division staff and other partners have used SSTP random site protocols for other stream surveys, providing additional survey data for tool use.

Table 1. Valley segment attributes, categories, and category breakpoints used when selecting stream valley segments for calculating benchmark values of survey parameters.

Attribute and categories	Breakpoint	Attribute and categories
Catchment area (mi²)		Great Lakes accessible
Stream	≤80	Yes
Small river	≤300	No
Large river	≤620	
		Great Lake basin - Management unit
July mean temperature (°F)		Western Lake Superior
Cold	≤63.5	Eastern Lake Superior
Cold-transitional	≤67	Northern Lake Michigan
Warm-transitional	≤70	Central Lake Michigan
Warm	>70	Northern Lake Huron
		Southern Lake Michigan
Average channel gradient (ft/mi)		Southern Lake Huron
Very low	≤5	Lake Erie
Low	≤10	
Medium	≤25	
High	>25	

The Stream Evaluator (SEv) tool (https://bit.ly/3XHzooT) enables users to easily compare relative abundance of game and nongame game fishes and habitat conditions from a stream survey conducted using MDNR SSTP random site protocols, with benchmark values calculated from surveys done at comparable stream segments. Users select categories of the valley segment attributes (Table 1) to specify the set of benchmark segments for comparison with their individual segment of interest. This flexibility enables users to obtain benchmark summaries to suit their needs; be they general, specific, or somewhere in between (e.g., all cold streams in Michigan; warm low-gradient streams with Great Lakes access in the Lake Erie Management Unit; or cold small rivers draining into Lake Superior) or to adjust selection criteria to reflect availability of benchmark segment data (e.g., selecting adjacent channel gradient categories to increase numbers of benchmark segments for comparison). Mean and standard deviation values of various survey parameters are computed for the set of benchmark segments in the SEv from individual survey summary values stored in the SEv (and originally computed from the FCS via Microsoft Access ODBC queries).

After SEv users identify their stream segment of interest and submit attributes of selected benchmark streams for comparison, the SEv displays parameter values from the chosen survey, along with mean and standard deviation values computed from benchmark streams (Figure 3). Parameters include relative abundance (number per acre) of fish by species (and density by size-class for game species), transect-based instream

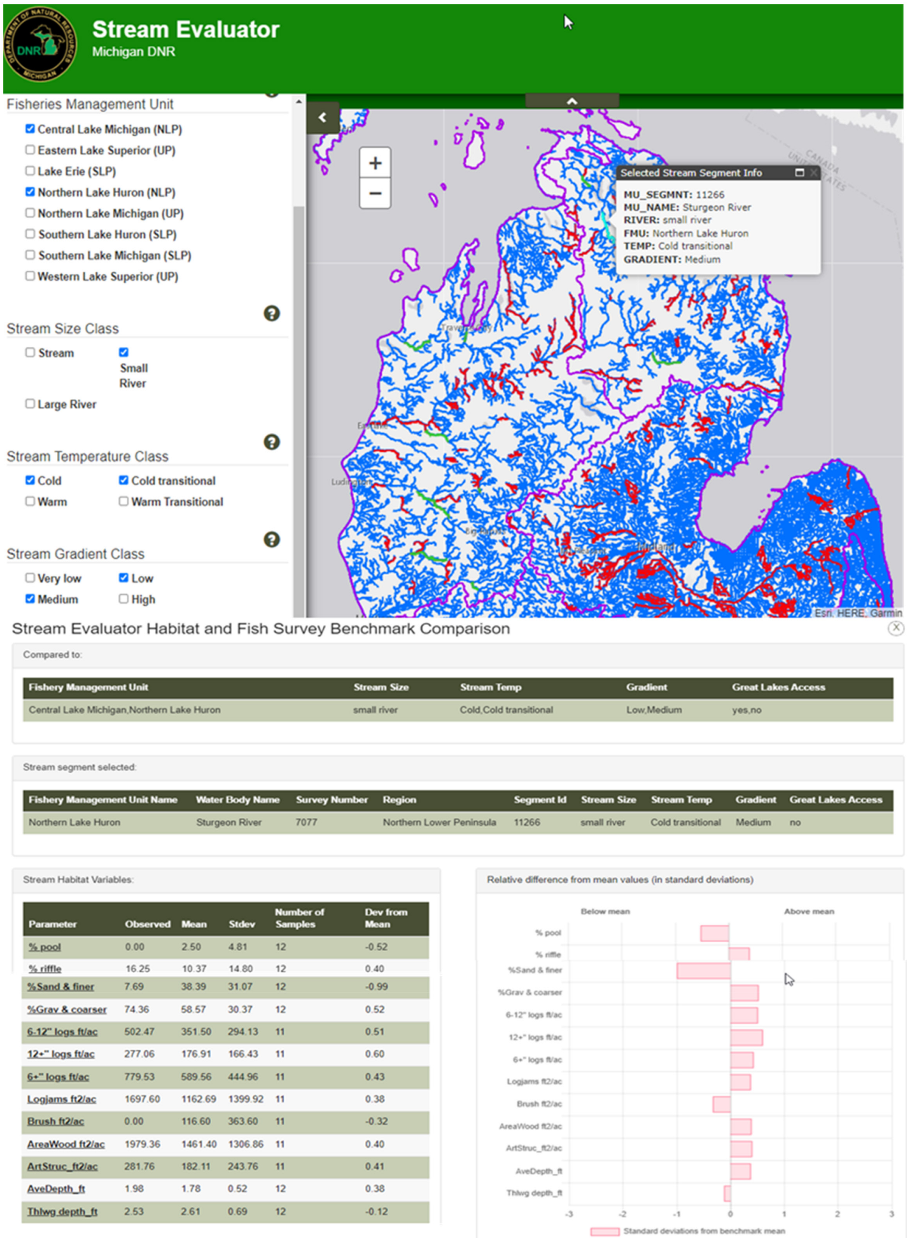

Figure 3. (Top) Stream Evaluator output showing comparison of substrate and woody habitat between a reach of the Sturgeon River (light blue) and several similar streams chosen for comparison (green). (Bottom) Survey values and comparison mean and standard deviation values occur for measures of lineal density (ft/acre) for individual logs by size-class and areal density (ft²/acre) of natural log jams, brush deposits, and artificial structures.

Table 2. Stream habitat and fish density metrics from standardized surveys delivered via the Stream Evaluator tool. Species codes are Brook Trout (BKT), Brown Trout (BNT), Rainbow Trout (RBT), Coho Salmon (COH) and Smallmouth Bass (SMB).

Name	Description
Habitat	
% riffle	Percent of transects classified as Riffle habitat type.
% pool	Percent of transects classified as Pool habitat type.
% run	Percent of transects classified as Run habitat type.
Ave width_ft	Average width of transects in feet.
Bank Stab %Fr	Percent of transect bank points in bank stability class 2: “Fair 25–50% of stream bank is bare soil.”
Bank Stab %Gd	Percent of transect bank points in bank stability class 1: “Good <25% of stream bank is bare soil.”
Bank Stab %Pr	Percent of transect bank points in bank stability class 3: “Poor 50–75% of stream bank is bare soil.”
Bank Stab %VPr	Percent of transect bank points in bank stability class 4: “Very poor >75% of stream bank is bare soil.”
% Undercuts	Percent of transect bank points containing undercuts.
Av shore dep_ft	Average depth at the stream shore (end of transect) in feet.
Av underc dep_ft	Average depth of undercuts in feet (depth = 0 when no undercut).
Riparian %agric	Percent of transect bank points that are agricultural (pasture or row crops).
Riparian %fores	Percent of transect bank points with forest riparian vegetation (large and small coniferous, deciduous and tag alder).
Riparian %other	Percent of transect bank points with grassland/forbs or other riparian vegetation types.
Riparian %resid	Percent of transect bank points with yard or residential riparian vegetation type.
Trans %wood	Average percent wood at transect points.
Trans %RPlants	Average percent rooted plants at transect points.
%Grav Not Embed	Percent of transect points having gravel embeddedness class = 0 (i.e., gravel <50% buried in fine substrate).
%Sand and finer	Percent of transect points predominated by sand or finer substrates.
%Grav and coarser	Percent of transect points predominated by gravel or coarser substrates.
6–12" logs ft/acre	Lineal feet of 6 to 12-in diameter logs per acre.
12+” logs ft/ac	Lineal feet of 12-in diameter or larger logs per acre.
6+” logs ft/ac	Lineal feet of 6-in diameter or larger logs per acre.
Logjams ft^2/ac	Area of natural log jams in square feet per acre.
Brush ft^2/ac	Area of beaver dams and brush deposits in square feet per acre.
AreaWood ft^2/ac	Total area of all structure (natural and artificial) in square feet per acre.
ArtStruc ft^2/ac	Total area of all artificial structure in square feet per acre.
AveDepth_ft	Average of transect point depth measurements in feet.
Thlwg depth_ft	Average thalweg depth (defined as deepest point along transects) in feet.
Fish density	
Number per acre	For all species.
Number ≤4-in per acre	For Brook Trout, Brown Trout, Smallmouth Bass, all salmonids, and Great Lakes salmonids.
Number ≥7-in per acre	For Brook Trout, Brown Trout, Smallmouth Bass, all salmonids, and Great Lakes salmonids.
Number ≥ 12-in per acre	For Brown Trout and Smallmouth Bass.

habitat data, bank and riparian habitat metrics, and density measurements of log and woody structure habitats (Table 2). For each parameter, a bar graph depicts the difference between observed value and benchmark mean, with the difference divided by the benchmark parameter’s standard deviation to normalize differences across parameters. The graphs provide a means for users to quickly identify parameters for the stream of interest that lie well above or below benchmark values. The SEv can be used to characterize potential expected conditions (i.e., average values of fish and habitat variables) for a stream segment that has not been previously sampled if users specify attributes of benchmark segments in the region matching their stream segment of interest. This feature can be useful for planning surveys, for answering stakeholder questions about stream segments lacking surveys, or as an empirical basis for characterizing an undersurveyed or unsurveyed system.

The SEv provides an empirically robust tool for managers facing various issues related to stream habitat improvement or fish populations. By bringing in comparable information from similar river segments, the SEv provides context for interpreting data from an individual survey and an empirical basis to support decisions on potential management needs within a reach. We demonstrate this with several examples.

Fishery managers are often asked whether additional woody habitat should be added to a reach to improve game fish populations. For example, consider the Sturgeon River, a small, cold-transitional, medium gradient river in Michigan’s northern Lower Peninsula. Standardized survey data from

Table 3. Mean, two standard errors (2 SE) and sample size (*n*) of benchmark values of wood habitat parameters for cold and cold-transitional streams versus warm and warm-transitional streams from three regions in Michigan. The first three (log) parameters represented lineal feet of individual logs in the specified diameter classes per surface acre of stream. The next three parameters quantify area of complex woody habitat (i.e., brush deposits, artificial structures, and log jams) per surface acre of stream. AreaWood represents combined surface area of individual logs counted and complex woody habitats per surface acre of stream. Regions (and constituent management units) were: Southern Lower Peninsula (SLP; includes Southern Lake Michigan, Southern Lake Huron and Lake Erie management units); Northern Lower Peninsula (NLP; Central Lake Michigan and Northern Lake Huron management units); and Upper Peninsula (UP; Northern Lake Michigan, Eastern Lake Superior and Western Lake Superior management units). All gradient and Great Lakes accessibility classes were included.

Parameter and region	Cold and cold-transitional			Warm and warm-transitional		
	Mean	2 SE	*n*	Mean	2 SE	*n*
6–12-in logs ft/acre						
SLP	645	579	9	219	69	61
NLP	1,008	328	55	445	363	8
UP	368	135	50	144	128	13
12 + in logs ft/acre						
SLP	190	212	9	43	19	63
NLP	239	71	55	110	62	8
UP	178	90	48	49	48	13
6 + in logs ft/acre						
SLP	830	776	9	257	83	61
NLP	1,259	388	55	554	399	8
UP	555	220	48	193	165	13
Brush ft^2/acre						
SLP	276	283	9	200	117	63
NLP	659	348	55	41	83	9
UP	229	122	48	155	174	14
ArtStruc_ft^2/acre						
SLP	76	152	10	23	22	64
NLP	126	106	55	0	NA	9
UP	75	96	48	89	132	14
Logjams ft^2/acre						
SLP	584	567	9	292	164	62
NLP	1,200	719	55	87	174	9
UP	312	183	48	50	46	14
AreaWood ft^2/acre						
SLP	945	665	9	519	189	62
NLP	1985	775	55	145	205	8
UP	616	238	48	293	229	14

river segments in the region having similar size, gradient, and temperature characteristics provide context for interpreting conditions at and making recommendations for a similar segment of the Sturgeon River (Figure 3). Data and plots show that a reach of the Sturgeon River surveyed using standardized SSTP random site protocols had greater individual log, artificial wood, log jam, and total wood structure densities than benchmark streams in comparable systems. These data suggest that the density of woody habitat is not unusually low, and additional woody habitat may not be needed, at least in this reach. For SEv users desiring a broader perspective on patterns in woody habitat across Michigan, statewide summaries provide benchmark values for different types of streams and show general patterns in woody habitat attributes among valley segment types and regions (Table 3). This perspective reveals additional patterns, such as more woody habitat in cold and cold-transitional thermal class streams than in warm and warm-transitional classes and higher densities of individual logs in northern Lower Peninsula streams compared to other regions.

Trout anglers often ask if a stream reach is unusually sandy and in need of management action to reduce bedload. By re-running the query for the Sturgeon River example to limit the comparison to medium gradient streams, since gradient influences stream power and substrate coarseness (Gorman et al. 2011; Zorn and Wills 2012), we found that this reach had a similar percentage of gravel and coarser substrates (74%) to that measured in five comparable reaches (mean = 79%). Again, broader summaries can provide the manager with benchmark conditions of percent gravel and coarser substrates, demonstrating associations between increased channel gradient and the percentage of gravel and coarser substrates in stream reaches across the landscape (Figure 4).

With an estimated 85% of dams having exceeded their operational lives by 2020 (Doyle et al. 2003), dam removal activities have been increasing throughout much of the country, and

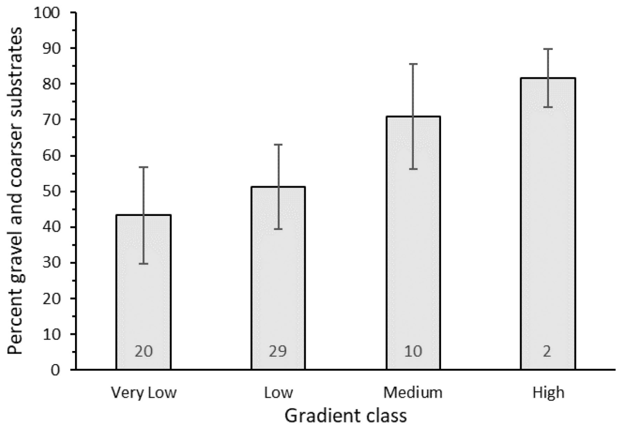

Figure 4. Mean percentage of gravel and coarser substrates by valley segment gradient class for standardized surveys conducted in small rivers in Michigan. Error bars indicate 95% CIs and number of segments surveyed is shown in each bar.

Michigan fishery managers commonly facing questions regarding pros and cons of dam removals on local rivers. Estimates of potential production of important migratory salmonids for different types of streams in the Great Lakes region would help inform prioritization of dam removal activities, since increased migratory fish production from tributaries would reduce agency expenditures for fish rearing and stocking. The SEv can be a useful tool for addressing these inquiries. For example, we estimated average summer densities of migratory salmonids in cold, medium to high gradient streams draining into Lake Michigan. Twelve surveys met these criteria and yielded the following single-pass electrofishing catch rate averages for Rainbow Trout (85.4 fish per acre), Chinook Salmon *O. tshawytscha* (10.2 fish per acre), and Coho Salmon (36.6 fish per acre). If 15 miles of a 20-foot-wide stream (36.4 acres) of this type were made accessible to Lake Michigan, a total summer electrofishing catch of 3,105 Rainbow Trout, 1,331 Coho Salmon, and 371 Chinook Salmon might be expected for the stream based on these catch rate averages. Such estimates show the potential for migratory salmonid production in Great Lakes tributaries, which should be considered along with the potential effects of these species on resident trout populations (Nuhfer et al. 2014; Zorn et al. 2020).

Fisheries managers are regularly faced with the need to estimate losses or damage when fish kills occur. In recent years, dam failures and releases from agricultural and industrial activity have caused fish kills in Michigan, and similar concerns exist regarding metallic mining activities in Michigan's Upper Peninsula. The SEv can be used to estimate the composition of the affected fish community when no data are available for a stream reach where a fish kill has taken place. Consider fish losses associated with a hypothetical fish kill along a stretch of a high-gradient, cold stream draining into Lake Superior in the western Upper Peninsula of Michigan. Here, a fishery biologist expected this stream to be similar to the Little Huron River, so it and others with similar attributes were selected for comparison (Figure 5). Based on surveys in 16 similar waters, we can reconstruct the affected fish community as one likely dominated by Coho Salmon, Rainbow Trout, sculpins (Slimy Sculpin *Cottus cognatus* or Mottled Sculpin *C. bairdi*), Brook Trout, Blacknose Dace *Rhinichthys atratulus*, Longnose Dace *R. cataractae*, and other fishes. If habitat restoration is needed or desired, data characterizing habitat parameters for the benchmark reaches are available in SEv output and could provide habitat restoration targets.

TECHNICAL DETAILS AND SURVEY DATA UPDATES

The TV and SEv are custom built Web applications hosted and maintained by the Michigan Department of Technology Management and Budget (DTMB). They use secure Windows-based State of Michigan servers running Internet Information Services. A Microsoft Structured Query Language server houses the GIS and tabular data for both tools. The ArcGIS server from ESRI provides the technology to serve the mapping data through a Web browser. Also, ESRI's JavaScript Application Programming Interface powers the mapping and GIS visualization analysis in the TV and SEv tools. Data analysis is provided by custom Web services created for TV and SEv written in Microsoft's C#. JavaScript charting libraries take that data and create the interactive data visualization of fish abundance and habitat specific information. The TV and SEv tools were designed to be Americans with Disabilities Act compliant, and their user interfaces were designed to be accessible to nonfisheries experts. Data are updated annually (typically in late winter) after fish and habitat survey and fish age data from the previous field season have been entered into the FCS and passed quality assurance/quality control review within the MDNR Fisheries Division. Data from recent surveys are pulled from the FCS and summarized via stored Microsoft Access ODBC queries, with summary results being pasted into one Excel worksheet for each tool. Michigan DTMB staff append the tabular data from each Excel worksheet to corresponding tables in each tool.

DISCUSSION

The TV and SEv tools provide an efficient means to summarize and present data collected across a broad region in an ecologically meaningful way that benefits river management. The tools provide relatively simple diagnostic information, though they represent the culmination of nearly three decades of technical work on Michigan streams, including landscape-scale classification efforts (e.g., Seelbach et al. 1997, 2006), long-term population dynamics studies (e.g., Zorn and Nuhfer 2007a, 2007b), statewide coordinated sampling efforts (Wills et al. 2008, 2015), database management, and integration of databases, GIS technology, and Website development. These relatively simple decision support tools should be useful to a diverse set of users including agency, university, and tribal biologists, conservation districts or groups, and tech-savvy anglers, citizen scientists, and interested publics. We anticipate these tools will aid the MDNR in its efforts to transparently share scientific data and understanding, and to foster collaboration with partners and stakeholders, a goal recently identified in the MDNR Fisheries Division's strategic plan (MDNR 2018) and Michigan's statewide Inland Trout Management Plan (Zorn et al. 2018). Tool uses already number in the thousands (Zorn, unpublished data), saving the MDNR Fisheries Division from expending effort to fulfill data requests and allowing users to see and acquaint themselves with river systems "on their own time." Surveying users for their evaluation and suggestions may enable further enhancement of the tools.

The TV and SEv tools provide important resource and agency level benefits by fostering decision making for rivers throughout the state. The flexibility of the tools enables

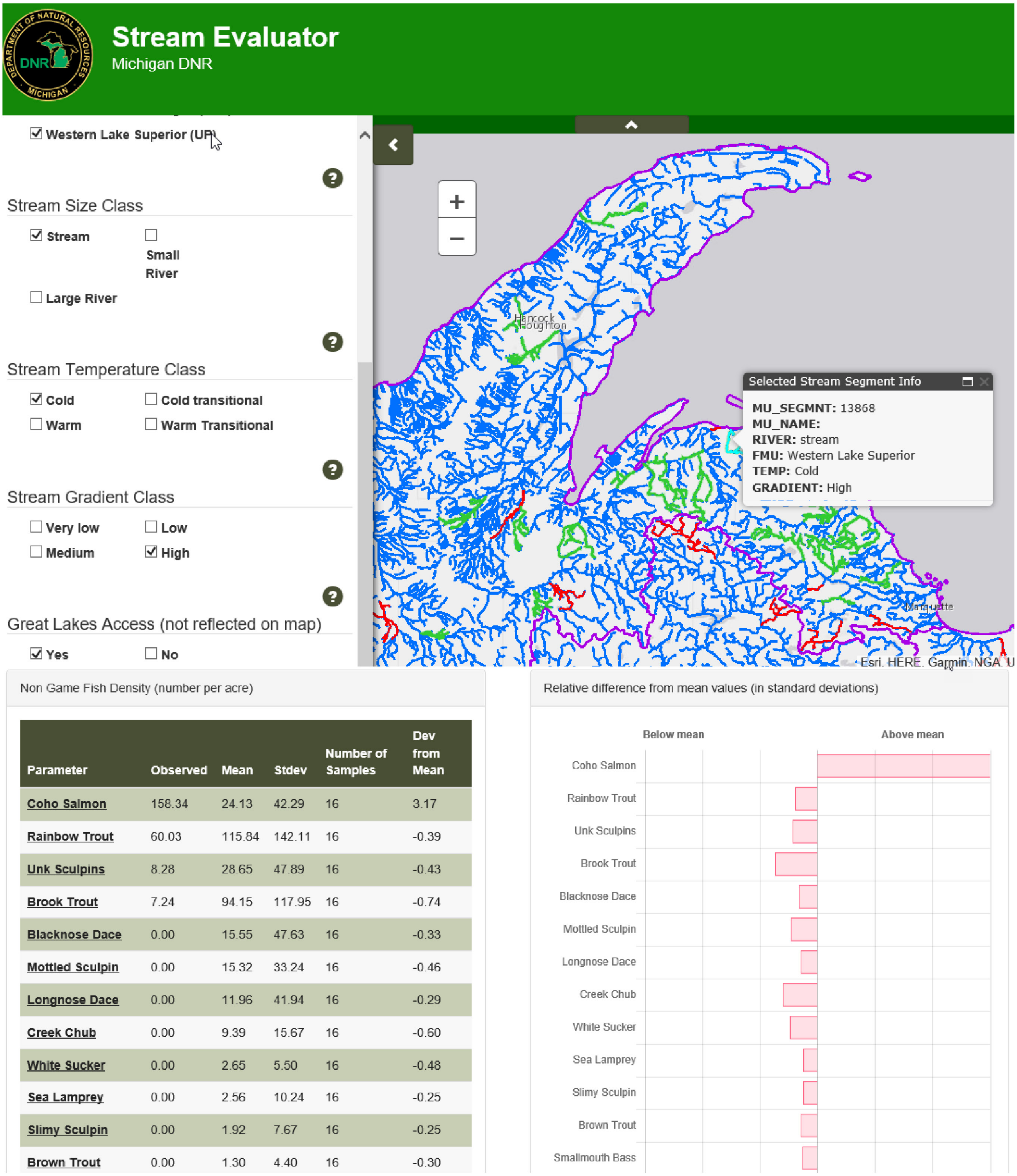

Figure 5. (Top) Comparable stream surveys selected (in green) for estimating losses due to an accidental fish kill. Note that reaches without Great Lakes access are filtered out in the database but are highlighted on the map. (Bottom) Observed densities for a similar stream (Little Huron River) and mean and standard deviation values for the set of comparable reaches. Note that some species were caught in benchmark reaches but not observed in the Little Huron River survey.

support of local, regional, and statewide analysis and decision support, making efficient use of scarce agency resources. Correctly used, the tools support management decisions that are robust, being supported by empirical quality controlled survey data and information from multiple observations (i.e., a broader spatial and temporal perspective) rather than an individual observation at one location. Ultimately, the tools guide the strategic prioritization of limited agency resources, leading to wise and effective management of rivers at the field management unit and state agency levels.

The TV supports wild trout management, research, and angler outreach by placing the latest survey data and data context directly in the users' hands. The data delivery interface, modeled after the U.S. Geological Survey's state-level, real-time, daily streamflow Webpages (e.g., https://bit.ly/3Xlo5CY), provides the latest stream fish trend information for Michigan in a simple, user-friendly manner. The parameters available (abundance, growth, and survival) are key drivers of population dynamics and important for evaluating effects of environmental or management changes, particularly those associated with flow, water quality, or sport fishing regulations. Since population trends for a given stream reach are often consistent upstream and downstream of survey locations (Wills et al. 2008), and in nearby waters (Zorn and Nuhfer 2007b; Zorn and Hessenauer, in press), the TV can help managers better interpret an individual survey since it shows whether recent abundance, growth, and annual survival values for trout populations in the region are trending high, low, or average. Trend Viewer data are also of interest to fishery managers, tackle shops, anglers, and guides because they closely track many of Michigan's most popular stream fisheries. The regional perspective of the TV provides a broader view of regional trends in stream sportfish populations, thus heightening awareness of climatic and other larger-scale processes that drive population dynamics of important stream fisheries in the state (Zorn and Nuhfer 2007b). Data on riverine Smallmouth Bass populations also support improved understanding of dynamics of this popular sport fish. Furthermore, the ability to export or download data at individual sites enables users to satisfy their curiosity through more detailed exploration of trends in fish abundance, growth, and survival.

The easy-to-use SEv represents a breakthrough for biologists managing streams because it provides geographically relevant, empirical benchmarks for comparison with individual survey results, enabling strategic prioritization of agency resources toward management. The strata used in establishing benchmarks (size, temperature, gradient, and region) are key large-scale factors that drive spatial variation in local stream habitat conditions and fish assemblages in Michigan and elsewhere (Zorn et al. 2004; Zorn and Wiley 2006; Steen et al. 2008). As a tool focusing on entire fish assemblages as well as habitat, the SEv provides a basis for examining relationships between stream habitat characteristics (e.g., strata or field-measured variables) and the distribution and abundance of many fish species. This public-facing tool builds on previous management-oriented models relating key aspects of stream habitat to fish abundance in Michigan (Zorn et al. 2009, 2011), enabling development of quantitative values (albeit sometimes coarse) for numerous habitat parameters previously not assessed or only occasionally commented on in survey notes (e.g., "many log jams" or "little woody structure"). The SEv is especially useful as a means of empirically characterizing expectations for a stream reach and flagging measured parameters that exceed expectations (positively or negatively) for further inquiry or possible management attention. It can be used to address management questions related to fish populations (e.g., "Are densities of larger trout unusually low at the site?") or fish habitat (e.g., "Is the reach unusually sandy or lacking in large woody habitat?"). By computing benchmark values from comparable river segments, the SEv provides relevant characterizations of expected fish communities and habitats, even for river segments lacking surveys. This information can prove useful to managers when they need to assess responses to dam removals or damage to habitats or fish populations (e.g., fish kills) and pre-impact survey data are limited or unavailable.

Given the utility of the data, simplicity of the tools, and ease of data updates and maintenance, we think the utility of the TV and SEv tools will increase over time. Some trout population data sets in the TV are among the longest in the country, and increased accessibility to the data will only increase their utility. The hundreds of surveys in the SEv may currently be somewhat limiting, given the diversity of stream types in Michigan, but this information base will improve over time as SSTP random site surveys accumulate and managers make increased use of SSTP random site sampling protocols for other surveys (the SSTP represents only a fraction of MDNR stream survey effort [Hayes et al. 2003]). As the survey database grows, comparisons and estimates from the SEv should become increasingly accurate, leading to increased utility, relevance, and robustness of the SEv tool over time. Strata used in the SEv represent foundational landscape factors that structure stream habitat and explain spatial variation in habitat and fish assemblage characteristics in streams across Michigan (Seelbach et al. 2006; Zorn and Wiley 2006) and will be useful over the long term.

No publicly available decision support tools comparable to the TV and SEv exist, based on contact with all National Fish Habitat Partnership coordinators and staff in the United States, and state agency and provincial biologists in various regions of the United States and Canada. We briefly mention some stream fishery tools that other agencies have developed or are developing. The state of Wisconsin is developing a "trout data dashboard" for viewing trout stream trend data; it is in development and not yet public (M. Mitro and J. Griffin, Wisconsin Department of Natural Resources, personal communication). The states of Minnesota and Illinois have stream tools that provide information for various biotic integrity metrics, but not field-measured fish or habitat parameters. Others, such as Alaska, Idaho, and Alberta, have tools that display fish distribution information, often paired with other information of use to anglers, such as sportfishing regulations. In states with many lakes (e.g., Minnesota), development of online decision support tools for lakes may take priority over streams. Bonar et al. (2015) provides an informative example of how data from lake and stream surveys can be incorporated and summarized in a single online tool when standardized methods are used across a large region. Our tool differs, being focused more on supporting local or water-specific management fish or habitat decisions than enabling comparisons of survey data collected across multiple states.

We think useful decision support tools can be developed by fisheries management agencies if they possess the key ingredients of a statewide stream classification linked to a statewide standardized survey program, staff committed to overseeing the program, and modest funding. Development of our tools required key partnerships with the state of Michigan's DTMB and Michigan State University Remote Sensing and Geographic Information Systems programmers, but only modest levels of external funding to cover project development. A 2013 grant of US$53,000 funded contractors for TV development, and a 2016 grant for $91,000 funded contractor costs for the SEv. Thus, development of similar decision-support tools for streams may be financially possible for many state or provincial fisheries management agencies.

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REFERENCES

Adams, P. B., L. B. Boydstun, S. P. Gallagher, M. K. Lacy, T. L. Mcdonald, and K. E. Shaffer. 2011. The California coastal salmonid monitoring plan: overall strategy, design, and methods. California Department of Fish and Game, Fish Bulletin 180, Sacramento, California.

Bonar, S. A., N. Mercado-Silva, M. Rahr, Y. T. Torrey, and A. Cate, Jr. 2015. A simple web-based tool to compare freshwater fish data collected using AFS standard methods. Fisheries 40:580–589.

Clark, R. D., Jr., G. R. Alexander, and H. Gowing. 1980. Mathematical description of trout stream fisheries. Transactions of the American Fisheries Society 109:587–602.

Doyle, M. W., E. H. Stanley, J. M. Harbor, and G. S. Grant. 2003. Dam removal in the United States: emerging needs for science and policy. EOS, Transactions, American Geophysical Union 84:29–36.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199–214.

Gorman, A. M., P. J. Whiting, T. M. Neeson, and J. F. Koonce. 2011. Channel substrate prediction from GIS for habitat estimation in Lake Erie tributaries. Journal of Great Lakes Research 37:725–731.

Hayes, D., E. Baker, R. Bednarz, D. Borgeson, Jr., J. Braunscheidel, J. Breck, M. Bremigan, A. Harrington, R. Hay, R. Lockwood, A. Nuhfer, J. Schneider, P. Seelbach, J. Waybrant, and T. Zorn. 2003. Developing a standardized sampling program: the Michigan experience. Fisheries 28(7):18–25.

Maxwell, J. R., C. J. Edwards, M. E. Jensen, S. J. Paustian, H. Parrott, and D. M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). U.S. Forest Service, North-Central Forest Experiment Station, general technical report NC-176, St. Paul, Minnesota.

MDNR (Michigan Department of Natural Resources). 2018. Charting the course: Fisheries Division's framework for managing aquatic resources. 2018–2022 Fisheries Division Strategic Plan. MDNR, Lansing. Available: https://bit.ly/3ZHnnS0. (July 2022).

Nuhfer, A. J., T. C. Wills, and T. G. Zorn. 2014. Changes to a Brown Trout population after introducing steelhead in a Michigan stream. North American Journal of Fisheries Management 34:411–423.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191.

Rypel, A. L., T. D. Simonson, D. L. Oele, J. D. T. Griffin, T. P. Parks, D. Seibel, C. M. Roberts, S. Toshner, L. S. Tate, and J. Lyons. 2019. Flexible classification of wisconsin lakes for improved fisheries conservation and management. Fisheries 44:225–238.

Seelbach, P. W., M. J. Wiley, M. E. Baker, and K. E. Wehrly. 2006. Initial classification of river valley segments across Michigan's lower peninsula. Pages 25–48 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Influences of landscapes on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Seelbach, P. W., M. J. Wiley, J. C. Kotanchik, and M. E. Baker. 1997. A landscape-based ecological classification system for river valley segments in Lower Michigan. Michigan Department of Natural Resources, Fisheries Research Report 2036, Ann Arbor.

Steen, P. J., T. G. Zorn, P. W. Seelbach, and J. S. Schaeffer. 2008. Classification tree models for predicting distributions of Michigan stream fish from landscape variables. Transactions of the American Fisheries Society 137:976–996.

Wehrly, K. E., M. J. Wiley, and P. W. Seelbach. 2003. Classifying regional variation in thermal regime based on stream fish community patterns. Transactions of the American Fisheries Society. Transactions of the American Fisheries Society 132:18–38.

Wiley, M. J., S. L. Kohler, and P. W. Seelbach. 1997. Reconciling landscape and local views of aquatic communities: lessons from Michigan trout streams. Freshwater Biology 37:133–148.

Wiley, M. J., and P. W. Seelbach. 1997. An introduction to rivers- the conceptual basis for the Michigan Rivers Inventory (MRI) project. Michigan Department of Natural Resources, Fisheries Special Report 20, Ann Arbor.

Wills, T. C., T. G. Zorn, D. B. Hayes, and K. E. Wehrly. 2015. Status and trends of Michigan's stream resources: 2002-2007. Michigan Department of Natural Resources, Fisheries Research Report 9, Ann Arbor.

Wills, T. C., T. G. Zorn, A. J. Nuhfer, and D. M. Infante. 2008. Stream status and trends program sampling protocols. Chapter 26. Pages 1–37 *in* J. C. Schneider, editor. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

Zorn, T. G., T. A. Cwalinski, N. A. Godby Jr., B. J. Gunderman, and M. A. Tonello. 2018. Management plan for inland trout in Michigan. Michigan Department of Natural Resources, Fisheries Report 30, Lansing.

Zorn, T. G., and J.-M. Hessenauer. In press. Spatial patterns of synchrony in recruitment of trout among streams. *In* J. Lobón-Cerviá, editor. Ecology of stream-dwelling salmonids. Springer Nature, Berlin.

Zorn, T. G., J.-M. Hessenauer, and T. C. Wills. 2020. Increasing connectivity of Great Lakes tributaries: interspecific and intraspecific effects on resident Brook Trout and Brown Trout populations. Ecology of Freshwater Fish 29:519–532.

Zorn, T. G., and A. J. Nuhfer. 2007a. Influences on Brown Trout and Brook Trout population dynamics in a Michigan river. Transactions of the American Fisheries Society 136:691–705.

Zorn, T. G., and A. J. Nuhfer. 2007b. Regional synchrony of Brown Trout and Brook Trout population dynamics among Michigan rivers. Transactions of the American Fisheries Society 136:706–717.

Zorn, T. G., P. W. Seelbach, E. S. Rutherford, T. C. Wills, S. Cheng, and M. J. Wiley. 2008. A landscape-scale habitat suitability model to evaluate effects of flow reduction on fish assemblages in Michigan streams. Michigan Department of Natural Resources, Fisheries Research Report 2089, Ann Arbor.

Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2002. Distributions of stream fishes and their relationship to stream size and hydrology in Michigan's Lower Peninsula. Transactions of the American Fisheries Society 131:70–85.

Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2004. Utility of species-specific, multiple linear regression models for prediction of fish assemblages in rivers of Michigan's Lower Peninsula. Michigan Department of Natural Resources, Fisheries Research Report 2072, Ann Arbor.

Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2009. Relationships between habitat and fish density in Michigan streams. Michigan Department of Natural Resources, Fisheries Research Report 2091, Ann Arbor.

Zorn, T. G., P. W. Seelbach, and M. J. Wiley. 2011. Developing user-friendly habitat suitability tools from regional stream fish survey data. North American Journal of Fisheries Management 31:41–55.

Zorn, T. G., and M. J. Wiley. 2006. Influence of landscape characteristics on local habitat and fish biomass in streams of Michigan's Lower Peninsula. Pages 375–394 *in* R. M. Hughes, L. Wang, and P. W. Seelbach, editors. Influences of landscapes on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Zorn, T. G., and T. C. Wills. 2012. A reconnaissance survey of the effects of sediment traps on Michigan streams. North American Journal of Fisheries Management 32:1005–1016. AFS