MANAGING FRESHWATER RESOURCES: A CRITICAL, INTERDISCPLINARY REIMAGINING

By

Emma R. Lundberg

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The dissertation is approved by the following members of the Final Oral Committee:
Caroline Gottschalk Druschke, Associate Professor, English
Matthew Mitro, Research Scientist, Wisconsin Department of Natural Resources
Eric Booth, Associate Scientist, Agronomy and Civil & Environmental Engineering
Samer Alatout, Associate Professor, Community and Environmental Sociology
Cleo Wölfle Hazard, Assistant Professor, Equity and Environmental Justice, UW-Seattle
Ingrid Diran, Assistant Professor, English

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DISSERTATION ABSTRACT

This dissertation consists of three distinct chapters that allow me to highlight knowledge and insight across multiple disciplines, while deeply engaging with the fields of freshwater management and restoration. The research presented here includes work on what I see as three central nodes of stream restoration projects: (1) the human dimensions; (2) fish movement and reliance on riverine connectivity; and (3) innovative inclusion of environmental justice into stream restoration projects. I utilize knowledge and methodologies across the social sciences in Chapter 1 (**Divergent Perspectives on Stream Restoration in the Driftless Area, Wisconsin: a Q-method survey of practitioners**), where I use Q-method to describe four distinct ways practitioners in the Driftless Area prioritize concerns in stream restoration projects and how these different perspectives relate to key aspects of conflict surrounding Driftless stream restoration. In Chapter 2 (**Seasonal Migration in a Brook Trout (*Salvelinus fontinalis*) Population, Upper Middle Inlet, Marinette County, Wisconsin)**, I use capture-mark-recapture methods from the freshwater sciences to describe movement behaviors of a brook trout (*Salvelinus fontinalis*) population in northeastern Wisconsin to contribute toward an understanding of the role that riverine connectivity plays in this region. In the final chapter of this dissertation (**Reimaging Dam Removal to Resist Settler Colonial Logics**), I take a critical humanities-based approach to understanding and interrogating the settler colonial logics that emerge between dam construction and dam removal, then offer a creative, collaborative alternative model of river restoration that might usefully undermine—rather than reinforce—settler colonial logics. I conclude the dissertation with what I describe as an unsettling approach to freshwater restoration and management that offers a critical, science-based path into the future.

DISSERTATION INTRODUCTION

Being an avid outdoor person from rural New Hampshire, I’ve always found myself drawn to water. Lakes, rivers, puddles, wherever water flows and accumulates, I have most likely found myself splashing through it. Though water was one of my first loves, after my first day in the field with electrofishing equipment as a seasonal technician at New Hampshire Fish and Game, I realized I didn’t just love water, I deeply appreciated everything about the underwater world, from the flow and habitat, to each organism that is able to find its own way in coldwater streams. For me, the simplest way to explain how this misfit dissertation has come into being, is to briefly share the path that led me here, to this three-chapter interdisciplinary dissertation, each disciplinarily grounded and seemingly disconnected, but from my perspective, intricately connected through a web of relations, peoples and practices. I share this personal narrative, not because I am the main character of this story, but because in sharing who I have become through my web of relations, I am sharing the position from which this dissertation is written, and with that, the intentionality behind this document.

My lived experience growing up in a rural community heavily invested in the use of natural resources from a lower-income family and being a first-generation college graduate has, in many ways, shaped who I am as a researcher. My dedication to interdisciplinary science has stemmed from being taught the value of conservation at an early age, but consistently wondering how individual practices, perspectives and values have come to be, and how these aspects of human society have created both useful and detrimental constructs. Applying knowledge from the social sciences, freshwater sciences and humanities has allowed me to work toward meaningfully understanding the power human values and perspectives associated with natural resources has to shape the material realities and ecologies of the freshwater world. With this understanding, I believe the settler colonial logics that weave through the use, management, and exploitation of the natural world can not only be critiqued but can be challenged and therefore changed. As a scholar, it is my desire to ground myself and my research in the critical humanities, allowing me to critique the logics and intentions of scientific and management practice, while conducting applied science from an unsettling orientation. This dissertation is the first step toward a life-long career of walking the lines among theory, practice and application.

While I describe my research as interdisciplinary, the dissertation I present here is organized into three chapters, each grounded in different disciplines and related to core concerns of stream restoration and freshwater management. My first chapter puts the perspectives and priorities of practitioners into conversation with management objectives and the key components of conflicts that emerge around stream restoration in the Driftless Area. My second chapter uses fisheries science techniques to quantify and describe brook trout (*Salvelinus fontinalis*) movement behaviors in Northeastern Wisconsin to understand the importance of riverine connectivity in this region. While my third chapter describes the settler colonial legacies that underpin river damming and dam removal of New England riverways. In this final chapter, I offer a creative, collaborative alternative that centers environmental justice concerns in Rhode Island. Taken together, these chapters demonstrate three important components of freshwater science and restoration: (1) the human dimensions; (2) the applied freshwater sciences; and (3) the critical reimagining of possibilities. As a whole, this dissertation takes the first steps of a life-long career toward demonstrating the entangled nature of social science, aquatic science and critical humanities in the context of stream restoration and freshwater management.

In this introduction, I work to provide necessary background literature about the field of ecological restoration, broadly, with special attention to the three key themes I see as necessary to the success of stream restoration projects: (1) the human dimensions; (2) applied freshwater science; and (3) the guiding influence of the critical humanities. I provide an overview of each chapter and conclude the introduction section with a discussion of how I see these chapters coming into conversation with one another, both within and beyond the pages of this dissertation.

Introduction to Restoration and Space for Intervention

The majority of ecosystems globally are either directly or indirectly impacted by human actions (Vitousek et al., 1997). These anthropogenic impacts have led to the rise in what has been termed ecological restoration (SER, 2004; Vaughn et al., 2010; Lake, 2001). Although the definition is fraught and contested, ecological restoration is often the term used to describe the study and practice of using human intervention to assist the recovery of degraded, impaired or destroyed ecosystems (Harris et al., 2006; Lake, 2001; SER, 2004; Vaughn et al., 2010). Through active interventions, restoration aims to initiate or accelerate the recovery process of ecological structures and cycles (Vaugh et al., 2010). Active restoration interventions also offer a process for testing ecological concepts and theories (Lake, 2001). Restoration practices have rapidly increased in popularity and are increasingly incorporated into natural resource management on a global scale (Wortley et al., 2013; Vaughn et al., 2010). The practice of restoration is an important tool for responding to changing environmental conditions (Harris et al., 2006) and plays a key role in environmental policy (Suding et al., 2015). Essentially, the practice of restoration aims to provide ecological and social—though the inclusion of the social aspect is often under debate—benefits through the regeneration of ecological conditions altered by natural or anthropogenic disturbances (e.g., logging, river damming, floods, etc.), while also reestablishing the resilience and biological sustainability of an ecosystem (Suding et al., 2015;

Vaughn et al., 2010). However, although restoration work attempts to repair a system to a previously unimpaired state, the “unimpaired” state can often be uncertain (Lake, 2001).

Knowledge of ecological history is crucial to characterizing reference conditions, or reference sites, but is increasingly described as a guide rather than a template (Harris et al., 2006; Jackson & Hobbs, 2009; Vaughn et al., 2010). In this line of thinking, some scholars argue that restoration practitioners must strike a balance between restoring historic ecosystems and adapting to future environmental conditions (Harris et al., 2006). This means that in certain situations where the historic conditions are no longer appropriate or feasible due to climate change or extensive environmental degradation, actions to mitigate the impacts of future climatic conditions ought to be included in the restoration design (Jackson & Hobbs, 2009; Vaughn et al., 2010). The need to think across past, present and future conditions pushes practitioners to make practical decisions based on both historic ecological conditions and possible adaptations that will support an ecological system under future climatic regimes and land use challenges. The combination of restoration and adaptation may entail embracing novel, or emergent, ecologies (Kirksey, 2015; Jackson & Hobbs, 2009; Vaughn et al., 2010), though this embrace may be controversial (Palmer et al., 2014). Overall, practitioner decision-making about how to restore a system and to what state comes with great responsibility and is inherently tied to individual practitioner perspectives and priorities (Nost et al., 2019), as I describe in Chapter 1 in the context of stream restoration in the Driftless Area of the Upper Midwest.

The general practice of restoration faces various challenges including, but not limited to, active participation of stakeholders, pre- and post-restoration monitoring, and the spatial and temporal scales of projects. Though the need for stakeholder collaboration is often recognized, many projects do not provide opportunities for meaningful participation (Jellinek et al., 2019;

Lake, 2001). Importantly, public support for and success of restoration programs has been shown to increase when projects actively work to incorporate stakeholder participation, particularly when it comes to aquatic restoration (Reyes-Garcia et at., 2019; Carlson, 2016; Druschke & Hychka, 2015). With regard to pre- and post-restoration monitoring, data collection can often be limited, in part due to political pressures and funding limitations (Lake, 2001), especially in river restoration (Bernhardt & Palmer, 2011; Palmer et al., 2005). Beyond data limitations and stakeholder participation, the spatial concerns many restoration projects are faced with can be large challenges, as restoration projects tend to be relatively small and isolated (Vaughn et al., 2010), while larger-scale projects—for example the Penobscot River restoration in Maine (Opperman et al., 2011)—are more rare, but are likely more successful at attaining restoration goals (Palmer, 2009; Lake, 2001). The mismatch in spatial (e.g., project size:basin size) and temporal scales (e.g., rate of ecosystem damage:rate of recovery) is a major challenge for the practice of ecological restoration (Rahel, 2013). Additionally, even when a restoration project is implemented "perfectly" the result may not be the intended outcome (Suding et al., 2015), leading to a big concern in restoration ecology: uncertainty.

Uncertainty is one of the biggest challenges of restoration ecology. Practitioners are faced with many forms of uncertainty, including the effectiveness of restoration practices, climate change conditions and land use challenges (Wright, 2021; Bernhardt & Palmer, 2011; Wortley et al., 2013; Vaughn et al., 2010; Wortley et al., 2013). Aptly navigating these uncertainties can be a major challenge, especially for practitioners who are making on-the-ground decisions about project design and implementation while trying to apply the best available science and maneuvering through political, organizational and funding constraints. Chapter 1 of this dissertation aims to address some of the uncertainty of how practitioners make decisions about stream restoration in the Driftless Area by identifying four main perspectives in the region related to prioritization of concerns and techniques. In that chapter, I identify re-connectivity, specifically between stream channels and floodplains, as a core component of stream restoration projects in the Driftless, but river connectivity is a key aspect of river restoration, globally (Wright, 2021; Bellmore et la., 2017; Kondolf et al., 2006)

Connectivity is a crucial factor in freshwater ecosystems (Harris et al., 2006; Lake, 2001), with many restoration projects centrally focusing on restoring or maintaining hydrological connectivity (Torterotot et al., 2014; Poplar-Jeffers et al., 2009; Lake, 2001). This strong focus on connectivity is central to restoration practices because many aquatic organisms demonstrate seasonal, annual and daily movement patterns within river networks among discrete habitats that are necessary to life-history requirements (Drouineau et al., 2018; McRae et al. 2012; Kondolf et al., 2006; Raemaekers et al., 2009). As such, barriers to movement, including human-made dams, fragment river systems and impair connectivity, which has in part led to the use of dam removal as important aquatic restoration tool (Bellmore et al., 2016; Lake, 2001; Lundberg et al., 2017). For example, dam removal and culvert replacement can reduce habitat fragmentation and restore connectivity and hydrologic processes (Magilligan et al., 2016; Poplar-Jeffers et al., 2009) and removal of post-settlement alluvium from stream banks and floodplains can restore channel floodplain connectivity (Booth et al., 2009). In Chapter 2, I demonstrate the importance of riverine connectivity for a brook trout (*Salvelinus fontinalis*) population in Northeastern Wisconsin, where seasonal movement behaviors may be necessary to sustain trout populations, making the maintenance of free-flowing conditions a regional priority (WDNR, 2019).

Though the success of many restoration projects is assessed based on ecological objectives (Palmer et al., 2014), solely focusing on the ecological outcomes may not be the most effective evaluation (Wortley et al. 2013). For example, addressing social and cultural needs and assessing the economic value of ecosystem services are frequently cited as important markers of success, and yet, it is relatively unclear how and to what degree these attributes are incorporated into project design or assessment (Jellinek et al., 2019; Wortley et al., 2013). In Chapter 3, I use a critical humanities framework to examine the rhetorical landscape of river restoration, specifically dam removal, to critically analyze the social and cultural components of dam removal as they relate to ongoing settler colonialism. This work to incorporate a settler colonial framework provides a necessary component to the field of restoration ecology; calling researchers and practitioners to evaluate historic and ongoing colonial logics at play and how these logics and power dynamics shape the social and ecological outcomes of restoration projects.

Dissertation Chapter Overviews

With stream restoration becoming increasingly more common within the United States, debates have emerged around what constitutes "success" in restored systems and whether or not this success should incorporate both scientific and stakeholder-defined endpoints. Drawing from the field of human dimensions of natural resources and contributing to the growing body of literature related to the human-aspects of stream restoration, in Chapter 1 (**Divergent Perspectives on Stream Restoration in the Driftless Area, Wisconsin: a Q-method survey of practitioners**), we use Q-method—a mixed method, inverted factor analysis increasingly used to find common ground in environmental conflicts—to identify and describe the four distinct practitioner perspective groups in the Upper Mississippi River Basin's Driftless Area. Through our Q-method results combined with our previously collected semi-structured interview data, we found that (1) the differences between perspective groups are related to concerns about best practices for stabilizing streambanks and about post-restoration monitoring. We also found that (2) all four Q-method identified groups agree that floodplain-stream channel re-connectivity is an important aspect of restoration projects and that erosion is a big concern in the Driftless Area.

Considering the driving force in stream restoration to improve riverine connectivity, especially for salmonid species (Erkinaro et al., 2017; Gowan et al., 1994), understanding instream movement of fishes is crucial to management plans and stream restoration prioritization. In Chapter 2 (**Seasonal Migration in a Brook Trout (Salvelinus fontinalis) Population, Upper Middle Inlet, Marinette County, Wisconsin**) we use freshwater research techniques to understand the role that riverine connectivity plays for the Upper Middle Inlet (UMI) brook trout (*Salvelinus fontinalis*) population in northeast Wisconsin. We use single-pass electrofishing to capture individuals for tagging with passive integrated transponder (PIT) tags. Using PIT tag data, length-frequency histograms and standardized catch-per-unit-effort (CPUE), we were able to describe some of the seasonal brook trout movement patterns across study sites in the UMI system. Most tagged brook trout (89%) were recorded moving less than 1 km, while a smaller portion of the tagged population (11%) moved recorded distances of up to 14.7 km over the study period. Our results indicate that brook trout in the UMI system follow instream trout movement trends described in other regions across their native range, where both sedentary and long-range movements are observed and timing of these movements largely coincide with spawning season for upstream movement and post-spawn, winter downstream movement. With these data, we gather a better understanding of the role that riverine connectivity plays for this population and create a watershed-scale description of brook trout movement patterns that occur from spring to the early winter season that may be impacted by fragmentation that may limit in-stream movement, such as increased beaver damming.

To question how to move beyond thinking and working within settler colonial frameworks, we discuss the colonial logics of river restoration and dam removal in Chapter 3 (**Reimaging dam removal to resist settler colonial logics**). We argue that while there are compelling reasons to see dam construction as an example of the physical manifestation of settler colonial logics on the landscape to which dam removal may offer a remedy, dam removal projects may be just as likely to reinscribe and reinforce dominant settler colonial logics of domination and control, acting as a palliative but not a remedy to settler colonial river management practices. We offer a creative, collaborative alternative model from Rhode Island that might usefully undermine—rather than reinforce—settler colonial logics, while achieving pragmatic goals for rivers and for the human and nonhuman communities they support.

Chapters in Conversation

Though each dissertation chapter is disciplinarily discrete, encompassing three different regions and vastly different contexts, the work is connected by a shared focus across freshwater restoration and management. Each chapter takes up the task of tackling an important freshwater conflict grounded within a specific discipline; however, in practice, these conflicts are often overlapping and intersecting, making it critically important to understand not only the specific conflict at hand, but also how these conflicts connect to one another and shape the material outcomes of freshwater projects, including this dissertation.

It is my belief that including the human dimensions and critical humanities into freshwater management and restoration is critically important, particularly when it comes to conducting research, developing management goals and completing and monitoring stream restoration projects. Approaching research initiatives solidly grounded in the critical humanities makes space to incorporate transparency into researcher and practitioner values and priorities.

The use of critical humanities frameworks makes meaningful inclusion of the historic context possible, allowing for research to be reoriented toward unsettling and environmental justice-focused actions in a form that makes sense in that particular project location. The critical humanities also allow researchers to set up the guiding principles of a project that make space for "thinking differently" about inclusion, collaboration and the intentionality behind projects and management practices, which I believe is necessary.

I believe it is also important to note that a dissertation is inherently an academic construction. The purpose of a dissertation is to demonstrate disciplinarily specific knowledge in an appropriate way. In a different iteration, my dissertation may have been in a more traditional format to foster a deeper discussion of connections among chapters. For instance, if I had structured my dissertation as the draft of a book manuscript, as is appropriate in some fields of study, the connections may have been more apparent. However, I chose to structure my dissertation into three separate chapters to demonstrate knowledge and expertise across multiple fields I identify with. Although the article format allows me to demonstrate knowledge across disciplines, I have constrained my opportunities to do the work of demonstrating the deep theoretical connections among the chapters and how they weave deeply into one another. As it stands, my dissertation represents the siloed nature of higher education and thus it is broken up into distinct chapters, each article almost seemingly produced in isolation. And yet, in practice and throughout the production of this dissertation, this was not the case. I worked simultaneously across disciplines; conducting semi-structured interviews, collecting trout movement data and thinking critically about the role settler colonialism has played across my fields of study. From the political context to the ongoing role that colonialism plays in freshwater management, to how systems are (re)imagined, to the very ways that fish move through the systems we study. All of this simultaneous work across these projects has led me to what I describe in the dissertation conclusion as the practice of unsettling freshwater science, restoration and management.

When I speak about unsettling freshwater science and management, I am speaking directly about a way of being and a daily practice. Unsettling is an orientation that shapes my personal approach to the design and implementation of research that incorporates a gratitude for the multitude of engaged stakeholders, an awareness of the political context and the impacts that historic and ongoing settler colonialism have on the humans and other-than-humans that I work with. Unsettling occurs both internally and externally. Internally, unsettling requires an iterative, reflective process, where I am continuously reassessing my intentionality and ability to remain open and transparent in my engagements with collaborators and stakeholders. Externally, unsettling has much to do with the way I conduct myself and act on the accountability and responsibility I have to my research subjects and the broader community. The practice of unsettling ties my dissertation chapters together, but largely this practice has occurred beyond the pages of what I describe in the dissertation. In thinking through how to best describe how I see my chapters connecting theoretically, I see the material application of unsettling concepts I describe in chapter 3 take root on-the-ground in the research practices of chapters 1 and 2, although they can largely be described as normative science based solely on the written material.

The practice of unsettling necessitates accountability and multiple forms of care. For instance, throughout the duration of the trout movement study (chapter 2), I prioritized building relationships with local stakeholders and maintaining communication because I am accountable to those relations. Each time I would replace batteries at one of our fish monitoring systems, I would be sure to catch up with the landowners who generously allowed us to install our equipment along the stream banks on their property. Beyond the human relationships, I did everything I could to care for the individual fish we captured, including finding efficient ways to move through the individual processing to reduce the period of time fish were out of the water. The practice of care takes many forms and incorporates both the mundane everyday tasks, like intentionally releasing individuals rather than “tossing” them back into the river, as well as larger transformative steps, such as adapting new protocols to reduce handling time.

While I could likely lean into the language of decoloniality as I work to describe my dissertation research, I made the intentional decision not to. This active decision is not because I do not care about decolonial work, nor is it because I do not see the value in pushing for decolonization within the academy. On the contrary, I see a deep need for decolonization across academic institutions and across research generally; however, I do not see my own research doing the material work of decolonization. As a white female settler academic, I see my use of decolonial terminology in this context to be a façade. This is because the work I present still maintains disciplinary structure and I am conducting this work largely through normative processes. I argue that my work is unsettling because for me, decolonization is a life and career-long process that I intend to support with the power and space I am able to occupy. Unsettling science, to me, is the first step toward walking in solidarity with decolonial actions led by Indigenous elders, scholars and leaders. In my dissertation work, I did not collaborate with Indigenous communities and I have not demonstrated real decolonial action throughout my dissertation research or in the presentation of the work in this document. However, I do believe this work holds value and demonstrates the importance of interdisciplinarity and critically engaged awareness to work in solidarity with decolonial efforts.

To individuals engaging with this work, I hope I am able to demonstrate the value and importance of interdisciplinary science and research. I also hope to demonstrate the importance of approaching environmental concerns and conflicts from a multifaceted, interdisciplinary standpoint. In the process of imagining these conflicts from multiple perspectives, I hope the complexity of freshwater science and management conflicts will become more visible.

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CHAPTER 1: Divergent Perspectives on Stream Restoration in the Driftless Area, Wisconsin: A Q-method survey of practitioners

ABSTRACT

Stream restoration has become increasingly common, both globally and specifically in the United States. Though stream restoration has become a common freshwater management practice, there are debates around what constitutes “success” in restored systems and whether this success should incorporate both scientific and stakeholder-defined endpoints. In our study context, the Upper Mississippi River Basin’s Driftless Area, conflicts over stream restoration practices often center on the management and use of Driftless streams, as practitioners navigate competing perspectives about restoration approaches alongside conflicts over whose needs and interests should be prioritized in restoration planning and implementation. Based on the importance of stream restoration practitioner perspectives for mediating uncertainty and shaping on-the-ground projects, we asked **(1) What are main areas of conflict that emerge around Driftless Area stream restoration? (2) Can stream restoration practitioners be categorized into distinct groups based on their varying perspectives on stream restoration practices in the Driftless Area? (3) If so, what are these groups and how do they map onto the main areas of stream restoration conflict in the Driftless Area?** We use Q-method to identify and describe four perspectives about stream restoration practices and priorities in the Driftless Area. Our results suggest that (1) the differences between groups are related to concerns about best practices for stabilizing streambanks and about post-restoration monitoring. We found that (2) all four Q-method identified groups agree that floodplain-stream channel re-connectivity is an important aspect of restoration projects and that erosion is a big concern in the Driftless Area.

INTRODUCTION

Stream restoration has grown into a global phenomenon, with the U.S. hosting a multi-billion-dollar industry (Wright, 2021; Palmer et al., 2005). Though stream restoration has become relatively common, there is ongoing debate about what constitutes "success" in restored systems and whether success should incorporate both scientific and stakeholder-defined endpoints (Nost et al., 2019; Palmer et al., 2005; Shields et al., 2003), as well as the acceptability of various stream restoration approaches and techniques. For instance, in recent decades, academic research into stream restoration has taken a conceptual turn from a reliance on hard-engineered solutions toward more "natural," process-based designs (Palmer et al., 2005; Johnson et al., 2020). And yet, in practice, hard-engineered structures are still widely employed, including rock riprap, artificial overhead cover, and engineered flow structures (Wright, 2021; Dauwalter et al., 2019; Belby et al., 2019; Roseboom et al., 1998), largely because of a focus on bank stabilization to offer private land protection and habitat enhancement to support economically viable recreational opportunities (Bond & Lake, 2003; Wohl et al., 2015). There is further debate across restoration research and practice related to riparian vegetation: in particular in regards to grassy or treed riparian areas (Lyons et al., 2000). Some restoration projects remove riparian woody vegetation to establish grasses in an attempt to narrow and deepen channels, while providing better accessibility for fly angling (Hunt, 1993), and others preserve or add woody vegetation in hopes of offering habitat structure and forage for terrestrial biota, providing allochthonous inputs of carbon and nutrients to stream ecosystems, and creating overhead cover that may buffer streams from climate change-induced temperature increases (Fisher et al., 2012; Cross et al., 2013). These unresolved questions and differences of perspective have prompted ongoing debate about best practices and about what metrics should be used to assess the success of aquatic restoration projects (Wright, 2021; Lave, 2012; Palmer et al., 2005; Shields et al., 2003; Wohl et al., 2015; Bernhardt & Palmer, 2011). Meanwhile, on-the-ground managers are forced to navigate these layers of uncertainty, practicality, and expertise, sorting through conflicting views on restoration approaches, project implementation, and success to make decisions about what streams should be restored to and for. Moreover, the perspectives and values of managers themselves often receive less research attention than scientific debates and public stakeholder perspectives when it comes to stream restoration.

This chronic uncertainty about both ecological outcomes and human values related to restoration (Wright, 2021; Bernhardt & Palmer, 2011), and the important roles practitioners and their perspectives play in how projects are designed and implemented (Primack et al., 2021; Sher et al., 2020; Stanford et al., 2018; Hychka & Druschke, 2017), has led to conflict over shared natural resources (Vesco et al., 2020). In our study context, the Upper Mississippi River Basin's Driftless Area, conflicts over stream restoration practices often center on the management and use of Driftless streams, as practitioners navigate competing perspectives about restoration approaches alongside conflicts over whose needs and interests should be prioritized in restoration planning and implementation. Not only are managers navigating a difficult field of interests, needs, and ongoing knowledge development, they are also forced to confront constraints related to funding and practical issues of making restoration projects work within particular time frames with large excavating equipment and ongoing land use challenges.

The challenge for environmental management in the face of conflict is to mediate scientific and social uncertainties and to bring diverse and invested stakeholders together—including resource managers themselves—to develop comprehensive, meaningful solutions to regional environmental concerns (Hossu et al., 2018). Understanding these diverse and sometimes competing perspectives can help regional management agencies make science- and stakeholder-informed decisions on prioritization and public investment, landowner engagement, and improved management on private land (Seymour et al., 2010; Dukes, 2004). We proposed to use a workshop-based Q-method survey with stream restoration practitioners, including fisheries and habitat managers, water quality managers, and active volunteers, to begin the work of bringing diverse, interested stakeholders together, while also working to better understand the contours of conflicting stream restoration philosophies in the Driftless Area. We argue that this work is essential to understanding how to move forward through environmental conflict about Driftless Area stream restoration.

Based on the importance of stream restoration practitioner perspectives for mediating uncertainty and shaping on-the-ground projects, we asked **(1) What are main areas of conflict that emerge around Driftless Area stream restoration? (2) Can stream restoration practitioners be categorized into distinct groups based on their varying perspectives on stream restoration practices in the Driftless Area? (3) If so, what are these groups and how do they map onto the main areas of stream restoration conflict in the Driftless Area?**

METHODOLOGY

Study Area and Context

The Driftless Area is a 55,000 km^2 region of the Upper Mississippi River Basin characterized by its unique topography of relatively flat uplands, steep hillsides and deeply incised valleys formed over millions of years of weathering and erosion (Knox, 2019). While not all of the Driftless escaped being covered by glacial drift during the Pleistocene, the entire region has similar topography due to the dominant process of fluvial incision. The stream-dissected bedrock geology of the Driftless is composed of carbonates and sandstones that act as high-yielding aquifers contributing abundant groundwater to streams (Heyl et al., 1959; Juckem et al., 2008; Dauwalter, 2019) that currently provide year-round refuge for coldwater obligate species (Haglund & Mitro, 2017; Dieterman & Mitro, 2019). Importantly, coldwater seeps buffer water temperature against warming air temperatures in the face of climate change, allowing the region to continue to support robust populations of native brook trout (*Salvelinus fontinalis*) and naturalized brown trout (*Salmo trutta*) (Deitchman & Loheide, 2012), which are ecologically, culturally, and economically valuable species (Sievers et al., 2017; Kelly et al., 2021). The regions' dendritic system of coldwater streams, coupled with impressive densities of trout populations, attracts a passionate network of stakeholders that support and engage in the practice of Driftless Area restoration.

In addition to fluvial incision, the agricultural history of the Driftless has shaped the landscape. Starting in the 1820s, Euro-American settlers began colonizing the region and developing the land for agricultural purposes (Knox, 1977). Early settlers removed trees from steep hillsides and valley bottoms, plowed upland prairies, and drained wetlands, leading to long-lasting landscape-scale degradation (Deitchman & Loheide, 2012; Dieterman & Mitro, 2019). Tree removal and prairie plowing caused an increase in upland erosion, which, over time, led to the accumulation of post-settlement alluvium in valley bottoms, sediment deposition in stream channels, and an increase in surface runoff into streams (Dieterman & Mitro, 2019; Knox, 2006). These changes in land use and sediment dynamics transitioned many stream channels from deep and narrow to shallow and wide, and caused significant losses of in-stream habitats and population declines of aquatic life (Belby et al., 2019), notably trout species (Dieterman & Mitro, 2019). Driven by both improvements in agricultural practices that began in the 1930s and regionally increasing precipitation (Juckem et al., 2008; Deitchman & Loheide, 2012; Neri et al. 2019), baseflows of Driftless streams have increased since the 1970s, likely buffering stream temperatures against rising air temperatures (Booth et al., 2009; WICCI, 2011; Stewart et al., 2015), while also providing a vast network for coldwater obligate species (Dieterman & Mitro, 2019; Mitro et al., 2019). All of this has led to a resurgence of recreational angling in the Driftless Area, with recreational trout angling contributing an impressive $1.6 billion annually to the local economy of the Driftless (Anderson, 2016).

Trout angling in the Driftless has made this comeback in large part because of the emphasis on habitat restoration that led to the eventual success of trout stocking events and the establishment of self-sustaining populations. Native brook trout were historically abundant but widespread stream degradation caused drastic population declines or extirpation from many streams (Dieterman & Mitro. 2019), leading to the management decision to stock brook trout, brown trout and rainbow trout (*Oncorhynchus mykiss*) beginning in the 1880s to mediate these declines (MacCrimmon & Marshall, 1968). Yet, most stocking events were unsuccessful because of the poor condition of in-stream habitat (Dieterman & Mitro, 2019). In Wisconsin specifically, a series of habitat studies and experiments were conducted between the 1930s to 1990s to better understand the loss of trout populations and why these introductions kept failing (Avery, 2004; Thorn et al., 1997; White & Brynildson, 1967). This research was used to guide early fish habitat management practices in the state (Dieterman & Mitro 2019) and over time has morphed into contemporary restoration practices used by state, federal and non-profit organizations, like the Wisconsin Department of Natural Resources and local Trout Unlimited chapters. Now, because of the success of reintroduction efforts and the more than 6,000 miles of over 600 coldwater streams across the four state regions (Anderson, 2016; WDNR, 2019), the Driftless has become a nationally recognized trout fishing destination (Anderson, 2016), with the resurgence of recreational angling seemingly tied to the region's growing interest in more sustainable agriculture and to habitat-focused stream restoration efforts and riparian practices.

Although managing riparian vegetation has been long advocated as a tool for protecting the integrity of stream systems (Wenger, 1999; Lyons et al., 2000), and is a core component of Driftless Area restoration, the physical scientific components of this debate have received much more academic attention than the socio-scientific aspects. For example, there is broad agreement that the structure of riparian areas has direct ties to water quality (e.g., water temperature, shading, erosion), channel geometry (e.g., width:depth ratio, pool-riffle-run ratio) and aquatic communities (see reviews by Lyons et al., 2000; González et al., 2015; Blann et al., 2002). Ongoing research explores the differences between tree-lined and grass-lined banks, with particular attention to water temperature, streambank erosion, channel morphology and habitat characteristics, often in the context of protecting or enhancing the viability of cold-water species (Gaffield et al., 2005; Moore et al., 2005). Even though the ecological relationships between riparian vegetation and water quality are robust research foci in the Driftless, much less attention is focused on how regional managers make decisions and prioritize locally-specific concerns about bank stabilization, angling access, and increases in stream temperature related to riparian vegetation, while also meeting established restoration project objectives.

Due to the complex relationships among science and practice, historic contexts, and many lingering social and scientific uncertainties, understanding how practitioner perspectives and priorities shape the structure and function of stream restoration projects in the Driftless becomes crucial, with lessons for freshwater ecosystems more broadly. We use a Q-method survey to describe stream restoration conflict and to understand how issues of erosion, water temperature, restoration techniques and devices, and project goals are prioritized in the process of designing and implementing restoration projects. We also use Q-method to highlight similarities and incongruities among practitioner perspectives, an arena that has received limited research attention relative to restoration science, yet shapes projects and produces ecological outcomes.

Q-Method Survey

Given the scientific and social uncertainties associated with stream restoration practice and the importance of first understanding what the main topics of conflict are, followed by learning how individual and group perspectives on stream restoration shape on-the-ground projects, we examined whether contested perspectives on stream restoration in the Driftless Area could be characterized into distinct groups. We also investigated how these groupings map onto the major concerns of stream restoration conflict in the Driftless Area. To answer those questions, we used an adapted version of Q methodology (Stenner & Rogers, 2004). The method has been widely applied across disciplines, including in environmental conflict research (Brannstrom, 2011; Ellis et al., 2007; Kangas et al., 2010; Mattson et al., 2006; Ray, 2011), and has more recently been used to demonstrate the method's practicality for understanding the role of stream restoration in state regulatory programs (Nost et al., 2019).

We join a suite of researchers who identify the methodology's limitations but still find value in its methods (Druschke et al., 2019; Nost et al., 2019; Robbins & Krueger, 2000). We have published on our adaptation of the method to focus not on participants' subjective experiences but on their identification with various persuasive arguments about the issue at hand: as "a process where participants demonstrate their affinities with particular statements and are placed in relation with other people, through statistical analyses, around those affinities or points of identification with particular discourses and arguments'' (Druschke et al., 2019; p 10). Though participants may align with one specific group, sorts that align with two or more are referred to as “confounding sorts” in Q-method (Zabala, 2014). Confounding sorts are often removed from data analyses and interpretations, but as Nost et al. (2019) articulate, confounding sorts highlight some of the duality of subjectivity and subject positions, highlighting “strategic choices or hybrid identities” (p. 25), adding valuable nuance to the interpretations.

Q involves a 5-step process: 1) developing a comprehensive list, or concourse, of arguments; 2) selecting a representative subset of arguments, or Q-set; 3) identifying participants, the P-set; 4) administering the prioritization exercise, called the Q-sort; 5) analyzing and interpreting the data collected through the Q-sort. Our concourse (589 statements) was informed by a series of semi-structured interviews (n = 16) with stream restoration managers, decision-makers, and researchers in the Driftless Area. Our research team coded the interview transcripts and selected representative statements. The 25 arguments used in the final Q-set for the participant survey were related to riparian management preferences, stream process versus form, flooding concerns, issues surrounding the best available science and the primary goals of stream restoration projects (Figure 1).

In February 2020, we held a Q-methodology workshop at the Trout Unlimited Driftless Area Restoration Symposium in La Crosse, Wisconsin. We asked participants (N = 35) to organize a paper-based set of 25 statements based on their affinity to these arguments in relation to one another along a pre-set distribution. We collected demographic information from participants (e.g., gender, age, occupation, years of interest and experience in stream restoration) to inform our interpretation of the resulting groups that emerged from the data.

Statistical Analyses

We used PQMethod, an open access, downloadable software designed for use with Q studies, to complete an inverted—by person as opposed to by variable—factor analysis and followed existing protocols for analysis (http://schmolck.userweb.mwn.de/qmethod/). Once intercorrelations among Q sorts were computed, we performed a Principal Components Analysis (PCA). We then performed a Varimax rotation in PQMethod (Nost et al., 2019). We selected relevant factors and flagged the Q sorts that heavily associate with each factor to include them in defining each factor. After performing final analysis of the rotated factors, we exported the results and qualitatively described each factor using distinguishing statements (http://schmolck.userweb.mwn.de/qmethod/).

RESULTS

Q workshop data confirmed the existence of conflicting viewpoints on stream restoration in the region and resulted in the identification of four distinct groups of participants based on their perspectives on stream restoration in the region. These distinct groups, known as “factors” in Q parlance, are summarized below, followed by demographic information about each group. We use the term group (rather than “factor”) for simplicity and include statements from the Q-sort to aid in the description process (Fig. 1). To show how each of the groups sorted a particular statement, we provide the statement number in parentheses, followed by the ranking of that statement from one to four by each of the four factor groups (e.g. #21; 2 1 2 0).

Participant Demographics

Seven participants in our Q-study self-identified as female and 27 as male. Age of participants ranged from 18 to 76+, with the majority falling between the ages of 36 and 55 (60%). All female participants were under the age of 55. Participants self-reported their knowledge of Driftless Area stream restoration on a scale of 1 to 5, with a median of 4, suggesting most individuals are confident about their stream restoration knowledge (range 2-5). Self-reported interest/years of experience in Driftless stream restoration had a median of 15 years (range 1-48 years). Participant occupations include: engineers (5); fisheries biologists (9); soil conservationists (7); watershed project coordinators (3); water quality biologists (1); habitat specialists (3); and non-profit volunteers (7).

Statement	Group 1	Group 2	Group 3	Group 4
1. Restoration won't truly improve a stream without good riparian and upland land management practices.	4	1	3	3
2. It's important for stream restoration projects to be designed based on the best available science.	3	2	3	4
3. We shouldn't try to restore back to oak savanna.	-2	-1	0	-1
4. Post-project monitoring is not an essential component of stream restoration.	-2	0	-2	-4
5. Box elders contribute to streambank erosion.	0	4	0	-1
6. Current stream restoration practices are as much about keeping anglers happy as they are about trout.	0	-1	0	0
7. Cattle are a useful stream restoration tool.	1	2	1	1
8. Floodplain reconnection should be a central focus of stream restoration.	3	3	4	3
9. You're going to see a lot of things called restoration that are really band-aids.	1	1	1	2
10. A stream that's 100% Brown Trout is not healthy.	-2	-2	0	0
11. Restoration projects should be planned and coordinated across watersheds.	2	3	1	2
12. Driftless stream restoration projects take too much of a cookie-cutter approach.	0	1	-1	0
13. We shouldn't be armoring streambanks with riprap because that limits what streams naturally do.	0	-3	-3	1
14. If you just leave everything in the stream alone it will eventually take care of itself.	-1	-1	-3	-1
15. Beaver are a valuable stream restoration tool.	1	0	-2	0
16. The primary goal of restoration efforts should be growing large Brown Trout.	-3	-2	-1	-2
17. Riparian reforestation is essential for cooling Driftless streams in the face of climate change.	0	-3	-1	-1
18. We shouldn't wait for stream healing to happen. We need to push things in a direction that we want it to go.	-1	1	2	-2
19. The best way to address erosion in the Driftless Area is to use rock riprap.	-3	2	1	-3
20. The biggest test of a stream restoration project is if it can withstand a major flood.	2	0	2	1
21. Stream restoration projects help alleviate flood impacts.	2	1	2	0
22. Does it really matter today what pre-settlement is? We should be thinking about what the condition should be in the future.	-1	0	-1	2
23. We should be more hesitant about constructing new stream restoration projects in light of recent flooding.	-1	-1	-2	1
24. We should work opportunistically to restore every stream reach that comes available for a project.	1	-2	0	-3
25. Erosion isn't as much of a problem in the Driftless as people think it is.	-4	-4	-4	-2

Figure 1: The Q-sort Factor Table shows the Q-set statements (n = 25) on the left and the four perspectives that resulted from an inverted factor analysis on the right. The right side of the table shows how an ideal sort for the specific group would organize the statements. The dark blue squares (+4) are the statements that each group most agreed with. The dark red squares (-4) are the statements that groups most disagreed with. As the colors fade and the numbers move from +4 – 0 and from -4 – 0, the statements become lower priority relative to the darker squares. Group 1 is ***beyond-the-channel****, Group 2 is* ***tree removal & bank stabilization****, Group 3 is* ***active intervention*** *and Group 4 is* ***post-restoration monitoring & best available science****.*

Group 1: Beyond-the-channel

Group 1 prioritizes upland land management practices and completing as many projects as possible, whether projects are opportunistic or coordinated across watersheds. Group 1 is distinguished by both the statements they prioritized (i.e., upland management practices, stream-floodplain reconnection, best available science, erosion is a major concern) and the statements they ranked neutrally (#5, #6, #12, #13, #17) in the Q-set. Group 1 did not prioritize statements about riparian tree management (e.g., box elder [*Acer negundo*] causing bank erosion [#5] and riparian reforestation [#17]), but they do agree restoration projects in the Driftless should be modeled after the historic oak savanna landscape (#3). Group 1 is also distinguished from other groups by their slight agreement that beaver may offer some value to stream restoration (#15). Although they believe erosion is a major concern in the Driftless (#25), they do not believe rock riprap is the best tool to address erosion concerns (#19).

The 17 participants who clustered on Group 1 reside in four states (Wisconsin [7], Iowa [5], Minnesota [4], Illinois [1]), with the majority (10) between the ages of 36 to 55. Two participants identified as female, and fifteen as male. Fifteen individuals identified as being professionally involved in stream restoration (e.g., biologists, district conservationists, fisheries and habitat specialists, and watershed coordinators). With regard to formal education, almost all (15) held bachelor’s or graduate degrees. Individual years of interest and experience in stream restoration ranged from 1 to 48 years, with a median of 15 years of experience. Self-reported knowledge of Driftless stream restoration ranged from 2 to 5, with a median of 4.

Group 2: Tree removal & bank stabilization

Group 2 prioritizes tree removal and bank stabilization practices as primary tools for reducing erosion concerns in Driftless streams. They see value in having access to a variety of restoration tools (e.g. rock riprap, velocity weirs, wooden habitat devices, etc.), including some more experimental techniques (e.g. rotational grazing, *in situ* project design changes, etc.), *in certain circumstances*. For example, these participants are open to using cattle, or rotational grazing, as a restoration tool (#7), an idea that has been gaining support in recent years (Hulvey et al., 2021). These individuals believe erosion is a major issue in the Driftless that can be mediated with the use of rock riprap (#19) without limiting the natural–but often human accelerated–process of erosion in streams (#13). Group 2 does not believe that riparian reforestation is essential to maintain stream temperature under increasing climate change risk (#17), and they do not highly prioritize good riparian and upland land management practices (#1), while the other groups do. This may suggest Group 2 is more invested in in-stream restoration practices and structural-based fixes (e.g., erosion control, streambank sloping, physical habitat structures, etc.) as opposed to taking a more landscape-based approach, though they do strongly agree restoration projects should be coordinated across watersheds (#11).

Ten participants clustered in Group 2, with nine providing demographic information. These individuals reside in three different states (Wisconsin [4], Iowa [3], Minnesota [2]), with the majority between the ages of 46 to 75. Eight identified as male, and one as female. Group 2 is composed almost entirely of stream-related professionals (e.g., biologists, district conservationists, fisheries and habitat specialists, watershed coordinators), and includes one farmer. With regard to highest education level attained, two participants hold high school diplomas or GEDs, six participants hold a B.A. or B.S. degree or equivalent experience, and one participant holds a graduate degree. Individual interest and experience in stream restoration ranges from 2 to 42 years, with a median of 10 years of interest and/or experience. Self-reported knowledge of Driftless stream restoration ranged from 2 to 5, with a median of 4.

Group 3: Active intervention

Group 3 takes an active intervention approach, where practitioners must take action using the best available science to shape the direction of stream healing. Group 3 is distinguished from other groups by their belief that if left alone, streams will not be able to simply repair themselves (#14). Rather than waiting for stream healing to slowly occur, they believe practitioners should support healing in the direction they want it to go (#18). Though all perspective groups generally agree that an important aspect of stream restoration includes reconnecting the stream to its floodplain (#8), Group 3 individuals agree more strongly with floodplain re-connectivity relative to the other statements in the Q-set. They do not believe Driftless restoration takes on a cookie-cutter approach (#12). As opposed to other groups' neutral ranking, Group 3 is not supportive of embracing beavers for stream restoration (#15).

Nine participants make up Group 3. These 9 individuals reside in three different states (Wisconsin [6], Iowa [1], Minnesota [2]). The majority of participants are between the ages of 18-55. Eight participants identified as male, and one as female. Most individuals in Group 3 are stream-related professionals (e.g., biologists, district conservationists, fisheries and habitat specialists, watershed coordinators), with one religious professional and one non-profit conservation employee. With regard to formal education, all individuals hold bachelors or graduate degrees. Individual interest and experience in stream restoration ranges from 5 to 42 years, with a median of 20 years of interest and experience. Self-reported knowledge of Driftless stream restoration ranged from 3 to 5, with a median of 4.

Group 4: Post-restoration monitoring & best available science

Group 4 prioritizes the combination of post-restoration monitoring and the use of best available science to complete projects using an intentional, not opportunistic, watershed-level restoration approach. Group 4 is distinguished from other factors by their strong belief that stream restoration projects should be guided by the best available science (#2), developed with insight from post-restoration monitoring (#4). Unique to Group 4, these individuals agree that some management actions called “restoration” are really more like ‘band-aids’ (#23), palliative but not solutions to the underlying issues. They do not believe restoration practitioners should take immediate actions to direct stream healing; sometimes leaving streams alone may be the best practice (#18). While Group 4 is concerned about erosion in the Driftless (#25), they do not believe rock riprap is the best solutions for unstable stream banks (#19). Group 4 is slightly hesitant about constructing new restoration projects in light of recent flooding events (#23), while all three other groups are less concerned about flooding.

Ten participants make up Group 4. These ten individuals reside in three different states (Wisconsin [5], Minnesota [3], Iowa [2]). Most individuals are between the ages of 36 to 55. Six individuals identify as male, while four identify as female. Group 4 is composed of all stream-related professionals (e.g., biologists, district conservationists, fisheries and habitat specialists, watershed coordinators, engineers, research scientists) and all hold bachelors or graduate level degrees. Individual interest and experience in stream restoration ranges from 1-29 years with a median of 18.5 years of interest and experience. Self-reported knowledge of Driftless stream restoration ranged from 3-5 years, with a median of 4.

Table 1: The Q-method summary table displays key points from each of the four perspective groups with associated distinguishing statements and demographic data. "n" column is the total number of individuals included in each group and the "CS" column is the number of confounding sorts included in each group.

	Summary	Distinguishing Statements	n	CS	Demographics
Group 1: Beyond the channel	• Supports upland land management practices. • Complete as many projects as possible, both opportunistically and coordinated across watersheds. • Prioritizes floodplain connectivity, upland land management, bank stabilization over debates in riparian vegetation. • Erosion is concerning, but rock riprap is not the best solution.	#15, #5, #17, #18, #3	17	8	4 states; 2 females 15 males; 15 stream professionals; 15 bachelor's or higher; experience 1 – 48 years; median of 4 out of 5 self-reported restoration knowledge.
Group 2: Tree removal & bank stabilization	• Supports riparian tree removal to stabilize streambanks and reduce erosion. • Values a diverse restoration toolkit (e.g., structural devices, rotational grazing, etc.). • Most invested in in-stream restoration practices and structural-based solutions opposed to landscape approach.	#5, #11, #7, #19, #1, #12, #18, #20, #4, #24, #17, #13	10	4	3 states; 1 female 8 males; 8 stream professionals; 2 high school diplomas or GED 6 bachelor's 1 graduate degree; experience 2 – 42 years; median of 4 out of 5 self-reported restoration knowledge.
Group 3: Active intervention	• Supports active intervention approaches rather than "hands-off" approaches. • Streams need help to heal and the goal of the manager should be to direct the stream healing process. • Strongest supporters of reconnecting stream channels to their floodplains.	#8, #18, #19, #16, #12, #15, #23, #13, #14	9	4	3 states; 1 female 8 males; 8 stream professionals; 9 bachelor's or higher; experience 5 – 42 years; median of 4 out of 5 self-reported restoration knowledge.
Group 4: Post-restoration monitoring & best available science	• Supports use of post-restoration monitoring to develop and use the best available science to direct stream restoration projects. • Does not support the use of rock riprap. • More invested in long-term stream healing opposed to immediate interventions.	#2, #9, #23, #21, #18, #25, #24	10	5	3 states; 4 females 6 males; 10 stream professionals; 10 bachelor's or higher; experience 1 – 29 years; median of 4 out of 5 self-reported restoration knowledge.

DISCUSSION

In our study of stream restoration practitioners in the Driftless Area, we used Q to describe stream restoration conflict and identify four unique approaches to stream restoration projects: **(1)** Beyond-the-channel; **(2)** Tree removal & bank stabilization; **(3)** Active intervention; and **(4)**

Post-restoration monitoring & best available science. Our use of Q has also allowed us to describe common goals and priorities that practitioners in the Driftless Area share.

Summaries of Each Stream Restoration Group

Group 1: Beyond-the-channel. Group 1 prioritizes upland land management practices that are beneficial to stream health and the success of restoration projects more so than the other three groups. Group 1 also prefers to complete as many projects as possible, regardless of whether these projects are purely opportunistic or coordinated across watersheds. Though erosion is clearly a major issue to Group 1, they believe alternatives to rock riprap would be more beneficial for controlling erosion and stabilizing stream banks than the current practice of installing rock riprap for bank stabilization.

Group 2: Tree removal & bank stabilization. Group 2 prioritizes riparian tree removal for bank stabilization more so than the other three groups and does not support the use of reforestation to maintain cold temperatures in streams (a contentious topic in the Driftless), even in the context of climate change-induced stream warming. Group 2 does not prioritize upland land management, a priority of the other groups. Similar to Group 1, Group 2 prioritizes more in-stream restoration practices and structural fixes, as opposed to the more hands-off approach preferred by Group 4. Group 2 is also set apart from the other three groups by their strong reliance on rock riprap for controlling streambank erosion.

Group 3: Active intervention. Group 3 prefers to take an active intervention approach to stream restoration, meaning they believe that in order for a stream to heal properly, practitioners must guide the healing process in the direction they want it to go. This preference for a hands-on, active approach differs greatly from Group 4, which has a preference for a more hands-off stream restoration approach, essentially allowing a stream to restore itself overtime when possible. The hands-on approach preferred by Group 3 points to a difference in temporal scale for stream restoration projects; practitioners work toward restoration goals that may be accomplished within a human life, which is vastly different from stream healing that might occur on a geologic time-scale over many lifetimes.

Group 4: Post-restoration monitoring & best available science. Group 4 is uniquely identifiable by their strong support for the use of the best available science developed through post-restoration monitoring efforts. Though Group 4 strongly prioritized post-project monitoring, while the other three groups did not, all groups support the use of best available science. Since post-project monitoring effectively leads to improving the best available science, it is important to better understand the absence of post-project monitoring and ways to increase its inclusion in future projects. Similar to Group 1, Group 4 does not support the widespread use of rock riprap.

Group 4 is demographically distinct from the three other groups. More self-identified females (n=4) were associated with Group 4 than the other groups. Group 4 also has with the narrowest range of self-reported interest and experience in stream restoration with the second highest median value (18.5 years).

Similarities & Incongruities Across Groups

Along with identifying four distinct perspective-based groups, our Q data revealed shared points of agreement among the groups. In Q terms, consensus statements are ideas or arguments that participants across groups rank exactly the same, effectively removing the statements from helping to distinguish between groups (van Exel & de Graff 2005). In our Q data, we did not have any true consensus statements; however, we did find key points of agreement ranked similarly across the groups, suggesting shared priorities across Driftless stream restoration more broadly. In line with previous research, our Q survey results reiterate that stream channel and floodplain reconnection, bank stabilization, and improving trout habitat are major concerns (Belby et al., 2019). Additionally, our results point to areas of conflict that arise over the use of rock riprap, the varying levels of concern about erosion, and about post-restoration monitoring.

All four groups prioritize floodplain reconnection (#8) and are concerned with streambank erosion (#25). None of the groups prioritize the goal of angler satisfaction over benefitting trout populations (#6). All groups are neutral toward or slightly agree that some restoration projects may serve as ‘quick fixes’ for in-stream concerns rather than long-term or landscape-scale solutions (#9). Three of the four groups strongly prioritize riparian and upland land management practices into stream restoration practices in the Driftless Area (#1), suggesting broad regional agreement among Driftless practitioners.

Interestingly, all groups rank statements related to brown trout (#10, #16) either neutrally or unfavorably. This lack of prioritization across all groups was surprising because (1) stream restoration projects often seem designed with brown trout in mind and anecdotally increase the abundance of large-bodied individuals and (2) recreational trout angling contributes approximately $1.6 billion to the local economy, annually. This divergence between explicitly stated priorities and project outcomes aligns with anecdotal observations from Dieterman and Mitro (2019), who noticed that although physical habitat structures benefit the production of large brown trout (e.g., pools >25-in deep with woody habitat, instream rocks, overhanging bank cover, etc.), few projects state the goal of increasing brown trout abundance.

Channel-floodplain connectivity & bank stabilization

The Q results demonstrate an obvious widespread desire to reconnect stream channels with their floodplains across all groups. This sentiment is reflected in state, federal, and non-profit organization restoration project designs, which often employ bank re-sloping at a 3:1 or 2:1 ratio completed along incised stream channels. The positive impact of current bank sloping practices on reducing local erosion and potentially reducing flood intensity is an open question; full floodplain-channel re-connectivity likely will not be achieved without significant removal of post-settlement alluvium soils that allows the stream channel to function naturally. However, full floodplain reconnection by sediment removal is very rare due to a variety of challenges, including lack of funding, sediment disposal issues, loss of agricultural production land for restoration and the uncertainty of long-term effectiveness of this technique (Belby et al. 2019). Although there are limitations with regard to true channel-floodplain reconnections, this concern is a high priority for Driftless Area stream restoration practitioners and current bank-sloping practices and floodplain restoration alternatives could likely benefit from flexibility to incorporate more innovative approaches with accompanied research attention.

Closely tied to channel-floodplain reconnection is the shared concern of bank stabilization (a.k.a. erosion control). In the context of Driftless Area stream restoration, it is not surprising that concern about erosion is a very high priority for practitioners. Bank re-sloping is often coupled with stabilization techniques that are used to reduce erosion. Current stream management and restoration regimes frequently require bank stabilization techniques (e.g., hard structural elements) to mitigate concerns of property damage or loss, flood hazards, and potential impacts to aquatic habitats caused by fine sediments (Florsheim et al., 2008). We were, however, interested to find that although three groups prioritize concerns about erosion, Group 4 did not. It is possible that although Group 4 is concerned about erosion, the other issues in the Q-survey were more important to them. Another alternative could be that Group 4 might have a more nuanced perspective about erosion, with some level of erosion being an essential component of a healthy, functioning riverine system.

Rock riprap

The use of rock riprap is allowable in the Wisconsin state code with a permit and is a commonly used technique for erosion control and bank stabilization (Florsheim et al., 2008; Belby et al., 2019). Not surprisingly, the use of rock riprap emerged from our Q data as an important and distinguishing issue among the stream restoration approaches. The groups are divided evenly over the use of riprap; Groups 2 and 3 support the use of riprap to reduce erosion, while Groups 1 and 4 do not. The use of large rock riprap and ‘dirting’ techniques to stabilize banks and reduce erosion has seen widespread use across the Driftless Area (Belby et al. 2019); however, this extensive use of riprap may actually cause additional erosion concerns, while also reducing hydrologic functioning and diminishing essential habitats (Massey et al., 2017). Essentially, by ‘rocking’ the streambanks and covering the riprap or large rock with dirt, restoration projects attempt to stabilize streambanks, but, in the process, are likely contributing to future bank erosion without addressing the underlying issue of the existence of post-settlement alluvium. Additionally, the cumulative effect of widespread bank stabilization structures may limit riparian function and reduce important habitats for riparian species (Florsheim et al., 2008). Since erosion is a natural process in stream systems and an active sediment supply is not necessarily always detrimental to aquatic species and habitats (Florsheim et al., 2008), future projects in the Driftless might benefit from experimental stream work that seeks to find a balance between beneficial and deleterious bank erosion with reduced use of hard bank stabilization structures.

Ideally, a better understanding of context-specific use of rock riprap and how these large bank re-sloping, rock riprap then “dirted” projects impact the local ecologies of streams would also be beneficial to improve stream restoration practices.

Riparian vegetation

We were surprised to find that while Groups 1, 3 and 4 generally were neutral about riparian reforestation as a tool for mitigating climate change-induced stream temperature warming [17], Group 2 strongly disagreed with the use of reforestation. This disagreement suggests Group 2 may be more invested in streambank tree removal, particularly removal of box elder (*Acer negundo*)—an early successional tree species with a shallow root system—to help reduce erosion, while working to restore the Driftless landscape toward a prairie oak savanna condition that may have existed historically. Based on the literature and our preliminary interviews, we expected the issue of riparian vegetation to be much more divisive and clear-cut than it appears from the Q results. One reason for this may be because participants were forced to make difficult choices about how to best prioritize the concerns provided in the Q-set. It is possible that although riparian vegetation is a major topic of contention, other concerns (e.g., erosion, floodplain reconnection, riprap, etc.) were prioritized over perspectives on riparian vegetation. Additionally, it is important to note that although stream restoration in the Driftless is slowly shifting from removal of all trees along the project corridor toward keeping select trees, depending on species, location, etc., most trees within the project area are removed to make space for safe and efficient movement of restoration equipment (e.g., excavators, backhoes, etc.) throughout the project area (personal communication), as well as improving access to the stream for recreational purposes.

Paradox of limitations

We find the term *paradox of limitations* useful to describe what we see as a missing component in the Driftless Area stream restoration conflict we have described above. Essentially, the paradox of limitations occurs when the practices available to practitioners are driven and bounded by established, and socially accepted practices, regardless of individual desires to make different decisions, or prioritize different concerns. For example, post-restoration monitoring is strongly supported by Group 4, but not highly prioritized by the other three groups even though all four groups support the use of best available science, which is inherently linked to post-restoration monitoring. Even with practitioner support for post-restoration monitoring, there are institutional limitations that cause practitioners to make difficult choices about how to best accomplish monitoring tasks, while also being required to move on to different projects. There are limitations of funding, labor and resources that create boundaries around what is feasible for on-the-ground practitioners. Hence, the paradox of limitations is the concept that helps make sense of the fact that what is possible for individual practitioners to do and prioritize is most often bounded within established guidelines, acceptable protocols, and funded structures and aspects of projects that are institutionally, socially, or contractually binding.

CONCLUSION

In this research, we set out to describe the contours of environmental conflict that emerge around Driftless Area stream restoration. Using a Q survey we developed from a set of semi-structured interviews with stream practitioners, we worked to understand if Driftless Area stream practitioners can be separated into distinct groups based on their affinities to particular statements, and when they did, we described each group and how they related to one another.

From our Q survey, we were able to identify and describe four distinct approaches to stream restoration in the Driftless Area: **(1) Group 1** (Beyond-the-channel) individuals who prioritize upland land management completing projects regardless of whether they're coordinated across watersheds or done opportunistically; **(2) Group 2** (Tree removal & bank stabilization) individuals who prioritize tree removal and the use of rock riprap to reduce stream bank erosion; **(3) Group 3** (Active intervention) individuals who believe stream restoration will only be successful with an active, hands-on approach; and **(4) Group 4** (Post-restoration monitoring & best available science) individuals who prefer to take a watershed approach to stream restoration using a more hands-off technique that utilizes the best available science developed from post-restoration monitoring efforts.

We found that all four groups align in their belief that floodplain-stream channel re-connectivity is an important aspect of restoration projects and that erosion is a big concern in the Driftless Area. When it comes to the actual debate surrounding stream restoration in the Driftless, we suggest that there exists what we call a paradox of limitations.

While the concepts and findings from this research may resonate with coldwater stream restoration elsewhere, it is important to note that the use of Q is context specific, meaning this work reflects the Driftless Area stream restoration community rather than the *Stream Restoration Community*, broadly. Although this research is context specific, it does provide a foundation for future human dimensions of stream restoration research in other contexts. Future and ongoing social science-based stream restoration research might consider a more robust narrative surrounding gender-based differences among stream restoration practitioners. We suggest researchers consider shifting focus toward the roles that non self-identifying males or nonbinary individuals find themselves carving out, and the ways that these roles have the potential to shape stream restoration into the future.

We also suggest taking a multidisciplinary and collaborative approach to stream restoration research. For example, because stream restoration projects are diverse and led by organizations and practitioners with specific perspectives, priorities, and opinions, the stream restoration projects are inherently context-dependent and require both multiple disciplines and collaboration across social and institutional boundaries. By integrating a diverse set of perspectives and disciplinary footings, diverse knowledge and experiences, project practitioners may be able to better work toward identifying core components of perceived project successes, while also working toward finding common ground among different perspectives associated with different practitioners and decision-makers that have real, material impacts on the landscape and socio-ecological outcomes of projects.

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CHAPTER 2: Seasonal Migration in a Brook Trout (*Salvelinus fontinalis*) Population, Upper Middle Inlet, Marinette County, Wisconsin

ABSTRACT

Movement behaviors of instream salmonids have broad ecological and evolutionary impacts, affecting individual fitness, metapopulation dynamics, distribution and abundance, gene flow, and the success of management practices. Additionally, effective fisheries management necessitates reliable information on population size, survival, and size structure, all of which are centrally linked to movement patterns. With temperature and habitat fragmentation both often cited as two of the most important conservation concerns for brook trout (*Salvelinus fontinalis*), coupled with the rise in popularity of beaver conservation and its implications for habitat fragmentation, movement has become a critical variable to understand in order to support management objectives for inland trout fisheries in Wisconsin. Given this context, we ask: **(1) What is the timing and extent of brook trout (*Salvelinus fontinalis*) seasonal movement in northeastern Wisconsin? And (2) How might observed movement patterns influence decisions about stream restoration and beaver management?** In the Upper Middle Inlet, we use single-pass electrofishing to capture individuals for tagging with passive integrated transponder (PIT) tags. Using PIT tag recapture data, length-frequency histograms and catch-per-unit-effort (CPUE) data, we were able to describe seasonal brook trout movement patterns across the UMI system. We found most tagged brook trout recorded within season movements less than 1 km (89% of sequential detections), while a smaller portion of the tagged population (11% of sequential detections) recorded distances of up to 14.7 km over the study period. Our results indicate that brook trout in the UMI system follow instream trout movement trends described in other regions, where both site fidelity and long-distance movements are observed. Timing of

these movements largely coincide with spawning season for upstream movement and post-spawn downstream movement in the early winter. With these data, we gather a better understanding of the role that riverine connectivity plays for this population and create a watershed-scale description of brook trout movement patterns that may be influenced by changes in riverine connectivity, including potential changes in beaver control.

INTRODUCTION

Freshwater scientists have invested decades of research into better understanding movement behaviors of instream salmonids (Kanno et al., 2021; Peterson et al. 2005; Curry et al. 2002; Burrell et al. 2000; Petty et al. 2012; Kahler & Quinn 1998). The ways salmonids move across riverscapes have broad ecological and evolutionary impacts, affecting individual fitness (White & Wagner, 2020), metapopulation dynamics (e.g., population size, population survival) (Rieman, & Dunham, 2000), distribution and abundance (Kanno et al. 2021), gene flow (related to adaptation and speciation) (Timm et al. 2016) and the success of management practices (Ousterhout & Semlitsch, 2013; Pine et al. 2003). Seasonal movement patterns are particularly important in regions with harsh winter environments where ice conditions may limit access to necessary habitats (Lindstom & Hubert, 2004; Cunjak, 1996; Chisholm et al., 1987). Like other regions, coldwater streams in Wisconsin are facing unprecedented changes in hydrology and increasing water temperatures (WICCI, 2011), which will likely cause seasonal declines in available trout habitat (Mitro et al., 2019). Changes in hydrology and temperature coupled with concerns about riverine connectivity issues have made the seasonal movement behaviors of coldwater obligate species, like the native brook trout (*Salvelinus fontinalis*), a high priority (WNDR, 2019). Adding a layer of complexity to the intersecting forces of hydrology, habitat, and movement dynamics of brook trout is the increased interest in co-management of beaver

(*Castor canadensis*) and salmonid populations in the United States (Charnley et al., 2020; Renik et al., 2020; Johnson-Bice et al., 2018), and specifically in Wisconsin (WDNR, 2015). Beaver are popularly known as ‘ecosystem engineers’ with their damming behaviors shaping local riverine connectivity, water quality and both aquatic and terrestrial habitats (Colleen & Gibson, 2020; Johnson-Bice et al., 2018), all of which may have lasting impacts on brook trout populations and their movement behaviors in northeastern Wisconsin (Avery, 2002; McRae & Edwards, 1994).

Previous research on instream salmonid movement across species and regions suggests that movement is highly variable, with some individuals showing high site fidelity and others demonstrating a preference for long-range movements (Gowan & Fausch 1996). Brook trout, specifically, exhibit high rates of movement and adaptive plasticity for habitat use (Rodriguez 2002; Petty et al. 2012). In north-central Pennsylvania, White and Wagner (2020) used radio telemetry to describe two movement trends in brook trout populations: a larger sedentary portion of the population (46%) that moved less than 200 m over the duration of the study and a smaller number of mobile individuals (18%) demonstrating long-distance movements of up to 13 km. In the Little Plover River in central Wisconsin, Schleppenback, Mohr and Raabe (2021) used passive integrated transponder (PIT) tags to describe diurnal and seasonal movements of brook trout, showing an increase in upstream movements (90%) of varying distances across three spawning periods. As brook trout movement is a key factor contributing to population dynamics (Huntsman et al., 2014), gene flow (Kelson et al., 2015), host-parasite interactions (Black, 1981) and more, it is critically important to assess the movement variation among individuals and across populations over short and long distances (Kanno et al. 2020). Over the past few decades, passive integrated transponder (PIT) tags have become widely used for this work, not only to understand movement patterns and behaviors of brook trout populations (Schleppenback et al., 2021; Bond et al. 2018; Zydlewski et al. 2006), but also for individual growth, survival, habitat use and population responses to environmental changes (Connolly et al., 2008), often in the context of habitat fragmentation (Torterotot et al., 2014; Hudy et al., 2008; Letcher et al., 2007).

Fragmentation is considered one of the most serious threats to biodiversity (Drouineau et al. 2018; Raemaekers et al. 2009) and is frequently cited as one of the most serious threats to brook trout populations across their native range (Hudy et al. 2008; Letcher et al. 2007). Widespread fragmentation has been linked to extirpation—or risk of extirpation—as disconnected habitats with isolated populations are at risk of genetic bottlenecks (Letcher et al. 2007; Kanno et al., 2015; Timms et al., 2016). Although stream restoration practices, including habitat improvements (Hunter, 1991) and re-connectivity at road crossings (Poplar-Jeffers et al., 2009), have increased over the last few decades (Lave et al., 2010), the narrative that supports riverine connectivity tends not to include the historic context of patchy discontinuous fluvial systems that existed prior to European settlement (Burchsted et al., 2010). This free-flowing narrative often prioritizes the stream and connectivity conditions observed following the near extirpation of beavers from North America in the 1800s (Johnson et al., 2019). Recent work by Burchsted et al. (2010) suggests that beaver-mediated spatial and temporal discontinuity significantly influenced historic species distributions and fundamentally shaped hydrologic, biogeochemical, and ecological cycles. Although management and research interest in the historic environmental conditions of beaver-mediated landscapes has increased in recent decades, a deeper understanding and inclusion of these historic environmental conditions are increasingly more necessary for place-based stream restoration and management practices (Johnson-Bice et al. 2018). Despite the potential benefits of beaver-induced fragmentation and habitat heterogeneity, fragmentation has been generally shown to negatively limit bidirectional movement, reduce access to spawning habitats, increase water temperature, reduce genetic diversity, restrict access to seasonally important habitat and limit potentially important spawning interactions among brook trout populations (Hudy et al. 2008; Humston et al. 2012; Pilgrim et al. 2012; Torterotot et al. 2014); however, these impacts are largely associated with human-made barriers, leaving speculation about how beaver dams influence brook trout movement and population dynamics (Lokteff et al., 2013).

Historic Wisconsin Department of Natural Resources (WDNR) led beaver-trout research coupled with field observations during a more recent age and growth study that suggested significant seasonal movement and redistribution patterns of brook trout led to our selection of Upper Middle Inlet (UMI) as they study system for this trout movement work. During the brook trout age and growth study in northeastern Wisconsin, Matthew Mitro (WDNR Coldwater Research Scientist) described how their research team would encounter very few trout during the early spring versus during the summer sampling months. Mitro also observed that trout tagged in one summer were rarely recaptured the following year but were rather replaced by untagged individuals. These field observations suggested that trout in UMI are likely making biologically significant seasonal movements and potentially randomly redistributing during the late-spring and early summer months. These movements may potentially be driven by season-related environmental changes, such as harsh winter conditions with near freezing water temperatures that are common between November to March (Ribic et al., 2017).

Beyond the field observations that spurred this research, northeastern Wisconsin is particularly important because of the historic beaver-trout research that has occurred and the ongoing efforts to maintain free-flowing conditions (e.g., beaver removal) on coldwater trout streams. Extensive beaver and dam removal has been an ongoing practice in northeastern Wisconsin since 1988 and is based partly on the findings of historic research on the impacts of beavers and dams on trout streams in the region (WDNR, 2015). For example, an 18-year study conducted by Avery (2002) on the Pemonee River between 1982 to 2000 reported that the removal of 546 beaver dams followed by the maintenance of free-flowing conditions until 2000 resulted in decreases in stream temperatures and increases in brook trout abundance (WDNR, 2015). However, the study has received recent critique for the lack of control streams and the inability to generalize and apply the findings equally across the state (WDNR, 2015). Nevertheless, beavers are considered a challenge to trout management throughout the state, partly due to the relatively low gradient common across most Wisconsin streams, especially in northern regions where beavers are considered an acute concern for trout streams (WNDR, 2015). This concern has led to a collaborative effort between WDNR Fisheries Management and the U.S. Forest Service that is focused on removal of beavers and dams on recreationally important trout streams (WDNR, 2015).

This trout movement study on UMI is nested within the larger WDNR led statewide beaver-trout study. Important to the justification for this UMI study is the fact that beaver dams are often cited as potential barriers to fish movement (Kemp et al., 2012); however, new research is increasingly pointing to the context-specific nature of fish movement through dams, suggesting beaver dams may not be as detrimental as previously suggested under certain circumstances (Lokteff et al., 2013). Even if beaver dams do not act as complete barrier to trout movement, they may limit a significant enough number of individuals from accessing spawning and overwintering areas that the population overall may be negatively impacted. But, in order to assess the impact beaver dams may have on the movement patterns and behavior of trout populations, understanding the movement patterns in the first place is a crucial first step.

Given the importance of stream connectivity, the critical need to characterize movement behaviors in the context of stream management practices, and the increasing emphasis on ecosystem rather than single-species management, we ask: **(1) What is the timing and extent of brook trout (*Salvelinus fontinalis*) seasonal movement in northeastern Wisconsin? And (2) How might observed movement patterns influence decisions about stream restoration and beaver management?** We use single-pass electrofishing to capture-mark-recapture individuals and use PIT tags to monitor seasonal movement within the study system, Upper Middle Inlet (UMI) in northeastern Wisconsin. We use two stationary PIT arrays in addition to electrofishing surveys to passively detect individual movement and record timing, duration, and patterns of seasonal movement. With these data, we gather a better understanding of the role that riverine connectivity plays for this particular population, while creating a watershed-scale assessment of seasonal brook trout movement that may be disrupted by changes in beaver management.

METHODS

Study Area

Middle Inlet-Lake Noquebay Watershed & Upper Middle Inlet

Our study system is part of the Northeast Sands Ecological Landscape, which encompasses 987,176 acres of land in northeastern Wisconsin and is characterized by extensive forest cover, conifer swamps and pine barrens (WDNR, 2020). Cold- and coolwater streams are common in this ecoregion due to the local geology and groundwater influence (WDNR, 2010). Upper Middle Inlet (UMI) is a 23.1 km long coldwater stream that drains 17,539 acres at the subwatershed level (HUC-12) into the Middle Inlet-Lake Noquebay Watershed (HUC-10) (97,280 acres) in Marinette County, Wisconsin (WDNR, 2010) (Figure 2). Land cover in the watershed is predominantly forested (46%) and wetlands (29%), with some agricultural use (14%), established grasslands (10%) and minimal urban or suburban development (5%) (WDNR, 2010). The Middle Inlet-Lake Noquebay watershed is composed of approximately 235km of stream miles, 3,254 lake acres, and about 30,000 acres of wetlands (WDNR, 2010). Middle Inlet, Lower Middle Inlet and UMI are the major tributaries to Lake Noquebay. These tributaries are classified in "good" or "excellent" condition and contribute low levels of nutrients into Noquebay (Marinette County, 2021). UMI is classified as a Class I (WDNR: *high quality trout waters; sufficient natural reproduction to sustain wild trout populations at or near capacity; often small contain small or slow-growing trout*) from the UMI headwaters downstream to 3.3 miles from the confluence with Middle Inlet, where the classification becomes a Class II trout stream (WNDR: *some natural reproduction but not enough to utilize habitat and food; stocking required to maintain a desirable fishery; good survival and carryover of adult trout*) (WDNR, 2011; 2002).

We collected habitat data during the summer sampling season across study sites following the *Guidelines for Evaluating Fish Habitat in Wisconsin Streams* (WDNR, 2002). Habitat variables included: flow; water depth; stream width (wetted and bankful); bankful depth; substrate composition; mesohabitat (pool, run, riffle); trout habitat features (undercut banks, boulders, woody habitat, macrophytes); riparian land use (5 m of stream edge); riparian buffer width (20 m of stream edge); and canopy shading (%). Habitat data was collected during summer baseflow. The length of the habitat assessment was calculated as the mean stream width x 35, with a minimum of 100 m per site to ensure the assessment was representative of all habitat features within the reach. We collected habitat data at 12 equally spaced transects, each consisting of four equally spaced transect-points.

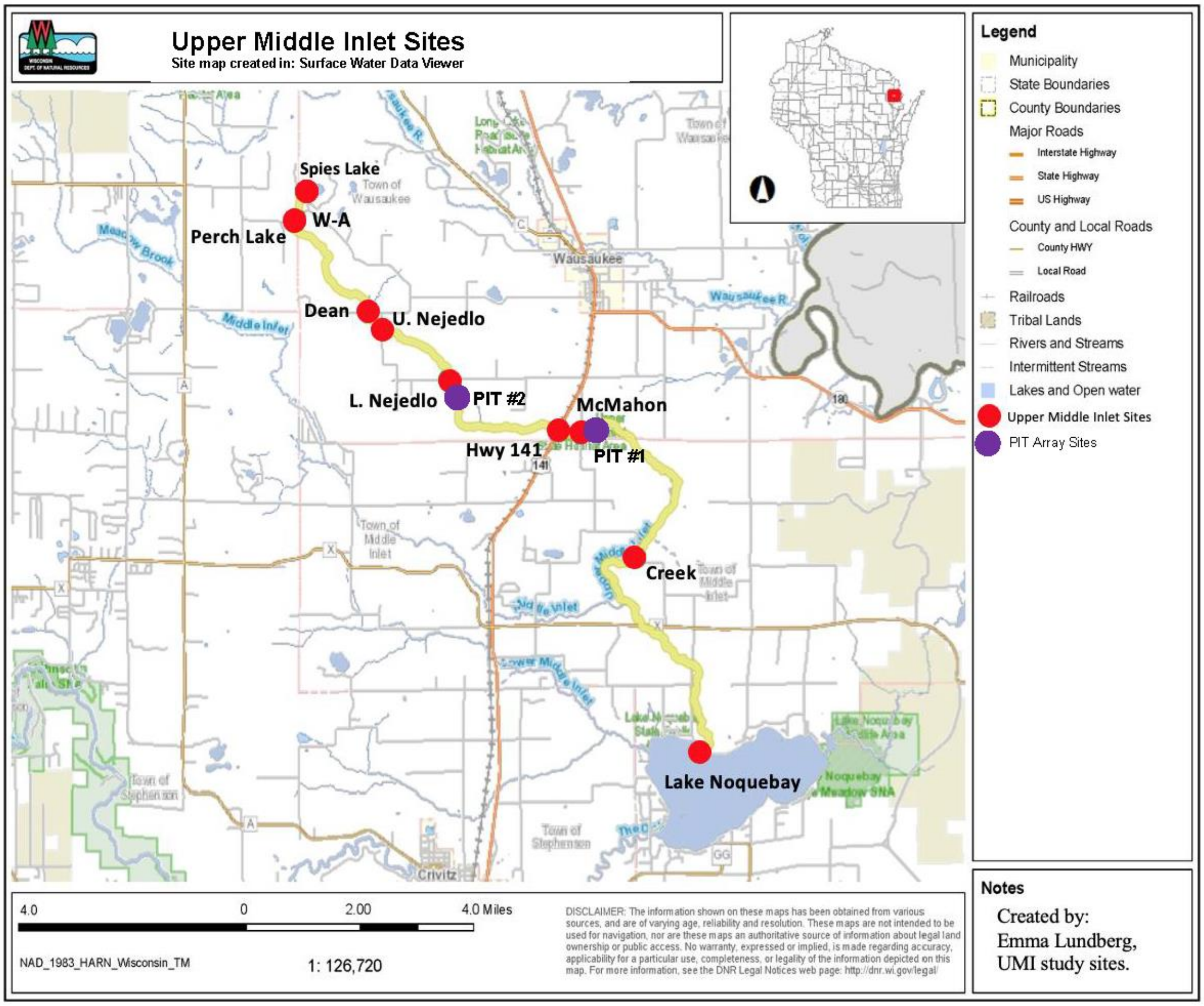

Figure 2: Upper Middle Inlet study site map. Map displays the study site locations (8) and the location of the Spies Lake UMI headwater and Lake Noquebay, which UMI drains into after joining with Middle Inlet. The name of each site and the PIT array systems are denoted on the map. Study site map was made in the WDNR Surface Water Data Viewer.

Study sites were identified at each road crossing along UMI, primarily due to accessibility (Figure 2). Starting downstream and moving into the headwater reaches, Creek Road is the most downstream site (2.5 km from the mouth), followed by McMahon Road (8.8 km from the mouth), Highway 141 (9.6 km from the mouth), Lower Nejedlo Road (13.9 km from the mouth), Upper Nejedlo Road (16.6 km from the mouth), Dean Road (17.2 km from the mouth), Perch Lake Road (21.1 km from the mouth), and our furthest upstream stream reach at the Wausaukee Athelstane Road (W-A Road) crossing (21.2 km upstream from the mouth).

Substrate. Sand is the dominant substrate in the UMI system, with more silt and detritus in the headwater (W-A Road) and the downstream sites (Creek Road, McMahon Road). The middle reaches of UMI are higher gradient (though still classified as low gradient), characterized by coarse gravels, boulders and rubble-cobble, interspersed with sand and minimal silt and detritus. Across all sites, fish cover consists of woody habitat, overhanging vegetation (streambank grasses and tag alder), undercut banks, exposed root systems and small areas of submerged macrophytes. Due to low water conditions, the headwater reaches offered minimal fish habitat (water depth must be > 0.20 m), while the middle reaches of UMI offered higher quantities and diversity of fish habitat, with boulders, woody habitat and flow under root systems in cedar swamp conditions common, as opposed to the lower gradient reaches that are dominated by sand, silt and detritus substrates, lower habitat diversity and minimal coarse gravel substrate for brook trout spawning.

Canopy cover & riparian area. Throughout the UMI system, canopy cover ranged from 10% to 100%, with the majority of the transects between 80% to 100% canopy cover. The riparian area (20 m out from the bank) is largely intact, with the only substantive impacts occurring along the roadside at stream crossings. The riparian area of the lower reaches of the system are composed of woodland and shrubs with some associated meadow and wetland habitat. The riparian area of the middle reaches of UMI is predominantly cedar swamp, while the headwaters are woodland interspersed with meadow.

Stream dimensions. The average stream width at the downstream site (Creek Road) is 5.6 m, with an average depth of 0.37 m (range: 0.08 m to 0.97 m). The average stream width in the middle reaches (Dead Road, Upper Nejedlo Road) ranges between 3.96 m, with an average depth of 0.19 m (range: 0.04 m to 0.36 m) to 7.26 m wide throughout the braided, higher gradient reaches, with an average depth of 0.20 m (range: 0.03 m to 0.34 m). In the most upstream most study site (W-A Road), the average stream is 2.0 m, with an average depth of 0.10 m (range: 0.02 to 0.22 m).

Discharge. In July 2020 in the middle of the study system (lower Nejedlo Road), discharge was 0.71 m^3/s, a much higher volume of water than what was observed the following year, coinciding with trends observed at the USGS water monitoring gauge on the Pike River in Amberg, Wisconsin (Figure 3). In July 2021, UMI discharge was 0.10 m^3/s at one of the upstream most sites (Dean Road) and was 0.26 m^3/s at the furthest downstream site (Creek Road).

Regional Climate. The climate in northern Wisconsin is often characterized by cold winters and short, mild summers (Gonzales-Abraham et al. 2007). The first snowfall in northern Wisconsin typically occurs in early November and most streams and lakes have ice cover from late November through early April (Ribic et al. 2017). Typically, winter air temperatures can fall to -40 degrees C or below and summer temperatures can reach 32.2 degrees C (Ribic et al. 2017). Northern Wisconsin is demonstrating a significant warming trend (Ribic et al. 2017), with temperatures projected to continue increasing, making this region of Wisconsin particularly important for considering how to adapt to the impacts of climate change (WICCI, 2011). Additionally, northern Wisconsin receives approximately 12.6 cm annually, but shifts in timing of precipitation have been observed; more recently, summer precipitation has decreased, while autumn precipitation has increased (Ribic et al. 2017). This shift in timing of precipitation is especially important for fall spawning species, including brook trout (Warren et al. 2012). Prior to European settlement, the landscape was characterized as a mix of old-growth hardwoods and mature hemlock (*Tsuga canadensis*), pine forests (*Pinus banksiana, P. resinosa, P. strobus*), quaking aspen (*Populus tremuloides*), yellow birch (*Betula alleghaniensis*), and sugar maple (*Acer saccharum*) (Gonzales-Abraham et al. 2007). Currently, vegetation is composed of mesic mixed northern hardwoods (Ribic et al. 2017) and the landscape has observable scars from previous logging practices (Williams et al. 2019).

Study Design

We established sample locations at eight road crossing locations (Figure 2), where we captured and tagged individual trout both upstream and downstream from the crossing location during the late-spring, summer, fall and early winter from 2019-2021 (Table 2). Our sampling events occurred monthly, excluding months during winter ice cover and during COVID-19 travel restrictions in 2020 (Table 2). We used a combination of active (single-pass electrofishing) and passive (stationary PIT monitoring systems) sampling techniques to collect seasonal trout movement data throughout the study period. Single-pass electrofishing is an effective method for sampling wadeable streams (Temple & Pearsons, 2004; Kruse et al., 1998). We used one or two backpack electrofishing units depending on the stream width at each study site to collect Index of Biotic Integrity (IBI) data, capture individuals for data collection and tagging purposes and to recapture tagged individuals. Following capture, individual weight (grams) and total length (mm) measurements were recorded. We collected gill lice data (presence of infection, number of lice, location on the body) and recorded sex during the spawning season when sex determination was possible. For trout of appropriate size (>100 mm), we implanted OregonRFID 12.0 mm (12.0 mm x 2.12 mm, 0.01 g) half-duplex (HDX) passive integrated transponder (PIT) tags.

Table 2: Distribution of sampling events by month and season, the number of surveys completed each sampling event and whether PIT array data was downloaded, installed, or removed from the field, and the total number of captured, tagged and recaptured individuals per sampling trip. Recaptured fish include both active (electrofishing) and passive (PIT array) detection methodologies.

Year	Month	Number of Surveys	Captured	Tagged	Recaptured
2019	August	1	111	64	0
	September	4	171	132	2
	October	6	335	196	46
	November	5	201	142	22
2020	April	No fieldwork (**COVID**)	0	0	0
	May	No fieldwork (**COVID**)	0	0	0
	June	3 & PIT equipment installed	39	31	0
	July	5 & PIT data download	231	123	20
	August	4 & PIT data download	366	281	41
	September	9 & PIT data download	625	207	79
	October	7 & PIT data download	893	32	195
	November	8 & PIT data download	358	25	103
	December	6 & PIT equipment removal	547	59	58
2021	March	PIT equipment installed	0	0	2
	April	5 & PIT data download	120	41	34
	May	10 & PIT data download	603	21	68
	June	4 & PIT data download	271	1	10
	July	7 & PIT data download	710	31	65
	August	PIT data download	0	0	15

When feasible—given time, location in the watershed, sampling distance, labor and access constraints—we extended the standard survey sites, including one hike-through sampling (example, we hiked-through from Upper Nejedlo to Dean Road and sampled the full distance between sites) to increase the likelihood of recapturing tagged individuals that had moved beyond the site boundaries. We installed two PIT array systems, which are commonly used to study instream trout movement (Kanno et al., 2014; Connolly et al., 2008; Zydlewski et al., 2006), to passively monitor movement and detect seasonal bidirectional movement of tagged individual trout. One PIT array system was installed on privately owned land (Lower Nejedlo, upstream array) and one on public land (McMahon, downstream array). Our PIT array systems operated from June through December during the pilot 2020 field season and were reinstalled in March 2021. Data through August 15, 2021 was used for analyses.

During the winter months when UMI was inaccessible and the PIT array systems were removed from the field, we attempted to sample for brook trout through the ice on Lake Noquebay near the river system inlet. We used Beaver Dam tip-ups, ice fishing jig rods and a wide variety of live and artificial baits (e.g., live earth worms, fathead minnows, rosy shiners, spinners) to sample for brook trout that may seasonally migrate from UMI to Lake Noquebay. This aspect of the study was based off local angler accounts of trout migrations from the lake into headwater systems during spawning season. We were unable to land brook trout on three discrete ice angling occasions.

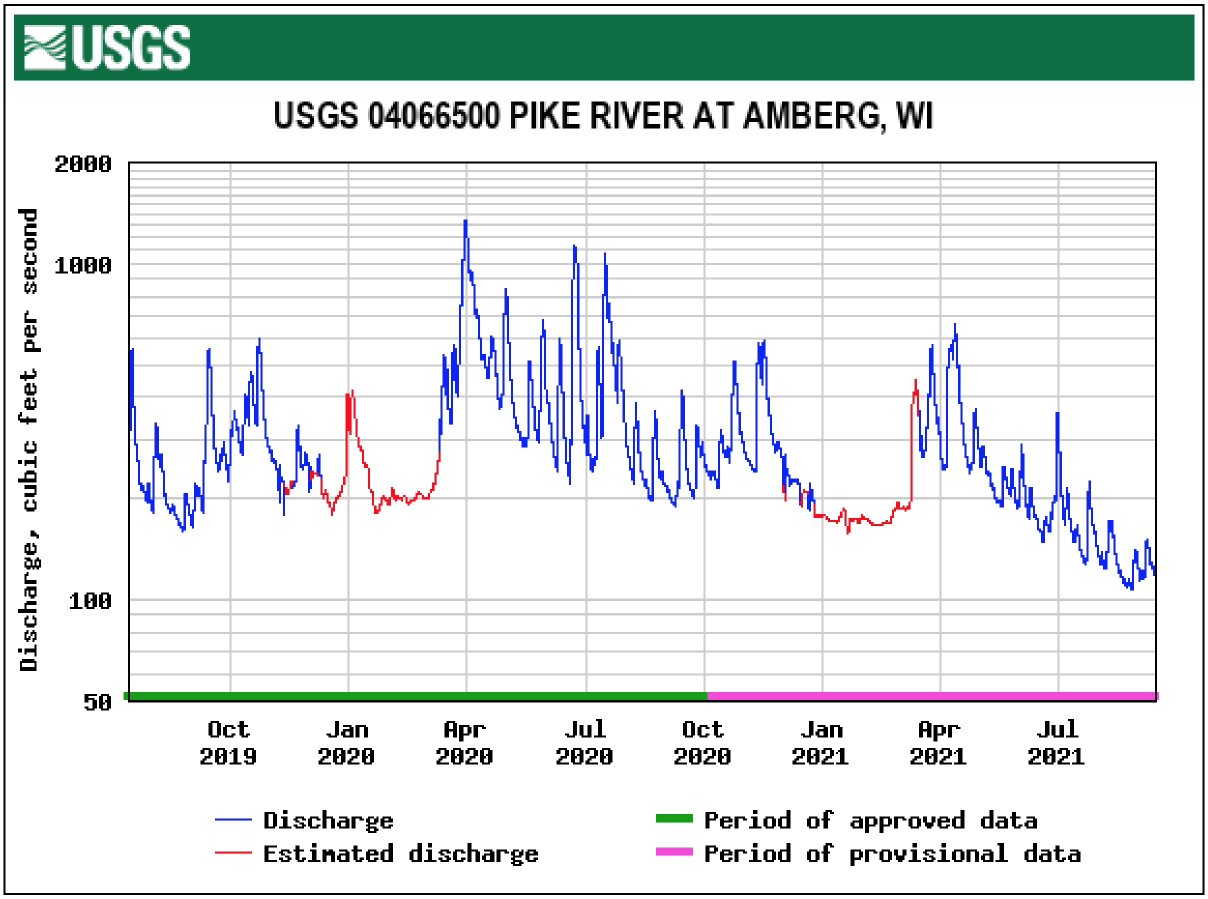

Figure 3: USGS discharge for the Pike River site in Amberg, Wisconsin. Amberg, WI is located 13 miles north from Upper Middle Inlet and offers insight into the local water conditions. The Pike River was not sampled for this study, but rather this graph provides some insight into the interannual variation in flow conditions in the region.

Passive Integrated Transponder (PIT) Tags

PIT tags are radio-frequency identification (RFID) tags encapsulated by glass and composed of an integrated circuit and an antenna for receiving and transmitting a signal. The tags are injected into the body cavity or musculature of an individual using a small incision or a gauged hypodermic needle. The PIT reader (multi-reader), which is powered by an external power source (e.g., deep-cycle marine battery, solar panel) that activates the tag with an inductive charge and initiates the transmission of the unique alphanumeric code (Pine et al. 2012). If implanted properly, PIT tags often have a relatively low shedding rate (Pine et al. 2012) and have minimal impacts on survival, swimming ability, and growth in brook trout (Dieterman & Hoxmeier, 2009). Though tag retention rates may exceed 95% for brook trout (Gries & Letcher, 2002), the tag insertion location, fish size, season, and environmental conditions (i.e., lab or field) influence tag retention rates (Dieterman & Hoxmeier, 2009).

Tagging Methods

Post-capture, we anaesthetized trout with AQUI-S®, an anesthesia alternative appropriate for field-based research (approved for use in New Zealand, Australia, Chile, and China; experimental in the U.S.) (Durhack, Jeffrey & Enders, 2020) to reduce fish stress and increase procedure speed. When AQUI-S® was not available, we used CO_2 to anaesthetize trout. We then recorded individual fish data (e.g., weight, length, gill lice, sex), followed by insertion of the PIT tag into the body cavity using a Biomark MK7 Implanter (12-gauge hypodermic needle). Following the tagging procedure, we clipped the adipose fin for quick identification of internal tags on future recapture occasions and to quantify PIT tag loss. Tagged individuals were observed until recovered, then were released within the capture site.

Installation of PIT Array Systems

Tagged individuals are able to be detected without physical recapture when they move through an array system (Pine et al. 2012). We built two OregonRFID fish monitoring systems in natural sections of UMI (Figure 4, Figure 5). The three main components of a PIT array system include a multi-reader, antennas, and a quiet electronic power source. OregonRFID multi-readers, the “brain” of the monitoring system, were configured for each site (e.g., site identification, charge/listen cycles, power source, shut down voltage preferences, etc.) and stored tag detection data with continuous timestamp data. The multi-reader for HDX tags emits magnetic pulses that run through the antennas and charge the capacitor within the HDX tag, allowing the tag to charge and use this energy to transmit the alphanumeric code back to the multi-reader (OregonRFID, 2020).

HDX antennas comprise simple loops of insulated wire that are either set in a frame or placed directly in the water. The antenna dimensions vary depending on the stream width, depth and water velocity. During antenna construction, the correct inductance value (magnetic capacity that a loop can store) is crucial to ensure appropriate design of the antennas (range is 8-80 µH). Changing the wire diameter, number of loops, and distance between corners changes the inductance value, allowing for a trial-and-error approach to antenna building. The read range, which is the distance that a tag can be detected from the antenna, varies depending on distance between bends in the antenna and tag size (OregonRFID, 2020). Our PIT systems spanned the full distance of the stream with detection coverage throughout the antenna with a read range between 40 to 66 cm for each antenna. Each array was composed of two antennas allowing for detection of bidirectional movement.

We used two power sources—3 connected deep-cycle marine batteries and 120watt solar panels—to run the monitoring systems. Through our 2020 pilot season experience, we found a combination of three deep-cycle 12V batteries and 120watt solar panels (without solar controllers to reduce electronic interference) allowed our systems to operate successfully up to 21 days before requiring a battery exchange, while with one battery the system would operate for approximately 7 days.

PIT Array #1: McMahon Road Crossing

Figure 4: The McMahon PIT array system was installed downstream of the McMahon Road crossing on public land. Image of the McMahon fish monitoring system, taken from the left bank of Upper Middle Inlet. The multi-reader, auto-tuners and deep-cycle marine batteries are located within the black locking box. The 120-watt solar panel is located to the right.

PIT Array #2: Lower Nejedlo Road Crossing

Figure 5: With permission from the landowner, we installed the Lower Nejedlo PIT array downstream of the road crossing. Image of the Nejedlo PIT monitoring system from both the right bank (top) and the left bank (bottom). Image shows the set-up and antenna placements.

The antennas for both arrays were systematically ordered, with the downstream antenna labeled “#1” and the upstream antenna “#2”. We installed metal fence posts in both streambanks and ran paracord across the stream width. We attached the antenna wire to the paracord with zip ties across the length of the stream and set sandbags, filled on location, along the bottom of the channel to stabilize the antennas in place and ensure they remained functional during high flow events (Connolly et al., 2008). We installed locking boxes at each monitoring site to safely store the multi-reader, auto-tuners and batteries. The boxes were locked to riparian trees to reduce risk of equipment loss from flood events or equipment theft.

Analyses

Data analyses were completed in RStudio version 1.4.1717 (Rstudio Team, 2021), the PITR (v1.2.0, Harding et al., 2018) and riverDist (v0.15.4, Tyers, 2021) packages. We used the Tagged Animal Movement Explorer (TAME, USGS open access online data analysis viewer) for early and quick exploration of the movement data and as a visualization tool to share ongoing work with stakeholders interested in the project. Site maps were made in the WDNR Surface Water Data Viewer using geospatial data collected in the field during sampling occasions.

In addition to PIT tag-based movement detections, we also plotted length-frequency histograms and catch-per-unit-effort, standardized to 100m, across sites and sample occasions to gather a better understanding of the movement trends we observed with the PIT tag data. Length-frequency histograms are one of the most common fisheries assessment techniques (Neumann & Allen, 2007) and show the count of individuals within each length category over the full range of observed lengths. Length histograms provide basic insight into population size structure, which reflects key dynamics such as growth, trends in year-classes and recruitment, and potential movement (Ogle, 2016). Using trout length data collected throughout the study, we plotted length-frequency histograms by site for each sampling occasion on the same axes in 10 mm width bins.

We combined data from adjacent sites (for example, up- and downstream reaches at each road crossing like Upper Nejedlo and Dean Road since these adjacent sites were often hiked-through and sampled with electrofishing equipment). While collapsing data in this manner in a study about trout movement may seem counterintuitive, there were good reasons to do so: combining the data provided a larger sample size to examine for trends; up- and downstream sites were not separated by impassible barriers (evident from PIT recapture data); and habitat characteristics remained similar across up- and downstream sites. Additionally, though we did collect fine-scale movement data within reaches from tagged individuals, one of the main objectives of this study was to identify and describe long-distance, system-wide movement patterns across seasons. One technique we have used to explore the data for movement trends was the construction of length-frequency histograms. The following length-frequency histogram plots are organized from downstream (Creek Road, Figure 10) to headwater site locations (Wausaukee Athelstane Road, Figure 17).

RESULTS

We combined electrofishing recapture data and PIT array detection data here to demonstrate the full extent of overall movement patterns we have observed throughout the duration of the study. Over the study period (August 2019 to November 2019; June 2020 to December 2020; March 2021 to August 2021, see Table 1) we recorded data from 5,895 captured individual brook trout across 15 discrete sampling events occurring at monthly intervals from the spring to early winter field season. Of these captured fish, we tagged 1,491 unique individuals that were 100 mm or greater in length with HDX 12 mm PIT tags. From the total 1,491 unique tagged fish, we recorded 2,348 recapture observations, a number that includes both active sampling methods (electrofishing) and passive detection (PIT array systems at two locations). Of the 1,491 PIT tagged individuals, 1,343 individuals were brook trout (90%) accounting for 2,078 recapture observations. The 2,078 total recapture observations figure includes both recapture by electrofishing (1760 recapture observations) and passive detection through the PIT array systems (318 unique detection observations). As the of the study focus is seasonal movement patterns of brook trout, brown trout (9%) (*Salmo trutta*) and tiger trout (0.1%) (*Salmo trutta* x *Salvelinus fontinalis*) have been excluded from further analyses here.

Of the total tagged brook trout, we identified 182 males, 168 females and were unable to determine the sex of 1,081 individuals included in study. The total lengths (length from snout to longest point of the caudal fin) of tagged trout ranged from 100 mm to 405 mm, with 67% of the sample population ranging between 125 mm and 220 mm in total length (1,000 individuals).

We recorded 70% (1,462 observations) of recaptures between the months of August and November, which aligns with our fieldwork effort that began in August 2019 and an increase in total number of individuals observed during the fall spawning seasons. The total number of observations per individual ranged from 0 to 30, with 27.6% of individuals (371) recaptured between one to four occasions (excluding first initial capture). The proportion of non-recaptured individuals, including both electrofishing and PIT array detections, was 71% (945 individuals). Of those captured on more than one occasion, 222 (16.5%) were recaptured once, 102 (7.5%) were recaptured twice, and 65 (5%) were recaptured three times throughout the study.

Individual brook trout were documented making short daily movements between up- and downstream adjacent sites locations, while a smaller portion of tagged brook trout population was documented making longer distance movements throughout the study seasons. Most of the recorded distances between capture occasions were less than 1 km (89% of sequential detections, including both active recaptures and passive detections), while 11% (of sequential detections, including both active recaptures and passive detections) of the total tagged population recorded distances greater than 1 km from the Creek Road downstream site to the outlet of Spies Lake in the headwater reaches of the system. The maximum recorded distance was 14.7 km over a 150-day period from November 11, 2020 to April 08, 2021; trout 1FBA was tagged November 11, 2020 in the upper watershed, moved downstream post-spawning season, was detected the following year moving upstream in March through the PIT array system installed at McMahon Road and was recaptured at the same location where this individual was initially captured (Dean Road crossing tributary) (Figure 6, Figure 7). The second largest movement distance recorded was 11.3 km over an 18-day period from September 21, 2020 to December 8, 2020; trout 1C70 was captured upstream of the upper PIT array system, detected moving downstream through the lower PIT array system four days later and was recaptured upstream of Creek Road with approximately 30 other individual brook trout December 8, 2020 (Figure 6, Figure 7).

Trout 1C4A recorded a total distance of 10.1 km over a 78-day period from September 23, 2020 to December 9, 2020. Trout 1C4A was captured downstream of the McMahon Road crossing in September (lower reaches), detected at the upstream PIT array (middle reaches), then recaptured back downstream of the McMahon Road crossing on December 9, 2020 post-spawning season (Figure 6, Figure 7). This pattern demonstrates a common trend observed across recapture data; downstream movement post-spawning at the onset of winter (Figure 8).

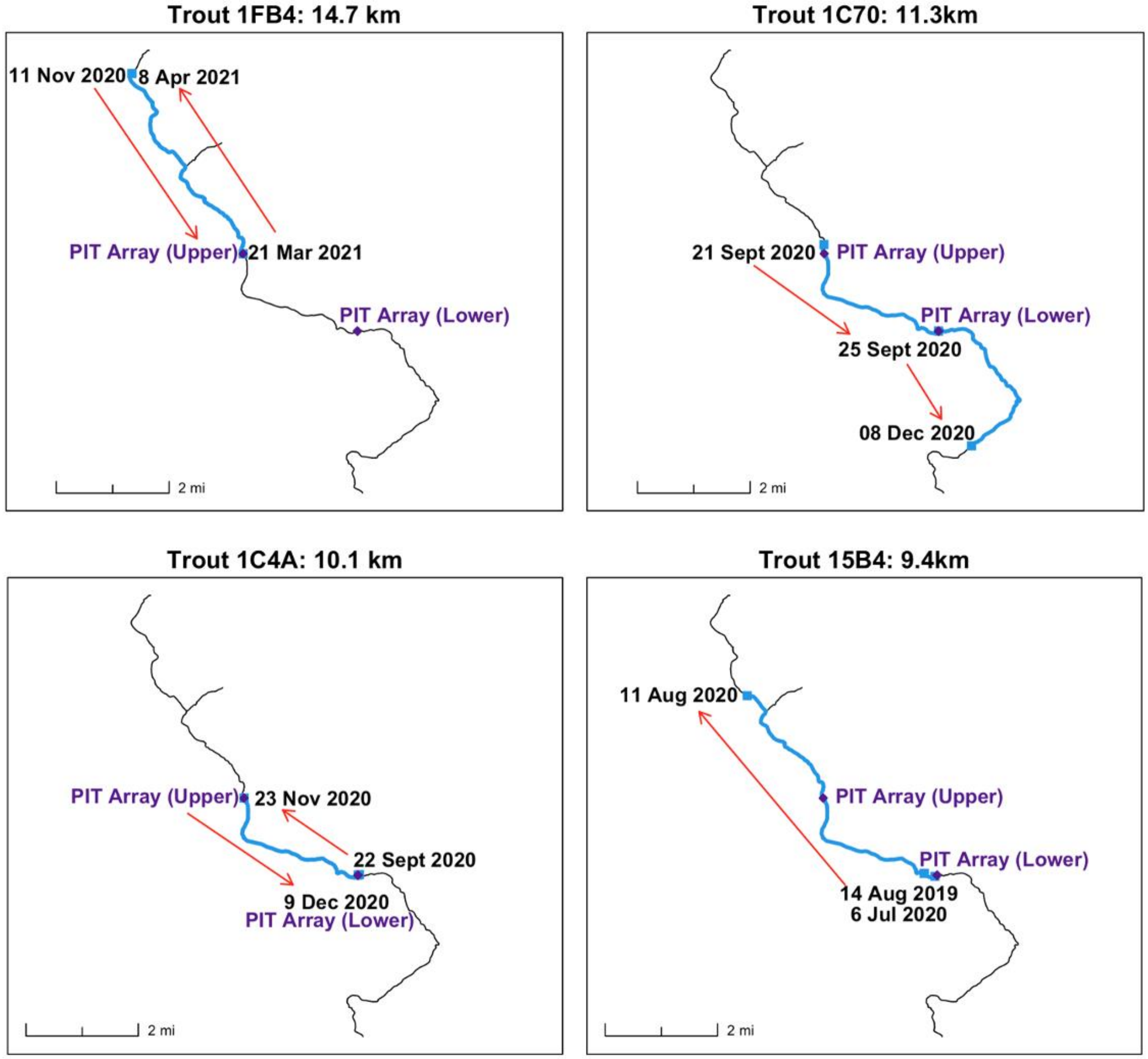

Figure 6: Individual trout featured in this figure coincide with trout featured in the result section. ***Trout 1FB4*** *(unknown sex, 210 mm 72 g) was first captured in the upstream reaches of UMI, moved downstream undetected, was detected moving upstream in March (2021) and was recaptured in April (2021) at the original tagging location, recording a recording a distance of 14.7 km, but it is possible this individual moved a further distance undetected.* ***Trout 1C70*** *(unknown sex, 167 mm 60 g) was initially captured in the mid-reaches of UMI, then detected 4 days post-tagging moving downstream through the lower PIT array and was recaptured in December (2020) upstream of Creek Road with approximately 30 other individuals. This relatively quick downstream movement following tagging could suggest a post-tagging response, as reported in other literature* ***Trout 1C4A*** *(unknown sex, 166 mm 37 g) was initially captured in the mid-reaches of UMI, then detected upstream during spawning season and recaptured in December (2020) at the tagging location.* ***Trout 15B4*** *was tagged in the mid- to lower-reaches of UMI, recaptured at the tag location and recaptured again upstream in mid-August, suggesting potential upstream movement for summer water temperature suitability or pre-spawning upstream movement. These individuals are highlighted because they demonstrate the major trends observed across recapture data: interesting long-distance movements (1FB4); downstream movement post-spawning season (1C70; 1C4A); and upstream movement in the late-summer into the early-fall (15B4).*

Over the period of 360 days from August 14, 2019 to August 11, 2020, Trout 15B4 recorded a total of 9.4 km, demonstrating upstream movement during the pre-spawning period in mid-August. Trout 15B4 was captured and tagged in the mid- to lower-reach of UMI, recaptured almost a year later in the same location, without being detected or recaptured during multiple survey event, and was recaptured in the upper reaches of the watershed the following month (Figure 6, Figure 7). This pattern also demonstrates a common trend observed across the combined recapture data; upstream movement that coincides with the fall spawning season.

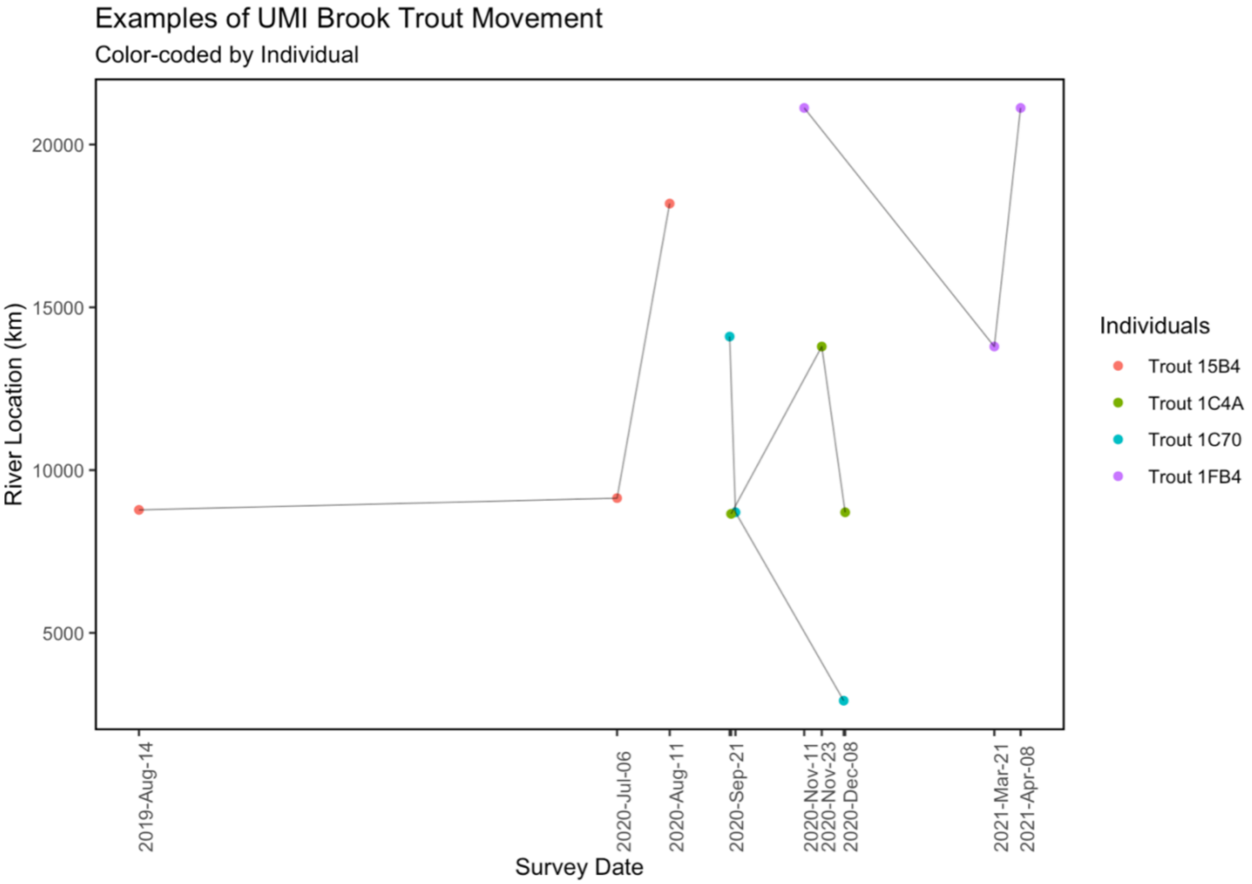

Figure 7: Plot visualized movement patterns with connected detections of Trout 15B4, Trout 1C4A, Trout 1C70, and Trout 1FB4, which are pictured above on the UMI flowline plot. This shows the extent of movement and some overlapping patterns, including the downstream movement detected during late-November and early-December by three of the four featured individuals. River Location (km) is the distance from the mouth of UMI where these trout were captured, recaptured or detected. 20,0000 km is the headwater region and 0 km is the mouth of UMI at the confluence with Middle Inlet.

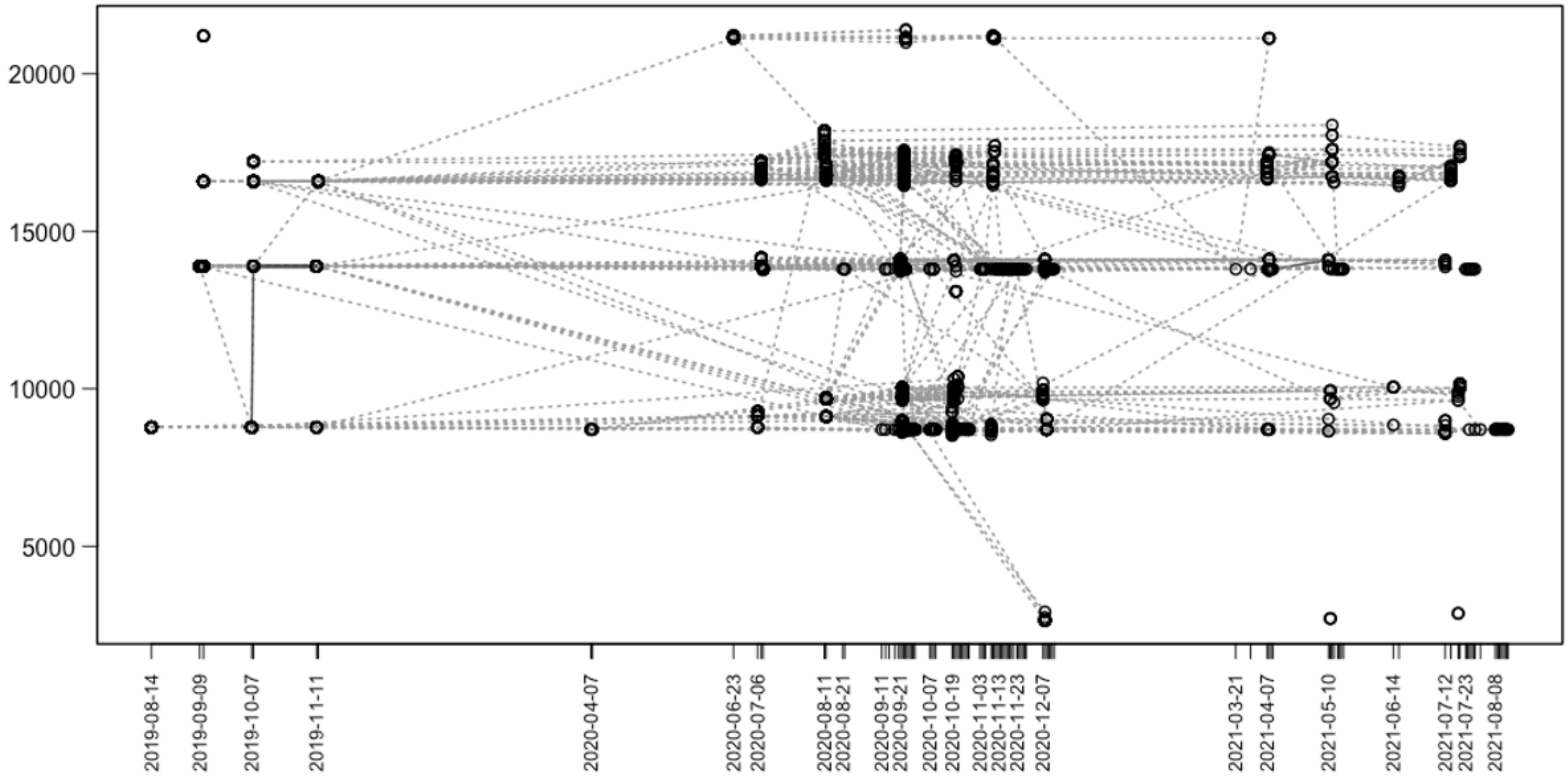

Figure 8: Dotline plot demonstrating the complexity of brook trout movement behaviors observed in the UMI system throughout the study period. Dots represent tagging and recapture encounters. Each unique tag is connected sequentially to each recapture occasion. Survey dates are along the x-axis and river location in km (distance from UMI confluence with Middle Inlet) is along the y-axis. Downstream movement is observed during late-fall and early-winter post-spawning season, likely related to movement toward overwinter habitats. Upstream movement is observed during the late-summer and fall seasons, coinciding with spawning season, demonstrating seasonal biologically significant upstream movement patterns.

Length Frequency Histograms: by site & sample event from downstream to upstream

Creek Road (2.5 km from UMI mouth)

Creek Road was sampled on three occasions (December 2020, May 2021, July 2021). Length-histograms for this site show a distinct change in both size and number of brook trout captured at this site location. During the winter (December 2020), a larger number of individuals were captured (including tagged individuals from upstream sites) in schools, while lower numbers of individuals were captured during spring and summer sampling events, suggesting downstream movement following fall spawning season, likely followed by upstream movement the subsequent spawning season the next year.

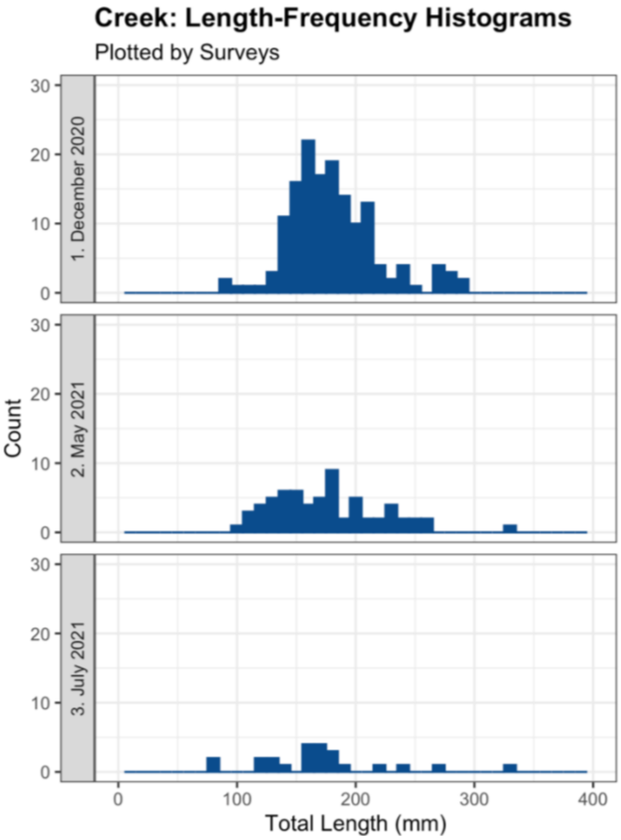

Figure 8: Length-frequency histogram grid for Creek Road site.

McMahon Road (8.8 km from UMI mouth)

McMahon Road was sampled on 12 occasions between August 2019 and July 2021.

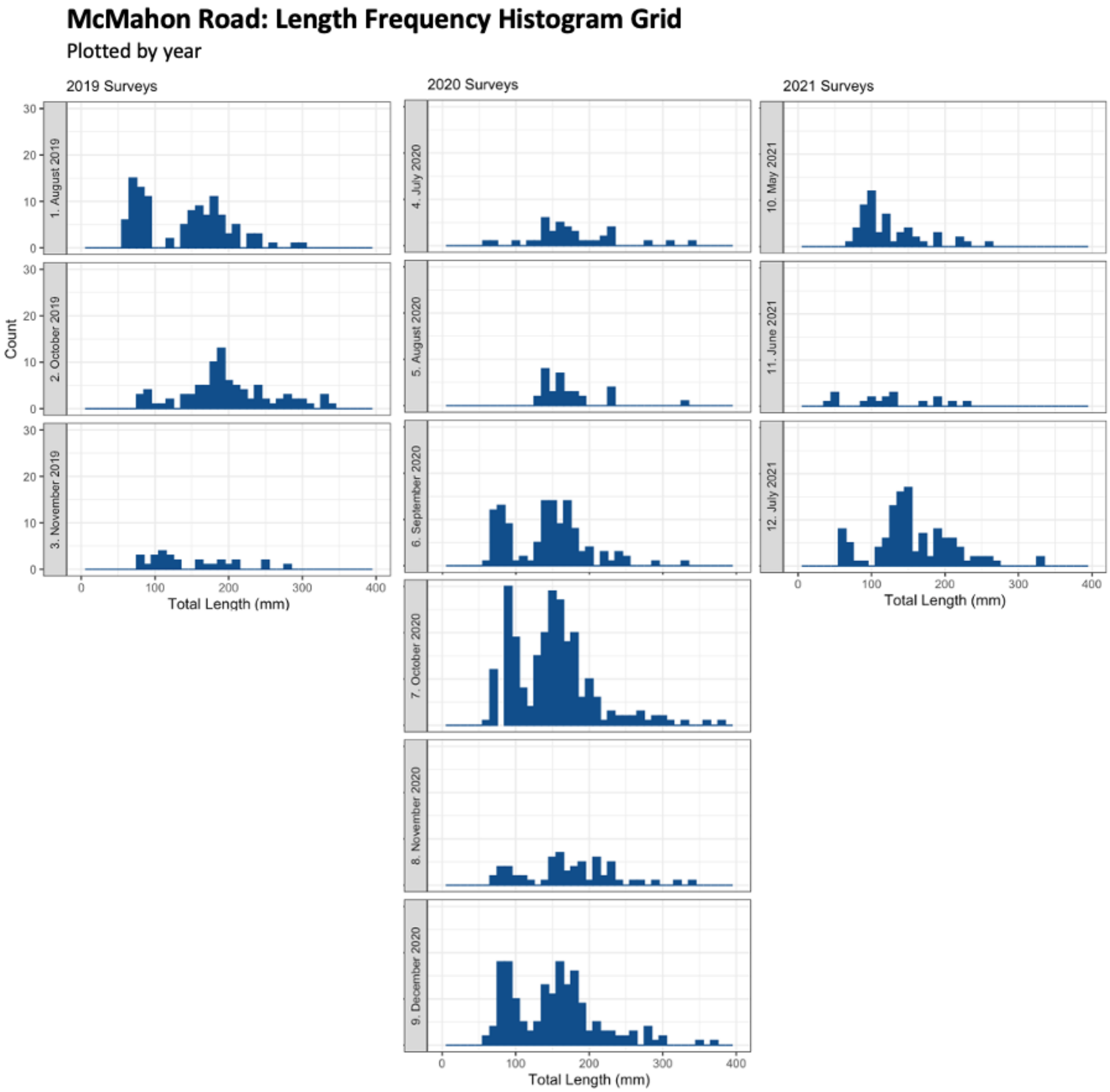

Figure 9: Length-frequency histogram grid for McMahon Road site.

In August 2019, we captured a higher number of young-of-the-year (YOY) than we captured in August 2020 or July 2021. By looking at the sampling occasions across seasons, there are distinct changes in length-size composition that cannot be attributed to growth alone.

From August 2019 to October 2019, there is an increase in larger individuals (> 300 mm) that is unlikely to be the sole result of capture evasion, suggesting individuals moving upstream during early fall for spawning season. This is also observed across 2020 length data, not only with increases in length observations, but increases in total observations from July 2020 to October 2020 and from May 2021 (predominantly YOY observations) to July 2021, where growth and an increase in total observations can be observed. The McMahon Road crossing is also the location of the downstream PIT monitoring system that recorded daily movements of resident fish and movement up- and downstream of individuals tagged at different locations.

Highway 141 (9.6 km from UMI mouth)

Highway 141 was sampled on seven occasions from August 2020 to July 2021. From the summer 2020 to fall 2020 season, there are increases both in size and total observations, following trends observed across most sites. December 2020 shows a drop in total fish observations, potentially suggesting downstream movement when paired with the December 2020 sampling occasion for the downstream Creek Road and McMahon Road sites.

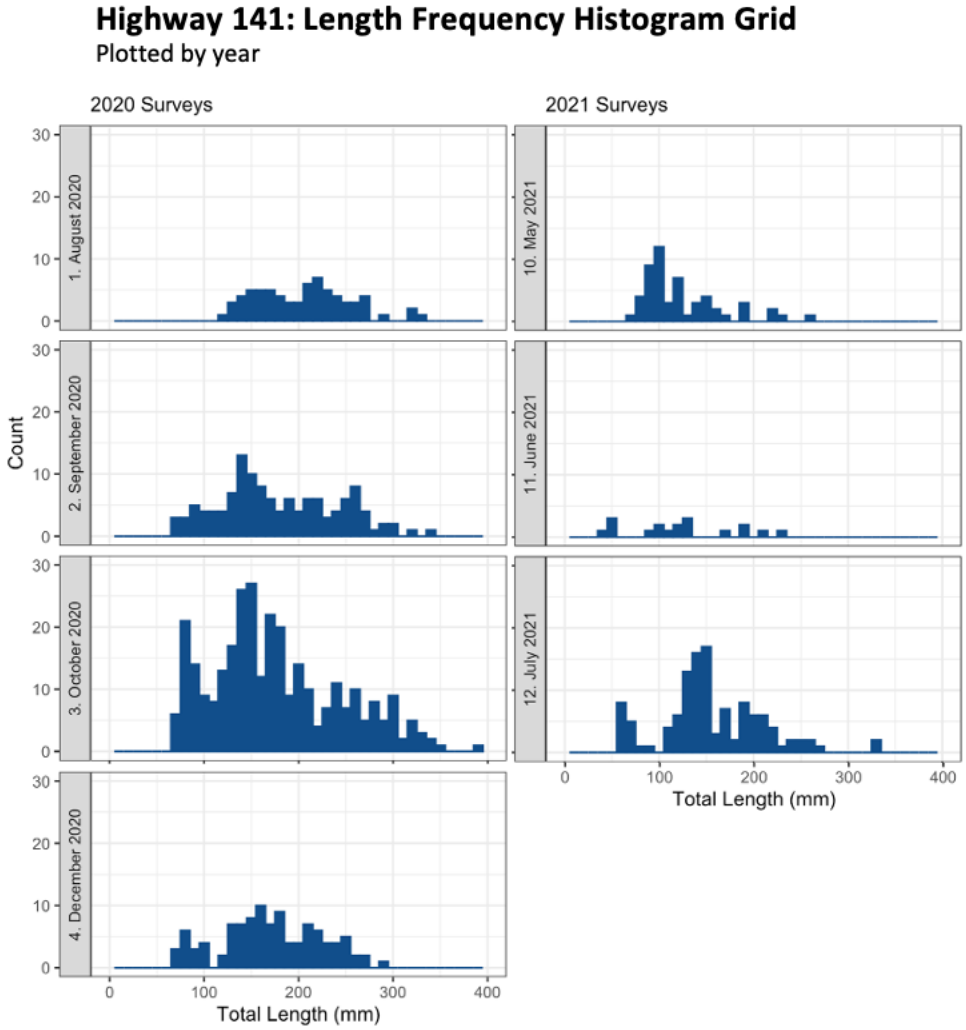

Figure 10: Length-frequency histogram grid for Highway 141 site.

Lower Nejedlo Road (13.9 km from UMI mouth)

The lower crossing at Nejedlo Road was sampled 10 times between September 2019 and July 2021. Fish observations increase from spring to early fall. Increases in size from May 2021 to July 2020 are likely to be related to growth, rather than movement. The lower Nejedlo Road crossing is also where the upstream PIT monitoring system was installed and recorded movement through both daily movements of resident individuals and movement up- and downstream of individuals tagged at different locations within the watershed.

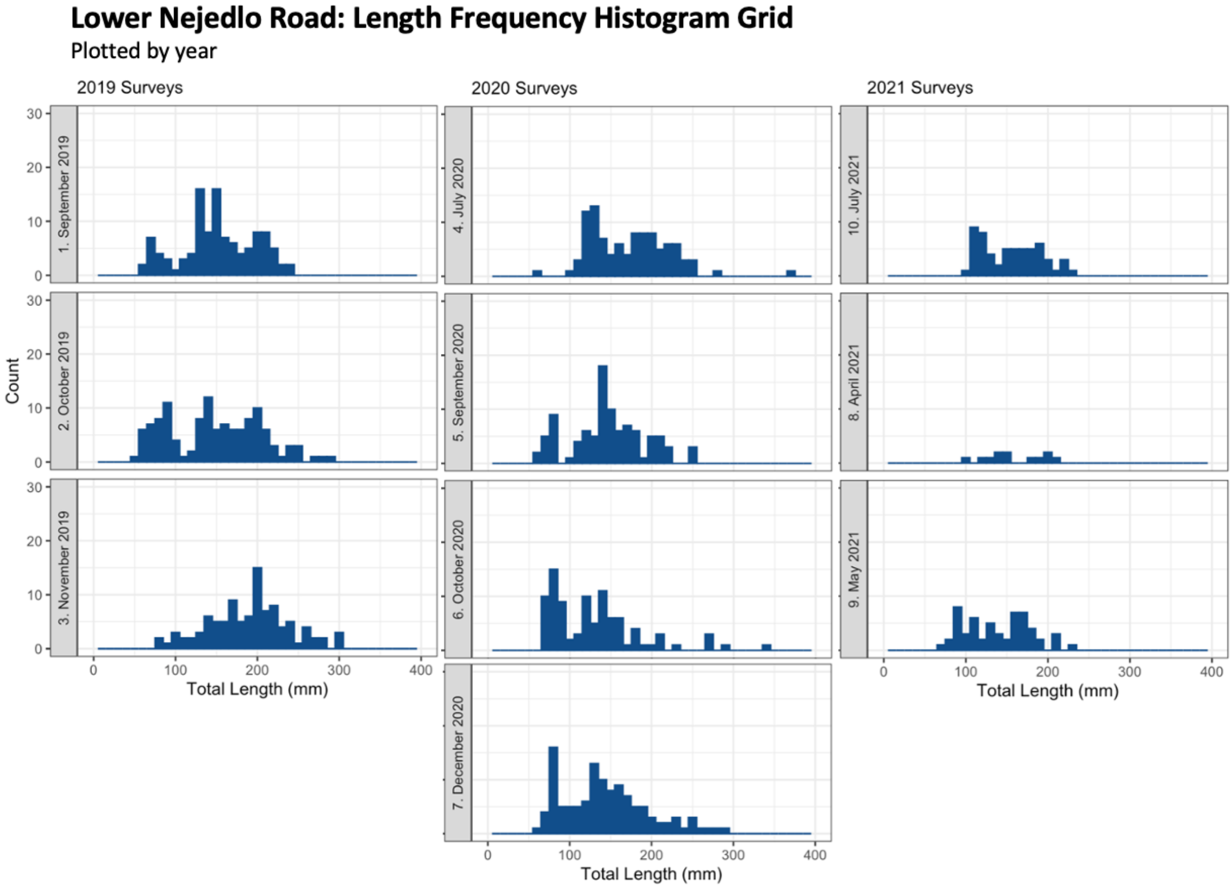

Figure 11: Length-frequency histogram grid for the lower Nejedlo Road site.

Upper Nejedlo Road (16.6 km from UMI mouth)

The upper crossing on Nejedlo Road was sampled on 12 occasions from September 2019 to July 2021. Between September 2019 and October 2019, there is a noticeable increase in both size and total fish observations, a trend also noticeable from August 2020 through September 2020, likely attributed to upstream movement during the fall spawning season, followed by a decrease in total observations and length in November 2020. The increase in total observations between April 2021 to May 2021 can likely be attributed to increase capture probability of YOY brook trout. Capture probability varies with habitat, gear type, environmental variables, and increases as fish size increases (Korman et al., 2009).

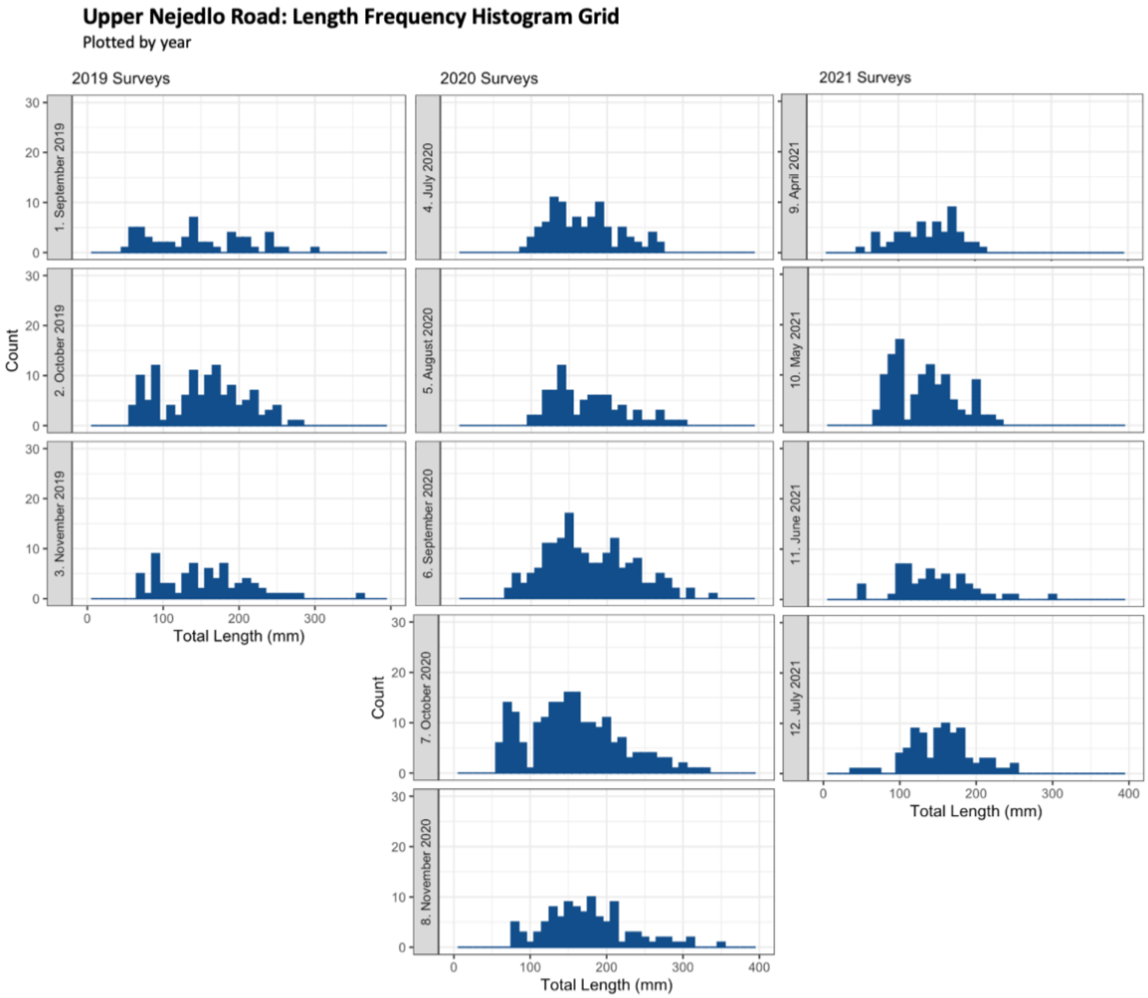

Figure 12: Length-frequency histogram grid for the upper Nejedlo Road site.

Dean Road (17.2 km from UMI mouth)

Dean Road was sampled on 6 occasions from August 2020 to July 2021. There is a visible increase in total fish observations from spring 2021 to summer 2021, but this is likely due to growth, an increase in capture probability, and upstream movement.

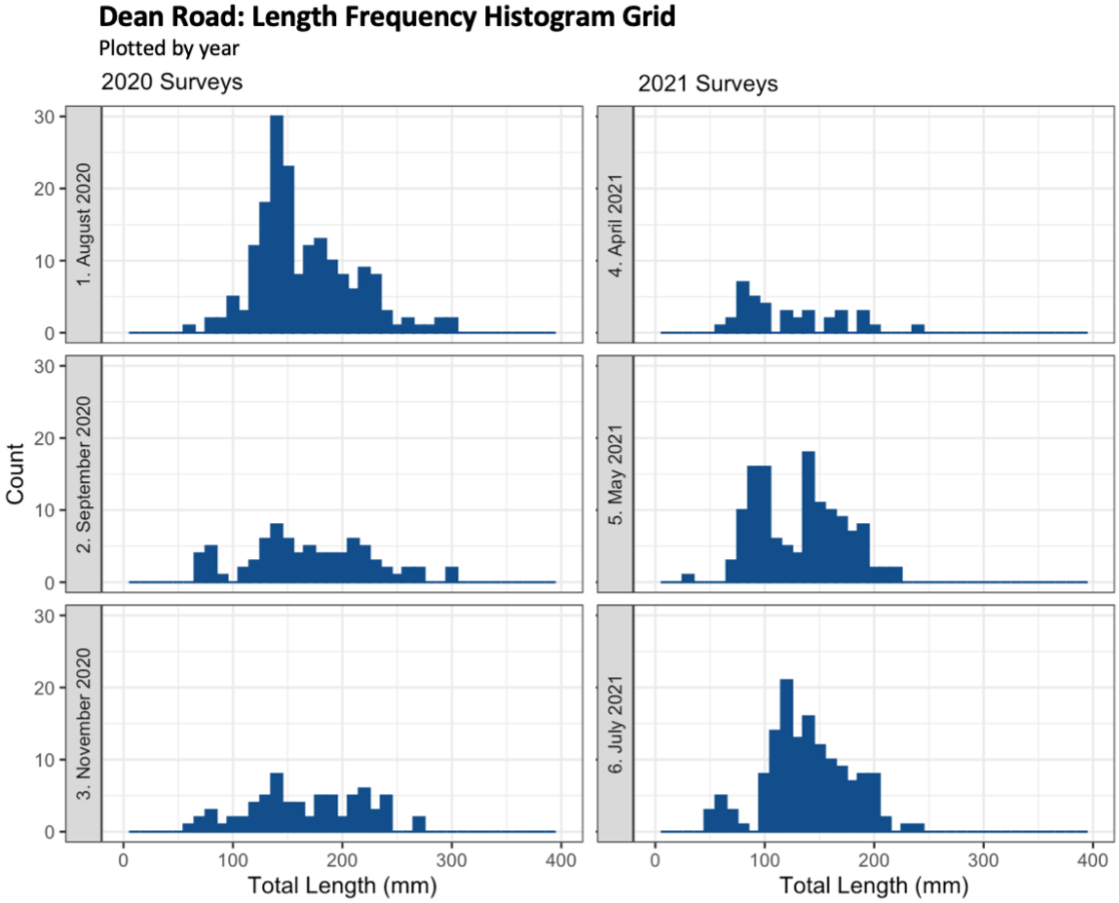

Figure 13: Length-frequency histogram grid for Dean Road site.

Perch Lake Road (21.1 km from UMI mouth)

Perch Lake was sampled on four occasions between June 2020 and June 2021. Predominantly smaller individuals (YOY, year 1) were observed in this upper watershed site.

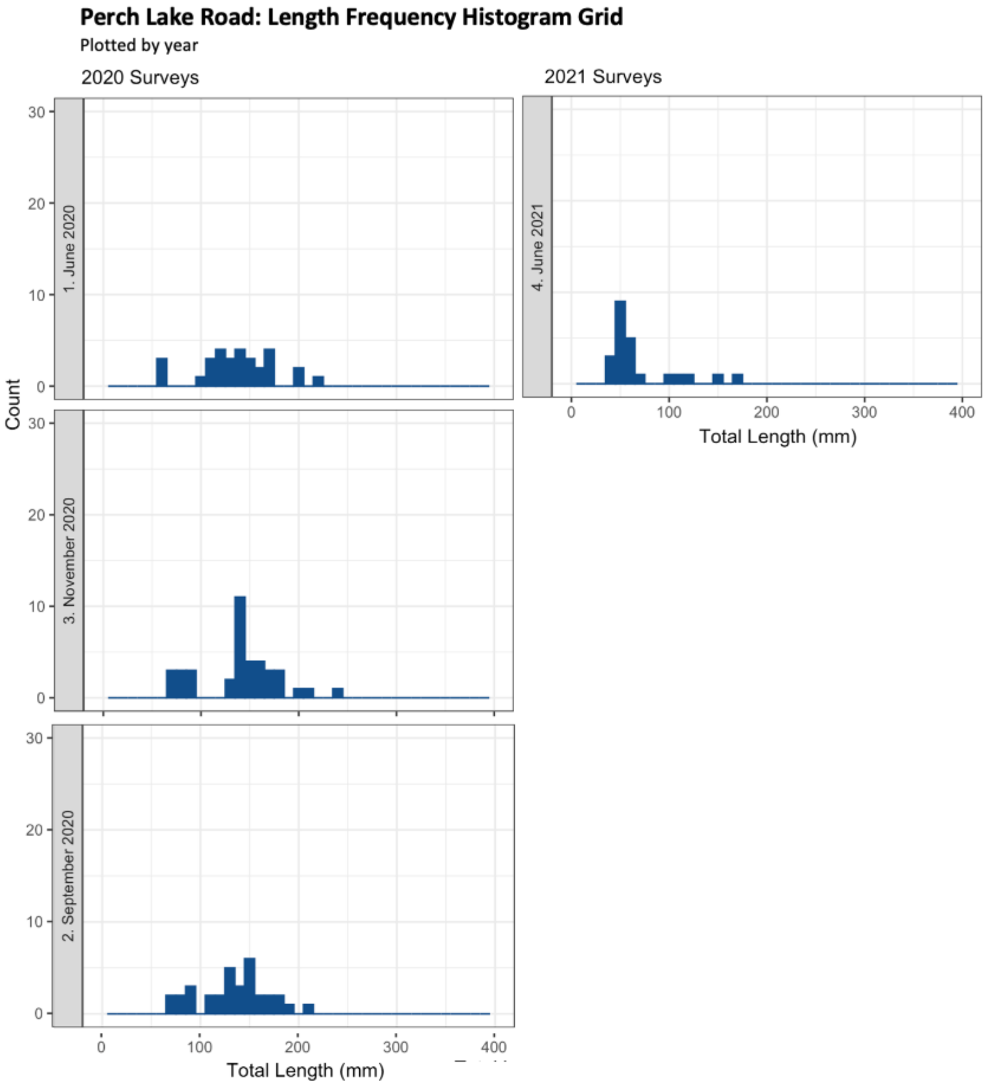

Figure 14: Length-frequency histogram grid for Perch Lake Road site.

Wausaukee Athelstane (W-A) Road Crossing (21.2 km upstream from UMI mouth)

W-A Road is the upper most site in the system and was sampled on 5 occasions from September 2019 to June 2021. Overall, trout numbers are low in the upper watershed; however, an increase in total observations was observed during the fall spawning season (November 2020).

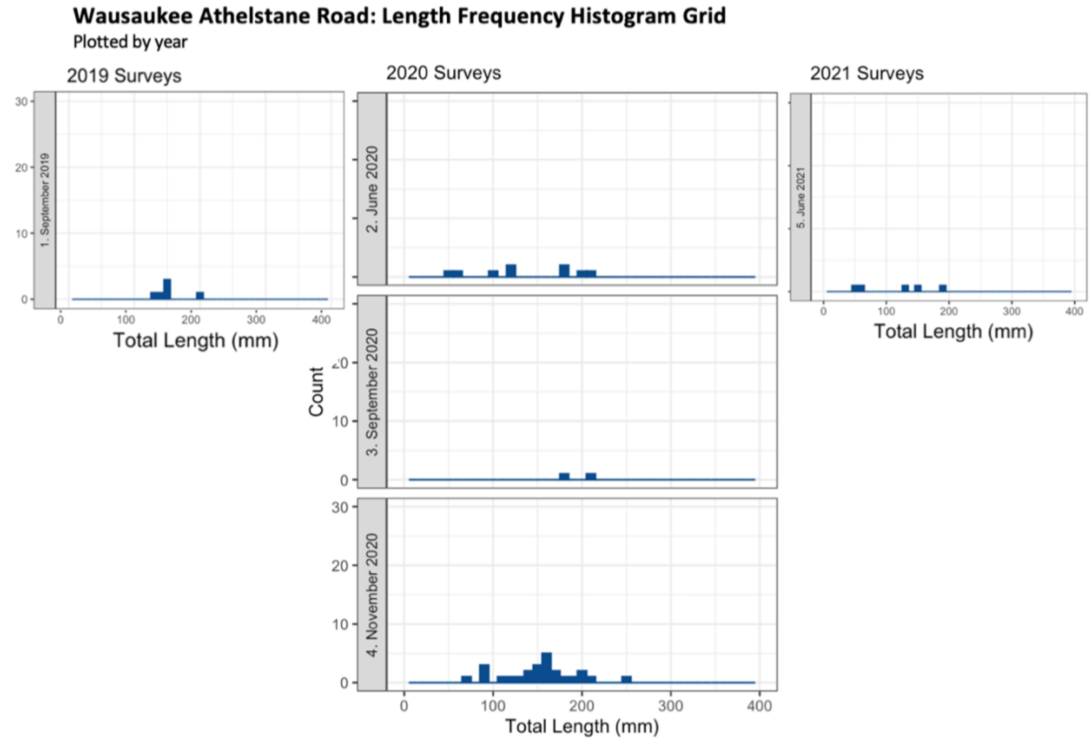

Figure 15: Length-frequency histogram grid for Wausaukee Athelstane Road site.

Based on field observations and USGS discharge monitoring on the Pike River in Amberg, Wisconsin, located 13 miles north of UMI (Figure 3), water levels varied among study years (2019, 2020, 2021). The capture efficiency of electrofishing depends on personnel, gear, environmental conditions (including water level) and individual fish characteristics (size, species, morphological characteristics) (Benejam et al., 2012). With higher water observed during the 2020 field season than the 2021 field season, it is possible that differences in capture observations in the length-frequency histograms might also be related to interannual variation in environmental conditions.

Catch-per-unit-effort: by site, by capture occasion

Catch per unit effort (CPUE) is calculated as the number of trout per distance sampled. We calculated the CPUE for each sample occasion and plotted the number of brook trout per 100 m of stream. Length-frequency histograms coupled with CPUE values across sample occasions provide insight into movement related behaviors across the study system. The CPUE data show noticeable peaks in the middle watershed during the early fall season, while the lower watershed shows an increase in CPUE during the early winter months, suggesting brook trout movement upstream to the middle watershed reaches during the fall spawning season, then subsequently move back downstream to the lower watershed at the onset of winter conditions (Figure 18).

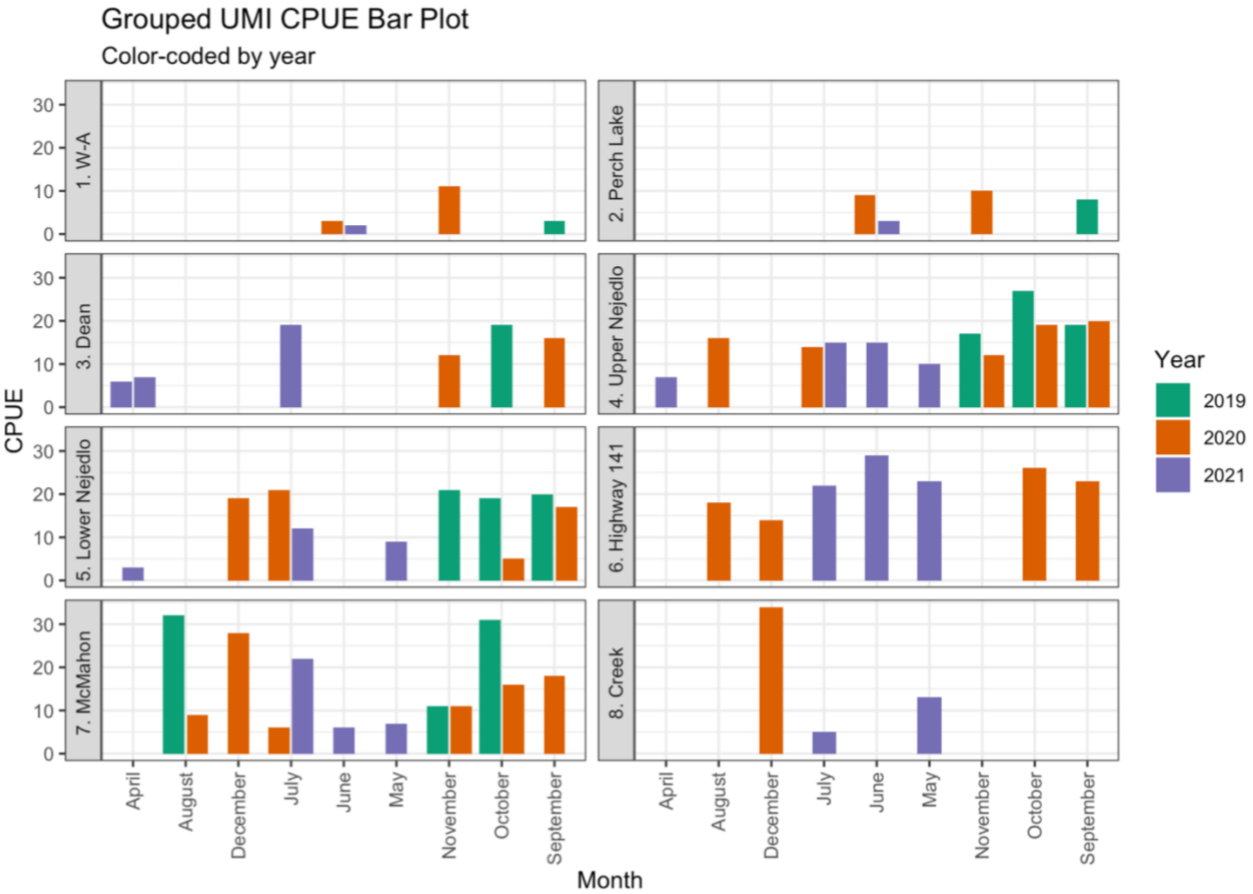

Figure 16: CPUE grouped and gridded bar chart plot, showing CPUE for all sample events throughout the duration of the study. CPUE is plotted by site, grouped by sampling month and color-coded by year Site 1 W-A is the most upstream site, while Site 8 Creek is the most downstream site.

DISCUSSION

Patterns of brook trout movement across riverscapes have broad ecological and evolutionary impacts that further shape the potential success of freshwater management practices (Kanno et al. 2021; White & Wagner, 2020; Pine et al. 2003). Previous research on instream movement of many trout species across various regions suggests movement patterns are highly variable, with some individuals showing high site fidelity while others demonstrate preference for long-range movements (Gowan & Fausch 1996). Our work on brook trout movement in UMI in northeast Wisconsin aligns with this previous research, as we observed a large portion of the tagged population making short-distance movements throughout the study duration, while a small portion of the population recorded long-distance movement, similar to other trout species and regions (White & Wagner, 2021; Kanno et al., 2014; Petty et al. 2012; Letcher et al., 2007; Curry et al., 2002; Rodriguez 2002; Gown & Fausch, 1996), as well as in Wisconsin (Schleppenbach et al., 2021). The major finding from our study in northeastern Wisconsin is that brook trout in this region are making long-distance movements that coincide with biologically significant seasonal events, including spawning related upstream movement (late-summer, early-fall) and downstream movements post-spawning at the onset of winter conditions.

Using PIT tag recapture data, length-frequency histograms and catch-per-unit-effort (CPUE) data, we have been able to characterize the timing and minimum extent of long-distance movements that occur across seasons throughout the UMI system, which likely applies to other brook trout populations in northeastern Wisconsin. We found that most tagged brook trout (89% of combined sequential observations) recorded movements less than 1 km, while a smaller portion of the tagged population (11% of combined sequential observations) recorded movements up to 14.7 km. Due to the nature of field sampling and study design generally, it is not likely that we would have captured the full extent of long-distance movements made by individual brook trout in the UMI system. This is important to note because these recorded distances could be thought of minimum recorded distances, as we have observed missed detections at PIT array systems that we know tagged trout have moved through. Additionally, we never recaptured a large portion of the tagged brook trout population (71% of all tagged trout were not recaptured), leaving lingering questions about where these trout may have moved to or redistributed within the UMI system.

With regard to the timing of brook trout seasonal movement, our results largely align with established brook trout literature previously mentioned, including work from central Wisconsin (Schleppenbach et al., 2021) that reports an increase in the occurrence of upstream movement during the late-summer into early-fall seasons coinciding with brook trout spawning season. This upstream pattern is followed by downstream movement in the early winter post-spawning season. The downstream movement that occurs post-spawn is likely related to movement toward biologically important overwintering habitat in the early winter, which is an important resource for brook trout populations in northern, harsh winter climates (Lindstom & Hubert, 2004). Another explanation for this downstream movement could be trout moving back downstream toward the individual's home range following the upstream spawning migration.

With the use of the installed PIT array systems, we were able to detect pass-through movements, where an individual was only detected once moving either up- or downstream, and daily short movements up- and downstream through the antennas on multiple occasions throughout the duration of the study. In attempt to design a study capable of characterizing long-distance movements as recommended by Kanno et al. (2020) and Gowan et al. (1994), we established as many study sites along UMI as possible, taking labor, time, equipment and land access constraints into consideration. Future research into brook trout movement in northeastern Wisconsin would benefit from an increase in monitoring efforts of the lower reaches of study systems, especially if these systems are connected to lakes and spring ponds that may be utilized for overwintering habitat by brook trout. For example, in our UMI study system we would have benefited from monitoring at the inlet to Lake Noquebay (Figure 2) to assess whether brook trout are migrating from and to the lake for spawning and overwintering habitat. This is especially interesting in the context of the large-bodied individuals we captured in the fall of 2020 but have not recaptured since that specific sampling event.

Another important note is that the UMI system has been under extensive beaver management practices (control and removal) since 2001 (WDNR, 2010). As stated in the *Wisconsin Watersheds* overview of the Middle Inlet-Lake Noquebay watershed, many of the concerns with water quality impairments and fragmentation have largely been alleviated following the initial removal and maintenance of free-flowing conditions. Due to these changes and perceived improvements, the beaver management program will likely remain a management priority into the future (WDNR, 2010). While fragmentation may have decreased due to the beaver management program on UMI, it is difficult if not impossible to assess whether or not the removal of beavers and dams significantly altered seasonal movement patterns or greatly improved access to biologically significant habitats due to limitations in previous beaver-inhabited brook trout movement data in this system.

Limitations of detecting movement

While some research has reported that high-flow events contribute to relatively high levels of up- and downstream trout movement (Connelly et al., 2008), we did not collect flow data during each sampling event throughout the duration of the study. Due to interannual variability in flow, it is possible our capture efficiency differed across years and study events based on hydrology. The ability to resolve this question of hydrologic diversity is beyond the scope of this study. We were also not able to assess the precision of our PIT array systems during high flow events, which would have been a useful piece of information to know as we worked to refine the functioning of our PIT array systems, particularly as high flow events have been documented to reduce precision of the systems (Connelly et al., 2008).

Although we completed an intense field aspect of this work, it was not feasible to sample the entire river system in search of tagged individual trout. It is likely that we missed opportunities to recapture tagged trout due to labor, land access, equipment and time constraints. With regard to the large-bodied individuals captured in September 2020 upstream of Highway 141 where we had never captured them before, we were unable to find where these individuals moved from, or where they moved post-spawning season.

MANAGEMENT IMPLICATIONS & BEAVER

We found that brook trout in the UMI system make long-distance and short-distance movements, many of which coincide with biologically important seasons. These observed movement patterns demonstrate the important role of riverine connectivity for brook trout populations in northeastern Wisconsin, generally. In order to both protect and maintain recreationally important brook trout populations that are comprised of resident and migratory variants, thinking about the importance of seasonal movement behaviors throughout the riverine system should be taken into management consideration (Meyers et al., 1992). Echoing the concept of taking a stream system approach to brook trout management (Meyers et al. 1992), conceptualizing the UMI system, and other river systems in northeastern Wisconsin, as a riverscape with diverse movement behaviors connecting populations as opposed to discrete populations may offer an important perspective on future management decisions that are working toward balancing the needs of recreational anglers, dynamic trout populations and the future of beaver management decisions that may alter the free-flowing conditions that allow trout access to important habitat types across the riverscape (Meyers et al., 1992).

With regard to beaver management, if changes occur that allow for beaver recolonization and system-wide damming, the long-distance movements of brook trout may be negatively impacted. Although a great deal of recent research largely from the Pacific Northwest has questioned the argument that beaver dams limit or fully impede fish movement (Pollock et al. 2014; Lokteff et al., 2013; Rosnell et al 2005; Collen & Gibson 2000; Leidholt-Bruner et al., 1992), beaver damming may impact the ability of fish to access biologically important habitats in lower gradient systems (WDNR, 2019). Nevertheless, other research has pointed to the possibility that beaver may play an important role in restoring fine-grained, low gradient stream channels because of their ability to trap sediment and reduce channel incision and erosion (Curran & Cannatelli, 2014), which would be important considerations in the UMI system and northeastern Wisconsin generally. While historic research into beaver-trout relationships that occurred in northeastern Wisconsin (Avery, 2002; McRae & Edwards, 1994) has helped shape the foundation for contemporary beaver management in the state (WDNR, 2019; WDNR, 2015), the need for more nuance in these relationships has been identified as regionally important topic (Johnson-Bice et al. 2018). With instream brook trout short- and long-distance movements now documented in this region, it becomes important to consider these movement patterns in the context of maintaining brook trout populations, while also balancing the current and future needs of beaver management in northeastern Wisconsin.

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CHAPTER 3: Reimaging dam removal to resist settler colonial logics

ABSTRACT

There are compelling reasons to see dam construction—at its peak in the United States (U.S.) in the mid-twentieth century but currently increasing throughout the world—as an example of the physical manifestation of settler colonial logics on the landscape. The construction of instream structures designed to extract the power of flowing water physically restructured and symbolically reimagined North American rivers and many human relationships to those systems. While most New England mill dams no longer generate power, their long-term persistence on the region's landscape serves as an ongoing and consequential scar from settler colonial actions. Therefore, dam removal—currently on the rise in the U.S.—would seem to offer to a remedy. And yet, we argue here that dam removals in the U.S. may be just as likely to reinscribe and reinforce dominant settler colonial logics of domination and control, acting as a palliative but not a remedy to settler colonial river management practices. In this work we ask, **(1) Does the shift from dam construction to removal offer a remedy for the environmental, social, and cultural degradation associated with dam development? (2) How might river restoration strategies perpetuate ongoing settler colonialism and impact instream and streamside inhabitants, both human and nonhuman? (3) What might an unsettling alternative to river restoration look like?** We suggest the Woonasquatucket River Watershed Council as a case study alternative for river restoration practice because the organization's creative, collaborative model might usefully undermine—rather than reinforce—settler colonial logics and achieve pragmatic goals for rivers and the diverse communities they support.

INTRODUCTION

There are compelling reasons to see dam construction—at its peak in the United States (U.S.) in the mid-twentieth century (Ho et al. 2017) but currently increasing throughout the world (Biello 2009)—as an example of the physical manifestation of settler colonial logics on the landscape (Schneider 2013; Griffith 2016). As articulated by Indigenous scholars, settler colonialism is a dominant social or political structure where a colonizer comes to a place, lays claim to it, and disenfranchises its people by stripping their autonomy as a means to exploit the land for monetary gain (Wolfe 1999; Tuck and Yang 2012; Arvin, Tuck, and Morrill 2013). Settler colonialism is not an event in time; it is an ongoing process (Wolfe 1999) and "a matter of life-world reordering… associated with death and the end of the world" (Boswell 2015, 1).

A settler colonial lens offers theoretical language for understanding the connections between the arrival of Anglo-European settlers in North America and the damming of waterways. For instance, in New England, Anglo-European populations began to intensify in the 18th century due to the advances of the Industrial Revolution, initially made possible by the use of small mill dams that harnessed the power of water, many of which still punctuate the landscape. The construction of instream structures designed to extract the power of flowing water physically restructured and symbolically reimagined North American rivers and many human relationships to those systems. As Eve Tuck and K. Wayne Yang (2012) argue, "Within settler colonialism, the most important concern is land/water/air/subterranean earth [...] what is most valuable, contested, required" (5). In the case of New England's dammed landscape, water—and access to it for the sake of generating power—became a primary concern; water-power was valuable, contested, required. While most New England mill dams no longer generate power, their long-term persistence on the region's landscape serves as an ongoing and consequential scar from settler colonial actions.

If dam building in New England is a settler colonial manifestation, then dam removal—currently on the rise in the U.S. (Ambers 2007; Gosnell and Kelly 2010)—would seem to offer to a remedy. River restoration practices, including dam removal—a process that attempts to return degraded aquatic ecosystems to healthier conditions through the removal of human-made barriers—have become an increasingly common strategy for repairing river connectivity and natural riverine processes (Graf 1999; Wohl et al. 2007; Bernhardt et al. 2007; Palmer et al. 2007). In addition to improving ecological function and supporting native species (Bellmore et al. 2019), aquatic restoration projects offer potential to strengthen social justice efforts by providing accessibility to green spaces, improving public health, and reconnecting human and nonhuman communities in riverine corridors, particularly in urban areas (Palamar 2008; Wolch, Byrne, and Newell 2014; Hychka and Druschke 2017). Thus, dam removals offer a potential solution to the settler colonial logics of dam construction: seeming to undo the damage of New England's 14,000 small and large dams that harnessed and privatized river flow for the financial benefit of Anglo-settlers.

And yet, we argue here that dam removals in the U.S. may be just as likely to reinscribe and reinforce dominant settler colonial logics of domination and control, acting as a palliative but not a remedy to settler colonial river management practices. As we will explain, the management discourse and logics that drive dam removals and fish passage projects in the U.S. Northeast often seem to repeat the same logics of efficiency and disconnection employed in dam construction. We also briefly work to describe how such restoration projects are often easiest to accomplish in economically privileged and politically savvy communities.

To offer an alternative, we build from one author's work directing the Woonasquatucket River Watershed Council in Providence, Rhode Island. The Woonasquatucket River Watershed Council is non-profit organization with a vision for community-based river restoration that includes dam removal and fish passage projects, and does so in ways that amplify the voices of marginalized community residents and encourages the reconnection of human and nonhuman relationships. We suggest this creative, collaborative model of dam removal and river restoration might usefully undermine—rather than reinforce—settler colonial logics, while achieving pragmatic goals for rivers and for the human and nonhuman communities they support.

Dam Construction in the Settler Colonial Context

Dams make present a literal, physical instantiation of settler colonial logics. In the U.S. Northeast—where we have researched, taught, and practiced—dams are an ubiquitous and often unquestioned feature punctuating the landscape. The National Inventory of Dams (NID) estimates there are more than 80,000 dams in the U.S., which amounts to roughly one dam built per day since the signing of the Declaration of Independence (Lieb 2015). New England boasts the highest concentration of dams in the U.S. The region features the single county with the highest number of dams in the U.S. (Worcester, Massachusetts) and hosts the oldest surviving U.S. dam: Connecticut's Mill Pond Dam, built in 1677 (Graf 1999). With the staggering number of dams built from European contact to present, it is not an exaggeration to say that Anglo-European colonization of the U.S. goes hand in hand with the damming of its free-flowing waters.

The U.S. Northeast hosts a staggeringly dense concentration of dams, estimated at 14,000 (Fox, Magilligan, and Sneddon 2016). While it is true that humans have used the force of free-flowing water to advance societal development for thousands of years (Kluune 2012), the demand for water power in the U.S. increased exponentially during and after the Industrial Revolution to meet settler communities' increasing demands (Gleick 2003; Magilligan et al. 2016; Magilligan et al. 2017). By the 1940s, hydropower dams provided approximately 75% of all electricity generated and consumed in the growing U.S. Pacific West, and constituted approximately one third of total U.S. electrical energy production (Kluune 2012). The damming history of waterways is a pointed example of colonial logics validating the understanding of the natural world as something to be controlled and harnessed. From this perspective, resource extraction often occurs at the expense of public well-being and ecological health, and without regard for Indigenous people's connection to place and relation to water (Desbiens 2014).

The damming of U.S. rivers is not an isolated enactment of settler disruption. To the north of the U.S. border, Canada boasts over 15,000 dams, almost one thousand of which are considered "large" dams (either 15 m and greater, or 5-15 m and impounding more than three million meters cubed of water) (Canadian Dam Association n.d.). Those dams have widescale ecological and social impacts. As Caroline Desbiens (2014) describes in *Power from the North: Territory, Identity, and the Culture of Hydroelectricity in Quebec*, hydroelectricity from dams in northern Quebec has ideologically and materially supported French Canadian nationalism, while marginalizing Aboriginal territories by way of dispossession and capitalization of place-based natural resources. In Newfoundland and Labrador, meanwhile, the Muskrat Falls Project, a proposed hydroelectric dam on the Churchill River, has been embroiled in controversy between the hydroelectric company, Nalcor Energy, and the Government of Nunatsiavut, representing the Inuit people of Labrador, who have concerns about possible methylmercury contamination (Fitzpatrick 2012; 2015; 2016). As the President of Nunatsiavut, Sarah Leo, claimed in 2015, "The Muskrat Falls development will put mercury into Lake Melville and negatively affect our people, our land, and the fish and wildlife we depend on" (Fitzpatrick 2015). Members of the Nunatsiavut have expressed frustration over the years about their concerns seeming to take a back seat to economic arguments in favor of the project (Fitzpatrick 2012; 2015; 2016), which would largely support the demand for energy in the U.S. Northeast. These examples support our claim that U.S. and Canadian past and present offer evidence of Anglo-European populations dislocating and marginalizing Indigenous peoples through a variety of means, including large and small projects to control and harness the power of free-flowing rivers.

The influences of settler colonialism on river development and the monopolization of water power are not isolated within the North American context; the development of large-scale dams and infrastructure projects are current and controversial, particularly in the Global South (McCully 2001; Braun 2011). Dam development projects globally, especially in the Global South, can be accompanied by social and ecological hardships and unfulfilled promises of community and economic development (McCully 2011) that reveal ongoing settler colonial structures and logics. Many large-scale dam projects come to life through significant domestic and foreign investments of capital and resources and are justified through neoliberal ideologies that promise economic returns (McCully 2001). Although projects promote economic returns to local residents, fulfillment of these promises are limited, as researchers have detailed in South Africa (Braun 2011), India (Chattopadhyay 2014), Myanmar (Simpson 2013), and elsewhere (McCully 2001). Indigenous peoples and ethnic minorities tend to be more frequently impacted by the 45,000 dams built globally since World War II (Johnston 1997). Though reported to be regularly excluded from development decision-making related to dams (Grumbine, Dore, and Xu 2012; Manoroma, Baird, and Shoemaker 2017), Indigenous groups are often on the frontline of resistance movements fighting for environmental protection and protesting large-scale development projects (Fisher 1995; Fulmer et al. 2008). Despite some of the very real benefits dams can offer for human development, including power, flood control, nutrient retention, and economic capital, dams present a variety of human and ecological drawbacks (Bednarek 2001; Ambers 2007), and their ubiquity on the global landscape demonstrates the power and extent of the colonial reach.

River Restoration as Ongoing Settler Colonialism

As we have detailed, ongoing settler colonialism renders itself visible on the New England landscape through the region's 14,000 small and large dams, put in place to harness the energy of free-flowing rivers that, in part, supported an industrial and more broadly capitalist agenda. It would seem, then, that the current U.S. shift from dam construction to removal would help to correct the inequities posed through dam development. Construction of dams in the U.S. has been on the decline since the 1970s, and the U.S. rate of decommissioning overtook the rate of construction in 1998 (WCD 2000; Gosnell and Kelly 2010). Dam removal now plays an important role as a tool for ecosystem restoration in the U.S. (Bednarek 2001; Ambers 2007; Bellmore et al. 2019). But we suggest the recent trend of dam removal seems to echo a similar sentience as historic dam building throughout Anglo-European development of New England waterways. Rather than acting as a tool for dismantling the settler impact on and control of rivers, we detail the ways that dam removal often serves, like dam construction, as a means for perpetuating the logics and physical spaces of management, control, and efficiency.

The support and extension of settler colonial logics is perhaps most visible in the official, managerial language of dam removal and river restoration. In Rhode Island, U.S., specifically, language that aims to protect the state's waterways and aquatic organisms employs verbiage that tends to distance restoration managers from the systems they manage, fitting river systems and aquatic organisms into frameworks of dominance and control. Efforts to support Rhode Island migratory fish passage with respect to the legacy of mill dams that impede fish's seasonal upstream migrations, for instance, are supported through a complex network of interlocking agencies at the watershed, state, and federal scales, but largely reside under the guidance of the Rhode Island Department of Environmental Management's "Strategic Plan for the Restoration of Anadromous Fishes to Rhode Island Coastal Streams" (Erkan 2002). The introduction to the Strategic Plan actually opens by pointing to the logics that drove the expansion of industrial era mill dams throughout the region, and describes their impacts on migratory fish populations in the state:

> "The dams of the Industrial Revolution were placed in rivers for an inexpensive and reliable source of power. Little thought was given to the effects on native fish populations. Fish passage efforts at the time met with little success. The end result was the extirpation of local populations of American shad, alewives, blueback herring, Atlantic salmon, and other species. As the Industrial Revolution waned, so has the need for the dams, but they remained." (Erkan 2002, 6)

We argue that settler colonial impulses offer the subtext and foundation for these industrial, managerial logics, where a concern for powering Anglo-European industry with "an inexpensive and reliable form of power" elided the needs of the river's resident and migratory fish, much less the needs of the Narragansett, Pequot, Niantic, and Wampanoag peoples native to the region now known as "Rhode Island."

Still, where the document does point to the ongoing impacts of these coupled colonial and industrial logics on fish species (but not humans), it seems to simultaneously articulate and perpetuate these same logics. Practically speaking, the solutions offered, while useful and important for restoring migratory fish populations in Rhode Island rivers and streams, largely consist of technical solutions that include constructing engineered fish passages, stocking of migratory fish species, and ongoing population monitoring efforts without questioning or undermining the very logics that drove dam construction in the first place.

These state-based logics echo federal perspectives on fish passage restoration efforts, evidenced in part in 2016 federal interagency guidelines for the construction of fish passages (Turek, Haro, and Towler 2016). As that technical memorandum details, “Both NMFS [the National Marine Fisheries Service] and USFWS [U.S. Fish and Wildlife Service] along with USGS [U.S. Geological Survey] seek to advance engineering design and technology in providing safe (from both physical injury and predator avoidance), timely, and effective upstream and downstream passage for all diadromous species targeted for restoration” (2). Again, though useful and timely at the level of practice, this language of management, safety, timeliness, and efficiency of fish movement past dams bears the trace of settler colonial logics. These discourses, as they play out in everyday discussions, management documents, and state policies, further support, extend, and normalize settler colonial logics and the structures they support.

Crucially, the Strategic Plan and federal policy discourse sets an agenda for funneling available resources towards priority watersheds that, as the Rhode Island document describes, offer, “the potential to restore, establish, or enhance anadromous fish populations through upstream passage for migrating adults and downstream passage for juveniles” (Erkan 2002, 7). As the Plan details, “In both cases, the primary goals are to minimize passage-induced mortality allowing expansion into unutilized and underutilized habitats with the most cost-effective method available. Reintroduction of spawning broodstock is another critical component of the restoration efforts” (Erkan 2002, 7). Technical/managerial logics are evident in the language of mortality rates, cost-effectiveness, and fish stocking, and these logics guide restoration efforts throughout the state. While migratory fish species like Atlantic salmon, alewives, blueback herring, and shad were all but extirpated in New England due to the rise of early industrial capitalist construction of some 14,000 dams region-wide, the solution to restoring these species is likewise envisioned through human control of natural processes and landscapes: through breeding programs, stocking, and ongoing monitoring and management of populations driven by perspectives on cost-efficiency. These impulses fundamentally illustrate the settler colonial logics present in natural resource management (Acheson 2006; Palmer 2006; Schneider 2013; Boswell 2015).

On the federal level, policy discourse supports the prioritization of watersheds and water bodies; rivers are categorized by management agencies from low- to high-priority systems, often with limited involvement from local communities in making these categorizations (Geist and Galatowitsch 1999; Petts 2007). Site selection for restoration projects is often associated with colonial value hierarchies, supported by inflexible institutional processes that limit meaningful trans-species relationships and reinforcing problematic structures of settler power and privilege.

Most of the 1,400 dams in the U.S. deliberately removed since the 1970s have been <5m tall and are aging, obsolete dams that pose potential threats to human health and safety, while impeding river connectivity (Ambers 2007; Magilligan et al. 2016; Bellmore et al. 2019). Crucially, the highest frequency of dam removals in the U.S. occur with small dams (WCD 2000), many of which, thanks to the ongoing legacy of the industrial revolution, occur in densely populated regions, and as we discuss further, occur where communities have access to monetary resources and where the restoration sites are connected to swaths of ‘pristine’ land (Pow 2009).

While not always the case, some evidence seems to suggest that communities with economic means and powerful political voices are those that have the knowledge and clout to initiate, direct, or support restoration activities (Hychka and Druschke 2017). Crucially, that trend can exclude communities that lack economic means and know-how from dam removal and river restoration efforts. Kristen C. Hychka and Caroline Gottschalk Druschke (2017) describe a variety of barriers to urban restoration initiatives that include dam removal, especially in under-resourced communities, including a lack of availability of funds in so-called "degraded," non-pristine river systems and a lack of capacity for spending among many small, under-resourced organizations. Among the interviews with restoration managers and community advocates highlighted in their work, Hychka and Druschke (2017) feature a restoration manager who summed up the funding challenge of working in urban areas: "You can get maybe a quarter of an acre of restoration in, where if you go down to [a more rural part of the state] the same money will buy you 20 acres… If you have $2 million, you can save a huge pristine [area]. Or you can restore a five-acre contaminated site in an inner city. And that is the challenge" (6). Urban restoration projects, including dam removals, in under-resourced communities are harder to justify, harder to fund, and often present more technical obstacles due to legacy effects of industrial pollution (Hychka and Druschke 2017). Some communities either do not have the educational empowerment to know about restoration activities, or do not know how to move forward in advocating for socially and environmentally just river management (Hychka and Druschke 2017).

Settler colonial logics have laid the foundation for and continue to sustain a particular management discourse within dam removal projects, including fish passage around dams, that, in many ways, distances humans from fish, while prioritizing efficiency and managerialism over human with other-than-human relationships. The status quo terminology of fisheries research and management offers fish as "units" or "products" that are stocked, planted, closely monitored, and even reared through industrial modes and logics, while the status quo terminology of river restoration prioritization privileges literal spaces of power and exclusion.

Despite the dominance of settler logics in dam construction and removal, we consider how to work toward the deconstruction of these structures within river restoration discourses and practices by using an unsettling framework, in solidarity with decolonization. As white, female settlers whose work does not bring “about the repatriation of Indigenous land and life” (Tuck and Yang 2012, 1) we aim to support decolonization without metaphorizing by using unsettling means. Unsettling work disrupts colonial structures and is attuned to the ways that privilege-based ideologies are perpetuated, instilled, and reinforced through social and scientific discourses. Below, we offer a practical case example, drawn from one author’s work as director of the Woonasquatucket River Watershed Council in Providence, Rhode Island, U.S., of local community members and technical scientists collaborating with fish and other river dwellers.

Countering Settler Colonial Dam Removal Logics: The Woonasquatucket River Watershed Council

To highlight this alternate perspective on river restoration, we feature an ongoing urban restoration initiative in Providence, Rhode Island that employs a variety of restoration techniques. The initiative, which includes dam removal projects, aims to restore aquatic connectivity and improve water quality, but also to increase the visibility of shared community resources, rebuild community connections to place, direct resources towards under-resourced communities of color, and amplify the voices of community members. This case example, Rhode Island’s Woonasquatucket River Watershed Council (WRWC), was one of the earliest urban river restoration projects in the U.S. The WRWC model has the potential to inspire other communities working to restore degraded, urban aquatic ecosystems by reconnecting and redeveloping human-community relationships to rivers. The work of WRWC demonstrates the possibilities for a group of creative advocates to contest 140 years of industrial domination of a river system that many city dwellers—as you'll read—had forgotten even existed, thereby engaging in dam removal projects that offer a model for productively interrupting settler colonial logics. Important to note is that although WRWC is not actively returning land to the Narragansett Tribe, the Indigenous peoples of this region, they do offer a model for undertaking restoration projects that support the initial unsettling steps toward decolonial work more broadly.

WRWC's restoration work continues to be accomplished in part through physical restoration of the river corridor—by way of removing dams and constructing fish ladders, green spaces, and a bike path—but also through the increasing reorientation of the lower Woonasquatucket's under-resourced human community towards the river itself and the reclaiming of habitat by the river's once nearly extirpated migratory fish species. As WRWC inspires human community members to reconnect to the Woonasquatucket River, this work—and the narratives they co-create about that work and about each other—redraws relationships with the river and bolsters the importance of trans-species connections that are mutually beneficial for diverse human communities, river organisms, and rivers themselves.

We point to the work of the Woonasquatucket River Watershed Council here because of the ways that their work seems to, at least partially, deconstruct dominant restoration narratives related to river management, restoration hierarchies, and place-based relationships to other-than-human worlds and species. We suggest that the WRWC model may prompt future dam removal projects to consider employing ecologically and socially equitable discourses and actions.

Working Within an Existing Settler Colonial Structure

Crucially, we argue that WRWC is such a useful model because it conducts its creative work within the very settler colonial structures we have described. For instance, WRWC has to work against the fact that the Woonasquatucket watershed is deprioritized in Rhode Island's "Strategic Plan for the Restoration of Anadromous Fishes to Rhode Island Coastal Streams" because, while it is cited as having "local interest in establishing fish passage," "the poor water quality and high number of dams make other watersheds more attractive alternatives" (Erkan 2002, 25). In other words, the state management plan documents local desire for river restoration projects like dam removal in the Woonasquatucket watershed that might reconnect human and piscine residents, but the system's "poor water quality," its current degradation—the consequence of colonial industrial transformation of the waterway from the 1700s through the 1970s (Greenwood n.d.)—excludes it from the mainstream restoration process. In the technical/managerial logics of effective and efficient fish passage around dams, the Woonasquatucket fails to offer a compelling argument for sustained state or federal attention, a stalemate that conspires to worsen the ecological health of the river. Further complicating the matter are the ongoing and extensive impacts of Superfund-level legacy pollution in the lower reaches of the watershed. Due to this complication, it is not likely that dam removal can offer anything like the sorts of recoveries that are touted as the outcomes of river restoration and dam removal, what a key environmental non-profit in Rhode Island, Save the Bay, describes as bringing a river "back to life," by ushering in a "return to their former channel and habitat function" (Save The Bay n.d.).

A Watershed Based, Systemic Approach for Supporting Human-Fish Interaction. And yet, dam removal and engineered fish passage solutions have become an increasing point of emphasis in the Woonasquatucket watershed. As WRWC describes on its web site:

> "Fish have once again become a common sight in the tidal portions of the Woonasquatucket. The Woonasquatucket River Watershed Council is working with NRCS and other partners to provide fish passage at the first five dams on the Woonasquatucket to allow fish such as shad and herring, which migrate from saltwater to fresh to spawn, and eels, which migrate from fresh to salt to spawn, to move up and down the lower river." (WRWC Fish Passage)

That work involves a systemic approach to fish passage at five sequential dam sites with various restoration approaches: Rising Sun Fish Ladder; Paragon Dam (Figure 19, 20); Atlantic Mills Fish Ladder; Dyerville Dam; and Manton Dam.

Figure 17:Paragon Dam prior to removal, looking west (above).

Figure 18: Paragon Dam dam removal after looking west & upstream (above).

In contemporary river restoration, basin-wide repair efforts are becoming more common but are still often the exception to the rule (Opperman et al. 2011; Magilligan et al. 2016). Recognizing that each dam location is site-specific, yet, related to the others within the watershed is an important component of restoration that can positively influence strategic restorations aimed at broad-scale recovery. Place-based solutions aimed at balancing riverine resources and reconnecting human-river actors cannot be achieved on an individual project scale (Opperman et al. 2011). Therefore, this turn towards a system-wide approach, as demonstrated on the Woonasquatucket, provides evidence for a shift in restoration discourse and implementation that aims to improve connectivity at the watershed-scale.

Beyond this watershed-scale approach to improving fish passage at existing dams, WRWC restoration efforts have worked to open opportunities for public interaction with the river and its annually returning migrating fish. The WRWC's restoration efforts that have aimed to expand beyond the physical river have fostered the visibility of trans-species relationships that we argue are essential for working to dismantle settler colonial structures. For instance, the Rising Sun Fish Ladder, completed in 2007 at the Rising Sun Mills complex, incorporates a viewing platform where community members can observe migrating river herring and American eel and count returning fish throughout the spawning season. Atlantic Mills Fish Ladder in Riverside Park, completed in 2009, also includes public engagement features such as a walk-on platform to look down into the ladder at migrating fish. The uppermost dam on the river—just over a half mile upstream of Dyerville and two miles downstream of the Centredale Manor Superfund Site—is Manton Dam (Figure 21, 22), where the WRWC has worked for several years to secure funding for a nature-like fishway.

Figure 19: Aerial view of fish ladder at the Manton Dam (above).

Figure 20: Manton Pond Dam nature-like fishway (above).

The Manton Project, completed in late 2016, allows migratory fish access to Manton Pond's nine acres of spawning habitat upstream and brings total available spawning habitat in the system from 4.6 to 5.3 river miles. In many ways, the Manton Project closes the loop on a vision for migratory fish passage past dams on the Woonasquatucket that seemed impossible in the framing of the 2002 Rhode Island anadromous fish report and its prioritization scheme.

Listening to Members of Under-Resourced Communities

The bulk of the work done by WRWC on the Woonasquatucket—including these dam removal and fish passage projects—takes place in the lower reaches of the watershed, largely in the Olneyville neighborhood of Providence, Rhode Island. In the early 1990s, stakeholders from the City of Providence, led by community advocate Jane Sherman, began working with neighborhood residents on reintroducing greenspace and recreational opportunities in abandoned industrial lands and public spaces along the Woonasquatucket River in Olneyville. The success of the environmental and community restoration movement was achieved through a blend of community networking and multi-stakeholder communication from planning to execution to ongoing monitoring and involvement, in coordination with community members, Rhode Island School of Design, the Army Corps of Engineers, the Narragansett Bay Commission, the Natural Resource Conservation Service, and many others.

Olneyville's demographics are shifting—potentially due, in part, to gentrification, a consequence of increased access to green space, visibility of ecological assets, increased housing costs and property values, and improvements to local community and environmental health, all of which have been reported elsewhere (Wolch, Byrne, and Newell 2014)—but the neighborhood has long been home to a large population of undocumented and transitional residents. Community activists have pointed to frequent resident turnover and political disconnection as challenges for organizing, as well as the frequent overlooking of the neighborhood as a political priority because it straddles two districts and does not offer any pristine habitat for restoration efforts (Hychka and Druschke 2017). Nevertheless, WRWC continued to build trust locally and worked towards community consensus on mutually identified goals. Though it was difficult because of a lack of political and financial power in the neighborhood and the general invisibility of the river due to its channelization behind and sometimes underneath abandoned industrial sites, one of the early central goals of WRWC was to listen to the concerns and interests of local residents and reposition the Woonasquatucket River as a neighborhood asset.

Public engagement was essential to these early discussions about neighborhood improvement and river restoration, and WRWC emerged out of that momentum and support for shared community objectives. Founding Executive Director Jane Sherman started her work in the neighborhood by attending existing neighborhood meetings, listening to the concerns and interests of neighborhood residents. She held block parties in parks that were then better known as sites for drugs and prostitution. Early public meetings with designers and architects from Rhode Island School of Design allowed residents to discuss opportunities for largely abandoned areas adjacent to the river. These meetings were bilingual, educational, and open-ended, designed to meet the needs of the Olneyville population, which the 2000 Census reported was 57.4% Hispanic, 13.6% African American, 7.4% Asian, and 30% foreign born (Providence Plan, n.d.). By design, according to Sherman, there was no master plan to be edited or policy to be followed. Instead, community members were given tours of newly renovated urban parks in Providence, existing greenspaces in the upper watershed, and derelict open spaces and hidden natural resources in the Olneyville neighborhood. The community was asked how the available land in Olneyville should be restored. A plan was developed out of these community meetings, which prioritized safe places for children to play and a corridor for safe transportation.

The project slowly started to generate funding by the same method of providing tours and soliciting suggestions from local actors. Sherman brought anyone who would go—members of the Southern New England Conservation Group, City Parks Department, Planning Department, Department of Transportation, Department of Environmental Management, and others—on tours around the Olneyville area showing the current conditions of public spaces as well as the hidden natural resource of the river and models for potential change. She started with small projects—sharing the burden of a seemingly insurmountable task across many shoulders and garnering confidence from other, potential funders—and eventually received several large pools of funding to establish a riverside greenway. The development of the greenway, now known as The Fred Lippitt Woonasquatucket River Greenway, was aimed a fulfilling the goals of increasing access to recreational opportunities and visibility of environmental assets, restoring the river and surrounding land, and working toward neighborhood stabilization (WRWC, n.d, website).

By extending opportunities for engagement and education to many stakeholders and actors (both inside and outside the neighborhood) (Figure 23, 24) and enlisting community residents in all stages of planning and design, the project generated support from the ground up that resulted in local, state, and federal support. The watershed council in its current form emerged out of this work and has become a nationally recognized leader in watershed stewardship, contributing to the designation in 1998 of the Woonasquatucket as a federally recognized American Heritage River.

Figure 21: Teaching the group (above).

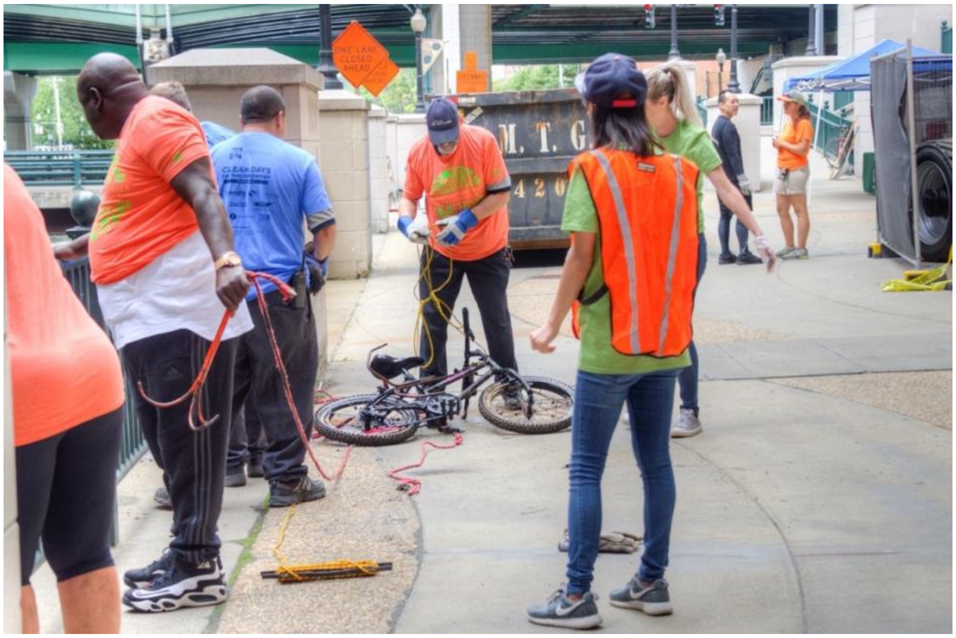

Figure 22: Community members involved in the Providence Place Mall river clean up (above).

The suite of projects along the Woonasquatucket River in Olneyville resulted in the fruition of plans envisioned by community members during public meetings. The Fred Lippitt Woonasquatucket River Greenway project—a bike route spanning from Johnston, Rhode Island to Waterplace Park in Providence—travels through Olneyville thanks to funding from a public bond issue and the Brownfield Showcase Community designation. Also, thanks to the latter, Riverside Park has been renovated from a neglected, high crime space into a usable public good for the Olneyville community featuring greenspace, river access, a functional fish ladder, and a community bike hub.

Restoration projects in the Woonasquatucket watershed offer lessons about the importance of educational access, networking, and the development of strong community support and subsequent political strength—all moves that we see as potentially countering the settler colonial logics typically present in dam removal discourse. As Sherman described of her early work in the watershed:

> “Everybody said, ‘Nothing good will happen here. We don’t have environment in this community. Anything you do in this community they’ll destroy.’ But what happened was, as you kept talking to more and more people about it you kept getting sort of indications, ‘Well I’ll support you. We won’t take on the whole thing but I can do a little bit.’ And, so it was a matter bringing all the different elements together in a way that no one felt that they were bearing the total burden… And people came by and said, ‘Where did you get the river?’ They didn’t know it was there.”

Further, it seems likely that those greenspace and restoration projects helped to galvanize a community-wide interest in related environmental projects, including the dam removal and fish passage projects.

Fish Passage and Human-Fish Relations on the Woonasquatucket

As the work of the WRWC progressed, one of the crucial ways of connecting neighborhood residents with the formerly hidden river was through restoring passage for migratory fish. While the state considered fish passage on the Woonasquatucket River a low priority, these projects have been integrated as an important component of community engagement and river restoration on the Woonasquatucket. As WRWC staff member described in a 2013 interview with one of the authors, these fish passage efforts are integral to WRWC’s work:

> “We also have fish restoration projects happening at the river, where we’re trying to bring back anadromous fish or migratory fish. The fish that live both in the river and in the open ocean for part of their life cycle. Because this was such an urban industrialized, dammed up river, we haven’t had those kinda migratory fish coming through the river for, since 1860. And in 2008 we opened our first fish ladder at the first dam on the river. And that has allowed the herring to return to that dam and since then we’ve gotten through the first four dams on the river and we’re trying to get through the fifth one. And once we get through that fifth one, we will have enough spawning habitat or reproduction space for about 40,000 adult herring, which are one of the target species we’re trying to bring back to the river, and they have lived here historically.”

Importantly, that work has enhanced the natural resources of the watershed for human community members, even if ongoing water quality issues in the watershed hamper long-term, significant changes. As WRWC staff described back in 2013, the goal of the organization has to do with the fact that:

> "[The river]'s pretty degraded, and, in fact, it's the only real natural resource for a lot of communities or a lot of neighborhoods. And my goal or, the organization's goal is the make the resources usable, available, enjoyable, safe, for the people and the wildlife that live here."

As a result, as that staff member explained, she's always asking:

> "How can we improve the water quality? How can we improve the sediment quality? How can we improve the land around it so that it protects the water better and to make it more accessible, usable, recreational, fun?"

This is an agenda of incremental change against daunting impossibility. The WRWC knows the disastrous realities it is up against. As WRWC staff described:

> "We constantly see people catching the fish down here and we're constantly like please don't eat those. This is not safe, because this is below the Superfund Site. They shouldn't really even be in the water. There's so many sewer overflows at this point going into the river. There's 19 that any time there's a half-inch of rain there's raw sewage pouring into the river. So that's fortunately being fixed by the Narragansett Bay Commission right now… So water quality will be improving very much, but until we get that Superfund site cleared up somewhat, it's still always gonna be dangerous."

Despite those real challenges, returning fish passage to the river, among other efforts, as this staff member explained:

> "Was really to like, revitalize, restore a community by revitalizing the natural resources."

The current and past work of WRWC has been about taking a river that was "shrouded," according to this staff member, making it more visible, and highlighting river connectivity. This focus on connectivity has allowed residents to see they were actually connected to pristine areas upstream and to Narragansett Bay downstream via the river, and to the creatures within the river. Dam removal and fish ladder construction became integral to that visibility—inviting community members to witness the benefits of connectivity, like observing migrating fish, padding the river, inviting them to view maps of connectivity, and taking them on field trips upstream.

Building from WRWC Restoration Efforts

We see WRWC utilizing an unsettling approach to dams and restoration. This unsettling approach attempts to understand and account for the positions and needs of impacted persons and other-than-humans within the hegemonic paradigm of dominance and control. Importantly, unsettling work aims to make visible and disrupt settler logics through processes that redistribute power and privilege, while re-centering community-based needs in place of institutional priorities and desires. Activities like watershed-scale dam removal and fish passage, reconnecting human residents with migratory fish, paddling the river together, offering technical assistance, listening to and amplifying resident voices in state political discussions, and working in legal arenas to address the ongoing impacts of the Superfund site on the river, have encouraged river restorationists and community members alike to understand their relationships with each other and with the river differently. This has been done through recognizing power inequalities associated with class, race and the river restoration prioritization processes, in addition to addressing both the exclusion and needs of under-resourced groups and the environmental conditions in which they live.

WRWC can prime us to learn from Indigenous scholars and communities in ways that challenge us to think of and examine New England dams differently, placing issues of equity, race, and privilege at the foreground of community engagement and natural resource management. WRWC restoration efforts aimed to be inclusive of the wide variety of potential community-river interactions, a move toward dismantling long instilled settler logics. Providing mechanisms for marginalized community members to reclaim voice and space is crucial to creating inclusive, sustainable, and just restoration projects.

We suggest there is an acute need for place-based work that adopts an approach grounded in the critique of settler colonialism to dam development and removal, like the work we offer here. We attempt to enter what we see as a relative silence in the literature related to human dimensions of dam construction and removal, where critical humanities grounded analyses of hydropower in the global north are largely absent, in places where dam decisions have transitioned into questions of dam removal rather than continued development of free-flowing rivers for power generation, navigation, and economic benefits.

River restoration strategies, including dam removal, can perpetuate ongoing settler colonialism by privileging managerial logics and reinforcing a narrow vision of success, without considering the impacts of river restoration projects on rivers and both their instream and streamside inhabitants, both human and nonhuman. The Woonasquatucket River Watershed Council offers an example of river restoration that does not conform to the structure of completely reversing anthropogenic action, but, instead, reimagines what the community's relationship to the river is and can be. The Woonasquatucket River restoration projects were aimed at both re-imagining the river and redeveloping the natural resources of the community. Through this re-imagining and redeveloping, communities along the banks of the Woonasquatucket River were able to begin to realize the potential of their mutually beneficial relationships with the river and see the river as a vital asset previously forgotten. By refusing to uphold unrealistic expectations for restoration—like returning the river to pre European-contact conditions—community members and restorationists were able to co-create new relationships with each other and with the river, while also making obvious gains for the ecological and residential health within the watershed.

Reimagining Dam Removal in Resistance to Settler Colonial Logics

In this chapter, we argued that a settler colonial lens can spark the deconstruction of problematic management and restoration narratives and structures. We hope this piece will contribute to the global retelling of dams and river restorations. And we offer this WRWC case study as a way to begin the unsettling of New England waterways in solidarity with and in support of decolonization efforts led by Indigenous communities worldwide. As Tuck and Yang (2012) have powerfully articulated, "decolonization in the settler colonial context must involve the repatriation of land simultaneous to the recognition of how land and relations to land have always been differently understood and enacted; that is, *all* of the land, and not just symbolically. This is precisely why decolonization is necessarily unsettling, especially across lines of solidarity" (7). Dam removal, in and of itself, is an unsettling disturbance for humans and other-than-humans, disrupting what has stood in place in recent memory (Stanley and Doyle 2003). But we take seriously Tuck and Yang's (2012) insistence that, "decolonization is not a metaphor" (1), and we offer this work as a call for the literal dismantling of the colonial structures and logics within river management and restoration, and do not suggest that this work is a model for decolonization. We encourage our readers to embrace unsettling work that supports Indigenous led projects and decolonial actions, and, even when uncomfortable, to continue incorporating and amplifying marginalized voices in restoration projects. Otherwise, we risk perpetuating the same paradigm of dominance and control that has led to widespread ecological and social degradation of the world's rivers.

We also encourage water researchers, restoration managers, and water workers to consider the settler colonial mechanisms at play in the ways we communicate about these topics. An early step to dismantling colonial structures within dam, hydropower, and dam removal discourses is to recognize that the ways we communicate information, prioritize spaces, and design management plans for human and other-than-human organisms in impacted systems can support colonial and distancing processes that limit relationships among terrestrial and aquatic realms. For instance, scientific discourses used to produce technical reports and develop management regimes frequently perpetuate narrow, western, colonial perspectives that contribute to ongoing colonialism. When language is used that allows for distancing, it becomes easy to "other" organisms, systems, and peoples that do not fit within the dominant narrative. This material form of dominance has the power to further strip autonomy, disregard inherent value, and situate human and non-human organisms and systems into the dominance and control paradigm. In this positioning, institutional power degrades marginalized groups' ability to organize, make decisions, and have their voices and needs heard and taken seriously.

Here we have utilized a settler colonial lens to critique both dam construction and dam removal discourse and practice, and to complicate what we see as a prominent restoration practitioner perspective that extols the benefits of river restoration in ways that can actually perpetuate an unjust status quo (Dhillon 2015). We have attempted to destabilize hegemonic dam removal discourses and highlight a long-term, real-life, watershed-based approach to restoration that attempts to resist colonial influences in favor of grassroots community-river-species reconnection, a model that might offer important pathways and strategies toward more diverse and justice-centered projects. We hope readers will join us in this ongoing work.

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DISSERTATION CONCLUSION & FUTURE DIRECTIONS

The research presented in this dissertation covers three central nodes of stream restoration work: (1) the human dimensions; (2) fish movement and reliance on riverine connectivity; and (3) critical evaluations of settler colonial logics that shape restoration projects. I utilize knowledge and methodologies across the social sciences in Chapter 1 (**Divergent Perspectives on Stream Restoration in the Driftless Area, Wisconsin: a Q-method survey of practitioners**), where I describe four practitioner perspectives on stream restoration projects in the Driftless Area. Then, in Chapter 2 (**Seasonal Migration in a Brook Trout (*Salvelinus fontinalis*) Population, Upper Middle Inlet, Marinette County, Wisconsin)**, I describe seasonal movement behaviors of a brook trout (*Salvelinus fontinalis*) population to assess the importance of riverine connectivity in northeastern Wisconsin. In the final chapter of this dissertation (**Reimaging Dam Removal to Resist Settler Colonial Logics**), I take a critical humanities-based approach to understanding and interrogating the settler colonial logics that emerge between dam construction and dam removal, then offer a creative, collaborative model of river restoration that might usefully undermine—rather than reinforce—settler colonial logics. In short, this dissertation argues that future management of freshwater ecosystems must continue to be innovative, collaborative, and increasingly more interdisciplinary.

Looking toward the future, I envision my research growing more meaningfully toward incorporating the critical framework of settler colonialism into applied freshwater science and research. Perspectives from settler colonial studies and Indigenous scholarship provide valuable insight into the shifts among natural resource-based colonial economies in Wisconsin: from the fur trade, to logging, to contemporary trout angling and recreational uses of freshwater ecosystems. As discussed in Chapter 3, and defined by Indigenous scholars, settler colonialism is a dominant social or political structure where a colonizer comes to a place, lays claim to it, and disenfranchises its people by stripping their autonomy as a means to exploit the land for monetary gain (Wolfe, 1999; Tuck & Yang, 2012; Arvin, Tuck, & Morrill, 2013). Settler colonialism is not an event in time; it is an ongoing process (Wolfe, 1999) and largely the context from which natural resources are managed in the United States. In chapter 3, I demonstrated the application of a lens critical of settler colonialism to draw connections among Euro-American settlement, dam building and dam removal (chapter 3), and I argue alongside other scholars (Voinot-Baron, 2020; Bacon, 2018) that settler colonialism is an apt framework from which to challenge contemporary management of North American rivers, especially with regard to beaver management and the narratives surrounding free-flowing rivers, which is where I see the direction of my research going in the near future. I hope this work and life-long commitment continues to support (in theory) decolonial action and eventually helps to push for meaningful change (in practice).

Across disciplines, I believe academic communities are living through a transformative season. We have come to an intersection where we must actively make choices about whether to maintain the colonial logics and institutions that have risen into power, or to fight for changes that best serve the diversity of local communities, both human and more. What I propose, and deeply care about embodying, is the latter. Over the years I have engaged with critiques of settler colonialism, I have felt the pull of white guilt, the discomfort of being a settler on stolen land, the unease of recognizing privilege and have often found myself centering my own discomfort with my settler past and present above the moments for personal growth and understanding. I share this because I believe it is important to make space for discomfort, to learn and to grow. It is my hope that as I move through my career as an interdisciplinary freshwater scientist that I continue to lean into discomfort, because even though it is unsettling, it is grounding to recognize the world is filled with diverse ontologies that deserve as much space and understanding as the reality I live in.

In academic conversations around this discomfort, decolonization will often arise as means to shift power dynamics and to make meaningful change. But, as Eve Tuck and K. Wayne Yang powerfully articulate, “Decolonization in the settler colonial context must involve the repatriation of land simultaneous to the recognition of how land and relations to land have always been differently understood and enacted; that is *all* of the land, and not just symbolically (pg7) … Decolonization is not a swappable term for other things we want to improve in our societies and schools (pg 3).” They also remind us that decolonization is necessarily unsettling (pg 3). In my personal and academic lives, I aim to embrace the ideas and actions of unsettling to make space for meaningful collaborations, ideas and critically grounded scientific practice.

What I mean by this embrace of unsettling is both ontological and epistemological. Unsettling is way of being, existing and engaging in the world that emphasizes accountability, responsibility, ethical practice and dedication to the systems that I work in with collaborators I deeply value. The practice of unsettling is being responsible for the work that I produce, the ideas and language that I support, cite, and reproduce, and being responsible for my actions and the impact they might have on the communities in which I work, live, study, and write about. As a researcher, I am not just studying and writing about a community, human or more-than-human; I am accountable to them because the power of academic knowledge and writing may have very real, material impacts on those communities.

Unsettling is not merely a buzz word; an academic vapid dedication to linguistic righteousness. Unsettling is a way of orienting oneself, a research practice, and an iterative process of exploration, self-reflection, and the commitment to responsible research that deeply, and meaningfully, acknowledges historic contexts and current positions of privilege. I see this unsettling approach as a way to orient myself toward being transparent about who I am in the work that I produce. As an interdisciplinary freshwater scientist, my research interests lay at the intersection of river networks, restoration and human communities – and I hope to do this work respectfully, justly and with a deep respect for the communities I work with, and I hope to remain open to the endless possibilities of reimagining the practice of freshwater science.

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