Notes

Rating the Potential Suitability of Habitat in Michigan Stream Reaches for Arctic Grayling

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Abstract

Present-day environments and anticipated future conditions often pose a significant challenge to efforts to reintroduce extirpated species, highlighting the need for collaborative, thorough approaches to reintroductions. Such is the case in Michigan, where numerous partners are working to reintroduce Arctic Grayling *Thymallus arcticus* with hopes of reestablishing self-sustaining populations. With $>$ 47,000 km of coldwater stream habitat in the state and limited numbers of eggs for reintroductions, a prioritization framework was needed to provide a standardized, fine-scale method for rating suitability of streams for reintroductions. Through facilitated discussions with stakeholders and experts, we developed an overall prioritization framework for rating Michigan streams with components evaluating a reach's thermal, instream habitat, biological, and connectivity characteristics. Within the context of this broader framework, we developed the habitat rating component for assessing suitability of instream conditions for egg, fry, juvenile, and adult life stages of Arctic Grayling. Life-stage-specific habitat metrics and scoring criteria from this effort were used to rate habitat conditions for 45 reaches in tributaries of Michigan's Manistee River, enabling identification of reaches likely having instream habitat most suitable for Arctic Grayling. Numbers of reaches meeting or exceeding 60%, 70%, and 80% of the maximum score for overall habitat suitability were 31, 8, and 1. Upon completion of the fish assemblage and connectivity components, the prioritization framework and habitat rating process described here will be used for comparing suitability among streams throughout the historical range of Arctic Grayling in Michigan and guiding reintroduction efforts. Though it will take considerable time before instream habitat suitability criteria can be evaluated for all life-stages of Arctic Grayling in Michigan, the collaborative stream prioritization framework developed for Arctic Grayling reintroduction can be readily adapted to reintroduction efforts for other species elsewhere.

Keywords: habitat suitability; Arctic Grayling; native species

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Introduction

Reintroductions of extirpated species to habitats within their historical range are occurring throughout North America and the world. Species reintroductions often or have occurred haphazardly (e.g., one-time efforts) or fail as a result of inadequate scoping and feasibility assessment prior to reintroductions (Dunham et al. 2011). In such cases, past failures may not necessarily indicate that well-thought-out and carefully undertaken future attempts are doomed to failure (e.g., see Cochran-Biederman et al. 2014). Here, we describe a renewed species' reintroduction effort and a collaborative approach to habitat assessment where the ultimate priorities are learning, and hopefully a different outcome.

Arctic Grayling *Thymallus arcticus* (hereafter, Grayling) are primarily found in sub-Arctic drainages in North America, Asia, and Europe, and were once abundant and widespread in the State of Michigan (Milner 1874; Figure 1) prior to their extirpation > 80 y ago. Historically, the Grayling fisheries in Michigan's Lower Peninsula were world-renowned (Vincent 1962), providing a valuable, albeit short-lived, recreational and commercial resource for anglers (Whitaker 1886; Bissell 1890). Large quantities of Grayling (sometimes > 283 kg/angler) were harvested commercially and exported to fish markets in Milwaukee and Chicago (Hinsdale 1932). Comparable catches in Michigan were reported in recreational fisheries, with > 45 kg/angler/day harvested from the Au Sable River and roughly 225 kg/angler over the course of 5 d on the Manistee River (Norris 1883). Grayling were likely the only native fluvial salmonid species in most of the Lower Peninsula of Michigan (Nuhfer 1992) prior to the range expansion and stocking of Brook Trout *Salvelinus fontinalis* (Smedley 1938), and the introductions of Rainbow Trout *Oncorhynchus mykiss* in 1876 (Bower 1910), and Brown Trout *Salmo trutta* in 1884 (Luton 1985).

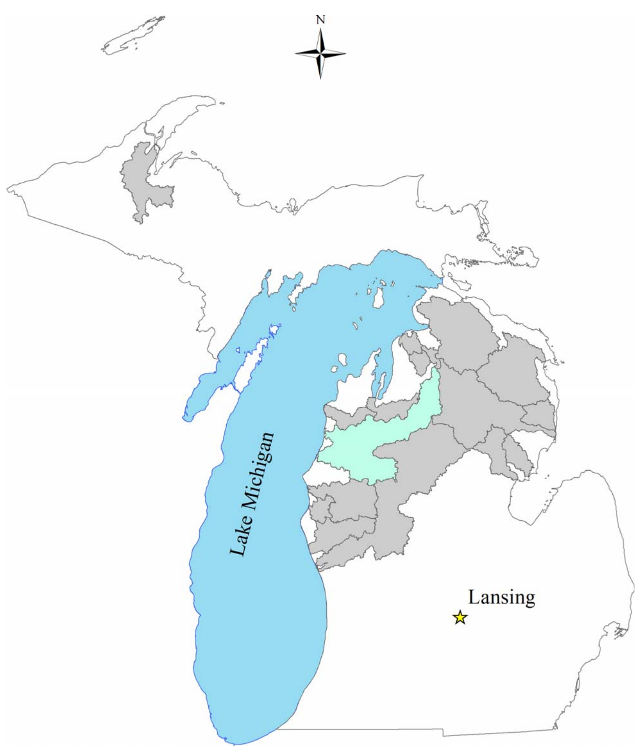

Figure 1. Michigan watersheds with reliable historical records of Arctic Grayling *Thymallus arcticus*. Watersheds in the Lower Peninsula reflect the historic range of Arctic Grayling prior to their extirpation from the peninsula by 1906. The Manistee River watershed is highlighted in teal. Records from the Otter River watershed in the Upper Peninsula likely reflect a population introduced from the Lower Peninsula by lumber barons in the 1860s or 1870s which persisted until the mid-1930s.

By the 1870s, newspaper accounts and sporting journals noted that Grayling populations were experiencing large declines in abundance in the Au Sable, Boardman, Jordan, and Manistee rivers (Metcalf 1880; Bebe 1887; Bissell 1890) prompting calls by anglers and conservationists for the supplementation and protection of the species (Hallock 1873; Bissell 1890). By 1910, Grayling could no longer be found in their native Lower Peninsula rivers (Vincent 1962). One holdout population in the Upper Peninsula's Otter River persisted until 1936 when the last individual was captured, but this population is believed to have been introduced from the Lower Peninsula in the mid-1800s (Kroll 1925). The loss of Grayling from Michigan parallels declines or extirpation of populations of native fish species in North America and elsewhere due to anthropogenic factors (Moyle and Williams 1990; Lepruier et al. 2008). Habitat degradation associated with commercial timber harvest, dams, angler overharvest, and introduction of potentially competing or predatory nonnative salmonids likely all contributed to the species' extirpation from Michigan (Norris 1879; Leonard 1939; Vincent 1962).

The State of Michigan's attempts to bolster its declining Grayling population and reintroduce the species after its extirpation were all unsuccessful. In the 1870s, as Grayling populations in Michigan declined, efforts to supplement and restore the species began by creating brood stocks from fish in other Michigan rivers with naturally reproducing populations and stocking eggs (Norris 1878; Jerome 1879). By 1900, nearly all Michigan waters lacked viable Grayling populations, so restoration efforts turned to acquiring eggs and fry from Montana (Leonard 1949). The Michigan Department of Natural Resources (MDNR) attempted to reintroduce the species by stocking yearlings during 1934–1941 and fingerlings in 1958–1960, but these efforts were unsuccessful (Nuhfer 1992). The State's last unsuccessful effort involved introducing fry, fingerlings, and yearlings, sourced from eggs taken from Grayling populations in Meadow Lake, Wyoming and Providence Creek, Northwest Territories, Canada, into Michigan lakes and rivers during 1987–1990 (Nuhfer 1992).

The State of Montana also historically struggled with restoring Arctic Grayling populations but has had more success in recent years. Between the 1920s and 1980s, tens of millions of Grayling eggs, fry, and fingerlings were stocked throughout Montana, but none of the efforts yielded self-sustaining populations (Kaya 1990). However, improved understanding of the genetic differences between fluvial and lacustrine strains of Grayling and the use of instream remote site incubator (RSI) techniques since the 1980s have led to restoration of some Grayling populations in Montana (Kaeding and Boltz 2004; Magee and McCullough 2008; Cayer and McCullough 2013). These successes hinted at the possibility that similar results could be achieved in Michigan.

By addressing issues from previous efforts and implementing the RSI approach to stocking used in Montana, the MDNR and the Little River Band of Ottawa Indians (LRBOI) believed another reintroduction attempt was worthwhile and were cautiously optimistic that it could ultimately lead to self-sustaining populations of Arctic Grayling in Michigan. Michigan DNR fisheries biologists drafted a proposal that received internal support from agency leadership, and then approached LRBOI (who were continuing with their re-introduction goals set in 2011) to join as founding partners in a statewide Grayling restoration effort. This partnership, called the Michigan Arctic Grayling Initiative is a "management experiment" with two primary objectives: 1) restoration of self-sustaining Grayling populations within the species historical range in Michigan; and 2) building knowledge to inform future Grayling reintroduction efforts in Michigan and elsewhere. Michigan DNR and LRBOI hosted a meeting in August 2016 and the initiative was enthusiastically embraced by nearly 50 partner organizations. This led to development of the Michigan Arctic Grayling Initiative Action Plan 2017, a project website (https://www.miGrayling.org/) for partner and public use, and the 2019 retrofit of an MDNR hatchery to safely isolate and rear newly acquired Grayling broodstock from Alaska until fish satisfactorily passed mandatory health screenings.

With $>$ 47,000 km of coldwater stream habitat in Michigan (Zorn et al. 2018) and limited availability of Grayling eggs, prioritizing locations for reintroducing Grayling is a challenge. Suitable stream habitat conditions, compatible fish communities, and connectivity among habitats are all thought to be important components for successful Grayling reintroduction (Kaya 1992; Heim et al. 2016; Danhoff et al. 2017; Goble et al. 2018). We hypothesized that successful reintroduction of Grayling in Michigan is most likely to occur where 1) habitat conditions are suitable for each life-stage of Grayling (i.e., egg, fry, juvenile, adult), 2) competitor and predator fish densities are low enough to allow survival and reproduction of reintroduced Grayling, and 3) connections exist between mainstem and tributary habitats to accommodate migratory movements of Grayling. However, an approach to integrating local habitat, biological, and connectivity information for Michigan streams into a scheme for prioritizing waters for Grayling reintroduction was lacking.

Analysis of several Michigan watersheds using landscape-scale data and models (Tingley 2010) and site-scale habitat surveys (Danhoff et al. 2017; Goble et al. 2018) indicated that suitable stream habitat for Grayling likely existed in many watersheds. For example, in their study of 22 reaches in 8 of the Manistee River's 109 named tributaries, Danhoff et al. (2017) found suitable adult habitat in 14 of 22 reaches and suitable age-0 and juvenile habitat in 15 of 22 reaches. With far more suitable habitat potentially being available within the historical range of Grayling than could be stocked with the limited amount of Grayling eggs available for reintroductions, managers needed a finer-grained rating of the suitability of habitat for all life-stages (i.e., the sum of values for each life-stage) of Grayling to identify best candidates for reintroduction efforts. Rather than reporting how often habitat metric values fell within the literature-reported range for Grayling (Danhoff et al. 2017), managers needed a tool that quantified how close observed habitat conditions were to optimal values for the species in Michigan and enabled standardized, quantitative comparisons among stream reaches. Our objectives were to 1) present an overall prioritization framework for rating Michigan streams for Grayling reintroduction that integrates reach-specific data on habitat, connectivity, and fish assemblages; and 2) describe the development of the habitat component of this framework and its use in rating suitability of instream habitat in reaches for each life-stage of Grayling from field-measured data.

Methods

Stream reach prioritization framework

Through facilitated discussion with 18 stakeholders and experts (e.g., Tribal, State, Federal, nongovernmental organizations, and University biologists) at a December 2016 Grayling partnership meeting, a draft overall framework was developed for ranking suitability of stream reaches for Grayling re-introduction. Each stakeholder was allotted three votes and asked to rank what they felt were the most important factors from a list of five factors nominated by the group: 1) stream size, 2) habitat for all life stages, 3) density of Brown and Brook Trout, 4) connectivity, and 5) presence of nontrout predators. Three factors received the large majority of votes from the group: 1) habitat (e.g., water temperature, substrate characteristics, etc.), 2) biological (e.g., densities of other fish species, food availability, etc.), and 3) stream connectivity (i.e., unimpeded access to habitats for all life stages). Individual weights for the habitat, biological, and connectivity components on the overall score were calculated as the proportion of the total number of votes

Table 1. Habitat parameters identified during 2017 partner meetings as most important to each life stage of Arctic Grayling *Thymallus arcticus* in Michigan.

Life stage	Life-stage weight (%)	Habitat metric	Within-life-stage metric weight (%)
Egg and spawning	30.1	% Sand and gravel	47.4
		% Silt and detritus	26.3
		Presence of pools and riffles	26.3
Fry	33.3	% Occurrence of aquatic vegetation	18.5
		% Areal coverage of large woody debris	18.5
		Presence of pools and runs	33.4
		% Silt and detritus	29.6
Juvenile	23.3	% Occurrence of aquatic vegetation	17.0
		% Areal coverage of large woody debris	20.0
		% Run	33.4
		% Gravel and cobble	29.6
Adult	13.3	% Pool habitat	41.4
		Mean depth (m)	34.5
		Low-flow discharge (m^3/sec)	24.1
All	NA	Mean July water temperature	NA

received for the three factors. The collaboratively developed and approved prioritization framework produces individual stream reach scores based upon A) mean July water temperature (unsuitable if $> 19.5^{\circ}C$), B) habitat for all life-stages of Grayling (37% of overall score weight); C) density of potential predatory or competing fish species (44% of overall score weight); and D) connectivity to upstream and downstream habitats (19% of overall score weight). Within the context of this broader prioritization framework, the following paragraphs describe development and implementation of the habitat rating component.

Habitat rating component development

A collaborative effort to investigate streams in the Upper Manistee River watershed for potential Grayling reintroductions provided the impetus for detailing the prioritization framework's habitat assessment component because fish community and habitat surveys would be occurring in 2017 as part of the project. The four main project steps involved 1) identifying key habitat metrics and scoring criteria for each Grayling life stage; 2) developing standardized habitat and fish survey protocols; 3) applying the protocols during field surveys on 22 stream reaches in the Upper Manistee River system; and 4) rating the suitability of instream habitat for Grayling in these reaches and Manistee tributaries surveyed in 2011–2013 (Auer et al. 2013).

In February 2017, 10 biologists from MDNR Fisheries Division, LRBOI, and Michigan Technological University (MTU) with expertise in Grayling habitat requirements and Michigan streams met to flesh out the "habitat for all life-stages" component of the prioritization framework. Their specific tasks were to 1) weight the relative importance of the egg, fry, juvenile, and adult components of habitat to Grayling reintroduction success in Michigan; 2) identify and weight key field-based parameters for assessing habitat for each life-stage of Grayling; and 3) review existing MTU–LRBOI and MDNR habitat survey protocols with respect to measurement of these parameters. The group developed a list of important field parameters for characterizing Grayling habitat for each life stage (egg, fry, juvenile, or adult) based upon studies conducted in Michigan and throughout the species' range (Kaya 1992; Auer et al. 2013; Danhoff et al. 2017). For each life stage, the experts then voted for their top three metrics characterizing key aspects of habitat. This resulted in a prioritized and weighted list of the top few habitat metrics for each life stage (Table 1). The percentage of votes an individual metric received relative to total number of votes received by top metrics for that life stage was used to weight the contribution of each metric to the total habitat score for each life stage (Table 1). We identified 15 abiotic metrics as important for characterizing habitat suitability for the 4 life stages of Grayling in Michigan (Table 1). The MDNR's existing Status and Trends Random Site stream survey protocols (Wills et al. 2006) enabled standardized measurement of all variables identified from this process and were selected for use in Grayling field surveys. Participants were asked to rank the importance of each life stage to grayling restoration success with sums of ranks for each life stage being used to weight the relative contribution of egg, fry, juvenile, and adult scores to the overall habitat (habitat for all life stages) score, collectively indicating the degree to which attendees thought each aspect of habitat would influence Grayling reintroduction success in Michigan streams (Table 1).

We developed draft numeric scoring criteria to assign suitability scores to field-measured values based on studies describing Grayling habitat preferences. We assigned scores ranging from zero to three to potential values for each parameter, indicative of that value's hypothesized suitability for Grayling (Table 2). Identifying scoring breakpoints represented an integration of literature studies (e.g., Kaya 1992; Danhoff et al. 2017) and habitat data for Michigan streams because quantitative data describing habitat requirements of Grayling in Michigan does not exist. Scores corresponded to suitability ratings of 'unacceptable' (score $=$ 0; values

Table 2. Scoring criteria developed during 2017 partner meetings for evaluating Michigan stream habitats for each life stage of Arctic Grayling *Thymallus arcticus*.

Life stage	Metric	Unacceptable (score = 0)	Acceptable (score = 1)	Preferred (score = 2)	Ideal (score = 3)
Egg and/or spawning	% Sand and gravel score:	Sand: < 5% *or* > 95%	Sand: > 5% *and* < 30% or > 70% *and* < 95%	Sand: > 30% *and* < 70%	
		Gravel: < 5% *or* > 80%	Gravel: > 5% *and* < 80%	Gravel: > 5% *and* < 40%	
	% Silt and detritus	> 40%	> 20% *and* < 40%	< 20%	
	Presence of pools and riffles	No		Yes	
Fry	% Occurrence of aquatic vegetation			< 15%	> 15%
	% Areal coverage of large woody debris	> 75%	< 10% *or* > 50% *and* < 75%	> 10% *and* < 50%	
	Presence of pools and runs	No		Yes	
	% Silt and detritus		< 50%	> 50%	
Juvenile	% Occurrence of aquatic vegetation			< 15%	> 15%
	% Areal coverage of large woody debris	> 75%	< 20% *or* > 50% *and* < 75%	> 20% *and* < 50%	
	% Run habitat		< 30% *or* > 70%	> 30% *and* < 70%	% Run habitat = Preferred *and* % Riffle and % Pool are both ≥ 10%
	% Gravel and cobble		< 25% *or* > 75%	> 25% *and* < 75%	
Adult	% Pool habitat		< 50% *or* > 90%	> 50% *and* < 90%	% Pool habitat = Preferred *and* % Riffle and % Run are both ≥ 10%
	Mean depth (m)	< 0.15 m	0.15–0.3 m	> 0.3 m	
	Low-flow discharge (m^3/s)	< 0.28 m^3/s	> 0.28 *and* < 1.23 m^3/s *or* > 16.99 m^3/s	> 1.23 *and* < 16.99 m^3/s	
All	Mean July water temperature	> 19.5°C			

outside of the range of literature-reported habitat requirements), 'acceptable' (score = 1; values within the range of literature-reported habitat requirements), 'preferred' (score = 2; values near the midpoint of the range of literature-reported habitat requirements), and 'ideal' (score = 3 values meeting criteria for 'preferred' and deemed by expert opinion as optimal considering habitats available in Michigan). The same MDNR–LRBOI–MTU group that met in February 2017 reviewed draft breakpoints, modified them slightly based on input received, and then approved them in April. Completion of the habitat rating component of the prioritization framework enabled habitat survey data to be turned into a rating score for each life stage, allowing for quantitative and life-stage-specific comparisons of the suitability of river reaches for Grayling.

We computed habitat rating scores by individual life stage as well as a total score across life stages for each reach sampled in the field. The habitat score for a life stage was the sum of the products of each habitat metric's weight and its score, divided by the maximum potential score (assuming ideal habitat conditions), and multiplied by 100 (Table 1). Thus, it indicates how close (as a percentage) the reach came to the maximum possible score, with a value of 100 equaling the highest possible score. The overall or habitat for all life stages score was the sum of the products of each life stage's score and weight (Table 1), again with a value of 100 being best. Based upon scores from the 2017 field surveys, we selected an overall habitat score of 60 as an initial (albeit somewhat arbitrary and subject to revision) threshold value for reaches to be considered for potential Grayling introductions. We classified reaches falling below the 60% threshold value as likely unsuitable and did not consider them priorities for introduction efforts.

Application of habitat rating system

We chose the Manistee River system (Figure 1) as the initial focus area for reintroductions (and application of the habitat rating system) because it historically held large populations of Grayling (Rozich 1998) and is of particular interest for native species restoration (Auer et al. 2013). This system has thousands of kilometers of high-quality unfragmented, coldwater habitat, including tributary streams recently identified as suitable for Grayling (Tingley 2010; Danhoff et al. 2017; Goble et al. 2018). Two dams, located in the lower third of the watershed, prevent upstream fish movement throughout the watershed, effectively dividing it into three distinct segments. The lower-most segment is the portion of the watershed downstream from Tippy Dam and has been excluded from all analyses because of its connectivity with Lake Michigan. The Middle Manistee River segment encompasses the portion of the watershed between Hodenpyl Dam and Tippy Dam while the Upper Manistee River segment encompasses the watershed upstream from Hodenpyl Dam. Most Middle Manistee River tributaries have been surveyed (Danhoff et al. 2017; Goble et al. 2018), but past MDNR records indicated many streams in the Upper Manistee River were not surveyed within the past 10 y. Additionally, where surveys had been performed in this area, the full suite of habitat and fishery data needed to assess suitability for Grayling reintroduction were not collected, making comparisons among streams impossible.

Fisheries biologists from MDNR, LRBOI, and other stakeholders met in March 2017, with agency managers identifying 20 reaches in the Upper Manistee River watershed for evaluation that summer. Field site visits began in May 2017 and included deployment of Hobo Water Temp Pro V2 loggers (Onset Computer Corporation, Bourne, MA) to record hourly water temperatures. Biologists conducted electrofishing and habitat surveys at sites from mid-June through July of 2017 following MDNR Status and Trends Random Sites protocols (Wills et al. 2006). Sampling reaches were 152 m in length for streams < 4.5 m wide, or 244 m in length for streams $>$ 4.5 m wide. Following standardized survey protocols (Wills et al. 2006), biologists collected stream habitat data at 5 points along 12–14 transects to quantify substrate composition, habitat type (i.e., riffle, pool, run), occurrence of submerged aquatic vegetation, stream depth, and wetted width. Additionally, we conducted counts and measurements of large wood and woody structure throughout the entire sample reach.

Results

By evaluating habitat suitability at different life stages the proposed framework allows for both broad-scale assessment (i.e., does suitable habitat for all life stages [necessary for successful respecies re-establishment] exist in a watershed?) and fine-scale assessment (i.e., which reaches are best suited for specific life stages and targeted reintroduction efforts?). Combining data from the 2017 surveys in the Upper Manistee River ($N = 22$) and previous surveys (Danhoff et al. 2017; Goble et al. 2018) in Middle Manistee River tributaries ($N = 23$), 45 stream reaches had all of the habitat data necessary for the Grayling habitat rating system. Three reaches were identified as "likely unsuitable" based upon mean July water temperatures exceeding 19.5°C (Table S1, *Supplemental Material*; Figure 2) leaving 42 reaches (93%) for further analyses. Of these, 15 reaches in the Middle, and 16 reaches in the Upper Manistee River watershed met or exceeded the overall habitat suitability threshold of 60% for all life stages (Figure 3e).

When viewed by specific life stage, Grayling reintroduction success was expected to be most affected by the survival of fry (i.e., individuals of 10–80 mm total length; Jones et al. 2003). Accordingly, fry habitat requirements comprised 33% of the total habitat quality score for all life stages (Table 1). Twenty-three sites (~55%) met or exceeded the 60% habitat suitability threshold for Grayling fry (Table S2, *Supplemental Material*; Figure 3b). Based upon these criteria, 17 sites did not meet the threshold for fry habitat and would be candidates to be removed from further life stage analyses. Additionally, of these 17 sites, 5 did not meet the 60% threshold for habitat during the egg development and spawning stage (identified as the second most important life stage and comprising 30% of the weight of the all life stages score; Table 1), further warranting potential exclusion. Approximately 86% ($N = 36$) of the remaining sites met or exceeded the 60% habitat suitability threshold for Grayling spawning habitat and egg development (Table S3, *Supplemental Material*; Figure 3a). The six sites not meeting the 60% threshold may provide suitable habitat for other life stages and were included in the remaining analyses.

Habitat requirements for juvenile stage (age-1 to age-at-maturity) Grayling and adult Grayling were considered to be the third and fourth most important components of the overall habitat quality score, contributing 23% and 13% of the all-life-stage score, respectively (Table 1). Thirty-three Manistee River sites (~79%) met or exceeded the 60% habitat suitability threshold for juvenile Grayling (Table S4, *Supplemental Material*; Figure 3c). Nine of the sites identified as 'likely unsuitable' juvenile habitat had also fallen below the 60% threshold for egg development and spawning ($N = 6$; Table S3) or fry habitat ($N = 8$; Table S2). However, two sites (Goose Creek and Pickerel Lake Outlet) that had scored poorly as egg development and spawning habitat (39.5% and 26.3%, respectively) ranked relatively highly as juvenile habitat (Table S4), highlighting the importance of habitat variability and connectivity for different Grayling life stages. Only three sites (~7%) met or exceeded the 60% habitat suitability threshold for adult Grayling (Table S5, *Supplemental Material*; Figure 3d). Nearly all surveys occurred in tributaries of the Manistee River; therefore, low-flow discharge (a measure of stream size) was the primary factor behind the relatively poor adult habitat scores, with all sites falling within the 'unacceptable' to 'acceptable' categories and none ranking as 'preferred.' Raw habitat data and scores can be found in the supplemental materials (Tables S1–S5, Data S1, *Supplemental Material*).

Discussion

Habitat suitability ratings

Our habitat rating system placed emphasis on suitable habitat for Grayling eggs and fry. As is the case with many salmonids, Grayling survival from egg-to-fry is generally quite low (i.e., $< 10\%$) even for 'healthy' populations. For example, Kruse (1959) found egg-to-fry survival rates ranged from 2% to 6% (average = 2.5%) for a native adfluvial Grayling population in Wyoming. Remote site incubators (RSIs) have the potential to substantially increase egg-to-fry survival. Wilson (2017) found egg-to-fry survival rates of ~50% in RSI lab trials with eggs sourced from Montana. Results from Grayling restoration in Montana (Kaeding and Boltz 2004) and from field trials of new RSI configurations using Rainbow Trout conducted in the Manistee River watershed (Ruetz

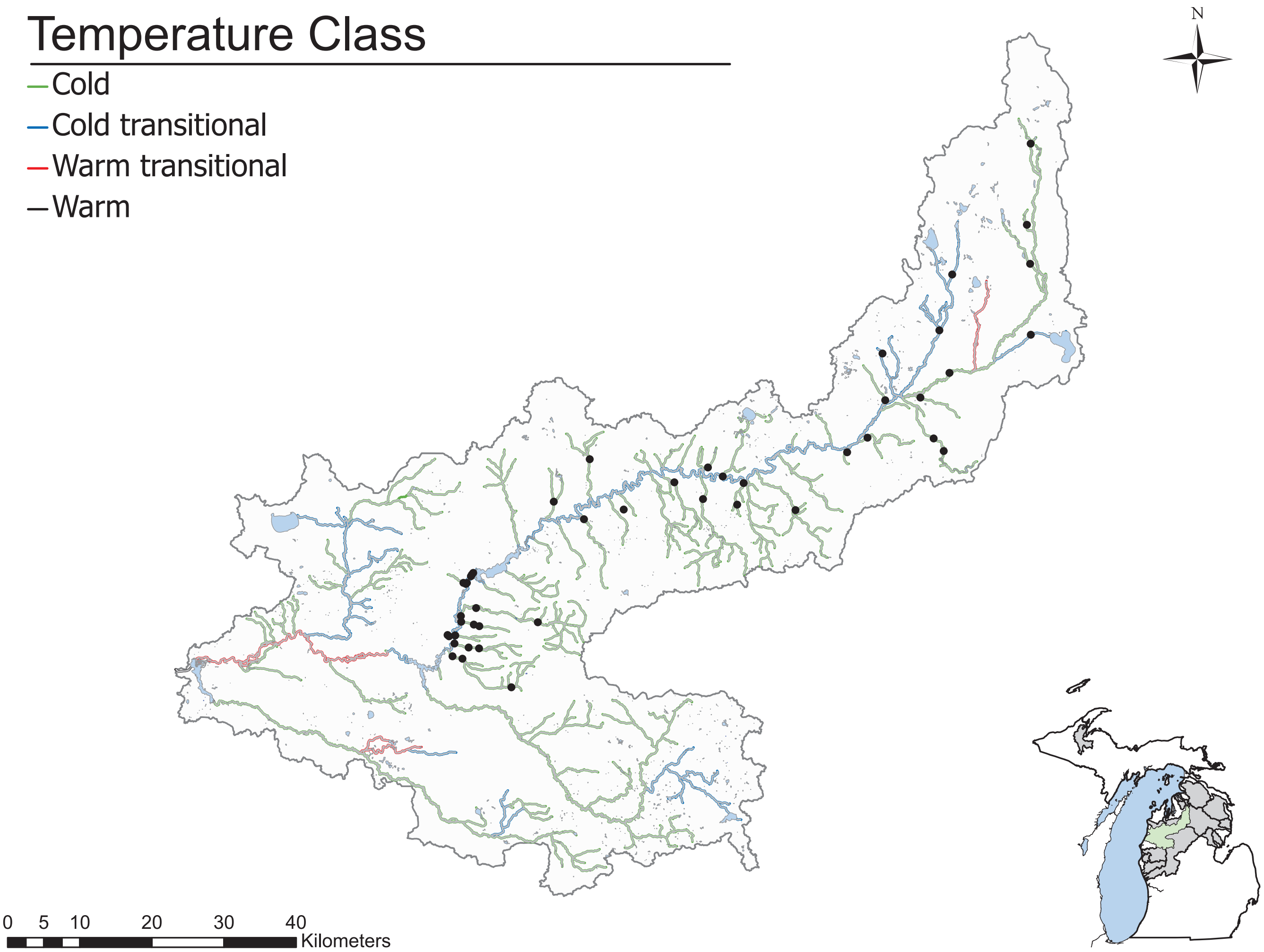

Figure 2. Michigan Department of Natural Resources temperature classes of stream segments in the Manistee River, Michigan, watershed (Zorn et al. 2008). "Cold" denotes stream segments with mean July temperatures < 17.5°C, "Cold transitional" denotes mean July temperatures > 17.5°C and < 19.5°C, "Warm transitional" denotes mean July temperatures > 19.5°C and < 21°C, and "Warm" denotes mean July temperatures > 21°C. Circles indicate 2012 (middle watershed) and 2017 (upper watershed) Arctic Grayling *Thymallus arcticus* habitat suitability sampling locations.

et al. 2018; Mock et al. 2021) show comparable survival. The ultimate goal of the initiative is to restore self-sustaining populations of Grayling within its historical range in Michigan (Michigan Arctic Grayling Initiative 2017), so identifying locations with suitable habitat for natural spawning and recruitment is important for determining where to concentrate RSIs.

Mortality during the juvenile life stage is believed to be lower than during the egg or fry stages and likely closer to mortality values reported for adult Grayling (Kruse 1959). Juvenile and adult survival can range from ~75% in unexploited Alaskan populations to as low as 24% in heavily fished populations (Clark 1995). Similarly, adult Grayling are considered less vulnerable to predation or competition than are fry or juveniles (McCullough 2017), and being more migratory than are fry or juveniles (Northcote 1995), are more likely to seek out suitable habitats in the watershed. High levels of adult mortality can certainly have negative impacts on population persistence (DeCicco and Brown 2006) and overharvest played a role in the extirpation of Grayling from Michigan, but this is a separate issue from ranking suitability of habitat for adult fish because adult Grayling in Michigan will be protected from excessive angler harvest.

Low-flow discharge was the primary factor behind the relatively poor adult habitat scores, but we do not think this is a major cause for concern because of connectivity between the tributaries surveyed and downstream reaches. We think juvenile and adult Grayling would likely outmigrate from natal tributary streams to more suitable feeding and overwintering habitats in the mainstem Manistee River as observed elsewhere in the species range (Northcote 1995). For example, Heim et al. (2016) observed adult Grayling in an Alaska drainage only spending the first few weeks of spring in small streams before migrating to larger tributaries for the summer. The Manistee River upstream of Hodenpyl Dam

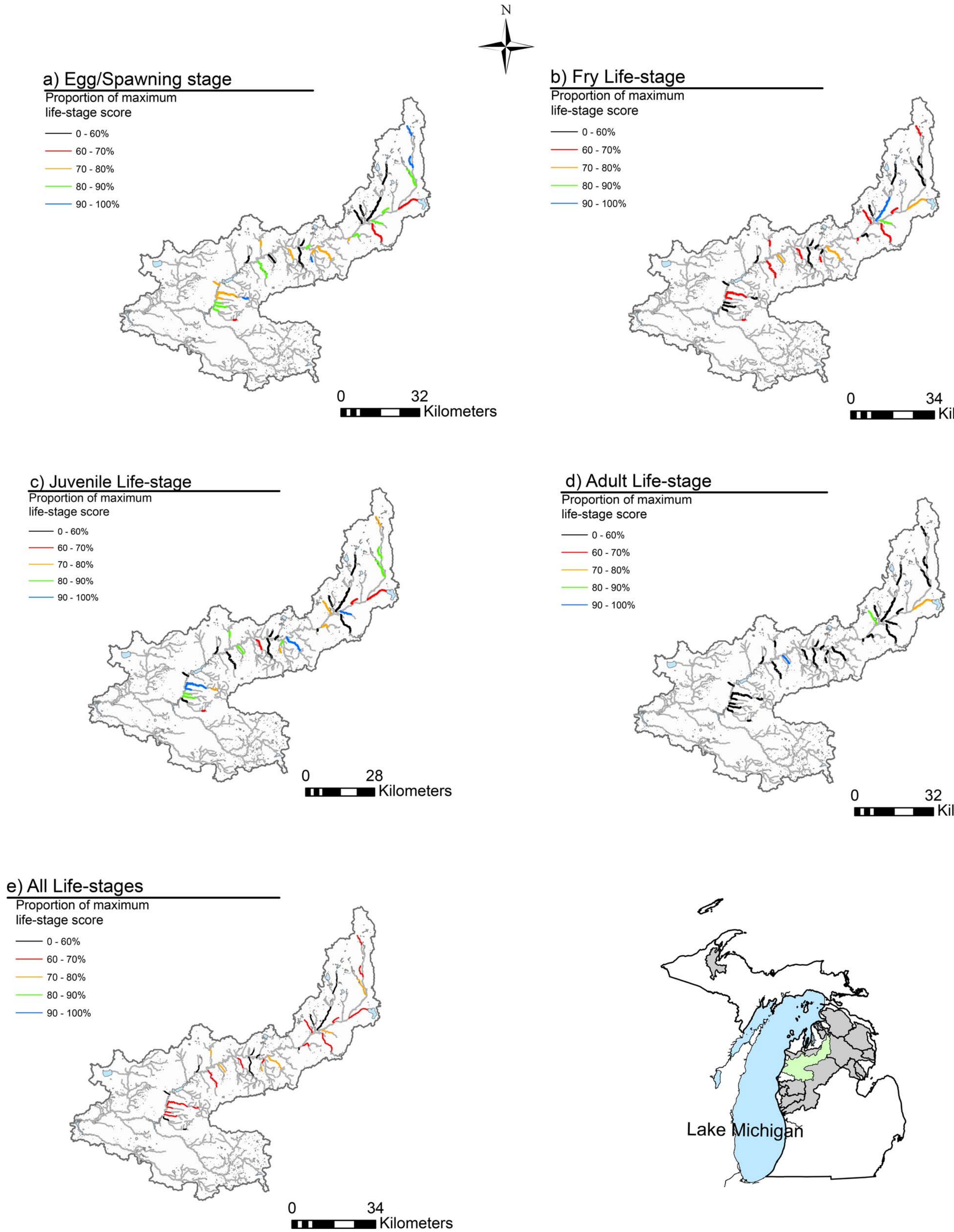

Figure 3. Suitability scores of Manistee River, Michigan, tributary stream segments assessed between 2012 and 2017 for Arctic Grayling *Thymallus arcticus*: a) spawning and egg development, b) fry life stage, c) juvenile life stage, d) adult life stage, e) all life stages.

Pond (the downstream boundary of the Upper mainstem) averages $\sim$25m^3/s during low-flow periods, indicating that 'preferred' stream-flow levels (i.e., between 1.13 and 16.99 m^3/s) are present in much of the mainstem. In addition, maximum summer water temperatures in the Upper mainstem are typically below the upper incipient lethal temperature reported for Grayling (i.e., $<$ 25°C; Lohr et al. 1996), so considerable suitable adult Grayling habitat is associated with tributaries (Danhoff et al. 2017).

Based upon findings of the 2017 field study and previous work (Danhoff et al. 2017; Goble et al. 2018), we have identified and prioritized sites within the Manistee River watershed for initial Grayling reintroduction efforts in Michigan. More than half of the sites surveyed met or exceeded the 60% suitability threshold for all life stages of Grayling, and all but five sites exceeded that threshold for at least one life stage, suggesting that reintroduction efforts are warranted. Most importantly, the methodology presented in this study allows restoration partners to quantitatively compare habitat conditions and focus reintroduction efforts on sites that are thought to provide the greatest chance for success. This initial assessment was focused on a single watershed, but other river systems in Michigan may also provide suitable habitat conditions for Grayling, and the framework and habitat rating process described here will be useful for comparing suitability among many streams and guiding reintroduction activities.

Limitations

The quantitative assessment criteria and suitability score thresholds are essentially hypotheses because they are largely based on best professional judgment, expert opinion, and the few directly comparable studies that are available. Ideally, the scoring assignments for these criteria would be refined and validated using field survey data from streams in Michigan supporting Grayling, where fish abundances and habitat parameters are consistently measured following standardized protocols. Unfortunately, such data will not be available for Michigan until Grayling populations are established; Michigan is currently building a hatchery brood stock, so population establishment could easily be $\geq$ 7 y from now. In the interim, we think that the knowledge from these efforts will enable managers to target reintroduction activities to streams where habitat conditions suggest the greatest likelihood of success.

Our analysis focused solely on habitat for all life stages, which in the prioritization framework represents 37% of the overall suitability score of a stream or reach for Grayling. The influence of predator and competitor fishes is considered the most important factor in the prioritization framework (44% of the total score for streams). Brook Trout and Brown Trout are widely distributed throughout the Manistee River watershed (Rozich 1998; Burroughs et al. 2010) and are known to be predators and competitors of Grayling (Kaya 1992; N. Watson Michigan State University, unpublished data). Previous research in the Middle Manistee River watershed (Goble et al. 2018) and in Montana (McCullough 2017) suggests that high densities of Brown Trout (i.e., $>$ 0.1 fish/m^2) may negatively affect Grayling reintroduction success. Previous studies show that co-occurring fishes may strongly influence fish reintroduction efforts (Harig et al. 2000; Ward et al. 2008), but developing biological criteria was beyond the scope of this study, given the lack of quantitative information relating either species to Grayling reintroduction success or population abundance. Researchers with the MDNR and Michigan State University are currently studying interspecific interactions between Grayling and resident Brook and Brown Trout in a laboratory setting, and their findings will enhance existing studies and survey data.

Grayling have shown a propensity to migrate (Vincent 1962; Kaya 1992), so river connectivity is thought to be an important (Januchowski-Hartley et al. 2013) component of Michigan's reintroduction effort, currently 19% of the total suitability score. Fishes migrate between spawning, refuge, and growth habitats over the course of their lives (Schlosser 1991), and Grayling are known to migrate up to 101 km to exploit seasonal resources available in lotic or lentic systems (West et al. 1992; Heim et al. 2019). Interestingly, Michigan Grayling were characterized as "nonmigratory" by Vincent (1962), whose work has often been considered the most exhaustive account of Michigan's native Grayling populations. Grayling could show less migratory behavior in Michigan's extremely stable, highly groundwater-fed streams (Wiley et al. 1997; Zorn et al. 2018) but this is unknown. The prioritization framework currently lacks an agreed-upon means for rating connectivity of potential Grayling reintroduction reaches. As such, MDNR and LRBOI are actively seeking partnerships to explore various tools, such as Fishwerks (Moody et al. 2017), for assessing this important habitat component.

Stream habitat ratings are based on data from relatively short reaches (hundreds of m) and the extent to which similar conditions occur further upstream or downstream is uncertain. Habitat conditions and fish assemblages can change abruptly in Michigan streams as a result of patchy groundwater inputs, tributary inflows, and inland lakes and ponds (Wiley et al. 1997; Zorn et al. 2002). Habitat assessment scores based on our surveys may not necessarily represent conditions over the entire length of each stream, so we recommend several surveys along the length of larger streams to provide a better overall characterization of habitat suitability for a stream.

Management Implications

The International Union for the Conservation of Nature Species Survival Commission (IUCN/SSC) provides guidelines for native species re-introductions and translocations that identify three key steps toward re-establishing native fish populations (IUCN 2013). A comprehensive pre-assessment is a key step and must be completed to determine if a re-introduction is feasible and to identify potential factors that may limit success (Dunham et al. 2011). Such assessments have long been common in terrestrial settings, so published feasibility studies for native fish re-introductions have been comparatively scarce (Seddon et al. 2005; Dunham et al. 2011). Recently however, feasibility assessments of potential salmonid population restorations are becoming more common. For example, Dunham et al. (2011) and Galloway et al. (2016) established frameworks for evaluating the feasibility of re-introducing and translocating native Bull Trout *Salvelinus confluentus* to conserve or re-establish threatened or extirpated populations. Galloway et al. (2016) further stressed the need for developing standardized frameworks for evaluating the feasibility and potential impacts of native fish re-introductions in order to maximize the likelihood of conservation and restoration success. We think the stream evaluation framework being developed for Arctic Grayling re-introduction will prove useful because it 1) provides a readily explained process that facilitates collaboration and public understanding; 2) uses clearly defined quantitative scoring criteria; 3) employs standardized surveys enabling comparisons of reaches within and among river systems; 4) facilitates standardization, centralization, and organization of survey data; 5) includes placeholders for information gaps, which helps in directing research effort; 6) can readily be adapted or updated as new information becomes available; and 7) can incorporate pre-existing standardized survey data when methods are compatible.

In their exploration of opportunities for expanding State and Tribal collaboration in fisheries management, Holtgren and Auer (2016) noted that the two groups often shared common and compatible restoration and management goals. Implementation of Michigan's Arctic Grayling Initiative is providing an excellent opportunity for MDNR, LRBOI, university biologists, additional partners, stakeholders, and the public to work together across a large geographic area toward the shared goal of restoring this iconic fish species to its native Michigan waters. Though it will take considerable time before all the instream habitat suitability criteria for Grayling can be evaluated in Michigan, the collaborative stream prioritization framework we developed for Grayling reintroduction can be readily adapted to recovery and reintroduction efforts for other species and locations. Given the potential benefits, we think this approach can be applied successfully in many situations where management discussions and decisions occur amongst biologists, stakeholder groups, and publics spread across a large region. The outcome of Michigan's Grayling restoration effort remains to be seen, but the collaboration is already benefiting the multitude of partners, the public, and perhaps most importantly, the coldwater ecosystems of Michigan.

Supplemental Material

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Table S1. Stream reaches in the Manistee River, Michigan, watershed assessed between 2012 and 2017 for Arctic Grayling *Thymallus arcticus* habitat suitability. An * denotes sites not meeting the water temperature criterion (19.5°C) and deemed "likely unsuitable" for Arctic Grayling re-introduction.

Available: https://doi.org/10.3996/JFWM-20-050.S1 (57 KB DOCX)

Table S2. Manistee River, Michigan, watershed stream evaluation scores for Arctic Grayling *Thymallus arcticus* fry-stage habitat. Sites are ordered (highest to lowest) by the proportion of the maximum possible life-stage score. Sites with percent of maximum life-stage scores $< 60\%$ are deemed "likely unsuitable" habitat for Arctic Grayling fry. Assessments occurred between 2012 and 2017.

Available: https://doi.org/10.3996/JFWM-20-050.S1 (57 KB DOCX)

Table S3. Manistee River, Michigan, watershed stream evaluation scores for Arctic Grayling *Thymallus arcticus* spawning and egg-stage habitat. Sites are ordered (highest to lowest) by the proportion of the maximum possible life-stage score. Sites with percent of maximum life-stage scores $< 60\%$ are deemed "likely unsuitable" as potential remote site incubator (RSI) locations for re-introduction attempts. Assessments occurred between 2012 and 2017.

Available: https://doi.org/10.3996/JFWM-20-050.S1 (57 KB DOCX)

Table S4. Manistee River, Michigan, watershed stream evaluation scores for Arctic Grayling *Thymallus arcticus* juvenile-stage habitat. Sites are ordered (highest to lowest) by the proportion of the maximum possible life-stage score. Sites with percent of maximum life-stage scores $< 60\%$ are deemed "likely unsuitable" habitat for Arctic Grayling juveniles. Assessments occurred between 2012 and 2017.

Available: https://doi.org/10.3996/JFWM-20-050.S1 (57 KB DOCX)

Table S5. Manistee River, Michigan, watershed stream evaluation scores for Arctic Grayling *Thymallus arcticus* adult-stage habitat. Sites are ordered (highest to lowest) by the proportion of the maximum possible life-stage score. Sites with percent of maximum life-stage scores $<$ 60% are deemed "likely unsuitable" habitat for adult Arctic Grayling. Assessments occurred between 2012 and 2017.

Available: https://doi.org/10.3996/JFWM-20-050.S1 (57 KB DOCX)

Data S1. Habitat assessment data from 2012 to 2017 Arctic Grayling *Thymallus arcticus* surveys in the Manistee River, Michigan, watershed.

Available: https://doi.org/10.3996/JFWM-20-050.S2 (37 KB XLSX)

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