Stream science to action: a decision-support tool for trout management amidst climate change

Science to Action Fellowship Completion Report

Andrew K. Carlson[1]
Michigan State University Mentor: William W. Taylor[1]
National Climate Change and Wildlife Science Center Mentor: T. Douglas Beard, Jr.[2]

[1]Michigan State University, Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, 115 Manly Miles Building, 1405 South Harrison Road, East Lansing, Michigan 48823, USA
[2]National Climate Change and Wildlife Science Center, U.S. Geological Survey, 12201 Sunrise Valley Drive, MS 516, Reston, Virginia 20192, USA

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Figure 3. Michigan stream rankings for a decision-support tool criterion about riparian land cover conditions. Streams are ranked according to the proportion of their riparian zones containing habitats that promote cool, thermally favorable conditions for trout (i.e., deciduous, evergreen, and mixed forest; grassland/herbaceous cover; and woody or emergent herbaceous wetlands), with higher rankings indicating greater coverage by thermally favorable habitats. The ten highest-ranked streams with respect to riparian land cover conditions are included above.

Figure 4. Overall Michigan stream importance rankings considering all six decision-support tool criteria (i.e., water temperature, trout relative abundance, groundwater contribution, watershed land cover, riparian land cover, projected future water temperature). Streams with greater scores for individual criteria receiving higher importance rankings. The ten highest-ranked streams with respect to all six decision-support tool criteria are included above.

Fellowship project summary for *Stream science to action: a decision-support tool for trout management amidst climate change*

Background and need

Occupying the interface between aquatic and terrestrial ecosystems, streams are embedded within landscapes, making them susceptible to land use alteration and climate change, stressors that often make streams warmer and less thermally suitable for coldwater-adapted organisms (Woodward et al. 2010, Kanno et al. 2015). Temperature-driven biological processes of coldwater organisms (e.g., growth, reproduction, survival) are expected to decline as streams become warmer and less thermally suitable (Raleigh 1982a,b, Kaushal et al. 2010). Moreover, warming air and water temperatures are projected to change fish population distribution, species interactions, and the timing of life history events such as migration (Comte et al. 2013, Ockendon et al. 2014, Peer and Miller 2014). As coldwater fishes, brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, and rainbow trout *Oncorhynchus mykiss* are predicted to be especially vulnerable to stream warming as their growth, reproduction, and survival depend on the availability of coldwater conditions (Thomas et al. 2015).

In an ecological context, "resilience" is an ecosystem's ability to absorb disturbances and retain its structure and function (Holling 1973). For instance, a resilient coldwater stream is one with the capacity to maintain cold temperatures and sustain thermally suitable conditions for trout. In this example, the stream's resilience is dependent upon its inherent properties (e.g., hydrological, physical, chemical) and the way in which it is managed by human institutions (e.g., fisheries agencies, water quality organizations). Maintaining or increasing the resilience of coldwater ecosystems is a promising paradigm for fisheries conservation as climate change and land use alteration affect water availability, water quality, and biotic communities across the globe (Hansen et al. 2015, Waldman et al. 2016). Moreover, adaptability – the capacity of humans to learn about and adjust to changes as they occur (Folke et al. 2010) – is a mechanism for applying resilience-based thinking to fisheries management. As coldwater streams and their trout populations are increasingly threatened by a warming climate and changing land use patterns, resilience and adaptability are critical concepts for trout management. Because coldwater streams and their trout populations provide ecological goods and services (e.g., fisheries, clean water, recreation; Loomis et al. 2000) to diverse stakeholders, resilience-based management of these systems necessitates collaboration among scientists, managers, policymakers, anglers, riparian landowners, and the general public (Carlson et al. 2016).

Although trout management rooted in resilience requires partnerships among multiple fisheries stakeholders, facilitating communication among these groups is often difficult. For instance, in the State of Michigan, which contains numerous populations of brook trout, brown trout, and rainbow trout distributed throughout 31,000 km of streams (Godby et al. 2007, Tyler and Rutherford 2007), fisheries professionals do not have up-to-date information about the attitudes, behavior, and demographics of trout anglers in relation to trout management. Moreover, they have little data regarding the accuracy and management utility (i.e., cost-effectiveness, applicability across spatial extents) of different approaches for modeling stream temperature (e.g., stream-specific, region-specific) and associated methods for managing stream thermal habitats such as riparian habitat protection, forest canopy rehabilitation, and groundwater conservation.

With these knowledge gaps in mind, it is an opportune time to conduct research at the interface of three management-relevant topics: 1) values, behavior, and demographics of Michigan trout anglers and fisheries professionals; 2) stream temperature modeling techniques; and, 3) stream thermal habitat management strategies. Until 2015, a survey of Michigan inland trout anglers had not been completed since 1981 (Fenske 1983). However, results from the 2015 Michigan Inland Trout Angler Survey (ITAS) provide important attitudinal, behavioral, and demographic information about Michigan trout anglers that will be useful for developing socially informed trout management approaches (Carlson and Zorn 2017). Combined with recent and ongoing research on Michigan fisheries professionals, stream temperature modeling, and thermal habitat management (Carlson et al. 2016, 2017), human dimensions research on Michigan trout anglers will be indispensable for designing management approaches that promote resilient, adaptable trout fisheries and associated management systems. But how can these distinct types of information be integrated? Decision-support tools systematically assimilate information and account for trade-offs and uncertainties (NRC 2010, Lynch et al. 2015), making them valuable for fisheries decision-making in a changing climate.

Goal and objectives

The goal of this Science to Action Fellowship project was to develop a user-friendly decision-support tool (DST) to assist fisheries professionals in planning management programs that promote thermally resilient streams and trout populations in Michigan amidst climate change. The first objective was to use existing air and water temperature data to compare the accuracy of stream-specific and region-specific (i.e., generalized) temperature models in predicting temperatures and thermal habitat suitability conditions for growth, reproduction, and survival of brook trout, brown trout, and rainbow trout. The second objective was to design and distribute a survey instrument to evaluate the perspectives of fisheries professionals regarding current trout thermal habitat management strategies; how resource availability (e.g., money, time, personnel) and thermal, hydrological, and biological conditions influence the strategies they select; and their perspectives regarding the essential components of a DST for trout thermal habitat management. The third objective was to synthesize results from the ITAS, fisheries professional survey (see objective two above), and stream temperature modeling to design a DST that enables fisheries professionals to simultaneously examine stream-specific resource availability and thermal, hydrological, and biological conditions and ultimately design management programs that promote thermally resilient streams and trout populations.

Methods

Air and water temperature data were collected in 52 coldwater streams throughout Michigan from 1990-2010 by the Michigan Department of Natural Resources (Figure 1). These data were collated into a single database to develop stream-specific air-water temperature regression models (Carlson et al. 2016). Then, future air temperatures in the headwater regions of all streams were projected in future years (2036, 2056) using three coupled climate models (CGCM3, Canadian Centre for Climate Modelling and Analysis; CM2, Geophysical Fluid Dynamics Laboratory at the National Oceanic and Atmospheric Administration; HadCM3, Met Office, United Kingdom's National Weather Service) under two carbon dioxide emissions scenarios (A2, B1). Using air temperature predictions averaged across models to minimize the impact of model bias and uncertainty, future stream temperatures in 2036 and 2056 were predicted using stream-specific air-water temperature regression models (Carlson et al. 2016) and generalized models developed in previous studies (Stefan and Prued'homme 1993, Krider et al. 2013).

Stream-specific and generalized models were compared with respect to their accuracy in predicting stream temperatures *and* thermal habitat suitability conditions (i.e., temperature *ranges*) for growth, reproduction, and survival of brook trout, brown trout, and rainbow trout. The accuracy of stream-specific regression models was evaluated by calculating the deviation between projected and actual stream temperatures and trout thermal habitat suitability statuses in 2006, a year with pre-existing stream temperature data (Carlson et al. 2017). Similarly, the accuracy of generalized regression models was assessed by calculating differences between projected and actual stream temperatures and trout thermal habitat suitability statuses. The relative accuracy of stream-specific and generalized models was evaluated by comparing each model's deviation between projected and actual temperatures and trout thermal habitat suitability statuses with those of the corresponding model (i.e., generalized or stream-specific; Carlson et al. 2017). Complete methodological details about stream-specific and generalized temperature modeling and model comparisons are available in Carlson et al. (2017).

An Internet-based survey instrument for Michigan fisheries professionals was developed concurrently with temperature modeling. Analysis of the 2015 Michigan Inland Trout Angler Survey indicated that Internet-based surveys can be completed quickly and inexpensively, which is valuable for inland trout management amidst constraints of time and funding (Carlson and Zorn 2017). The fisheries professional survey was designed to yield information on current trout thermal management strategies and the essential components of decision-support tools for trout thermal habitat management. In addition, the survey included questions regarding how fisheries professionals use information on the following factors to develop trout thermal habitat management strategies: current and future (i.e., predicted) water temperatures; groundwater and surface water contributions; presence, relative abundance, size structure, and recreational importance of brook trout, brown trout, and rainbow trout; riparian vegetation (e.g., species composition, shading); watershed land cover (e.g., grassland, forest, agricultural); and availability of money, time, and personnel. Information from temperature modeling, the ITAS, and the fisheries professional survey was synthesized to develop a map-based decision-support tool that allows fisheries professionals to efficiently allocate resources for trout thermal habitat management in high-priority streams, thereby promoting the translation of science into policy and management actions.

<u>Project results</u>

Objective 1 (Stream-specific vs. region-specific water temperature modeling)

I completed Objective 1 in spring and summer 2016. The principal product associated with Objective 1 is a *Reviews and Fish Biology and Fisheries* manuscript ("Comparing stream-specific to generalized temperature models to guide coldwater salmonid management in a changing climate") that I co-authored with Drs. Taylor, Beard, Infante, and Lynch and Kelsey Hartikainen. I presented the paper via an oral presentation in the Climate Change Symposium at the 2016 World Fisheries Congress (WFC) in Busan, Korea. The manuscript was published in *Reviews and Fish Biology and Fisheries* as part of a climate change special issue stemming from the WFC Climate Change Symposium. The manuscript presents results and conclusions derived from of a comparison of stream-specific and generalized temperature models. Between 2016 and

2056, my co-authors and I projected that temperatures will increase by 0.1–3.8°C in groundwater-dominated streams and 0.2–6.8°C in surface-runoff dominated systems in Michigan. Although they were less accurate than stream-specific models in predicting exact stream temperatures, generalized models projected thermal habitat suitability statuses with 82% accuracy in groundwater-dominated streams with brook trout (80% accuracy), brown trout (89% accuracy), and rainbow trout (75% accuracy). However, generalized models predicted thermal habitat suitability in runoff-dominated streams with only 54% accuracy. These findings indicate that amidst climate change and limitations in resource availability (e.g., personnel, funding, time), fisheries professionals can use generalized models to accurately forecast thermal conditions in groundwater-dominated streams. In addition, generalized models applied on regional scales would promote trout management strategies (e.g., harvest regulations) that, by virtue of their regional scale, would be relatively straightforward compared to the wide variety of site-specific regulations that would result from using stream-specific models. I anticipate that stream-specific models will still be valuable to use in runoff-dominated systems containing high-priority fisheries resources (e.g., trophy individuals, endangered species) that will be directly impacted by projected stream warming. Results from this study represented a key component of the DST, along with various ecological data (e.g., stream hydrology, trout relative abundance) and results from the fisheries professional survey (see below). Collectively, this information will enable fisheries professionals to prioritize streams for thermal habitat management with respect to their ecological and resource availability conditions in a changing climate.

Objective 2 (Fisheries professional survey)

I spent the majority my time in Reston, VA in summer 2016 (July 12 – August 19), working on Objective 2. I collaborated with Drs. Beard and Taylor and decision-support experts from the United States Geological Survey (Karen Jenni, USGS Science and Decisions Center; Cindy Thatcher, USGS Eastern Geographic Science Center) to develop a survey instrument for Michigan fisheries professionals. The specific objectives of the survey instrument were to: 1) gauge the perspectives of fisheries professionals regarding current trout thermal habitat management strategies; 2) evaluate how resource availability (e.g., personnel, funding, time) and thermal, hydrological, and biological conditions influence the thermal habitat management strategies fisheries professionals currently select and will select in the future; and, 3) assess the perspectives of fisheries professionals regarding important components of a DST to inform trout thermal habitat management amidst climate change. This information has been critical for developing a DST that is grounded in scientifically valid ecological and social information. In addition, the survey represented a mechanism for coproduction of the DST because fisheries professionals had considerable involvement in the design and delivery of the tool. Drs. Beard, Taylor, and I received approval to distribute the survey from the Institutional Review Board at Michigan State University in early November 2016. I made the survey available for completion by fisheries professionals on November 15, 2016 and closed it in early February 2017.

Perhaps the most important question asked in the survey related to fisheries professionals' perceptions of the relative importance of various stream attributes. The most important stream attributes for inclusion and weighting in the DST were current water temperature, trout population characteristics (e.g., presence/absence, relative abundance), and groundwater contribution, followed by watershed land cover, riparian land cover, and projected changes in water temperature resulting from climate change. (Table 1). These findings were important for designing a DST that weights Michigan trout streams according to their overall importance for thermal habitat management (i.e., all stream attributes considered) and thereby allows fisheries professionals to prioritize trout streams for management and conservation actions based on the categories they deem important. Considering all six criteria simultaneously, the highest-ranking streams (i.e., greatest stream importance) were the Au Sable, Manistee, Rapid, West Branch Sturgeon, and East Branch Fox rivers (Table 2). Complete results from the fisheries professional survey are available upon request and will be presented in an upcoming manuscript (Carlson et al. *in preparation*).

Objective 3 (Decision-support tool)

In Reston, I collaborated with Zeenatul Basher (post-doctoral research associate and research technologist with NCCWSC/MSU) to complete a prototype DST with the ecological data I had available in summer 2016 (e.g., stream-specific trout presence/absence, past [i.e., 2006] and projected future [i.e., 2036, 2056] stream temperatures). We have since revised the prototype DST into a final DST using Data Basin, an open-access mapping and analysis platform. Data Basin is a user-friendly, map-based interface that is an effective medium for delivering the final DST to fisheries professionals. In the survey, fisheries professionals indicated their order of preference for various attributes that were featured in the final DST: map-based delivery > Internet delivery > color coding > symbol coding > GIS delivery > written case studies.

A point-and-click interface allows users to turn DST data layers on and off and thereby visualize streams with particular characteristics, such as the presence of brook trout and brown trout and projected 2056 water temperatures that are optimal for growth and survival of these species (Figure 2). This enables fisheries professionals to identify streams that have (or are projected to have) characteristics that they consider desirable for trout management now and in the future. For example, if a fisheries professional seeks to conserve brook trout populations in Michigan's northern Lower Peninsula amidst climate change, she can use the DST to locate streams that have features that are necessary and/or desirable for achieving this objective (e.g., contain brook trout, have groundwater inputs, have sufficient riparian vegetation to promote stream shading; Figure 3). This process of stream identification will allow fisheries professionals to prioritize streams for trout management in a changing climate (Figure 4). Complete DST results, presented on a criterion-specific basis, are available upon request and will be included in an upcoming manuscript (Carlson et al. *in preparation*).

Experience as a Science to Action fellow

My time in Reston, VA in summer 2016 (July 12 – August 19) and winter 2016 (December 18–24) was rewarding and productive. I enjoyed the opportunity to work with federal scientists on my fellowship project and gain exposure to a federal research environment. I attended a number of NCCWSC and USGS events (Table 3) and appreciated the warm, welcoming environment that the NCCWSC community provided. I had the privilege of meeting with all NCCWSC staff members individually to discuss their job responsibilities and insights regarding DST design and implementation. I am thankful for the knowledge I gained in these meetings and for the pleasant, professional way that NCCWSC staff members treated me. My close collaboration with Zeenatul Basher resulted in a DST that combines important thermal, ecological, and resource availability information and will hopefully facilitation robust trout management decision-making in a changing climate. Many thanks to Basher for his outstanding guidance. I also appreciated the many opportunities for professional growth available during weekly NCCWSC staff meetings, including a formal research presentation that I delivered and received constructive feedback on and a chance to lead a group discussion on a scientific paper (Carpenter et al. 2015 *PNAS*; Table 3). These experiences, combined with my exposure to natural resource policy via the 2015 Demmer Scholars program (in which I attended Capitol Hill briefings; met with leaders of USFWS, USFS, and other natural resource agencies; and had other unique policy and political experiences), provided me with unparalleled exposure to the world of natural resource research and policy-making at the federal level. Such exposure was invaluable for my doctoral education and could not have occurred without the Science to Action Fellowship and the Science to Action Fellowship Committee members. Finally, I enjoyed the opportunity to give two scientific presentations about my Science to Action work at the 2017 Midwest Fish and Wildlife Conference, and I look forward to speaking about my Science to Action Fellowship experience with graduate students and professionals and publishing my DST results in a peer-reviewed journal.

Lessons learned

I learned a number of valuable lessons during my time as a Science to Action Fellow. Here I describe those lessons in reference to the specific phases of my project in which they occurred, and I conclude by explaining the overarching themes that encapsulate my Science to Action Fellowship experience. First, the temperature modeling phase of my project taught me about the value of exploring existing data sets prior to data collection. The Michigan Department of Natural Resources has monitored stream temperatures for decades and maintained superb data sets to which I gained access via Dr. Dana Infante. Had I not known about these data or investigated how I could use them, I would have expended unnecessary time, energy, and money collecting stream temperature data myself. It was certainly necessary for me to measure temperatures in certain streams to fill data gaps, but taking the time to explore pre-existing data proved to be incredibly valuable for developing a DST efficiently in less than one year. The temperature modeling phase of my project also taught me that higher accuracy is not always a better outcome (compared to lower accuracy). Whereas stream-specific models predicted water temperatures more accurately than generalized models, the latter projected trout thermal habitat suitability with sufficient accuracy (82%) in groundwater-dominated streams to warrant using them in place of more resource-intensive stream-specific models. Although using less accurate models is not necessarily intuitive, in the case of Michigan trout streams, it is highly important for using trout management (e.g., time, money, personnel, equipment) resources in a cost-effective manner.

The fisheries professional survey also taught me valuable lessons. First, I learned about the breadth and depth of knowledge necessary for designing an effective human dimensions survey instrument. A survey cannot be created by simply brainstorming relevant questions and writing them on paper. A truly successful survey instrument requires input from multiple people, including human dimensions specialists, experts in survey design, and members of the intended target audience. Many survey attributes must be considered (e.g., goals, length, word choice, question type), and survey designers are forced to "think outside themselves" to understand how survey users will interpret and respond to a survey instrument. Moreover, the DST phase of my Science to Action Fellowship taught me the importance of thinking about logistical and mechanistic aspects of delivering a web-based tool. Through an excellent collaboration with Basher, who is fluent in the "language" of DST design and delivery, I learned how to select a delivery medium (i.e., closed- versus open-access), visuals (e.g., maps, tables, figures), and user-friendly colors and symbols. DST design and delivery reinforced the significance of "thinking outside myself" to consider how users will interpret and respond to a DST. What may seem obvious to me may not seem obvious to them, and vice versa. Maintaining an audience-first perspective is important for designing an effective DST.

Taken together, the various phases of my Science to Action Fellowship taught me overarching lessons. First, I learned about the logistics and mechanics of translating science to action. Producing actionable science is valuable for researchers and managers alike, but the journey from science to action is not always straightforward. Not only is this journey often complicated, it requires a leader who starts with tangible goals and makes them happen. Although I relied heavily on the talented professionals around me (and the DST would have been impossible without them), I was impressed by the degree of personal commitment and self-starting necessary to translate science to action during my fellowship. An individual in charge of generating actionable science must have both hands on the steering wheel at all times, in addition to being supported by a network of knowledgeable professionals. Moreover, I learned to appreciate the value of mentor-mentee relationships in natural resource research and policy at the federal level. What first appeared to be a disconnected, yet valuable supplement to my doctoral education was actually a fellowship that was interwoven with my on-campus research in a manner that promoted my professional development. Having consistent, focused exposure to the interface of natural resource research and policy at the federal level opened my eyes to career opportunities and illustrated how actionable science is created outside of academia. Finally, the concepts of resilience of adaptability – overarching themes for my project – became more tangible and management-relevant as, throughout my fellowship experience, I realized how fisheries professionals may use the DST to promote these themes in the context of trout management. Resilience-based management is a two-pronged, ecological and social endeavor wherein resilience and adaptability serve as guideposts for management of fisheries and associated human systems, especially agencies and their stakeholders.

Advice for future Science to Action fellows

Explore the broader context behind NCCWSC and USGS

Familiarize yourself with the purposes and responsibilities of NCCWSC and, more broadly, USGS. What do they do? Why do they do it? How can you use the resources provided by NCCWSC and USGS to maximize your fellowship experience? In turn, how will conducting science-to-action research enable you, as a fellow, to contribute to NCCWSC and USGS?

Use the human capital around you

The Science to Action Fellowship is directed by a Fellowship Committee composed of academic and federal natural resource professionals. Collectively, these individuals possess many decades of experience dealing with important topics for Science to Action success. Realize that Committee members can help you. Also recognize that past Science to Action Fellows, equipped with first-hand knowledge of the Science to Action experience, are only an email or phone call away. Use them to benefit your fellowship and, more broadly, your professional development. The same goes for NCCWSC staff members and other USGS employees. They are a talented, experienced, helpful group of people that can enrich your fellowship experience and beyond.

Begin with the end in mind

Have concrete goals and objectives for your fellowship experience, and take necessary steps to achieve them. In particular, visualize what the end of your fellowship experience will look like (e.g., end products, delivery mechanisms, professional contacts). Brainstorm a game plan for achieving your goals and objectives, and monitor your progress. Pay particularly close attention to end users (e.g., fisheries managers, wildlife biologists, public stakeholders) of any fellowship products you produce. Design your products using an audience-first approach.

Stick with it

Translating science to action is not always straightforward, but it yields results – basic and applied – that are often meaningful for the research and management sectors. If you become frustrated with the process of generating actionable science, consult your mentors, NCCWSC/USGS staff, and/or past Science to Action Fellows. Translating science to action is filled with ups and downs, certainties and uncertainties. But if one notion is certain, it is that actionable science combines the dedication of leaders (i.e., you) with the expertise of a supportive network of professionals.

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Criterion	Variable(s)	Source	Weight
Water temperature (current)	Temperature (°C)	MDNR	0.23
Trout population characteristics	Presence/absence, catch-per-unit-effort (# fish/mile)	MDNR	0.20
Groundwater contribution	Base flow index	USGS, Neff et al. (2005)	0.17
Watershed land cover	% land cover in watershed	NLCD 2011 (Homer et al. 2015)	0.14
Riparian land cover	% land cover in riparian zone	NLCD 2011 (Homer et al. 2015)	0.14
Future/projected water temperature	Temperature (°C)	Carlson et al. 2016, 2017	0.11

Table 2. Overall stream rankings considering all six criteria simultaneously. Species denotes the trout species present in a particular stream (i.e., brook trout [BKT], brown trout [BNT], rainbow trout [RBT], all three species [ALL]). Overall scores are stream-specific scores representing the sum of weighted scores for the six criteria: water temperature (WTemp), trout population characteristics (Trout), groundwater contribution (GW), watershed land cover (WLC), riparian land cover (RipLC), and future/projected water temperature (FWTemp).

Rank	Name	Species	Overall score	WTemp	Trout	GW	WLC	RipLC	FWTemp
1	Au Sable River	ALL	85.6	16.8	20.0	15.9	12.8	11.3	8.7
2	Manistee River	ALL	83.6	18.8	20.0	11.9	13.5	10.1	9.4
3	Rapid River	ALL	80.6	16.8	18.0	10.8	13.5	12.8	8.7
4	W. Branch Sturgeon River	ALL	80.4	19.3	20.0	11.9	13.0	6.1	10.1
5	E. Branch Fox River	BKT, BNT	76.5	17.3	8.0	16.4	12.4	14.0	8.3
6	Sturgeon River	ALL	74.6	17.6	8.0	17.0	12.2	10.9	8.9
7	Pigeon River	BNT, RBT	68.6	16.8	10.0	11.9	13.2	7.7	9.0
8	Boardman River	BKT, BNT	68.0	15.7	12.0	10.8	12.6	8.8	8.2
9	S. Branch Pine River	RBT	67.8	16.6	4.0	15.9	11.6	11.1	8.7
10	W. Branch Maple River	BKT	67.8	17.0	4.0	11.9	13.8	12.4	8.8

Table 3. List of meetings, webinars, presentations, and related events that I attended or delivered as part of my Science to Action Fellowship experience.

Event	Date	Description
Individual meetings with all NCCWSC staff members	7/13/-8/17/16	Discussed job responsibilities and fellowship objectives
NCCWSC Staff Meeting, introduction and research overview	7/13/16	Weekly NCCWSC staff meeting
NCCWSC Staff Meeting	7/20/16	Weekly NCCWSC staff meeting
NCCWSC Staff Meeting	7/27/16	Weekly NCCWSC staff meeting
NCCWSC Science Meeting	7/27/16	Facilitated group discussion on Carpenter et al. 2015
NCCWSC Staff Meeting	8/3/16	Weekly NCCWSC staff meeting
Presentation by Dr. Marcia McNutt, National Academy of Sciences	8/4/16	Presentation on scientific communication
NCCWSC Staff Meeting	8/10/16	Weekly NCCWSC staff meeting
NCCWSC Staff Meeting	8/17/16	Weekly NCCWSC staff meeting
Science to Action Progress Meeting # 1	10/11/16	Progress update meeting
Presentation to NCCWSC about fellowship experience	12/21/16	Progress update presentation
NCCWSC Staff Meeting	12/21/16	Weekly NCCWSC staff meeting
Two talks about fellowship work, 2017 Midwest FW Conference	2/6/17	Two talks at meeting in Lincoln, NE
Science to Action Progress Meeting # 2	4/13/17	Progress update meeting
Science to Action Completion Webinar	TBD	NCCWSC webinar about fellowship experience

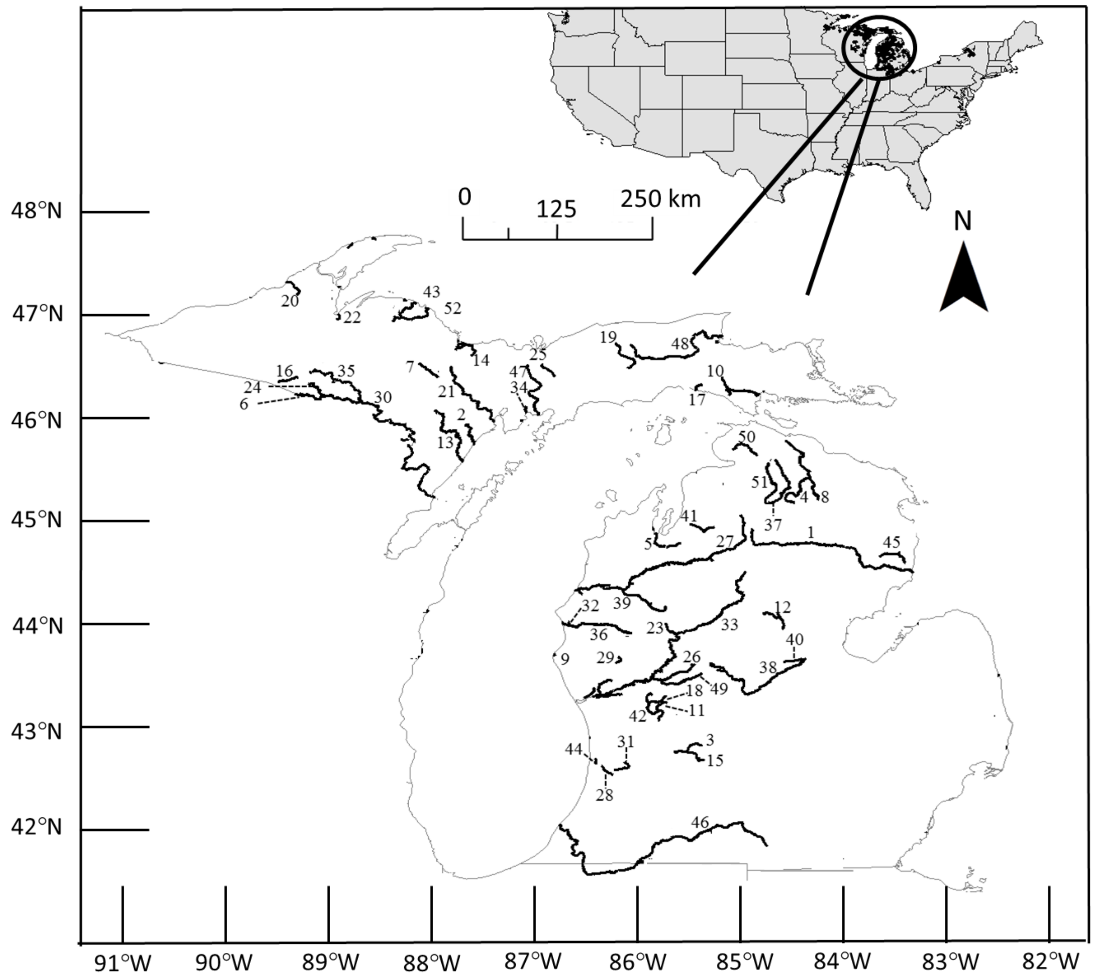

Figure 1. Map of 52 brook trout, brown trout, and rainbow trout streams used for air–stream temperature modeling in Michigan. Streams and corresponding identification numbers are available in the online decision-support tool and Table 1 of Carlson et al. (2017).

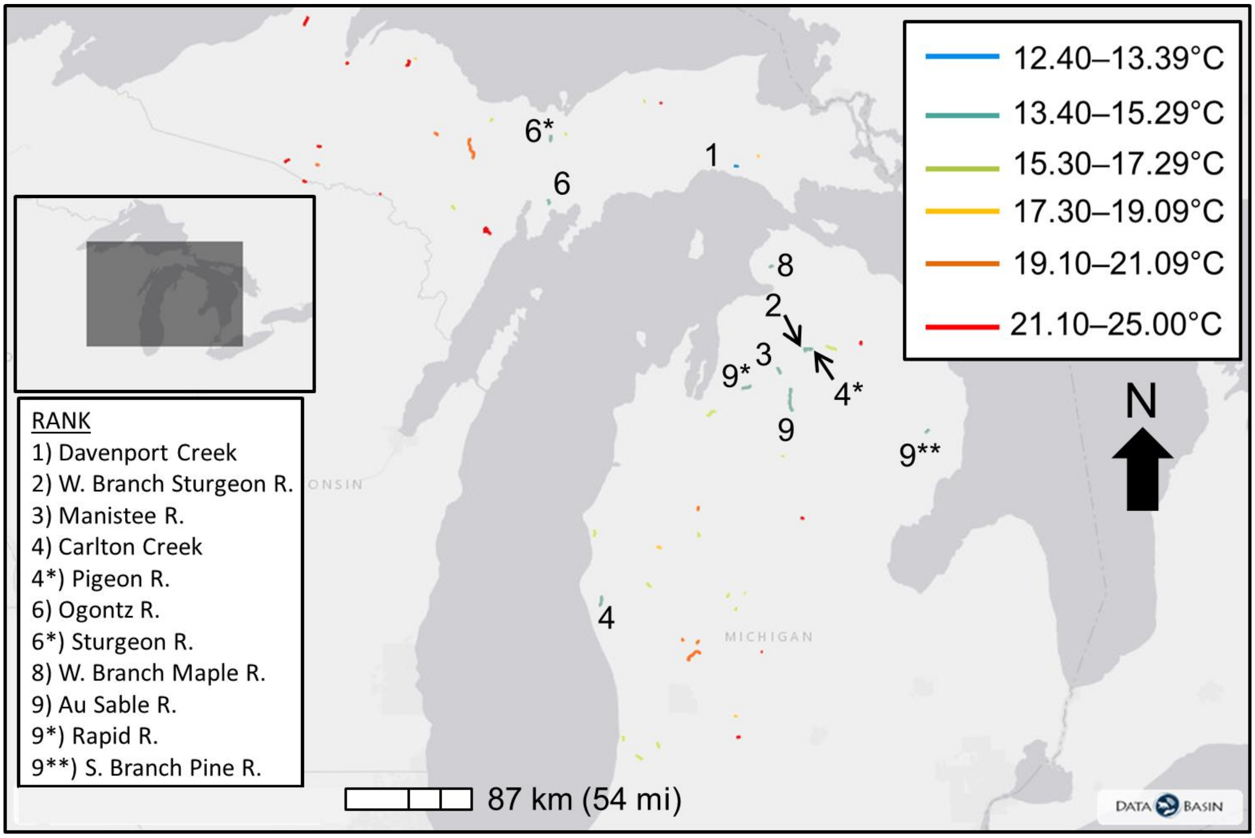

Figure 2. Michigan stream rankings for a decision-support tool criterion focused on future water temperatures (i.e., those projected in 2056). Streams with cooler projected temperatures received higher rankings. The eleven highest-ranked streams with respect to future water temperature are included above.

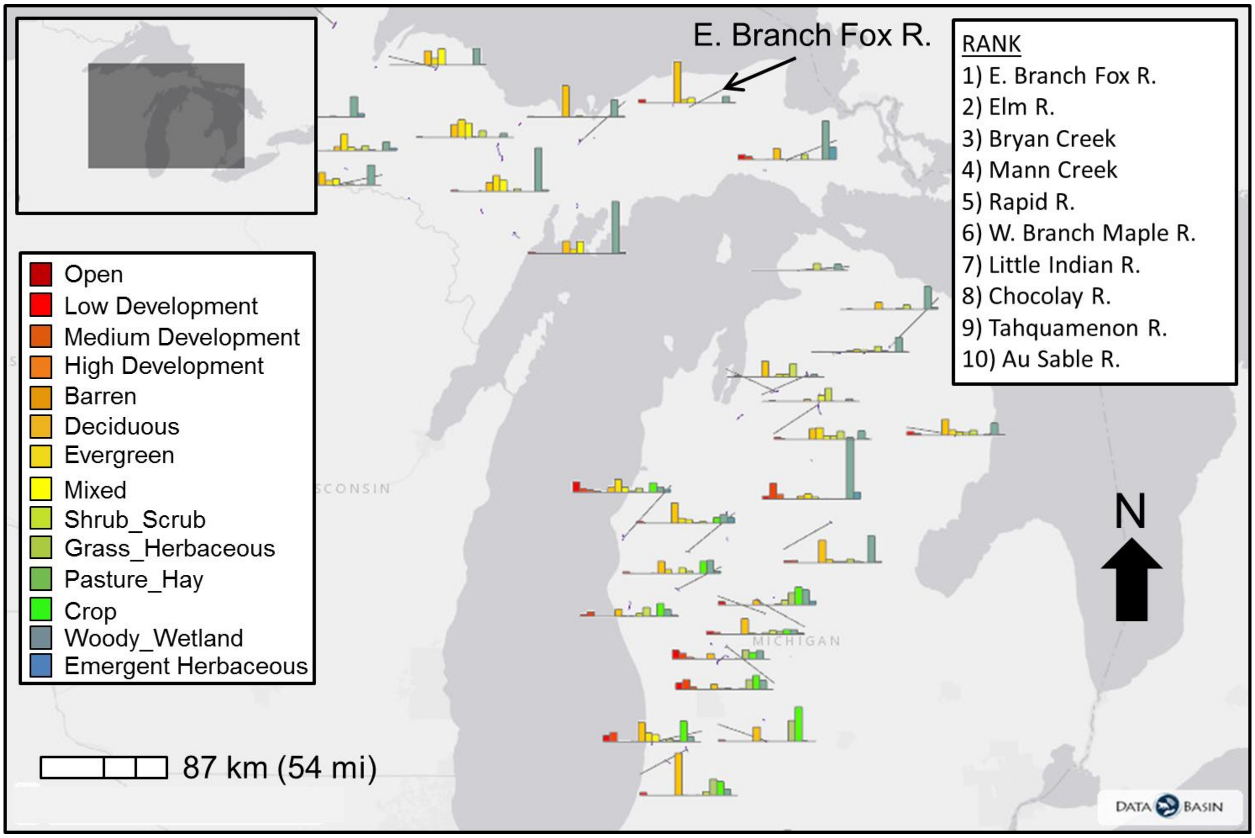

Figure 3. Michigan stream rankings for a decision-support tool criterion about riparian land cover conditions. Streams are ranked according to the proportion of their riparian zones containing habitats that promote cool, thermally favorable conditions for trout (i.e., deciduous, evergreen, and mixed forest; grassland/herbaceous cover; and woody or emergent herbaceous wetlands), with higher rankings indicating greater coverage by thermally favorable habitats. The ten highest-ranked streams with respect to riparian land cover conditions are included above.

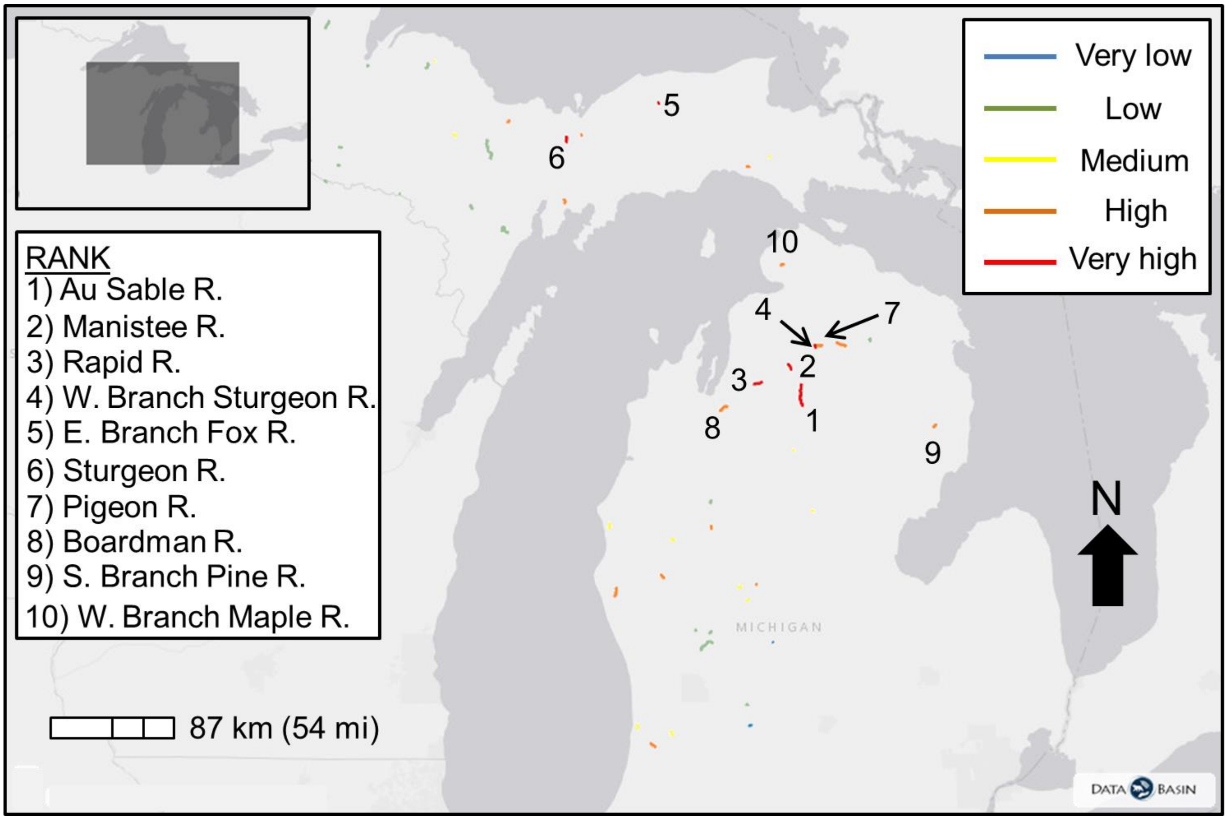

Figure 4. Overall Michigan stream importance rankings considering all six decision-support tool criteria (i.e., water temperature, trout relative abundance, groundwater contribution, watershed land cover, riparian land cover, projected future water temperature). Streams with greater scores for individual criteria receiving higher importance rankings. The ten highest-ranked streams with respect to all six decision-support tool criteria are included above.