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Big Manistee River Tributaries as Potential Arctic Grayling Habitat

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BIG MANISTEE RIVER TRIBUTARIES AS POTENTIAL ARCTIC GRAYLING HABITAT

By

Brian M. Danhoff

A THESIS

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Preface

Chapters one and two of this thesis were a collaboration between six authors. I collected the data, analyzed the data, and wrote the chapters. Cameron Goble of Michigan Technological University, Houghton, MI assisted with data collection and data analysis. Dr. Casey Huckins of Michigan Technological University assisted in sample design, data analysis and editing of the chapters. Dr. Nancy Auer of Michigan Technological University assisted with sample design, data collection, and the editing of the chapters. Marty Holtgren and Stephanie Ogren of The Little River Band of Ottawa Indians, Manistee, MI assisted sample design and data collection.

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Abstract

The Big Manistee River was one of the most well known Michigan rivers to historically support a population of Arctic grayling (*Thymallus arcticus*). Overfishing, competition with introduced fish, and habitat loss due to logging are believed to have caused their decline and ultimate extirpation from the Big Manistee River around 1900 and from the State of Michigan by 1936. Grayling are a species of great cultural importance to Little River Band of Ottawa Indian tribal heritage and although past attempts to reintroduce Arctic grayling have been unsuccessful, a continued interest in their return led to the assessment of environmental conditions of tributaries within a 21 kilometer section of the Big Manistee River to determine if suitable habitat exists. Although data describing historical conditions in the Big Manistee River is limited, we reviewed the literature to determine abiotic conditions prior to Arctic grayling disappearance and the habitat conditions in rivers in western and northwestern North America where they currently exist. We assessed abiotic habitat metrics from 23 sites distributed across 8 tributaries within the Manistee River watershed. Data collected included basic water parameters, streambed substrate composition, channel profile and areal measurements of channel geomorphic unit, and stream velocity and discharge measurements. These environmental condition values were compared to literature values, habitat suitability thresholds, and current conditions of rivers with Arctic grayling populations to assess the feasibility of the abiotic habitat in Big Manistee River tributaries to support Arctic grayling.

Although the historic grayling habitat in the region was disturbed during the era of major logging around the turn of the 20^{th} century, our results indicate that some important abiotic conditions within Big Manistee River tributaries are within the range of conditions that support current and past populations of Arctic grayling. Seven tributaries contained between 20-30% pools by area, used by grayling for refuge. All but two tributaries were composed primarily of pebbles, with the remaining two dominated by fine substrates (sand, silt, clay). Basic water parameters and channel depth were within the ranges of those found for populations of Arctic grayling persisting in Montana, Alaska, and Canada for all tributaries. Based on the metrics analyzed in this study, suitable abiotic grayling habitat does exist in Big Manistee River tributaries.

Chapter 1 – The Decline of Michigan Grayling, Historical Conditions of the Big Manistee River, and Habitat Requirements of Arctic Grayling[1]

Introduction

The Arctic grayling (*Thymallus arcticus*) was once abundant in the state of Michigan (Creaser & Creaser 1935) where populations ranged as far south as the White River (Newaygo, Oceana and Muskegon counties) and the Riffle River (Ogemaw and Arenac counties) for the western and eastern Lower Peninsula, respectively, and in the Otter River (Houghton and Baraga Counties) where the only verified Upper Peninsula grayling population existed (Whitaker 1886). It has been hypothesized that heavy fishing pressure, habitat loss due to logging, and the competition with introduced non-native fish species caused these glacial relict populations to decline near the turn of the 20th century (Whitaker 1886, Bissell 1890, Mershon 1923, Creaser and Creaser 1935, Leonard 1949, Fukano et al. 1964), and become extirpated from Michigan by the middle 1930s (Vincent 1962, McAllister and Harington 1969). Despite past attempts by the State of Michigan that were not successful at re-establishing self-sustaining populations of grayling in the state, recent research (Tingley 2010) and a continued interest in this goal for tribal cultural value has supported the question of whether Arctic grayling

[1] The material in this chapter is planned for submission.

populations could once again be viable in Michigan waters. This literature review was conducted to gather information about the history of grayling in Michigan, the historical conditions of the Big Manistee River where they previously flourished, and the habitat conditions where contemporary populations of Arctic grayling persist, to examine the feasibility of the potential reintroduction of Arctic grayling to the Big Manistee River, Michigan. Along with species such as Lake Sturgeon (*Acipenser fulvescens*) and Elk (*Cervus canadensis*), the Arctic grayling was historically, and continues to be a significant part of Aníšhinaábek (Native American population of the Great Lakes region) culture. Throughout tribal history grayling were harvested from the Big Manistee River as a source of sustenance, and as a cultural indicator species the Little River Band of Ottawa Indians believe reintroduction to the Big Manistee River would strengthen the tribal community's bond with their ancestral heritage. Additionally, this project was developed to foster collaboration with land managers such as the US Fish and Wildlife Service, US Environmental Protection Agency, US Forest Service, and educational institutions such as Michigan Technological University.

Presently, Arctic grayling populations are found throughout Alaska (Fleming 1998, Deegan et al. 1999), northwest Canada (Cowie and Blackman 2003, Clarke et al. 2007), and a limited area of the Big Hole River drainage in the western contiguous United States (Magee 2002). Populations in the Big Hole River drainage occupy a small fraction of their historic range (Lamothe and Magee 2004a) and conservation efforts in Montana as well as some grayling rivers in Canada have provided critical data regarding the habitat characteristics for existing populations (Northcote 1993, Magee 2002, Lamothe and Magee 2004a) since grayling have been absent from the Big Manistee River for over 100 years (Vincent 1962). This ongoing management strategy combined with grayling research of the 20th century and accounts of the Michigan grayling from the mid-19th to early 20th century has given a glimpse of what conditions existed and may be required in order for grayling to successfully return as a member of Michigan's native fish community.

Decline of the Michigan Grayling

Prior to the introduction of the brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*), and the southward expansion of brook trout (*Salvelinus fontinalis*), the Arctic grayling was the dominant Salmonidae in Michigan's Lower Peninsula rivers (Leonard 1949). Records of Arctic grayling in Michigan date back to the mid 19th century (Bissell 1890, Metcalf 1961). In Michigan's Lower Peninsula, populations were notable in the Manistee and Au Sable Rivers, and were bounded to the south by the White and Riffle Rivers (Whitaker 1886, Babbitt 1900) (Figure 1.1). Despite their broad distribution in the Lower Peninsula of Michigan, the only Upper Peninsula river confirmed to have a population of grayling was the Otter River in Houghton County (Creaser and Creaser 1935); and although there are recorded accounts of grayling in the eastern branch of the Ontonagon River (Bissell 1890, Babbitt 1900) as well as the Little Carp River

(Ruthven 1906) it has been suggested that these may have been incorrectly identified (Vincent 1962). In addition to being admired for their physical appearance the grayling was known to be abundant and easily caught (Northrup 1880, Norris 1883, Bissell 1890, Creaser and Creaser 1935, Leonard 1949). Written accounts describe a day's worth of fishing resulting in hundreds of grayling (Mather 1874, Whitaker 1886, Bissell 1890, Hinsdale 1932), and as a result of this reputation anglers flocked to Michigan rivers in order to take advantage of the grayling's availability. Concerns regarding the declining numbers of grayling were made publically as early as 1886 (Whitaker 1886) as populations continued to decline through the early 1900s when by around 1936 the last remaining grayling population in the Otter River was considered extinct (Vincent 1962, McAllister and Harington 1969). In the Big Manistee River, grayling likely disappeared around the turn of the 20th century. As late as 1901 there was debate on where and in what abundance the grayling existed in the Manistee River watershed; A Mr. Sullivan Cook of Hartford, Michigan wrote the editor of Forest and Stream Magazine in September 1901 claiming that grayling were found "plentiful" in the Pine River. However, two weeks later an individual with the initials N.F. wrote in stating that grayling had been absent from the Pine River since approximately 1895, and that the few grayling left in the Big Manistee River were further upstream in Kalkaska County. This sentiment was shared by Harris (1905) when discussing a five day guided fishing trip along the Manistee in 1902 that resulted is many trout, but only two grayling.

Overfishing

The exploitation of grayling in Michigan has been hypothesized as one of the reasons for their extirpation (Mershon 1923, Creaser and Creaser 1935, Vincent 1962). Historical accounts describe grayling as being an easily caught fish (Whitaker 1886) which resulted in large numbers of individuals taken during many fishing expeditions. Norris (1883) recounted killing 54 kg of grayling in one day of fishing on the Au Sable River and 227 kg in five days on the Big Manistee River. Hinsdale (1932) describes how catching over 1300 kg of grayling between four people in two weeks was not uncommon. He further cites H. B. Roney from an 1878 article in *Michigan Sportsman's Association for the Protection of Fish, Game, and Birds* where Roney recalls 5000 fish caught in four weeks by a group from Chicago. In the western United States commercial fisheries were established in the late 1800s to provide trout (which likely consisted of grayling among other species) to local mining operations (Vincent 1962). Similarly, Arctic grayling where exported from Michigan to Milwaukee and Chicago fish markets until 1885 (Vincent 1962). These endeavors however, were not sustained as catch numbers declined throughout the late 19th and early 20th century (Vincent 1962). Vincent (1962) makes the case that because logging did not peak until after 1880 and brook trout was not abundant in the lower peninsula of Michigan until after 1890, that overfishing, beginning sometime in the early 1870s was likely the first major impact on grayling populations and initiated their decline.

Logging

Logging efforts in the state of Michigan began in 1835 and increased throughout the second half of the 19th century for the state, and took place during a 20 year period starting in the mid 1870s for much of the middle and northern Lower Peninsula (Spalding 1899, Vincent 1962). Within this timeframe, logging of the upper Big Manistee River occurred around 1885 and continued through the turn of the century when the harvest of Michigan white pine (*Pinus strobus*) was all but exhausted (Maybee 1960). Based on records from the Manistee Boom Company, Vincent (1962) hypothesized an inverse relationship between the volume of lumber floated down the Manistee and Au Sable Rivers and the decline in the number of grayling being caught in these rivers. Vincent, however, believed that due to logging practices calling for harvesting only the largest trees, the cutting of forests did not significantly affect instream habitat or the ability of rainfall to infiltrate the soil and become the groundwater feeding rivers such as the Manistee. There seems to be little evidence that sustainable logging practices were used while harvesting lumber in the Manistee River watershed (Maybee 1960), and aside from the channel scour caused by floating lumber down rivers, entire stand removal would have increased storm water runoff, which in turn would have decreased the retention of rainwater to recharge groundwater inputs. Although grayling may have been in decline prior to logging in the Manistee River watershed, the impacts of logging, both the cutting and the transport of lumber, would have further harmed the already stressed grayling.

By combining these written accounts with historical maps we are provided with a view of the conditions and physical disturbances that may have existed around the time of the grayling extirpation from the Big Manistee River. The Manistee County Historical Museum maintains hand-drawn survey maps that allowed us to visualize the Big Manistee River during the late 1800s and early 1900s. One map of the Big Manistee River from the early 1880s indicated at least 36 logjams (courtesy of the Little River Band of Ottawa Indians and U.S. Forest Service) while another specified the approximate location of 10 rollways in the Manistee mainstem between the headwaters and Lake Michigan (courtesy of the Manistee County Historical Museum). Rollways were clear-cut areas along riverbanks that were used to transport harvested timber to the banks of a river, and these rollways would have created erosion and sources for sediments to enter the channel. Decreased rainwater infiltration in rollways would have likely increased the volume and velocity of surface runoff, which in turn could have created local scour where water plunged into the channel. These rollways and log floats caused large amounts of scour, sediment deposition, and habitat alteration throughout the Manistee and Au Sable Rivers (Rozich 1998). Some accounts offer a glimpse of what conditions may have existed prior to the logging (Page

1882, Norris 1883), but unfortunately there is little river survey data available to confirm what these systems looked like in the 19th century.

Interspecific Competition

Although there is little argument over the impacts of logging and fishing pressure on grayling, there are questions regarding how grayling interact with other Salmonids, specifically with brook trout. In the Otter River, grayling were known to be present with brook trout for some time (Creaser and Creaser 1935, Taylor 1954), first documented in 1884 (East 1930 as cited in Vincent 1962). However, the length of time brook trout and grayling would have been found together and whether the two species actually coexisted is unknown. Additionally, the native southern distribution of brook trout populations in Michigan is uncertain. Early accounts mention that brook trout were absent from waters south of the Straits of Mackinaw (Hubbard 1887) while others indicate they were found in some northern Lower Peninsula rivers (Strang 1855, Clark et al. 1875, Whitaker 1886). A letter to the editor of Forest and Stream Magazine by an individual with the initials S.H.S of Toledo, OH dated April 29, 1874 (prior to the introduction of rainbow or brown trout) stated that a trout and grayling were caught together in the Jordan River, Michigan, weighing approximately 0.6 kg and 0.5 kg, respectively. Based on historical reports, Vincent (1962) hypothesized that brook trout migrated naturally to the Lower Peninsula sometime before 1850 and therefore may have found their way to the Big Manistee River. A report of brook trout in the Pine River, which empties into the Big Manistee River near the current location of Tippy Dam, was made in an 1869 edition of the Manistee Times:

> "*Our piscatorial friends around Manistee will be surprised to learn that there are speckled brook trout within a few miles of Manistee. On Friday last Mr. Ruggles with other gentlemen camped at Pine Creek and thought they would like some fish for supper. The first fish caught was a speckled brook trout and being elated with their success they kept on fishing and soon had enough for a good mess. It had been the general opinion of our people and tourists that if they wanted speckled thought they would have to go to the neighborhood of Traverse City to catch them. Pine Creek is 18 miles from Manistee so let us patronize home institutions and catch speckled trout in our own creeks*."
>
> -*Manistee Times,* September 11, 1869 (Vol. 5 No. 27).

However, two weeks later it was noted that speckled (brook) trout were a recent member of the Big Manistee River:

> "*Trout – The appearance of speckled trout in the creeks around Manistee, where they have never been found until recently has caused much speculation among the older settlers here. R. Risdon, Esq., informs us that*

the streams were formerly well stocked with pickerel, and that pickerel probably destroyed trout. Therefore the disappearance of pickerel undoubtedly accounts for the presence of trout, and they are now quite plenty in most of our streams. Speckled trout are frequently caught in goodly numbers by our fishermen in Lake Michigan."

-*Manistee Times*, September 18, 1869 (Vol. 5 No. 28)

There seems to be little doubt that brook trout were appearing in the Big Manistee River throughout the latter half of the 19th century. There is debate, however, as to how far back in time the brook trout existed in the Big Manistee River and whether it was introduced by humans or migrated naturally (Mershon 1923). Vincent (1962) stated that brook trout were not found in the upper reaches of the Big Manistee River until after 1890 by way of stocking rather than migration from where they were found in the Lower reaches of the Big Manistee River. Hubbard Jr. (1901) recalled the absence of brook trout from the Big Manistee River (approximately 10 km from Kalkaska) as late as 1890. These support claims of a decrease in the quality of grayling fishing shortly after brook and rainbow trout numbers increased. Vincent (1962) noted that grayling populations were declining in some rivers prior to the arrival of brook trout. However, Metcalf (1961) recalled "swarms" of brook trout and grayling caught together in many streams during an 1880 expedition along the Grand Rapids and

Indian Railroad which ran through western Michigan from the Straits of Mackinac to southeastern Indiana.

A more recent study suggests that although Arctic grayling and brook trout are believed to prefer similar habitats they do not actively compete at the microhabitat (pool) level (Byorth and Magee 1998). In the present, Arctic grayling are found in the western United States along with other Salmonidae, including brook trout and mountain whitefish (*Prosopium williamsoni*) (Lamothe and Magee 2003). Despite what has been observed in the west, Vincent (1962) illustrated that as brook trout abundance increased, Arctic grayling numbers continued to decline in the Manistee as well as in the Jordan, Boyne, and Au Sable Rivers. Whether brook trout actively competed with the Arctic grayling for resources, or was filling the position of the deteriorating grayling population is undetermined, what is known is that as grayling numbers continued to decline throughout the late 1800s, brook trout abundance increased.

Stocking Attempts/ Recent Research

Records regarding Arctic grayling stocking in Michigan date back to 1877 when 300 grayling from the Big Manistee River were transplanted into other southern Michigan waters (Fukano et al. 1964), and state records indicate that between 1900 and 1933 more than three million fry were transplanted from Montana to

Michigan (Nuhfer 1992). Numerous stockings took place throughout the 20th century with the most recent attempt between 1987 and 1991. Despite efforts to restore grayling populations there have been no indications of sustained success (Leonard 1949, Nuhfer 1992). During this recent attempt grayling were planted into lakes and streams throughout the state with stocking location based on isolation, the ability of waters to support trout, and minimal suspected competition with other fish species (Nuhfer 1992). It has been hypothesized that survival of lake stocked grayling was hindered by larger predatory fish (largemouth bass, *Micropterus salmoides*), competition for food, loss of vision caused by the parasitic *Ornithodiplostomum* species, illegal harvest by anglers, and water quality issues such low pH for some Upper Peninsula lakes (Nuhfer 1992). Additionally, Nuhfer (1992) suggested many factors attributed to the failure of grayling stocked into rivers, including genetically driven downstream migration, water temperature, and competition with other Salmonids in Lower Peninsula rivers, and to a lesser extent, river size, mortality due to hooking and harvest, and a bacterial infection (furunculosis) in 1987-1988 stockings. More recently, Tingley (2010) used a combination of landscape data and instream sampling to develop a scoring system in order to identify the suitability of Michigan rivers as Arctic grayling habitat. A total of six streams in the state were determined to contain suitable grayling habitat based on variables considered at multiple spatial scales, two of which, the Pine and Little Manistee Rivers, are within the Manistee River watershed, however only the Pine was within our study area.

Big Manistee River Historical Conditions

The Big Manistee River has been known historically for its stable flow (Page 1882, Norris 1883) with a maximum discharge less than twice the minimum discharge (Wisler and Brater 1959), akin to being a mostly spring-fed waterway (Harris 1892). Prior to damming of the river it was said to be mostly immune to drought, freezing, and flooding due to the vast number of springs feeding into the channel; which were said to be spaced approximately every 10 meters (Page 1882). The Big Manistee River was historically cold and described by Harris (1892) as having water the temperature of “a rock-gushing spring”. The water of the Manistee was fast moving in some areas, reaching velocities of 2.7 m/s, and the streambed was marked with “islands” of aquatic vegetation scattered about a mostly sandy landscape (Harris 1884, 1892).

One of the more detailed accounts of conditions along the upper portion of the Big Manistee River can be found in an 1869 survey by A. S. Wordsworth of the River Improvement Company (Page 1882). Wordsworth writes of beginning their journey in the headwaters of the Big Manistee River (Section 18, Township 28 north, Range 4 west) where the landscape was dominated by hardwood forests that gave way to mostly red pine (*Pinus resinosa*) near the southern end of Township 29. At the west end of range 6, section 6, township 25, a straight-line distance of 32 km from their starting point, Wordsworth and company encountered the first large log jam on the Big Manistee River, stretching 20 rods

(100 meters) along the length of the channel (Page 1882). Continuing downstream they encountered the second large jam, this one 90 meters in length, followed by a dense white pine forest. As the company worked their way through the next nine jams they eventually met the last of the large log jams, number eleven, which was 151 meters in length. It should be noted that aside from jam two all the jams were between 20-30 rods in length (100-151 meters).

At this point Wordsworth and the River Improvement Company reached the future location of the Hodenpyl Dam Pond. A map of the Big Manistee River obtained by the Little River Band of Ottawa Indians and the U.S. Forest Service (Unknown 1872-1874) indicates that at one point there existed a not quite disconnected oxbow lake that created a distinct circular channel feature where the current dam pond resides (Figure 1.2). Wordsworth notes that approximately 1.6 km downstream of this area began the rollways which were a prominent feature of the landscape as they continued towards the town of Manistee, and 3.2 km further downstream a “saw log” jam stretching nearly 2.5 km in length (Page 1882). Here, approximately at the current location of Red Bridge is where Wordsworth declared to be the furthest downstream that one might see an Arctic grayling (Page 1882). Based on their size alone, most of the large jams in the upper Big Manistee River encountered had likely been there for many years. Wordsworth’s account describes jam #3:

“ On Section 6, Township 24 north, Range 8, west is jam No. 3, at crossing of the Ah-go-sah trail; twenty rods in extent… These jams date back in buried centuries. As evidence, we find deep-worn trails around them, where Indians have dragged their canoes, and packed their trophies on the chase and war path; also soil accumulations from fallen leaves and freshet of the stream, with forest growth. Cutting to the heart of a cedar twenty inches in diameter, growing over the center, I counted 160 years’ growth.”

- A. S. Wordswroth (1869) in H. R. Page & Co. (1882) History of Manistee County, Michigan

It is difficult to say that the cedar described by Wordsworth started as a sapling, however it can be inferred that the tree had existed on the jam long enough to take root. Similar accounts were made by Norris (1883) where in the book *Sport with Gun and Rod in American Woods and Waters* he recounts the numerous downed trees and sweepers (cedars that have fallen into the channel oriented perpendicular to the flow) to maneuver through as they worked their way down the Big Manistee River. Additionally, Wheeler (1903) echoed this experience for a man by the name of B. W. Hall, who is said to be the first settler of Wexford County, Michigan. Hall came across a number of large jams along the Big Manistee River, including one such dam named the “Pony Dam” due to Native American’s use of it for crossing the channel on horseback (Wheeler 1903). The drastic change in landscape features of the watershed were noted by Wheeler:

“These “jams” were made of the trunks of trees which had been torn from the banks by the ever-changing channel of the river and carried downstream until arrested by some projecting point of land… To see the Manistee river today one would almost think this statement was a fairy tale, but it is nevertheless true, as a number of people yet living in Wexford county can testify from actual and personal knowledge.”

-Wheeler (1903) in History of Wexford County, Michigan

Another hand drawn map of the Big Manistee River obtained by the Manistee County Historical Museum indicates a total of ten rollways starting approximately 1.5 kilometers downstream of where Cedar Creek empties into the Big Manistee River mainstem, extending to approximately 34 kilometers downstream to the current High Bridge Road crossing. The approximate locations of these rollways, along with the accounts of large log jams by Wordsworth (Page 1882) were transposed onto the 1872-1874 map of the Big Manistee River (Figure 1.2).

Contemporary Arctic Grayling Habitat

Very little information is available regarding what habitat conditions existed while grayling persisted in the Big Manistee River, and any future attempts at identifying habitat needs for reintroducing grayling would likely rely on existing North American populations, possibly from the Big Hole River, MT; therefore it is important to consider what abiotic conditions are observed where graying currently exist. Based on available literature, we have gathered such data, and on conditions needed for Michigan grayling.

Thermal Conditions

The Arctic grayling is a cold water fish of the family Salmonidae found throughout northwestern North America in Alaska and Canada; although relict populations existed further south in Montana and Michigan (since extirpated). Water temperatures within grayling habitat appear to vary depending on geographic location, therefore some populations may be adapted to elevated water temperatures while others may be restricted to cooler temperatures. An experiment conducted on Alaskan Arctic grayling measured the thermal tolerance for four size classes of fish acclimated to 4.0 - 8.5^{o}C (±1^{o}C) and found median thermal tolerances (50% survival) of 20.0 – 24.5^{o}C for adult grayling (LaPerriere and Carlson 1973). Additionally, Lohr et al. (1996) considered a similar metric for Montana grayling as compared to summer temperatures in the Big Hole River, MT. Fish were acclimated to 8.4, 16.0, and 20.0^{o}C and exposed to elevated temperatures in order to determine their upper incipient lethal temperature (UILT), the temperature at which a minimum of 50% of test subjects survive for at least one week. UILT was 23.0^{o}C for acclimation temperatures of

8.4^{o}C and 16.0^{o}C, while UILT for grayling acclimated to 20.0^{o}C was 25.0^{o}C. Lohr et al. (1996) also concluded that grayling persisted in the Big Hole River even though mainstem temperatures were observed to exceed 25^{o}C during summer months. Similarly, Magee (2002) and Lamothe & Peterson (2007) measured summer temperatures in the Big Hole River above 21^{o}C and a maximum temperature greater than 25^{o}C in 2000 and 2001, and 2006, respectively. Despite the measured temperatures, it is very likely that when temperatures reach stressful levels for grayling they will seek out cooler-water refuge in tributaries as observed by Magee (2002).

Although grayling show survival at temperatures above 20^{o}C, Alaska populations have been observed to display signs of stress at temperatures approaching 17^{o}C (Wojcik 1953). In August 1960, Schallock (1966) observed grayling in the Chatanika River, AK migrating upstream after water temperatures reached approximately 18^{o}C. More generally grayling tend to reside in water temperatures ranging from 7-18^{o}C depending on location (Hallock 1873 as cited by Vincent 1962, Harris 1884, Henshall 1900 as cited by Vincent 1962). In addition to what has been reported for Michigan grayling and what has been found for Alaskan grayling, Hubert et al. (1985) developed a habitat suitability index for fluvial Arctic grayling based on a literature review of data and determined the ideal average annual maximum water temperature for adults to be between 8-16^{o}C based on grayling found in Odell Lake, Montana and the Chena River, Alaska.

Channel Characteristics

Historically, detections of grayling in Michigan were most often in the riffles of rivers (Mershon 1923, Smedley 1938), potentially due to their proximity to feeding location (Hubert et al. 1985, Hughes 1998). Typically, grayling inhabit pools and utilize riffles for feeding and spawning (Krueger 1981, Hubert et al. 1985, Hughes 1992). The usage of pools as habitat by grayling has been well established in a number of studies in Alaska, Montana, and Canadian rivers (Tack 1972, Liknes and Gould 1987, Hughes and Dill 1990, Byorth and Magee 1998, Lamothe and Magee 2003, 2004a, Blackman 2004).

Grayling have been found to utilize a range of substrate sizes depending on life stage. In tributaries to the Williston Reservoir and the Table and Anzac Rivers, British Columbia, Canada, grayling fry have been detected in sites dominated by cobble/gravel, and fines/gravel (Cowie and Blackman 2003, Blackman 2004). Young-of-the-year (also known as age-0) and adult grayling more often are found occupying and spawning on (in the case for adults) gravel/cobble substrates with low embeddedness by fine particles (Nelson 1954, Shepard and Oswald 1989, Lucko 1992 as cited by Northcote 1993, Barndt and Kaya 2000, Blackman 2004). In Michigan it has been hypothesized that grayling streams were dominated by a mixture of fine gravel and course sand and had finer substrates than their counterparts in the western United States (Vincent 1962). More broadly, Hubert et al. (1985) determined that a minimum of 20% gravel/pebble substrate was considered optimal for grayling spawning sites based on studies in Canada, Alaska, and Montana.

Although Arctic grayling habitat does compare to that of other Salmonids, their association with woody debris does not parallel that of brook, brown, and rainbow trout. It has been shown that some Salmonids utilize woody debris as habitat (Inoue and Nakano 1998), and though Blackman (2004) observed a strong association between grayling fry and woody debris this was not the case for adult grayling. Nonetheless, the ability of woody debris to create pools (Fausch and Northcote 1992, Dolloff and Warren Jr. 2003) ultimately attributes it as a component to grayling habitat. Grayling streams tend to be low gradient, both in the west (Liknes and Gould 1987, Northcote 1993, Barndt and Kaya 2000, Lamothe and Magee 2004) and what is known historically for Michigan (Vincent 1962). Vincent (1962) considered a typical Michigan grayling stream have a gradient between 0.10 - 0.28% and in the Big Hole River, Liknes and Gould (1987) and McMichael (1990) found the greatest abundance of grayling where gradient was between 0.25 - 0.29%. Grayling are also found in a range of stream velocities. Mean velocity has been measured between 0.2-0.3m/s for the Upper Big Hole River (Liknes and Gould 1987) and Sunnyslope Canal (Barndt and Kaya 2000), Montana, and for an Alaskan population (Elliott 1980). More generally, Vincent (1962) stated that “typical” grayling habitat ranged from 0.3-0.6m/s.

Migration and Spawning

Arctic grayling migrate during the spring and fall for spawning and overwintering habitat use. Spring spawning migration happens between April and May, although Whitaker (1886) stated that the 1878 spawning period in the Big Manistee River occurred prior to March 30th. Migration happens when water temperatures are between 0-4^{o}C (Wojcik 1955, Tack 1972, Krueger 1981, Shepard and Oswald 1989, Northcote 1993) and when water becomes more navigable following ice-out (Tack 1980, Krueger 1981). The distance of migration is variable and can reach over 100 km for some populations (Tack 1980, West et al. 1992). Henshall (1907) observed grayling migrating approximately 23 km to spawn in Red Rock Lake, Montana. More recently, Lamothe and Magee (2003) tracked grayling (n=15) in the Big Hole River with radio transmitters from April to August of 2002 and found an average distance traveled of 8 km. Migration of Michigan grayling was likely dependent on river conditions and it was quite possible that some systems offered suitable habitat throughout the year, thus negating the need for seasonal migration (Vincent 1962).

Arctic grayling will spawn in the mainstem and tributaries to rivers, as well as near the boundary of rivers and lakes (Vincent 1962, Tack 1980). Spawning occurs in spring when water temperatures are between 2-11^{o}C (Bishop 1971, Krueger 1981, Hubert et al. 1985) although a mountain lake population in Eastern Washington was observed to spawn between June and August which may be related to the timing of ice-out and warming (Tack 1980, Beauchamp 1990). Spawning location characteristics vary, but appear to be dominated by sand to gravel sized particles and within or near riffle habitat (Henshall 1907, Nelson 1954, Tack 1980, Krueger 1981, Shepard and Oswald 1989, Beauchamp 1990, Barndt and Kaya 2000) where grayling broadcast their adhesive eggs rather than build redds such as with other Salmonids (Tack 1980). Velocity in spawning sites has been measured between 0.3m/s and 1.4m/s for locations in Montana and Alaska (Krueger 1981, Barndt and Kaya 2000). Male grayling move into spawning sites and establish their territory, which is heavily guarded throughout the spawning process (Kruse 1959). In contrast, females briefly enter spawning locations to lay their eggs, which may be fertilized by multiple males (Barndt and Kaya 2000) before moving from the spawning sites to pool habitat (Tack 1980). The spawning period can last several weeks (Kratt and Smith 1977), but factors such as water temperature (Krueger 1981) and climate seem to determine the timing and duration (Northcote 1993). Egg development and hatching time for grayling is believed to be temperature dependent (Hubert et al. 1985) and research has shown hatching time to range between 8-21 days with water temperatures between 3-16^{o}C (Henshall 1907, Nelson 1954, Kruse 1959, Krueger 1981). Newly hatched grayling will spend up to ten days sheltered in the spawning substrate before emerging (Nelson 1954, Kratt and Smith 1977), and will occupy areas with low/moderate water velocity (Elliott 1980, Krueger 1981) remaining near spawning locations until fall migration (Craig and Poulin 1975, Tack 1980). In some cases these grayling fry will return to these same streams the following year as juveniles (Craig and Poulin 1975).

After spawning, adult grayling have been observed relocating to summer habitat (Craig and Poulin 1975, Tack 1980), however if conditions are ideal migration may not occur (Wojcik 1955, Vincent 1962). Although not as extensive as spawning and overwintering migration, movement into summer holding habitat can take place upstream or downstream of spawning locations. Additionally, if spawning takes place in smaller tributaries, grayling may move to other rivers were resources such as food and usable habitat are more abundant (Hubert et al. 1985). As water temperatures approach $0^{o}C$ grayling begin migrating to overwintering habitat, usually to larger rivers and into the deep pools of groundwater or spring fed rivers where the water column stays at least partially ice free throughout the winter (Vincent 1962, West et al. 1992).

Discussion

Although much is known regarding the apparent habitat requirements of Arctic grayling in western and northwestern North America, the timing of their disappearance from Michigan's waters makes it difficult to determine what comprised grayling habitat prior to their decline. The earliest accounts of Michigan grayling only go back as far as the mid 1800s, after logging in the state had begun (Spalding 1899). Even with these early fishing journals, little is mentioned regarding the habitat conditions of the rivers, and most only account for a specific time of the year. Despite this lack of data, some documents give a general view of what existed during this period, and with available literature we were able to approximate some of the abiotic conditions that existed in the Big Manistee River prior to the extirpation of grayling. Combining past and contemporary literature values shown to represent conditions where Arctic grayling exist, ranges for abiotic conditions, such as temperature, substrate, and water quality (dissolved oxygen, pH) are summarized for Arctic grayling (Table 1.1).

The untimely disappearance of Michigan graying was likely due to the compounding effects of logging, over fishing, and competition with other Salmonids; all of which on their own may not have been enough to push local populations to extinction. This may support why grayling were observed in decline prior to logging and the introduction of brook and the nonnative rainbow trout (Vincent 1962).

Figures

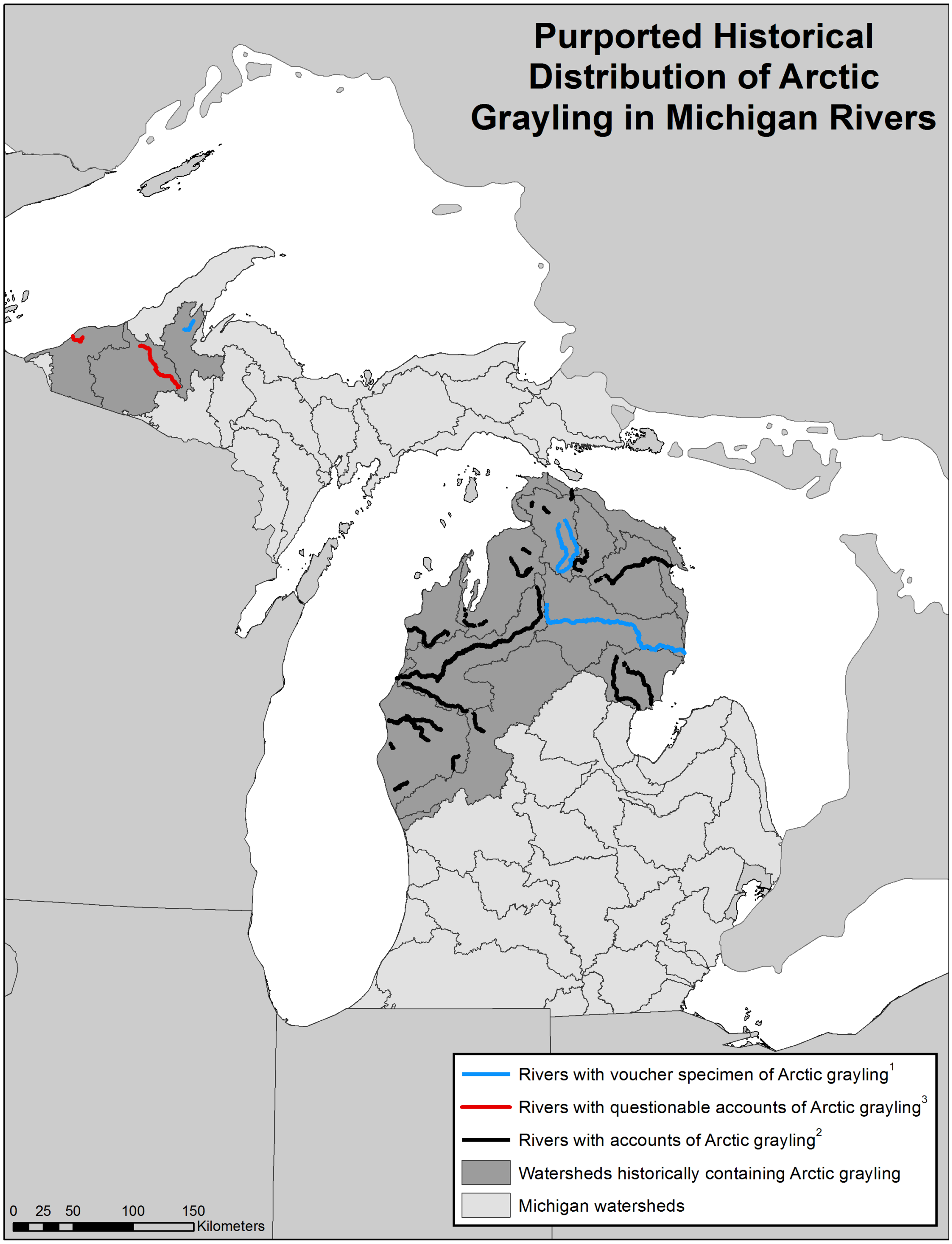

Figure 1.1: Purported historical distribution of Arctic grayling in Michigan Rivers. [1]Voucher specimens are part of a collection at the Museum of Zoology at the University of Michigan. [2]Rivers as reported by Vincent (1962) to historically support grayling. [3]Rivers believed to be misreported to have Arctic grayling (Vincent 1962). Map data from USGS, NOAA, and MiGDL.

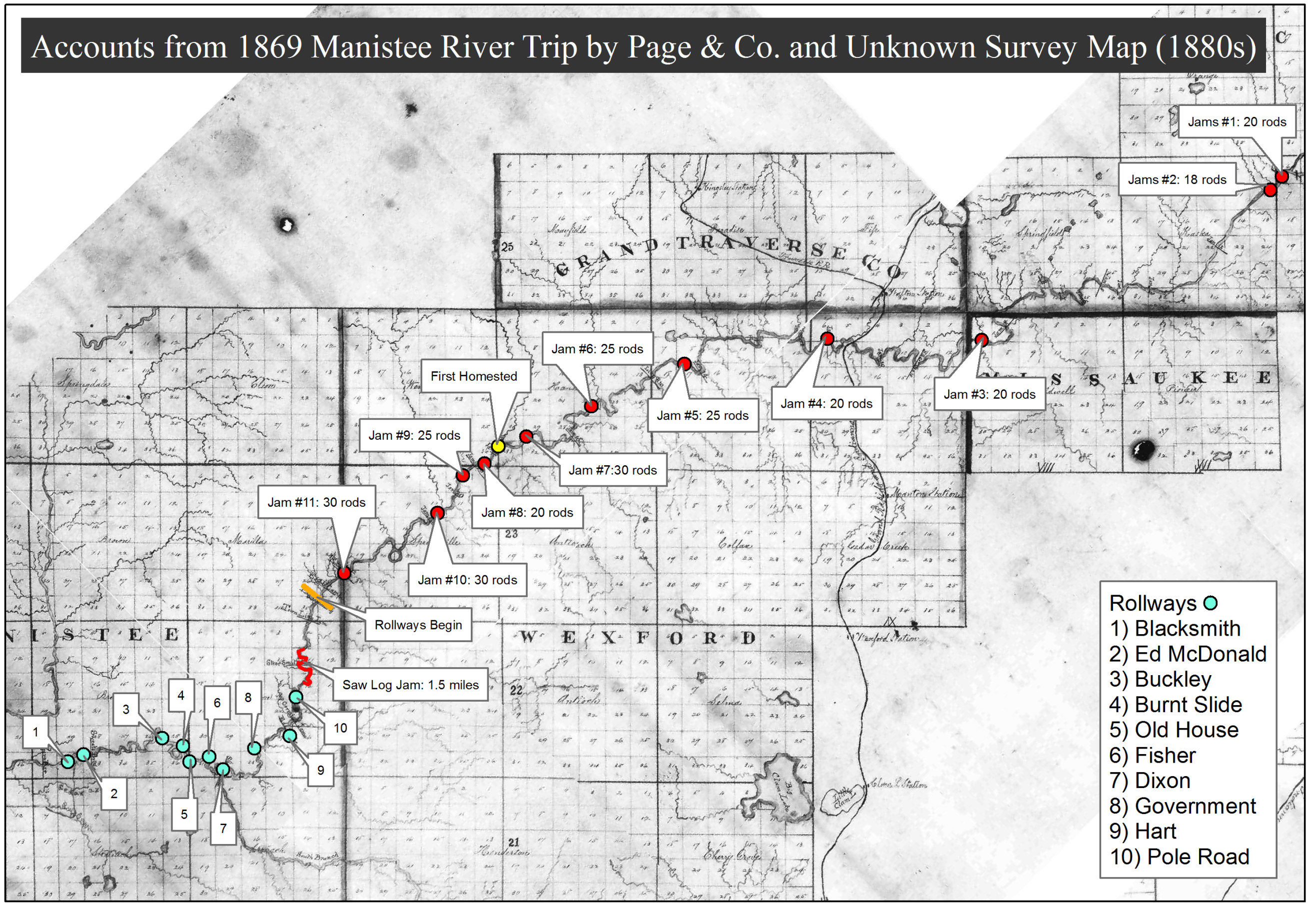

Figure 1.2: Big Manistee River Historical Log Jams and Rollways. River survey map (Unknown 1872-1874) with accounts from 1869 Page & Co. trip from headwaters to the town of Manistee (jam sizes, beginning of rollway marking, and location of homestead) (Page & Co 1882) and hand drawn rollway map (turquoise points) (Unknown 1880s) overlaid. Survey map courtesy of the LRBOI and US Forest Service and hand drawn rollway

Tables

Table 1.1: Range in observed abiotic characteristics of Arctic grayling habitat Data based on literature review and represents values observed in systems that support grayling

Habitat Metric	Range in Observed Literature Values	Data Source
Spawning Temperature (^{o}C)	2.0 – 10.0	9
Summer Temperature (^{o}C)	4.7 – 18.3	3,10,17
Spawning Velocity (m/s)	0.34 – 1.46	9,15
Adult Summer Velocity (m/s)	0.21 – 0.61	1,3,9,10,17,19
Y.O.Y Habitat Velocity (m/s)	0.04 – 0.78	11,19
Adult Mean Water Depth (m)	0.26 – 1.50	3,10,13,17,19
Channel Width (m)	4.0 – 15.0	1,2,10,16
Y.O.Y Water Depth (m)	0.10 – 0.40	12,17
Spawning Substrates	Gravel – Pebble	1,9,11,15
Adult Spawning Substrates	Course Sand – Pebble	7,17
Fry Habitat Substrates	Fines – Pebble	3,11
Adult Median Sediment Size (mm)	4.0 – 89.0	20
Pool : Riffle Ratio	0.27 – 1.51	10
Dissolved Oxygen (mg/L)	1.7 – 11.2	5,10
pH	7.0 – 8.2	9,15
Stream Gradient (%)	0.075 – 0.29	3,9,10,12
Summer Habitat	Deep Pools	3,9,19
Winter Habitat	Large streams and deep pools in small streams	3,7,9.17
Feeding Location	Drift feed in riffles/pools	4,7,9,17

1) Nelson (1954) 2) Taylor (1954) 3) Vincent (1962) 4) Scott & Crossman (1973) 5) Bendock (1980) 6) Elliot (1980) 7) Kruger (1981) 8) Kruse (1981) 9) Hubert et al. (1985) 10) Liknes & Gould (1987) 11) Shepard & Oswald (1989) 12) McMichael (1990) 13) Hughes & Dill (1990) 14) Hughes (1992) 15) Bruce and Star (1985) as cited by Northcote (1995) 16) Byorth & Magee (1998) 17) Barndt & Kaya (2000) 18) Cowe & Blackman (2003) 19) Blackman (2004) 20) Lamothe & Magee (2007)

Chapter 2 – Contemporary Fluvial Habitat Conditions in Big Manistee River Tributaries[2]

Introduction

Arctic grayling (*Thymallus arcticus*) is a species native to Michigan that has been regionally extinct since approximately 1936 (McAllister and Harington 1969). Although past attempts at reintroduction have been unsuccessful, recent research has revived interest in reestablishing Arctic grayling in the Big Manistee River, Manistee County. The Manistee River watershed is a major natural feature within the lands of the Little River Band of Ottawa Indians (LRBOI) and they have tribal goals to bring back culturally significant, native species such as grayling. This restoration goal is a driving force behind this research. Successful reintroduction and establishment of Arctic grayling in the Big Manistee River will depend on availability of suitable habitat and biotic conditions. While both are critical in the sustainability of grayling populations, in this work we initially focus on the abiotic components, including temperature, physical stream habitat (e.g., channel morphology, instream structure, and substrate) and water quality.

[2] The Material in this chapter is planned for submission.

As with other fish of the family Salmonidae, Arctic grayling are a cold-water species indicating their optimal thermal condition occurs in cold to cool water. Sensitivity to warmer temperatures has been documented (Nelson 1954, Schallock 1966), and can become lethal above a certain threshold (LaPerriere and Carlson 1973, Lohr et al. 1996), which appears to be dependent on factors such as geography, acclimation and local adaptation (Nelson 1954, Schallock 1966, LaPerriere and Carlson 1973, Lohr et al. 1996). Because warmer water temperature can be limiting to the physical condition of Arctic grayling it is important to assess the thermal conditions within the Manistee River watershed, and if warm conditions exist, determine whether cold-water microhabitat exists within the river and its tributaries. This refuge habitat can be formed by the cooling effects of groundwater inputs and/or by the confluence with cooler tributaries. The life history of grayling also dictates the need for certain attributes of their environment. Spawning by grayling takes places after ice-out when water temperatures reach approximately 4°C, which has been purported as early as late March in the Big Manistee River (Whitaker 1886), and occurs in habitat that is generally characterized by substrates with abundant interstitial spaces (Nelson 1954, Bishop 1971). Following spawning and throughout the summer months, Arctic grayling spend much of their time in deep pools while drift feeding along the margins between pools and riffles (Krueger 1981, Hughes 1992). In the fall, fluvial grayling migrate to overwinter areas where water continues to flow throughout the winter months, which is more often the case for the mainstem Big

Manistee River. Though regionally variable and ultimately dictated by the distance between habitats, this spring and fall migration has been known to take place over 150km for some populations of grayling (Nelson 1954).

Guided by the life-history of Arctic grayling and their habitat needs, in this project we conducted an extensive survey of the current habitat conditions of the Big Manistee River and its major tributaries to assess their suitability for the reestablishment of Arctic grayling.

Methods

Study Sites

The Big Manistee River stretches from the southwest corner of Otsego Co., Michigan, approximately 20km from the town of Gaylord, to the town of Manistee where it empties into Manistee Lake and finally Lake Michigan (Figure 2.1). The watershed has an area approximately 5076 km^2, making it one of the largest in the state (Rozich 1998). Much like the neighboring Au Sable River, the Manistee is known to have some of the most stable flow throughout the year due to the abundance of groundwater inputs that account for over 90% of base flow in some parts of the watershed (Holtschlag and Nicholas 1998). Current abiotic conditions in the Big Manistee River watershed were assessed along a 21 km stretch of the

Big Manistee River in eastern Manistee County, MI between Hodenpyl and Tippy Dams (Figure 2.2). Eight tributary streams and the mainstem of the Big Manistee River were selected due to records indicating they support Salmonid populations and because they represent a range of biotic and abiotic conditions within the watershed (Table 2.1). Abiotic conditions in each tributary were measured between May and August for three years starting in 2011. Within all but one tributary we designated an upstream, a midstream, and a downstream sampling location. Sand Creek was sampled at the midstream site in 2011, and the midstream and upstream sites in 2012. Due to accessibility and near backwater conditions, the downstream site was not sampled during this study. Sample site length was set at 40x the mean wetted width (Kaufmann et al. 1999) and ranged from 120 meters to 325 meters. Data was also collected along the mainstem of the Big Manistee River between Hodenpyl Dam and Tippy Dam pond.

Water Temperature

Starting in 2009, water temperature loggers (Onset® HOBO v2, accuracy: ±0.21^{o}C) and in 2011 HOBO U20 Water Lever Data Loggers (Onset® HOBO U20, accuracy: ±0.37^{o}C) were deployed in into each of the study tributaries and the Big Manistee River mainstem. Loggers were secured to log jams and roots wads and configured to collect temperature (0.1^{o}C) hourly. Data was retrieved and loggers were redeployed once in the summer and fall before being left to collect data throughout the winter months. Temperature logger data was used to consider July temperatures, which was determined to be one of the warmest months of the year. The approximate location of each temperature logger was recorded using a handheld GPS unit and visual descriptions of the anchor points. One temperature logger was located in the downstream sites of Arquilla and Cedar Creek and in the midstream site of Sand Creek. Slagle Creek contained temperature loggers in the downstream and midstream sites while the remaining tributaries, Eddington, Hinton, Peterson, and Woodpecker each contained a logger in the downstream, middle, and upstream sites. Not all loggers were in the tributaries from 2009-2013 (Table 2.2) and therefore Peterson Creek, Slagle Creek, and Woodpecker Creek are the only tributaries for which we obtained five years of data.

Although much of this study was focused on conditions in the tributaries it was important to assess water temperature in the mainstem, as grayling would likely use the larger Big Manistee River during parts of their life history (Nelson 1954, Tack 1974, Craig and Poulin 1975). In 2011 two large pools in the mainstem were utilized to determine the extent to which water temperature varied between upstream and downstream locations as well as whether the selected pools exhibited a thermal gradient (e.g. cooler temperatures at the bottom). Tethered temperature loggers (one at the bottom and one at mid water column) were secured to a weight and positioned in the deepest part of each of the two pools. Additionally, temperature data has been collected for the Big Manistee River near the Hodenpyl Dam (USGS gaging station #04124200) and further downstream at the Red Bridge River Access Site (Figure 2.2). All the loggers deployed were programed to collect temperature in one-hour intervals throughout the summer months (May-August). Temperature data collected was compared to rivers and streams where grayling historically and/or currently exist.

To determine any cooling effects of tributaries on mainstem temperatures and identify potential thermal refugia in the mainstem, during June of 2013 temperature loggers were deployed in the Big Manistee River at locations around the confluences of Woodpecker and Slagle Creeks. Loggers were secured to a log jam or root wad within the mainstem channel upstream, 33 meters downstream, and 66 meters downstream of each confluence. The loggers recorded water temperature on five-minute intervals throughout the month of July and were retrieved during the second week of August. The approximate location of each temperature logger was recorded using a handheld GPS unit (typical accuracy: ± 2-5 meter) and a visual description (Figure 2.3).

To capture the longitudinal surface temperature profile at the confluence of each tributary and the mainstem, a tethered temperature logger was drifted down the channel through each confluence excluding Slagle and Peterson Creek. Slagle Creek was excluded due to limited access and we did not detect flow at the mouth of Peterson Creek, potentially because it empties into the Big Manistee River where it is backed up by Tippy Dam Pond. The logger was configured to record temperature every second and attached to a float in order to measure surface temperature as it naturally drift from just upstream of tributary confluences to a maximum distance of 91 meters downstream. Duration of each float ranged from 2 - >14 minutes depending on river current and whether the temperature logger became trapped in bank vegetation or eddy current.

Substrate

Tributary substrate composition was assessed by conducting pebble counts based on a modified Wolman method (Wolman 1954) and estimating percent fines (250μm–2mm) from bulk sediment samples collected in riffles and runs (glides) (Hames et al. 1996). Pebble counts were based on 100 substrate particles measured from each of the 23 study sites in 2011 and 2012. Within each site a particle was withdrawn arbitrarily from a point in the channel determined by a randomly generated percentage across the wetted width of the channel (i.e. 0 to 100% from the left bank). In addition to measuring the diameter along the intermediate axis of each pebble, the water depth and type of channel geomorphic unit mesohabitat (i.e., pool, riffle, or run) of each point was recorded. Pebble count measurements for each tributary were used to calculate the median substrate diameter (D50) as well as characterize the substrate composition.

In 2012, additional substrate measurements were made using the shovel-based method to assess the percentage of fine particles (0.25 – 2mm) in a bulk substrate sample collected with a number 2 round point shovel (Hames et al. 1996). In each study site, samples were collected within each channel geomorphic unit (CGU) at the downstream, middle, and upstream regions (or middle if the CGU was too short to collect 3 samples) of each defined riffle and run. A portable stilling well (see Hames et al. 1996) was placed at the upstream of each sample point to divert stream current and minimize loss of particles from the sample. Volume of each bulk sample was measured as the displacement after being placed into a measuring bucket containing a known volume of water (3.0L). The percent fine material (250µm-2mm) in the substrate was then calculated as the ratio of volume of fine materials (collected after rinsing the bulk sample through 2mm and 250µm sieves) and total initial bulk volume *100.

Basic Water Chemistry

Basic water chemistry data (i.e., dissolved oxygen, pH, and turbidity) were collected multiple times throughout the 2011, 2012, and 2013 field season at the upper, middle, and lower locations in each study site (Hydrolab DS5 Multiparameter Sonde, Hach-Hydromet®). Accuracy for dissolved oxygen, pH, and turbidity sensors were ±0.1-0.2 mg/L, ±0.2 units, and ±1%, respectively. All sites were sampled in June and July of 2011, while in 2012 sampling occurred in June, July and August. For the 2013 field season only Hinton Creek (all sites) and Woodpecker Creek (downstream and midstream sites) were sampled in June, July, and August. Dissolved oxygen data for the mainstem was taken from the United States Geological Society (USGS) website for the Big Manistee River USGS gaging station near Mesick (USGS #04124200). For this analysis we used data from May-July of 2011, 2012 and 2013 so that it could be compared to data collected at the tributary sample sites.

Stream Velocity/Discharge

Stream discharge was estimated at an upstream, midstream, and a downstream transect across each study sites within tributaries. We measured water velocity at 60% of total depth (Marsh-McBirney Flo-Mate, Hach®, accuracy: ±2%) and depth at 10 points evenly distributed along each transect (Rantz 1982). Discharge for each site on a given sampling date was estimated as the mean of three discharge measurements.

Channel Morphology

Profile**:** Transects every two meters up the river during the 2012 field season provided wetted widths and the total site length used to estimate the area of each of the 23 study sites. At each transect we measured the water depth at 0, 20, 40, 60, 80, and 100% across the stream.

***Channel Geomorphic Unit*:** As a way to quantify habitat within the tributaries and compare to what is reported in the literature, a longitudinal profile map for channel geomorphic units (CGU) was developed for each site using Arcmap 10.1 (ESRI®) and physical measurements. CGU classifications were standardized based on Hawkins et al. (1993). In the 2011 field season, starting at the downstream end of each site and following the midpoint of the channel to the upstream end, a hip chain (Forestry Suppliers Inc., accuracy: within ±0.2%) was used to record the longitudinal length of each CGU to the nearest 0.1m. In June 2012 CGUs were measured in a similar manner using a handheld GPS unit to mark a waypoint at the downstream end of each classified CGU transition.

Results and Discussion

Temperature

Across all tributaries in this part of the Manistee River watershed, mean July temperatures ranged from 9-15^{o}C between 2009 and 2013 (Table 2.3). Peterson Creek was the warmest stream overall during July 2012 (15.0^{o}C ±1.5, mean ± standard deviation) while Eddington Creek was the coolest during July 2013 (9.0^{o}C ±1.0) (Figure 2.4). From 2009-2013 all tributaries have mean July temperatures below the upper incipient lethal temperature of 25^{o}C for Arctic grayling (Lohr et al. 1996) and 18.3^{o}C, which was observed to prompt an Alaska population of Arctic grayling to migrate to cooler water (Schallock 1966) (Figure 2.4).

Temperatures measured in mainstem Big Manistee River pools indicate a little change with increasing depth, and overall minimal difference between upstream and downstream location mean temperatures (Table 2.3). Difference in mean July temperatures (± standard deviation) at the stream bottom and middle of the water column of the upstream and downstream pools were 0.4^{o}C (±2.2) and 1.0^{o}C (±2.3), respectively, while the difference in mean temperature between the two pool locations was 0.2^{o}C (±2.3). Further downstream, Red Bridge mean July temperature for 2012 was 22.7^{o}C (±0.9). Temperature data acquired from the USGS gaging station at Hodenpyl Dam spanning from 2009 to 2013 indicates mean July temperature ranged from 18.8^{o}C (±0.3) in 2009 to 23.2^{o}C (±0.5) in 2012.

Temperature data from above and below the confluence of Slagle Creek indicated that the tributary created a plume of cool water detectable at greater than 33 meters downstream of the confluence (Figure 2.5). The mean difference between mainstem temperature above Slagle Creek and 33 meters downstream the confluence was approximately 8.0^{o}C (±1.2) and dropped to less than 1.0^{o}C (±0.2) difference 66 meters downstream (Table 2.4). The differences between water temperature upstream and downstream of Woodpecker Creek was smaller than that of Slagle Creek (Table 2.4).

The decrease in Big Manistee River mainstem surface water temperature at the mouths of tributaries was the greatest at Eddington, Hinton, Arquilla, and Woodpecker Creeks, and less strong at Sand and Cedar Creeks (Figure 2.6). Maximum temperature differential was measured at Woodpecker (7.1^{o}C) and Eddington (6.8^{o}C), and the minimum at Sand Creek (0.6^{o}C). Distance traveled by the temperature logger also varied between tributaries (Figure 2.3). Eddington Creek and Cedar Creek each drifted approximately 91 meters while Hinton Creek and Woodpecker Creek traveled approximately 65 and 62 meters, respectively. The Arquilla Creek logger drifted into vegetation along the bank at 24 meters and Sand Creek traveled between 3-5 meters before getting caught in an eddy pool.

Substrate

All tributaries had similar relative abundances of pebbles and gravels (4mm-250mm) and finer material (i.e. sand, silt, clay) in the streambed substrates in 2011 and 2012. In 2011, all tributaries excluding Sand Creek contained greater than 20% pebble/gravel, which is the minimum percent thought to be important for spawning habitat (Hubert et al. 1985), Percentage of pebble and gravel ranged from 4% in Sand Creek to 61% in Arquilla Creek (Figure 2.7). In 2012, similar results were observed in all tributaries with Sand Creek having the lowest relative abundance of pebble and gravel. Woodpecker Creek, was the only tributary that had the same approximate percentage of sand, silt, clay in both 2011 and 2012.

Comparison of substrate median diameter to minimum (4.0mm) and maximum (89.0mm) observed for grayling habitat in the Big Hole River, MT revealed that all tributaries except Peterson Creek and Sand Creek had median substrate diameters within the range for what has been measured in pool and riffle habitat in the Big Hole River, Montana by Lamothe and Peterson (2007) (Figure 2.8). Median pebble size ranged from 22mm in Arquilla Creek to 2mm in Sand and Peterson Creeks.

Across all tributaries, percent fine composition (250μm - 2mm) of the substrates was greater in runs than in riffle habitat ($p < 0.001$, one-tailed t-test, Figure 2.9). Woodpecker Creek samples contained the lowest average percentage of fines in runs at 47% while Arquilla Creek had the lowest in riffles at 29%. Percentage of fines peaked in runs at 82% for Sand Creek and 48% in riffles. Percent fines in all tributary riffles were below the suboptimal level of ≥50% for spawning habitat as determined by Hubert et al. (1985).

Basic Water Quality

Turbidity, pH, and dissolved oxygen measurements in sample sites of tributaries across the three years of field data indicate that water quality is similar throughout this part of the watershed (Figure 2.11). Tributaries tended to be slightly alkaline, with average pH ranging from 7.9 (±0.3) for Woodpecker to 8.2 (±0.4) for Peterson. All tributaries were within the range of pH values where grayling have been observed (pH = 7.0-8.2). Mean turbidity in this part of the watershed was relatively low and was peaked in Peterson Creek at 4.0NTU (±4.2). Slagle Creek water had the lowest turbidity of all the tributaries with a mean of 1.4NTU (±1.3). All sites were well below the reported maximum turbidity (30.8NTU) for reference conditions for this sub-Ecoregion by the EPA (EPA 2001). Dissolved oxygen (DO) levels were similar across all tributaries with mean DO ranging from 8.8ppm (±1.6) in Sand Creek to 10.4ppm (±0.6) in Eddington Creek, while the mainstem Big Manistee River's mean dissolved oxygen was detected at 8.4ppm (±0.8) (Figure 2.10). Grayling have been observed in water with dissolved oxygen as high as 11.6ppm (Liknes and Gould 1987) and as low as 1.7ppm (Bendock 1980) and all Big Manistee River tributary samples were above the lower limit.

Velocity/Discharge

Velocity measurements taken in early, middle, and late summer 2012 were variable temporally as well across tributaries (Figure 2.11). For each sampling date, Slagle Creek had the largest mean velocity, of which the middle summer measurement was highest (0.38m/s ± 0.1) and Sand Creek the lowest in middle summer (0.07m/s ±0.0). All measured tributary velocities were near or within the range for mean velocity in present-day Arctic grayling habitat (Nelson 1954, Hubert et al. 1985, Liknes and Gould 1987, Shepard and Oswald 1989, Barndt and Kaya 2000, Blackman 2004) except for the mid summer measurement in Sand and Peterson Creeks. Calculated discharge ranged from 0.01 m^3/s (±0.0) to 0.54 m^3/s (±0.4) for the eight Big Manistee River tributaries (Figure 2.12). Slagle Creek followed by Peterson Creek were the tributaries with highest discharge estimates while Sand Creek and Eddington Creek were the lowest (Table 2.5).

Channel Morphology

Based on 2012 measurements, mean wetted width ranged from 1.8m (± 0.6) in Sand Creek to 7.5m (± 2.3) in Slagle Creek, and mean depth ranged from 0.11m (± 0.1) in Eddington and Sand Creek to 0.26m (± 0.2) in Slagle Creek (Table 2.1). Boxplots of depth measurements indicate that although Arquilla and Hinton Creeks had lower mean depths, there were some pools measuring more than 0.5 meters deep (Figure 2.14). In 2011 areal percentage of pools ranged from 31.5% in Peterson Creek to 80.7% in Sand Creek, while riffles ranged from 2.3% in Sand Creek to 56.7% in Eddington Creek (Figure 2.10). Runs (also known as glides) were the lowest percentage of tributaries, with a mean areal percent of

19.6% (± 6.8) and a range from 13.4% in Cedar Creek to 31.7% in Slagle Creek. Channel geomorphic unit estimates based on longitudinal GPS mapping for 2012 revealed that between 16% and 39% of tributary study sites were comprised of pool habitat, while riffles made up less of the area (mean = 16.8% ± 11.5) (Figure 2.14). Sand Creek and Eddington Creek had the lowest percent riffles at 0.0% and 5.5%, respectively, while Peterson Creek had the highest at 30.5% of the total area. The dominant CGU was 'run' and ranged from 36.2% to 72.7%. Areal pool to riffle ratios between the reported literature values of 0.27 – 1.51 were observed in Cedar, Peterson, and Slagle Creek while remaining tributaries were either above this range as in the case for Arquilla, Eddington, Hinton, and Woodpecker Creek, or did not contain riffle habitat, such as for Sand Creek (Figure 2.15).

Which Tributaries Best Match Arctic Grayling Habitat Conditions?

To determine whether the Manistee River watershed is suitable for Arctic grayling reintroduction it is informative to characterize the state of abiotic conditions in Michigan waters prior to their extirpation (Chapter 1) as well as define the conditions where Arctic grayling continue to persist (especially in the western United States) and what conditions currently exist in Big Manistee River tributaries. Using the data collected in this study we scored each tributary based on whether the abiotic conditions fell within the ranges found for historical and existing conditions where grayling were/are found. We did not rank the different environmental attributes so weighting was not assigned to a given category, although it should be noted that some conditions might be biologically more important to grayling than others (e.g. stream temperature verses areal pool: riffle ratio).

Slagle, Arquilla, and Woodpecker Creeks received the highest score with fourteen (Arquilla and Woodpecker) and fifteen (Slagle) of sixteen abiotic conditions being met (Table 2.6). Cedar, Eddington, and Hinton Creeks met thirteen conditions, while Peterson Creek met twelve conditions. Sand Creek met the fewest conditions with six (Table 2.6). The one condition not considered in this study was winter habitat availability due to the timing of our sampling. It would be difficult to conclude winter conditions based on summer sampling, however, year round temperature logger data does suggest most tributary sites reached freezing temperatures during winter 2010/2011 (Table 2.7). Not all temperature loggers were located in deep pools that would potentially be used by grayling during winter months, but these data raise the question of whether these tributaries could act as winter habitat, and this warrants further investigation into conditions that exist from November to May.

It is also important to discuss the reality that Big Manistee River tributaries may play different rolls for the various life stages of grayling. Slagle Creek, for example, is the largest tributary in terms of mean width, depth, and velocity (Table 2.1), and may be one of the most suitable streams for adult Arctic grayling based on its size and depth. In contrast to Slagle Creek, all other tributaries are smaller and might be more suitable for the early Arctic grayling life stages.

Overall, based on the habitat criteria and literature values used to quantify Arctic grayling habitat, it appears that Arquilla, Slagle, and Woodpecker Creeks may be the most suitable tributaries in this part of the watershed. Sand Creek is the tributary least predicted to support grayling (Table 2.6).

Discussion and Further Considerations

Based on the abiotic habitat assessment conducted, our study portion of the Manistee River watershed is within parametric ranges for where grayling are presently established in Alaska, Montana, and Canada (see chapter one Table 1.1). We were able to assess the abiotic conditions of eight tributaries to the Big Manistee River between Hodenpyl and Tippy dams and compare those to conditions where grayling historically and currently exist. Once coupled with biotic conditions (food sources/abundance, competition with Salmonids) this glimpse of habitat observed during the three summers between 2011 and 2013 will assist managers in determining if Arctic grayling reintroduction is appropriate.

One of the challenges in assessing the potential for Arctic grayling reintroduction is considering the most critical abiotic habitat components. In regards to this study, it is evident that water temperature in Big Manistee River tributaries during summer months is within the reported ranges for Arctic grayling (Figure 2.4), and likely would not be a limiting factor in the suitability of tributaries as habitat. However, this was not always the case for the mainstem, where temperatures were recorded at levels documented to cause avoidance in Arctic grayling (Wojcik 1955, Schallock 1966). Although Big Manistee River mainstem temperatures did not reach lethal levels as defined by Lohr et al. (1996), as water temperature exceeds 18-20^{o}C there is an increased chance of physiological stress to grayling (Wojcik 1955, Tack 1980, Hubert et al. 1985, Lamothe and Peterson 2007). Despite this, we demonstrated that Big Manistee River tributaries create cool water microhabitat within the mainstem, lowering the temperature by as much as 8^{o}C (Table 2.4). Coupling the cooling effects we observed near tributaries with available groundwater inputs within the Big Manistee River mainstem would allow for an approximation of the cool-water refugia that is potentially available to Arctic grayling during the warmest times of the year. The ability of fish to locate and utilize cool water microhabitat was illustrate by Baird and Krueger (2003) for Salmonids implanted with temperature sensors where the internal body temperature of brook and rainbow trout in the south branch of the Moose River, New York, averaged 2.3 and 4.0^{o}C cooler, respectively, than water temperatures measured ≥20°C. A similar situation is conceivable for grayling in the mainstem Big Manistee River during times when summer temperatures peak.

Based on the results of this study I believe the availability of suitable spawning substrates will be the most limiting abiotic habitat components in Big Manistee River tributaries. As illustrated by McMichael (1990) and Suttle et al. (2004), increased substrate embeddedness can negatively impact spawning, and the survival of early life stage Salmonidae. Mean percent fines (0.25-2mm) in Big Manistee River tributary riffles ranged from 29-48% (Figure 2.9), which although below the limit for suitability (50%) as defined by Hubert et al. (1985), was above the optimal percentage (10%). It should be noted, however, that our study characterized entire tributary suitability rather than identifying specific habitat for reestablishment. Therefore it is plausible that spawning and rearing locations with optimal embeddedness (~10%) do exist within Big Manistee River tributaries.

One of the many difficulties in research is capturing the temporal variability in a natural system, which is especially true for fluvial systems. We were able to characterize eight Big Manistee River tributaries as a snapshot of the conditions that can occur between seasons and years, and therefore care was taken in interpreting results so as not to assume that the conditions we observed were fixed. This was particularly the situation for variables such as water velocity/discharge and quality (dissolved oxygen, pH, turbidity), which are strongly associated with changes in weather (e.g. rainfall events). With these challenges in mind this study was able to report what abiotic conditions were present and how they related to historical and contemporary Arctic grayling habitat.

The implications of this research could be far reaching if used as a springboard towards bringing Arctic grayling back to the Manistee River watershed. Reintroduction as part of a Tribal Native Species Restoration Plan could strengthen and preserve the culture of the Little River Band of Ottawa Indians as well as foster a personal philosophy of conservation in tribal and non-tribal members. Additionally, anglers with a fondness for native species would be catching a fish more closely aligned with the natural state of the watershed than current non-native Salmonids. Efforts aimed at restoring and reintroducing populations of Arctic grayling in Montana have shown signs of success using remote site incubators to rear stocked Arctic grayling (Lamothe and Magee 2004b, Magee et al. 2012). Similarly in the Pacific Northwest, there has been success at reintroducing spring Chinook salmon (*Oncorhynchus tshawytscha*) to Lookingglass Creek, part of the Snake River Watershed, through hatchery and captive broodstocks (Boe et al. 2010). Using studies such as the aforementioned along with the body of literature available regarding successful reestablishment, reintroduction, and restoration of native fish species will help to ensure that the methods used in a potential reintroduction of Arctic grayling are suitable and offer the greatest chance of success.

Along with supporting the goals of a native species restoration plan this research has collected data that could eventually become part of a watershed scale assessment. Since data for tributaries in this part of the watershed is limited, tribal, state, and federal government agencies can use this information as part of a management plan or monitoring program. Assessments of this unique landscape could foster future research related to potential effects of regional and global climate change or anthropogenic stressors (i.e. deforestation, watershed development) when compared to the current conditions.

Many factors will dictate the future of grayling in the Manistee River watershed. Combing the results of this study with data for the biotic component (food sources, potential interacting species) will ultimately determine the likelihood of an attempt to reintroduce Arctic grayling to this part of the Manistee River watershed.

Figures

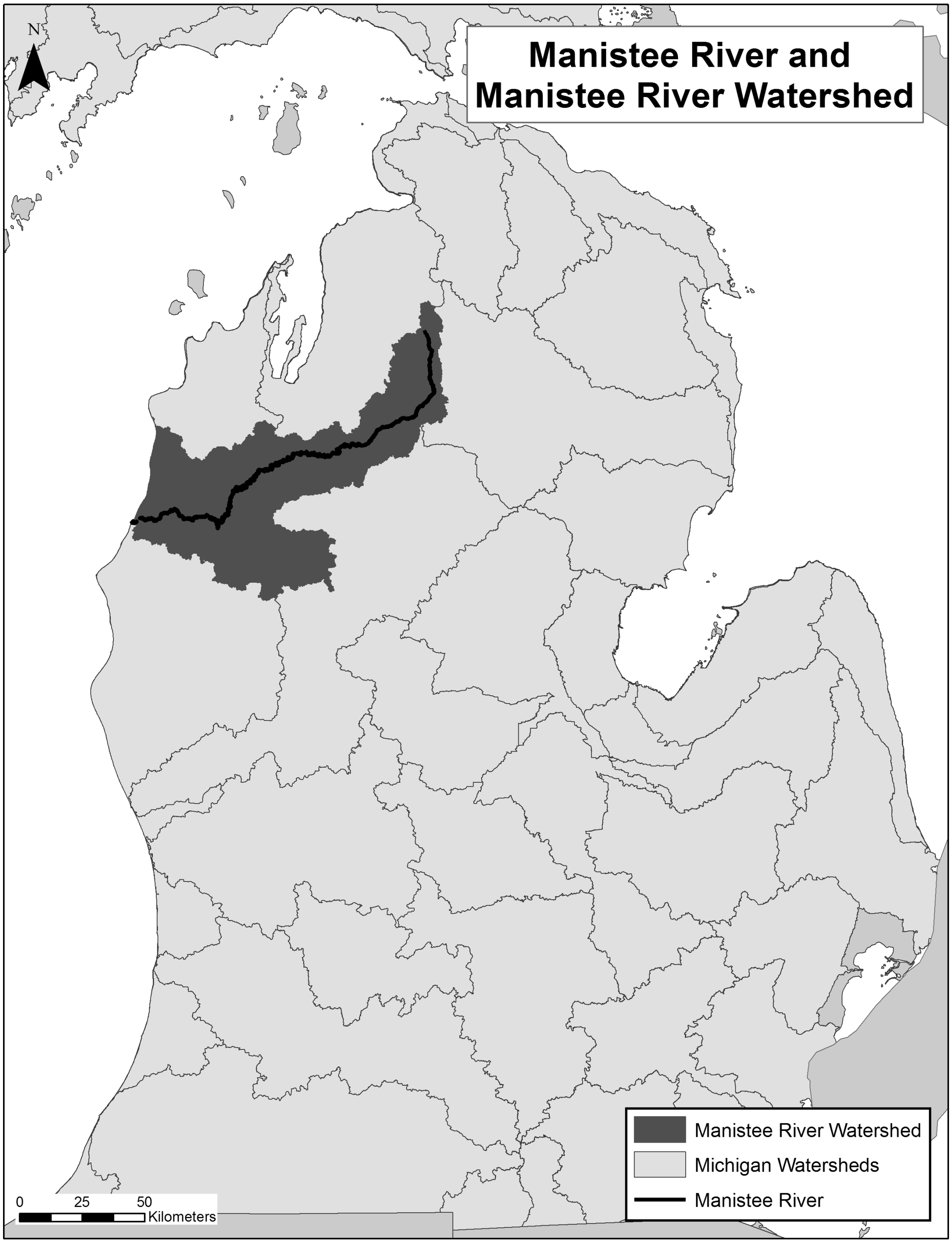

Figure 2.1: Big Manistee River and Manistee River Watershed, Michigan. Location of watershed and river within the State of Michigan relative to other Lower Peninsula watersheds. Map layers sources: MiGDL and NOAA.

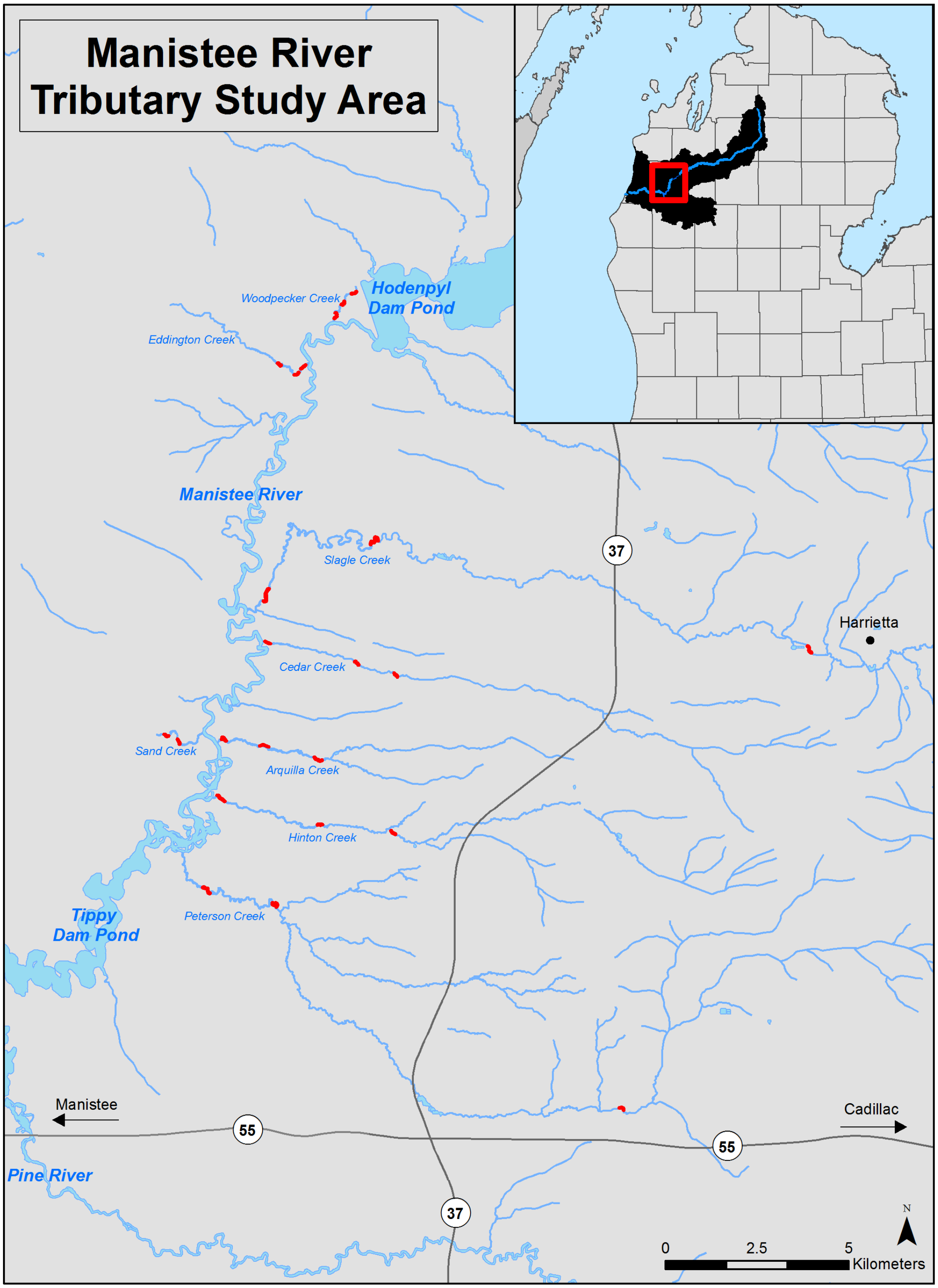

Figure 2.2: Manistee River watershed, Michigan study area. Study region and tributary sites (red lines) for (2011-2013) sampling. Map layers sources: MiGDL, USGS.

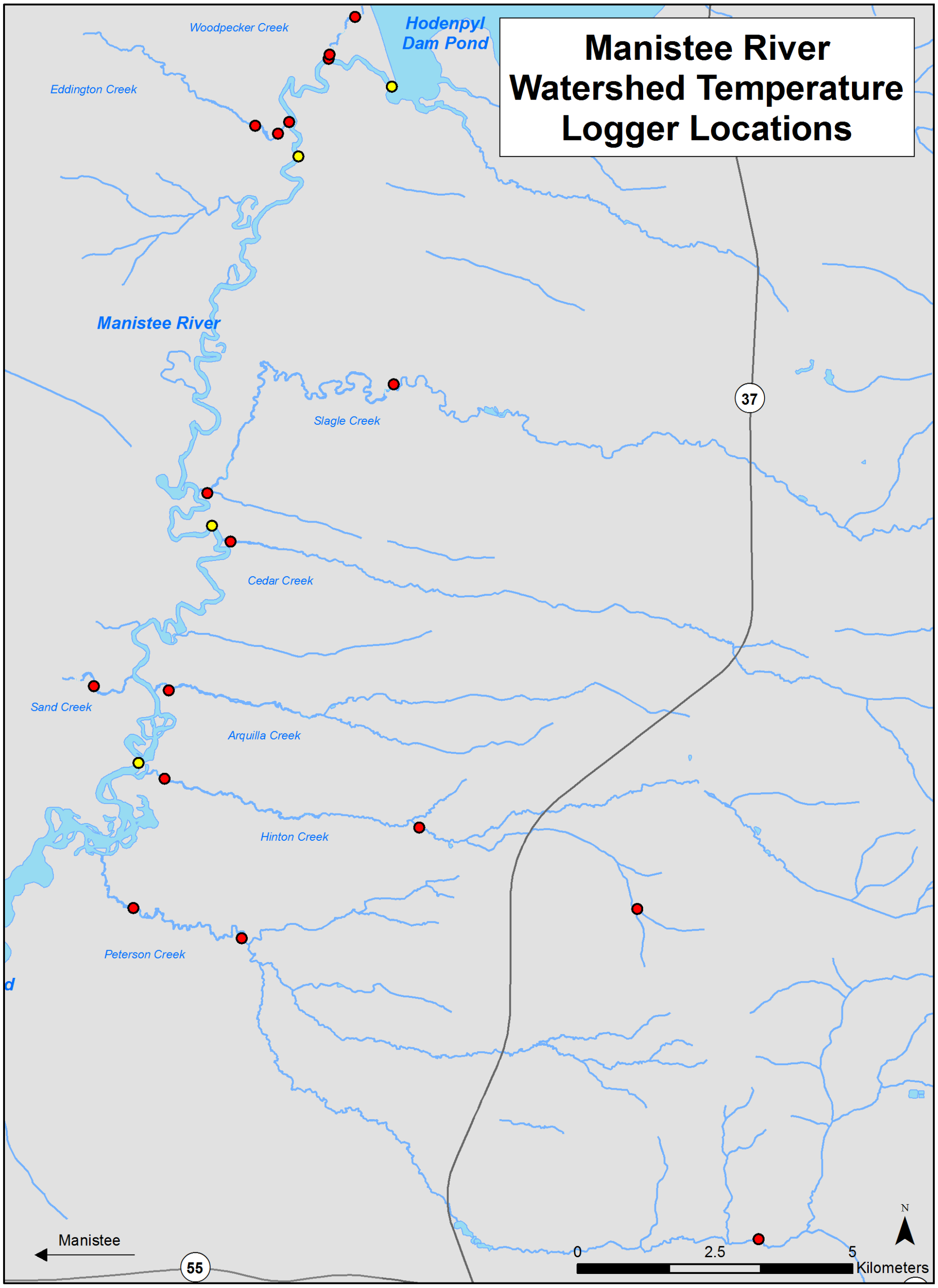

Figure 2.3: Manistee River watershed, Michigan 2009-2013 temperature logger locations. Red and yellow marks represent temperature loggers located in tributaries and Big Manistee River mainstem, respectively. Map layers source: MiGDL.

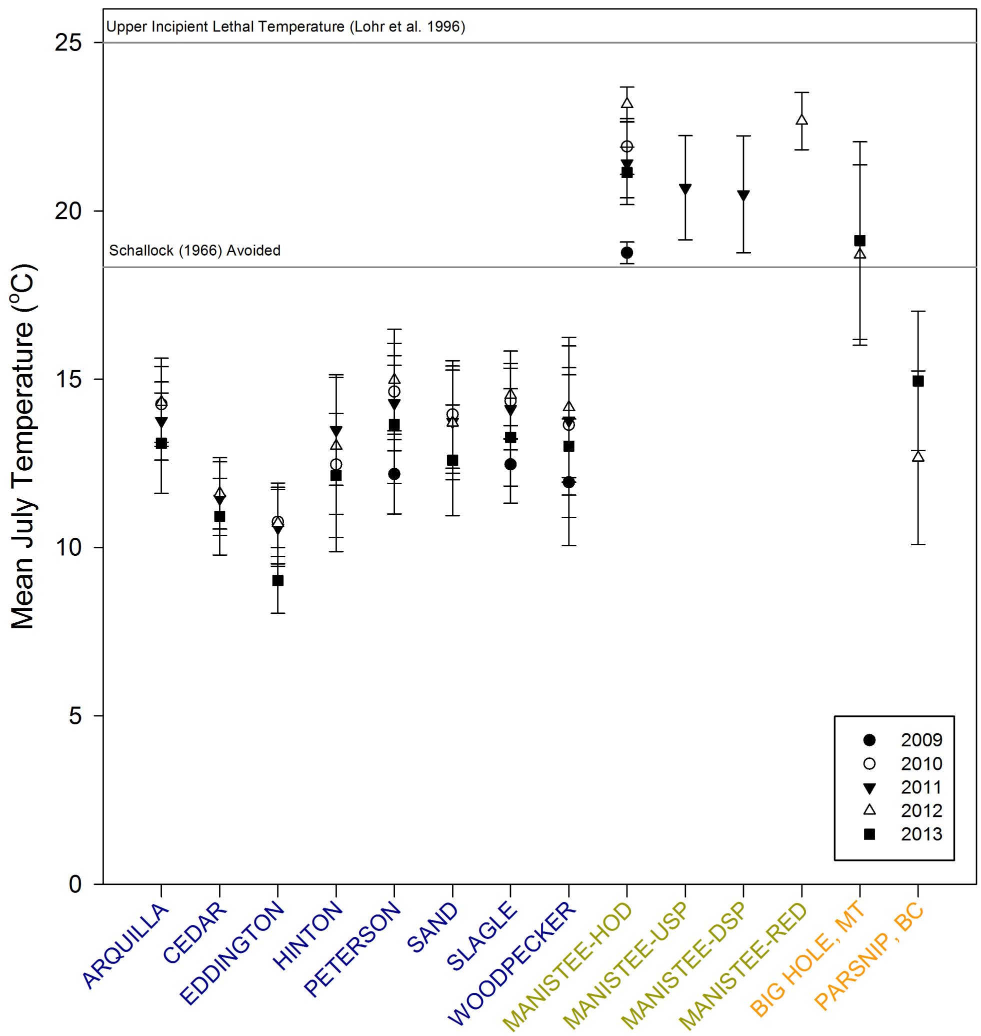

Figure 2.4: Big Manistee River, Michigan tributary and mainstem mean July temperature for 2009-2013. Data is mean + stdev. The line at 18°C represents temperature at which Arctic grayling were observed to 'avoid' (Schallock 1966). The line at 25°C signifies temperature at which 50% survival of grayling acclimated to 20°C (Lohr et al 1996). Blue labels represent Big Manistee River tributaries, green labels represent Big Manistee River locations, and orange labels represent western systems that currently support grayling. MANISTEE-HOD and BIG HOLE RIVER, MT data from USGS gaging stations. PARSNIP,BC data from Water Survey of Canada.

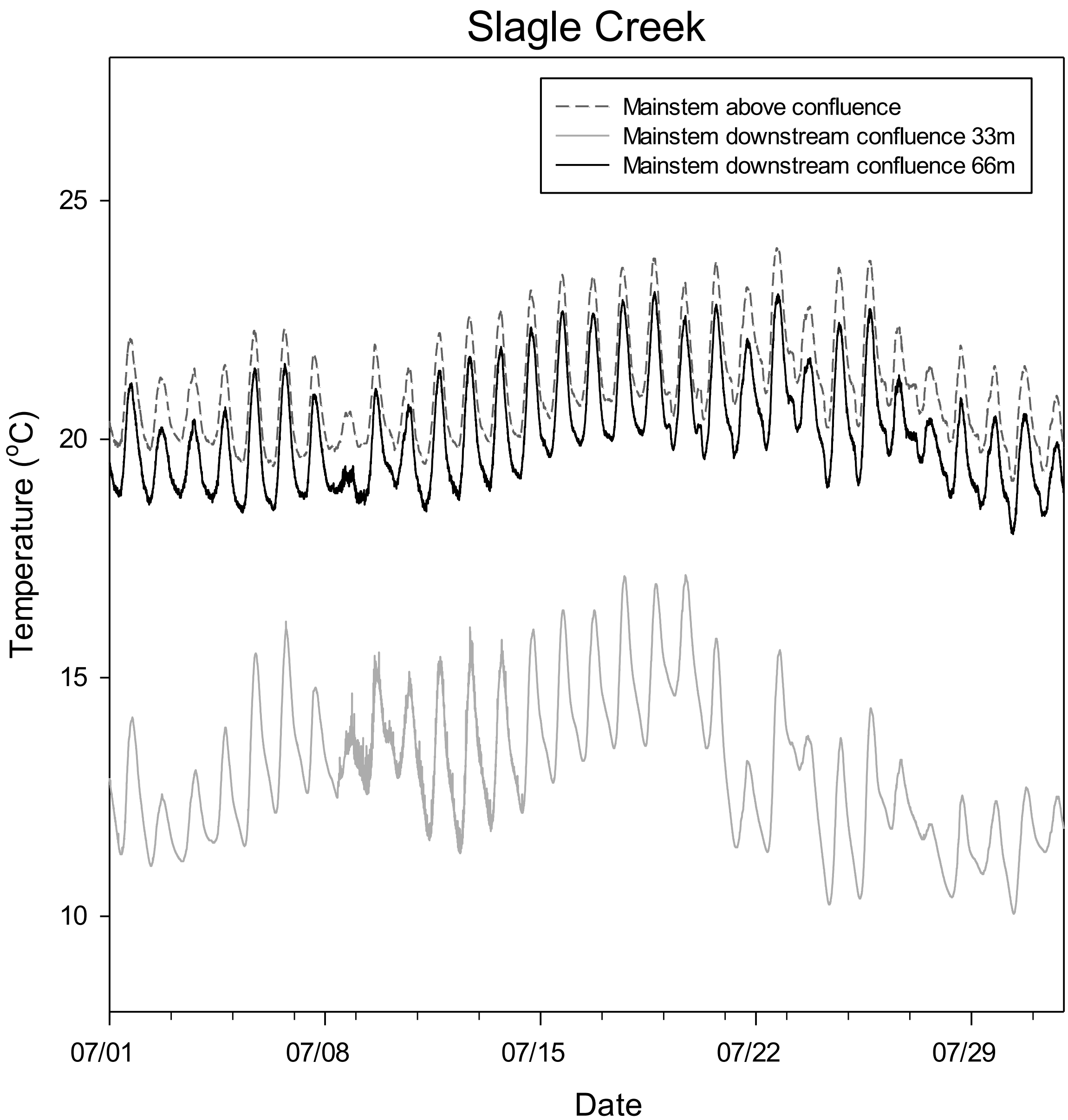

Figure 2.5: July 2013 water temperatures above and below Slagle Creek, Wexford Co, Michigan. Data for mainstem temperature loggers located above, 33m below, and 66m below the confluence of Slagle Creek.

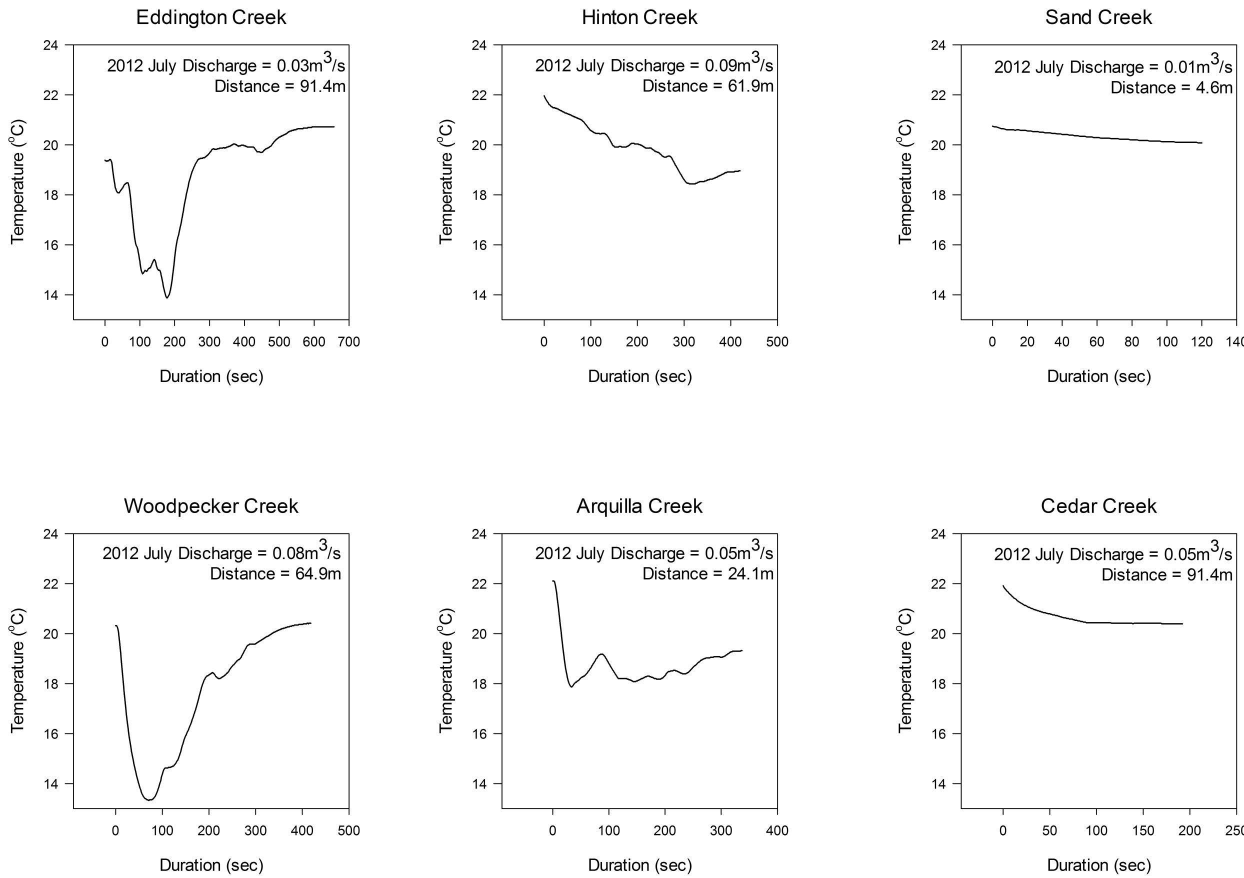

Figure 2.6: Longitudinal surface temperature of Big Manistee River, Michigan across tributary confluences. In July 2013 temperature logger was released upstream each confluence and allowed to drift downstream

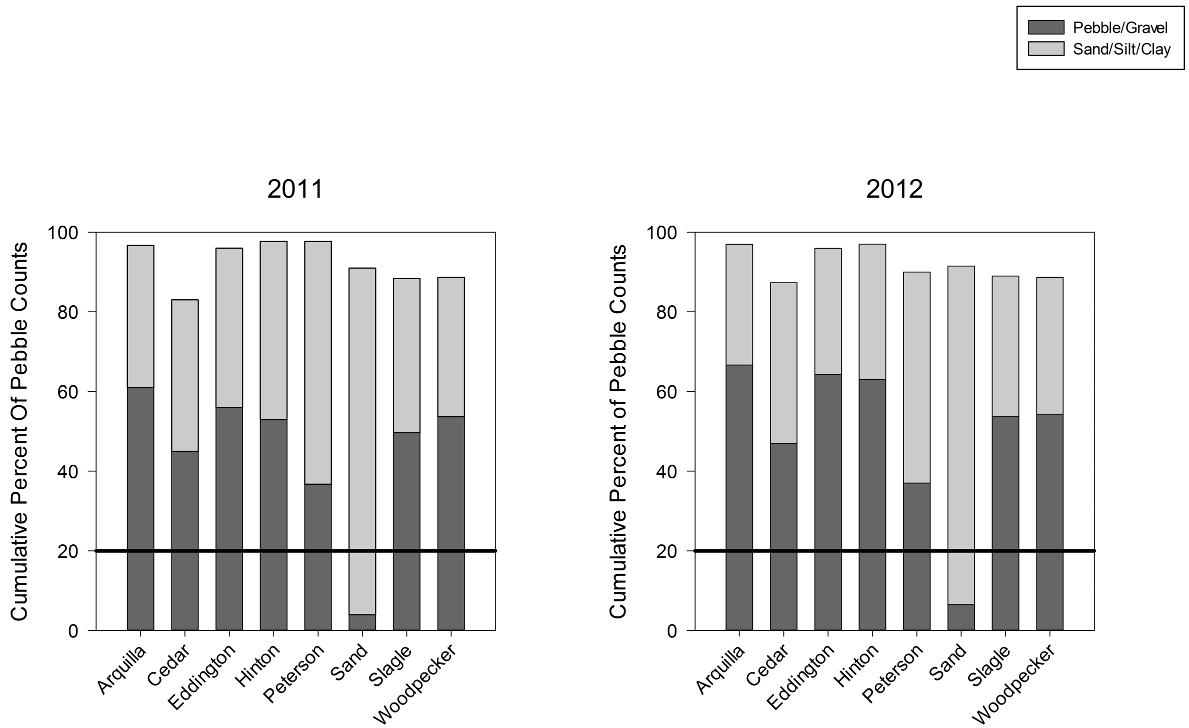

Figure 2.7: Big Manistee River, Michigan tributary substrate composition Data based on modified Wolman pebble counts conducted in 2011 and 2012. Black line represents what is believed to be the optimal percentage of spawning sites as gravel/pebble (Hubert et al 1985). Liknes and Gould (1987) determined dominant substrate in typical grayling habitat to be gravel/pebble.

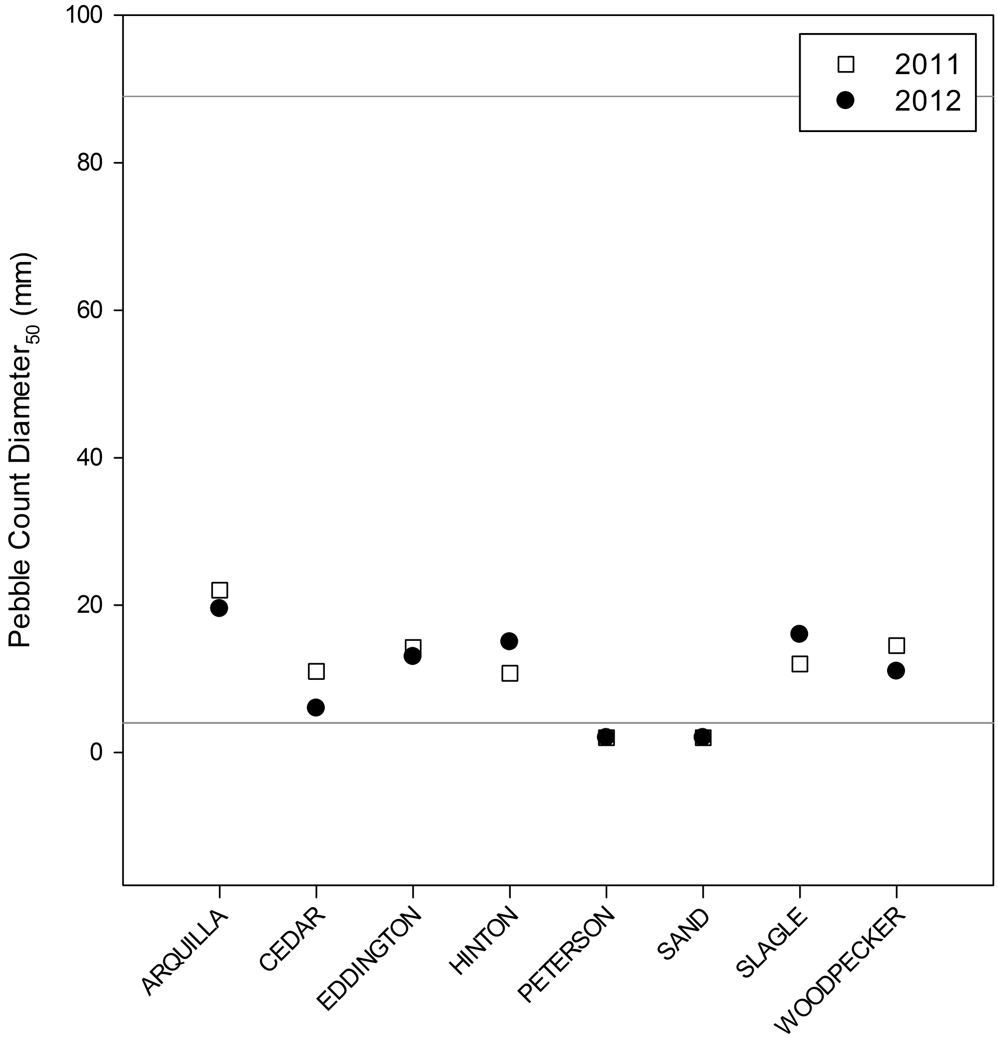

Figure 2.8: Median pebble diameter (D50) within Big Manistee River, Michigan tributaries. Based on modified Wolman Pebble Counts from 2011 and 2012. Sand Cree 2012 included an additional upstream site that was not sampled in 2011. Gray like represents the minimum and maximum observed median pebble size in the Big Hole River, MT by Lamothe and Peterson (2007).

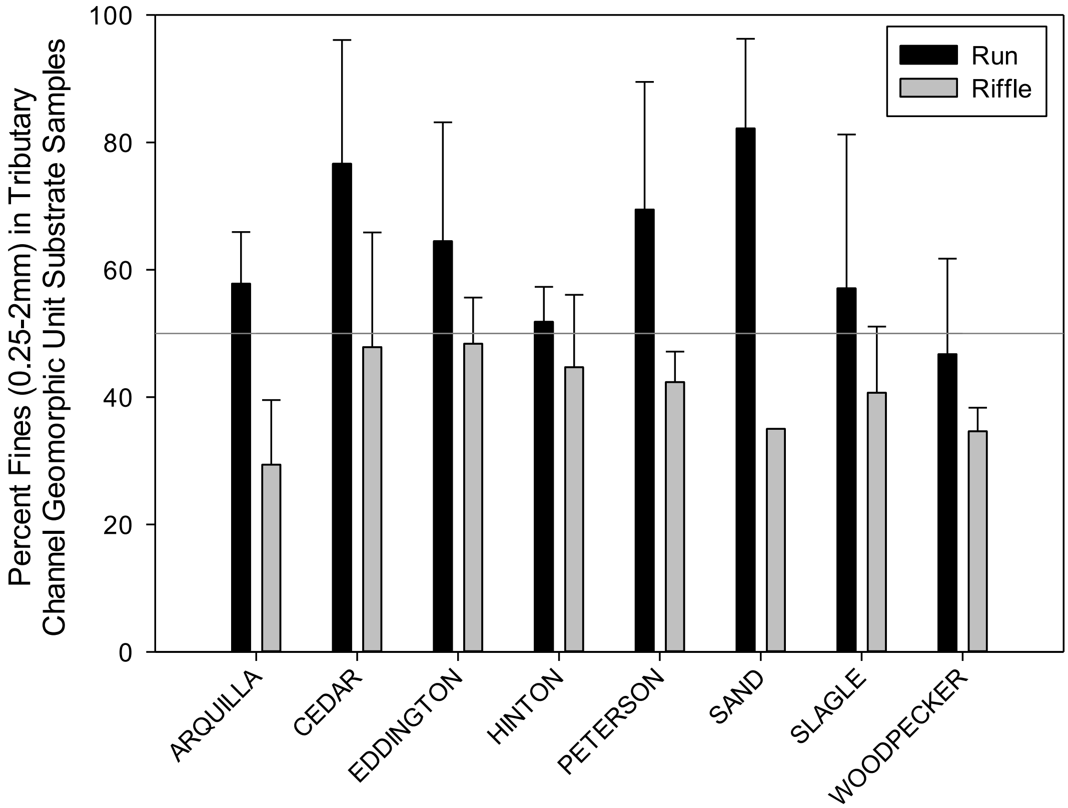

Figure 2.9: Percent fine substrate (0.25mm-2mm) in riffles and runs. Based on bulk shovel samples in 2012. Data represents mean plus standard deviation from bulk shovel samples of Big Manistee River tributaries. Hubert et al. (1985) determined less than 50% fines within spawning sites was optimal for newly emerged grayling (gray line).

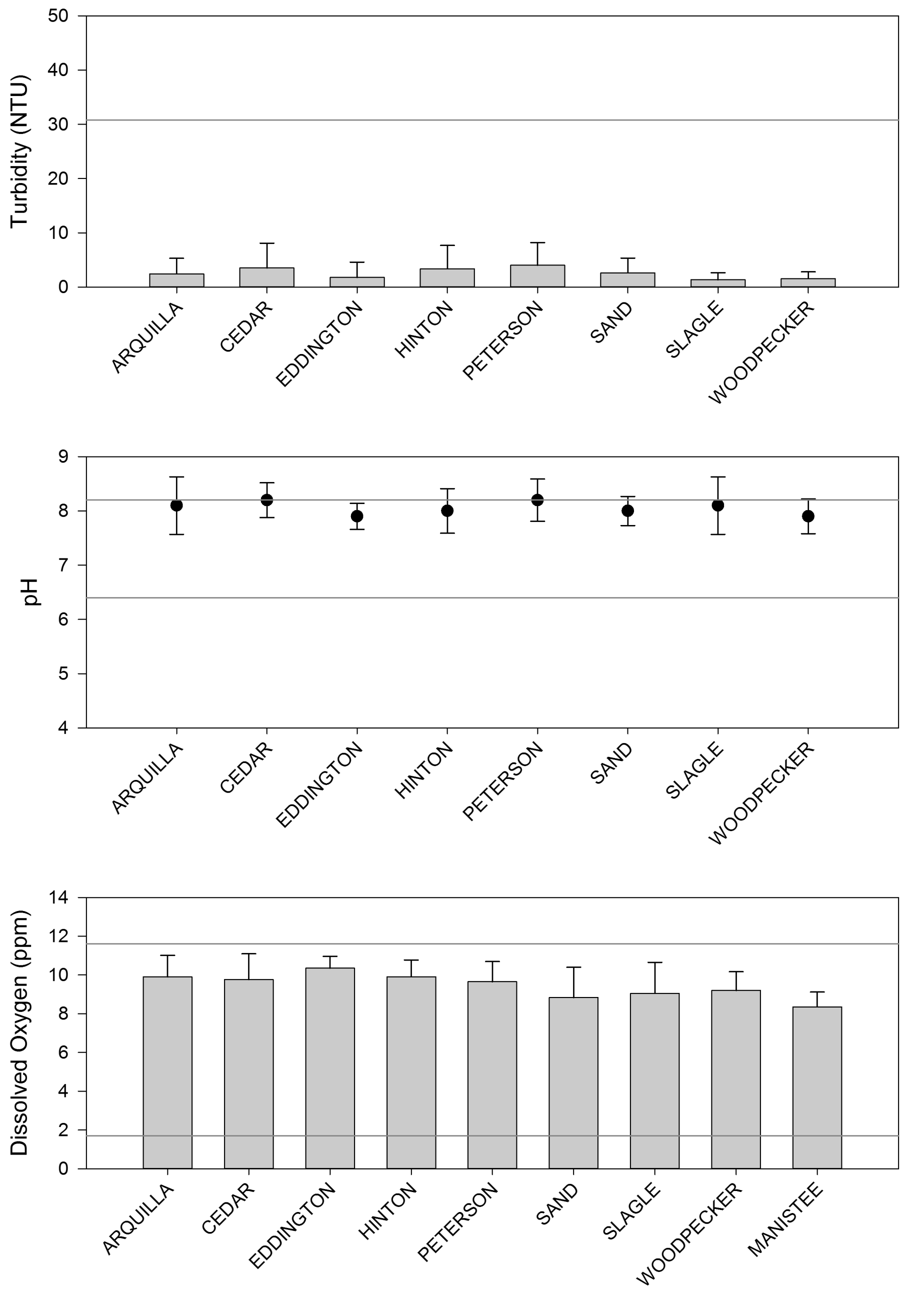

Figure 2.10: Big Manistee River, Michigan tributary basic water quality. All values represent mean plus standard deviation for data collected in 2011 and 2012. Gray line for turbidity is the EPA maximum based on reference sites in sub-ecoregion VIII. Gray lines for pH and dissolved oxygen represent the range of values in literature where grayling are found.

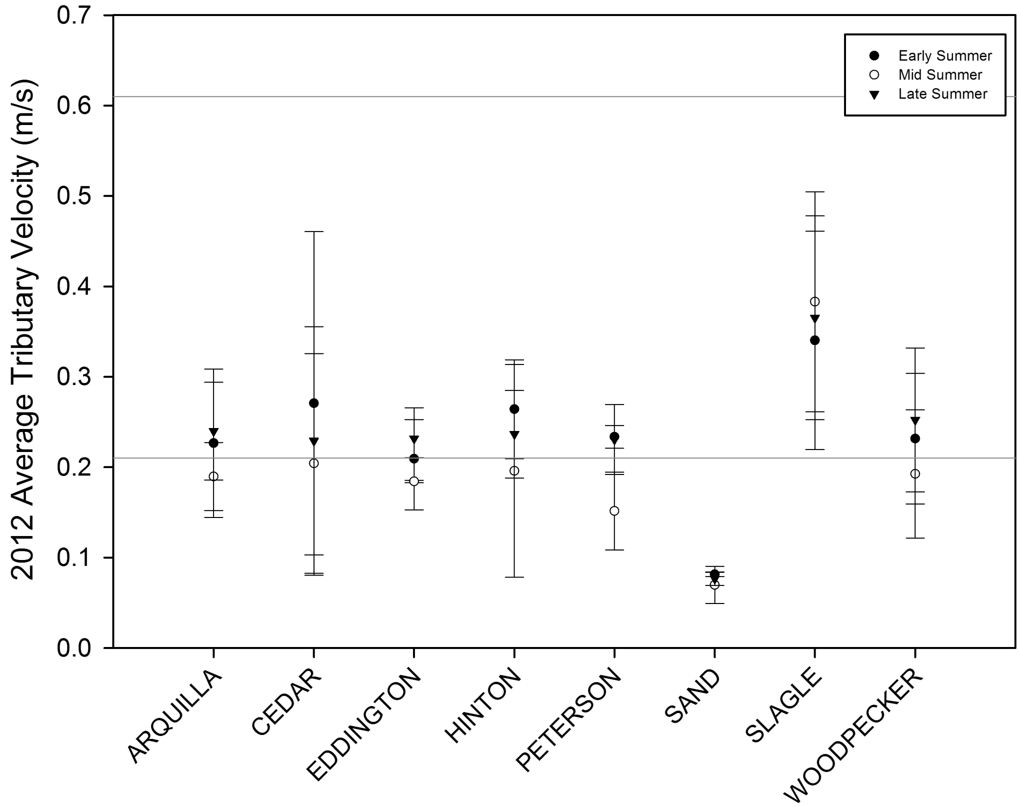

Figure 2.11: Big Manistee River, Michigan tributary mean velocities Data represents 2012 mean and standard deviation in early (May-June), middle (June-July), and late (July-August) summer. Lower line represents velocity measured in site supporting grayling by Liknes and Gould (1987). Upper line is the velocity that Vincent (1962) believed to be the maximum typical velocity that would be observed in a grayling river.

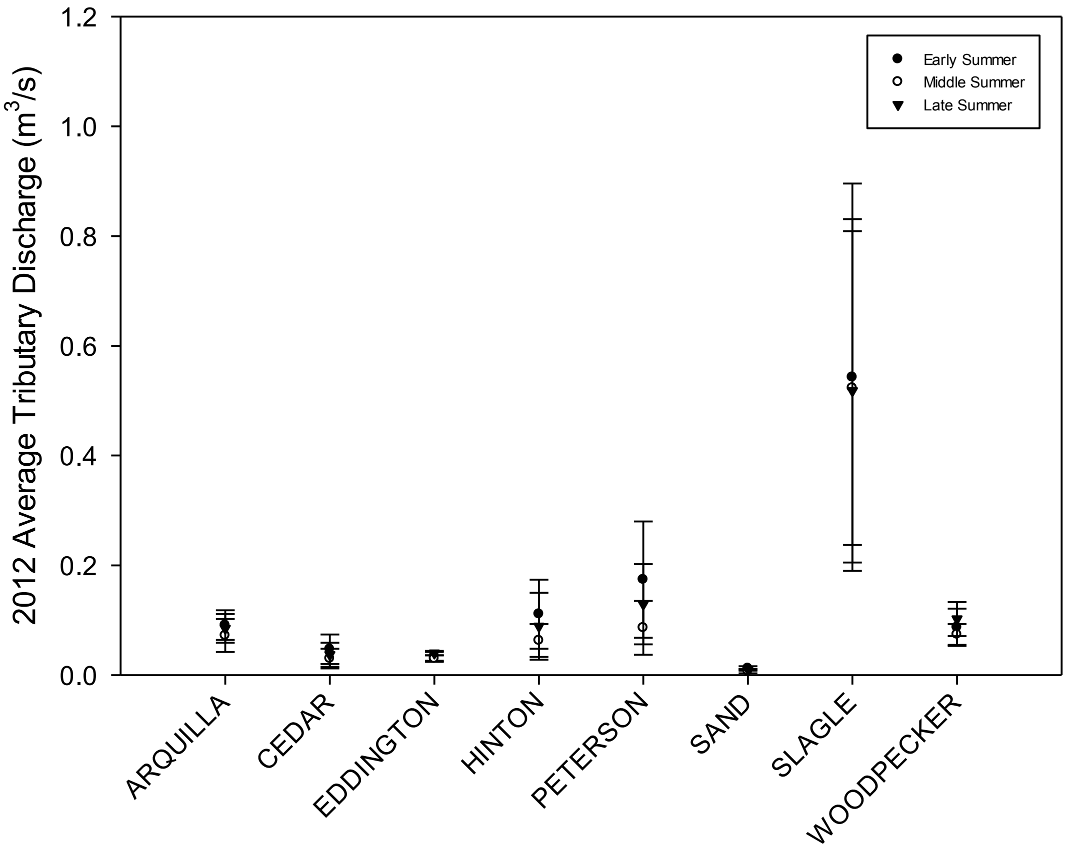

Figure 2.12: Big Manistee River, Michigan tributary mean discharges. Data represents 2012 mean and standard deviation for early (May-June), middle (June-July), and late (July-August) summer.

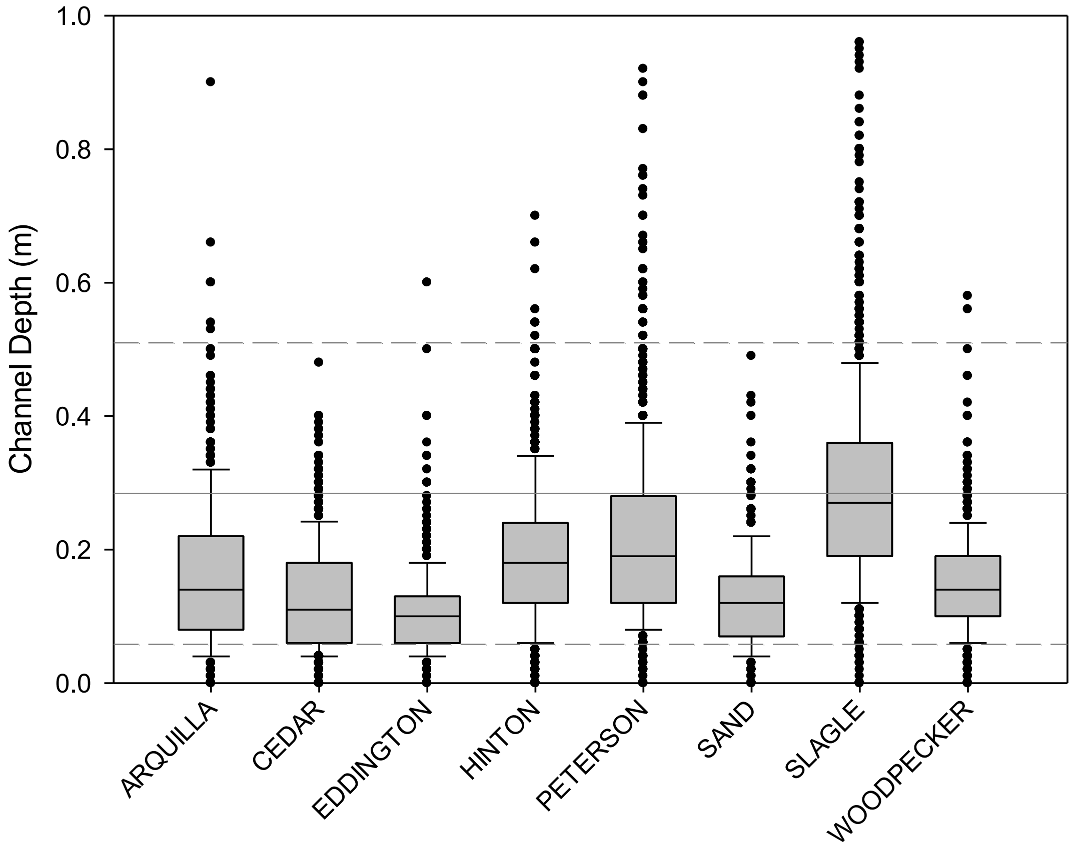

Figure 2.13: Big Manistee River, Michigan tributary boxplot of measured channel depths. Data from 2012 site transects. Boxplots represent 25th, 50th, 75th percentile with 10th and 90th percentile as whiskers. Measurements outside of 10-90th percentile marked as black dots. Gray line represents the mean depth (solid) and standard deviation (dashed) for Big Hole River, MT sites containing grayling (Liknes and Gould 1987).

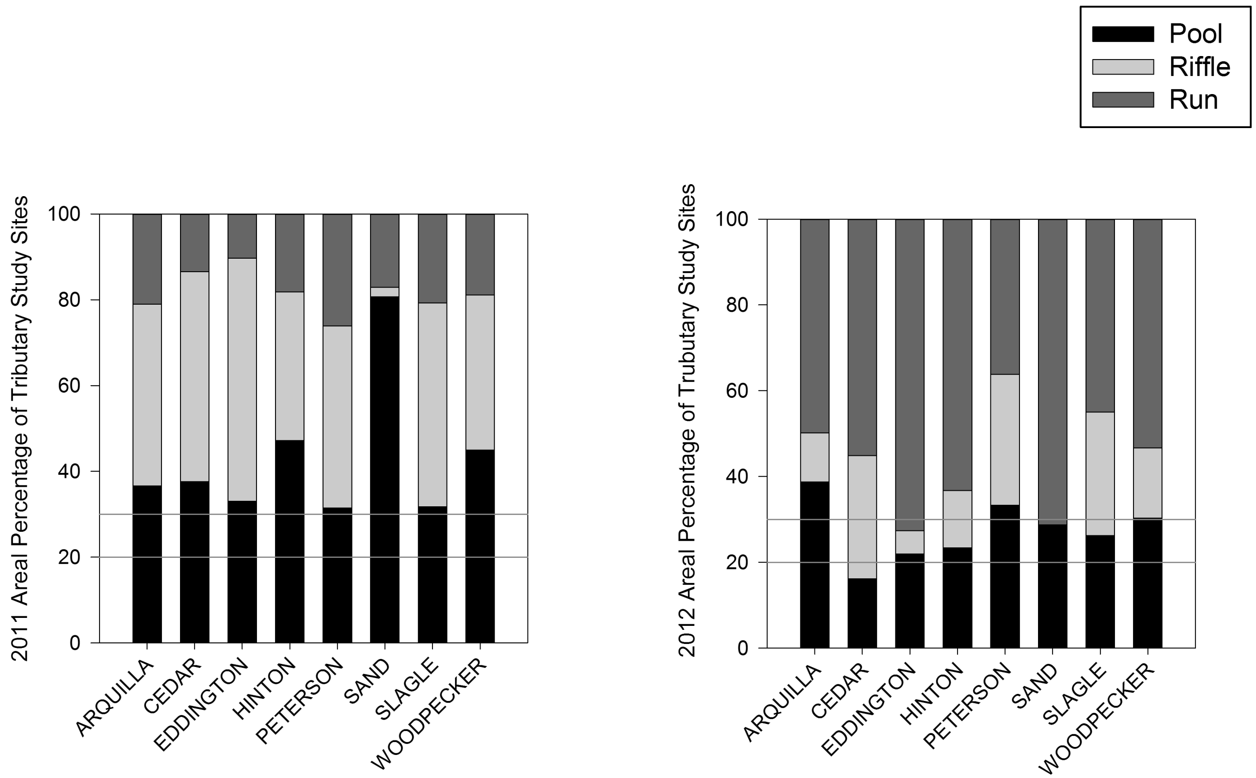

Figure 2.14: Areal percent channel geomorphic unit composition in Big Manistee River, Michigan tributaries. Data from 2011 and 2012 pebble counts. Upper and lower gray lines represent the optimal percent of pools in spawning locations (Hubert et al. 1985) and the observed percentage of pools in grayling habitat (Lamothe and Magee 2004), respectively.

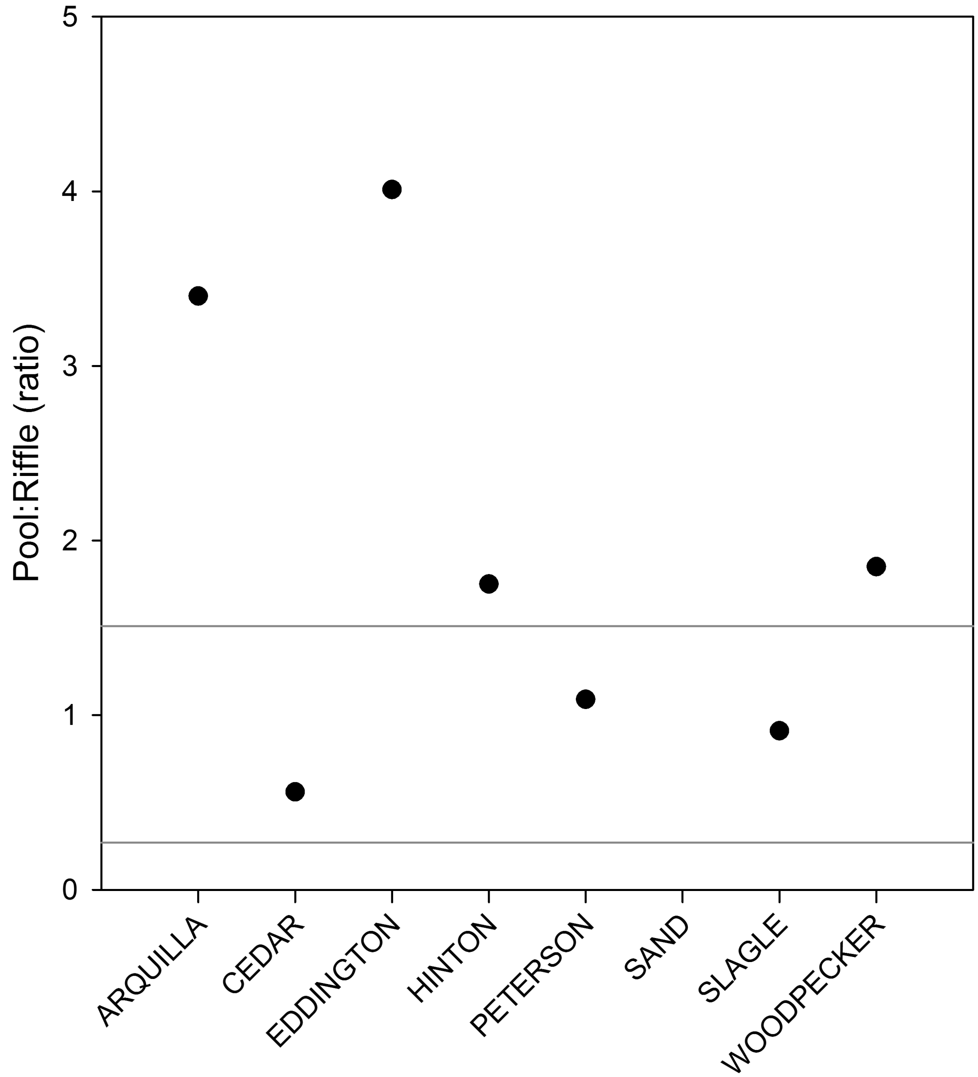

Figure 2.15: Big Manistee River, Michigan tributary areal pool to riffle ratio. Data from 2012 channel geomorphic unit measurements. Gray lines represent the range for grayling habitat Hole River (Liknes and Gould 1987).

Tables

Table 2.1: Big Manistee River, Michigan tributary abiotic condition summary. All values represent mean (standard deviation) unless noted otherwise.

Tributary	Wetted Width (m)	Depth (m)	July Temperature (°C)	Max July Temperature (°C)	Turbidity (NTU)	pH	Dissolved Oxygen (ppm)	Embedded Percent Fines (0.25-2.00mm)
Arquilla	4.3 (1.6)	0.16 (0.12)	14.3 (1.3)	18.1	2.5 (2.8)	8.1 (0.5)	9.9 (1.1)	29.40 (10.13)
Cedar	2.2 (0.8)	0.13 (0.08)	11.6 (1.1)	16.1	3.5 (4.6)	8.2 (0.3)	9.8 (1.3)	47.88 (18.00)
Eddington	2.2 (0.6)	0.11 (0.07)	10.7 (1.2)	17.3	1.8 (2.8)	7.9 (0.2)	10.4 (0.6)	48.39 (7.25)
Hinton	3.5 (1.3)	0.19 (0.11)	13.0 (2.0)	18.9	3.4 (4.3)	8.0 (0.4)	9.9 (0.9)	44.72 (11.36)
Peterson	4.2 (1.4)	0.22 (0.14)	15.0 (1.5)	19.4	4.0 (4.2)	8.2 (0.4)	9.7 (1.0)	42.38 (4.78)
Sand	1.8 (0.6)	0.11 (0.07)	13.7 (1.7)	19.2	2.6 (2.7)	8.0 (0.3)	8.8 (1.6)	35.00 (NA)
Slagle	7.5 (2.3)	0.26 (0.15)	14.5 (1.3)	17.9	1.4 (1.3)	8.1 (0.5)	9.1 (1.6)	40.71 (10.39)
Woodpecker	3.6 (1.2)	0.14 (0.07)	14.2 (2.1)	20.1	1.6 (1.2)	7.9 (0.3)	9.2 (1.0)	34.63 (3.70)

Tributary	Percent Grave/Pebble (2-256mm)	Percent Sand/Silt/Clay	D50 (mm)	Pool (%)	Riffle (%)	Pool:Riffle Ratio	Mid Summer Velocity (m/s)
Arquilla	66.66	30.33	19.5	38.75	11.40	3.40	0.19 (0.04)
Cedar	47.00	40.33	6.0	16.14	28.70	0.56	0.20 (0.12)
Eddington	64.33	31.66	13.0	21.89	5.45	4.01	0.18 (0.01)
Hinton	63.00	34.00	15.0	23.38	13.38	1.75	0.20 (0.11)
Peterson	37.00	53.00	2.0	33.31	30.53	1.09	0.15 (0.04)
Sand	6.50	85.00	2.0	28.72	0.00	NA	0.07 (0.02)
Slagle	53.66	35.33	16.0	26.19	28.81	0.91	0.38 (0.12)
Woodpecker	54.33	34.33	11.0	30.28	16.38	1.85	0.19 (0.07)

Table 2.2: Big Manistee River, Michigan mainstem and tributary temperature logger locations and years of data. Big Manistee River downstream pool and upstream pool each had two temperature loggers, while all other locations had a single temperature logger.

Temperature Logger Location	Location	2009	2010	2011	2012	2013
Arquilla Creek	Lower		x	x	x	x
Cedar Creek	Lower		x	x	x	x
Eddington Creek	Lower		x	x	x	
Eddington Creek	Middle		x	x	x	x
Eddington Creek	Upper		x	x	x	x
Hinton Creek	Lower		x	x	x	x
Hinton Creek	Middle		x	x	x	x
Hinton Creek	Upper		x		x	x
Peterson Creek	Lower			x	x	x
Peterson Creek	Middle	x	x	x	x	
Peterson Creek	Upper		x	x	x	x
Sand Creek	Middle		x	x	x	x
Slagle Creek	Lower		x	x	x	
Slagle Creek	Middle	x	x	x	x	x
Woodpecker Creek	Lower	x		x	x	x
Woodpecker Creek	Middle				x	x
Woodpecker Creek	Upper			x	x	x
Manistee River	Downstream Pool			x		
Manistee River	Upstream Pool			x		
Manistee River	Red Bridge				x	
Manistee River	Hodenpyl Dam	x	x	x	x	x

Table 2.3: Big Manistee River, Michigan mainstem and tributary mean July temperature (+stdev). Big Manistee River pool logger locations were at the bottom of each pool (bottom) and mid-column of each pool (middle). Temperature data for Hodenpyl Dam is from USGS #04124200.

Temperature Logger Location	2009	2010	2011	2012	2013
Arquilla Creek	-	14.3 (1.1)	13.8 (1.2)	14.3 (1.3)	13.1 (1.5)
Cedar Creek	-	-	11.5 (1.1)	11.6 (1.1)	10.9 (1.1)
Eddington Creek	-	10.8 (1.0)	10.6 (1.1)	10.7 (1.2)	9.0 (1.0)
Hinton Creek	-	12.5 (2.6)	13.5 (1.6)	13.0 (2.0)	12.1 (1.8)
Peterson Creek	12.2 (1.9)	14.6 (1.4)	14.3 (1.4)	15.0 (1.5)	13.7 (1.8)
Sand Creek	-	14.0 (1.6)	13.7 (1.5)	13.7 (1.7)	12.6 (1.6)
Slagle Creek	12.5 (1.2)	14.4 (1.1)	14.1 (1.2)	14.5 (1.3)	13.3 (1.4)
Woodpecker Creek	11.9 (1.9)	13.7 (1.7)	13.8 (2.2)	14.2 (2.1)	13.0 (2.1)
Manistee River - Downstream Pool (Middle)	-	-	21.0 (1.7)	-	-
Manistee River - Downstream Pool (Bottom)	-	-	20.0 (1.6)	-	-
Manistee River - Upstream Pool (Middle)	-	-	20.9 (1.5)	-	-
Manistee River - Upstream Pool (Bottom)	-	-	20.5 (1.5)	-	-
Manistee River - Red Bridge	-	-	-	22.7 (0.9)	-
Manistee River - Hodenpyl Dam	18.8 (0.3)	21.9 (0.8)	21.4 (1.2)	23.2 (0.5)	21.2 (0.8)

Table 2.4: Big Manistee River, Michigan mainstem 2013 mean July temperature (+ standard deviation) at Slagle and Woodpecker Creeks.

Tributary	Temperature Logger Location	Mean July Temperature (^{o}C)
Slagle Creek	Above confluence	21.1 (1.1)
	Downstream confluence 33m	13.1 (1.5)
	Downstream confluence 66m	20.1 (1.1)
Woodpecker Creek	Above confluence	21.2 (0.8)
	Downstream confluence 33m	21.0 (0.8)
	Downstream confluence 66m	20.9 (0.7)

Table 2.5: Big Manistee River, Michigan 2012 tributary discharges. Data represents (mean standard deviation) for early (May-June), middle (June-July), and Late (July-August) summ

Tributary	Early Discharge (m^3/s)	Middle Discharge (m^3/s)	Late Discharge (r
Arquilla Creek	0.09 (0.03)	0.07 (0.03)	0.09 (0.03)
Cedar Creek	0.05 (0.03)	0.03 (0.02)	0.04 (0.02)
Eddington Creek	0.03 (0.01)	0.03 (0.01)	0.04 (0.00)
Hinton Creek	0.11 (0.06)	0.06 (0.03)	0.09 (0.06)
Peterson Creek	0.17 (0.12)	0.09 (0.05)	0.13 (0.07)
Sand Creek	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Slagle Creek	0.54 (0.35)	0.52 (0.29)	0.52 (0.31)
Woodpecker Creek	0.09 (0.03)	0.07 (0.02)	0.10 (0.03)

Table 2.6: Big Manistee River, Michigan tributary abiotic habitat score. Data from 2009-2013 and based on whether measured values fell within the ranges for what is considered typical Arctic grayling habitat. No weighting was applied to scores.

Tributary	Arquilla	Cedar	Eddington	Hinton	Peterson	Sand	Slagle	Woodpecker
Summer Water Temp	X	X	X	X	X	X	X	X
Adult Velocity	X	X	X	X	X		X	X
YOY Velocity	X	X	X	X	X	X	X	X
Adult Depth	X	X	X	X	X	X	X	X
YOY Depth	X	X	X	X	X	X	X	X
Adult Substrate	X	X	X	X			X	X
Fry Substrate	X	X	X	X	X		X	X
Spawning Substrate	X	X	X	X	X		X	X
Spawning/fry Habitat	X				X		X	X
Adult Habitat	X		X	X	X		X	X
D_{50}	X	X	X	X			X	X
Pool:Riffle Ratio		X			X		X	
Water Quality	X	X	X	X	X	X	X	X
Winter Habitat	?	?	?	?	?	?	?	?
Total Score	12	11	11	11	11	5	13	12

Table 2.7: Big Manistee River, Michigan tributaries minimum recorded temperature for winter 2011/2012. No data was available for Cedar Creek and Slagle Creek.

Temperature Logger Location	2010/2011 Minimum Temperature (^oC)
Arquilla Creek	0.5
Cedar Creek	-
Eddington Creek	0.0
Hinton Creek	-0.1
Peterson Creek	-0.1
Sand Creek	0.0
Slagle Creek	-
Woodpecker Creek	0.5

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