An Interdisciplinary Framework to Address Complex Water Quality Issues: A Collaboration with the Coeur d'Alene Tribe

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Authorization to Submit Dissertation

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Abstract

The leaching of toxic metals (i.e., Pb, Cd, As) from historical mining activities has caused extensive environmental and public health disparities among Native American communities across the United States. In response to this issue from a water resources context, I pursued an interdisciplinary dissertation in collaboration with the Coeur d'Alene Tribe of northern Idaho, USA to address complex water quality issues resulting from legacy mining contamination in the Coeur d'Alene Basin. Guided by expertise provided by aquatic ecologists and educators employed by the Tribe, we developed an interdisciplinary research framework drawing from disciplinary approaches in community engagement, aquatic ecology, and science, technology, engineering, and mathematics (STEM) education. The framework informed the establishment of the community-university partnership and associated limnological study and culturally-relevant STEM education program for Coeur d'Alene Tribal youth. Collectively, these outcomes are intended to support the Tribal community's capacity to mitigate water quality issues caused by toxic metal contamination resulting from historical mining activities through ethical collaboration, increased access and availability of scientific data, and community youth interest and leadership in STEM.

Acknowledging approaches in community-engagement, Chapter 2 assesses the benefit of applying participatory research methodologies when conducting research in complex human-water systems through a comparison of two community-university partnerships within the Coeur d'Alene Basin. The first partnership reflects the collaboration described in this dissertation and the second partnership involved non-Indigenous, rural communities and University of Idaho researchers. Informed by fundamental principles of aquatic ecology, Chapter 3 discusses a limnological study that examined the phenology of submerged aquatic macrophytes in three temperate lakes. The results from this study are intended to inform future study on the role of macrophyte in metals and nutrient dynamics in lake ecosystems. Guided by culturally responsive pedagogy and informal educational methods, Chapter 4 reflects a two-year STEM education program and affiliated study. This study examined the impact of the culturally-relevant STEM education program on Native American high school youth understanding of water quality issues impacting their local environment and interest in the STEM fields. Chapter 5 synthesizes the interdisciplinary studies by discussing the role of each disciplinary approach in supporting the Tribal community capacity in mitigating their contaminated waters. Each approach and affiliated study are appraised in relation to the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind*. Together, the studies included in this dissertation explore how an interdisciplinary research framework can support Native American communities address complex water quality issues resulting from historical mining contamination.

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I am greatly indebted to the community of the Coeur d'Alene Tribe, as this dissertation would not have been possible without their continued support over the past five years. Thank you for exemplifying the true meaning of relationship, respect, responsibility, and reciprocity over the course of this research partnership. This partnership provided me with a privileged perspective in water resources management that I will consciously employ throughout my career. I thank the community members and employees which helped to shape this perspective through their collaboration in this dissertation; Caj Matheson, Laura Laumatia, Scott Fields, Rebecca Stevens, Phillip Cenera, Dr. Raymond Brinkman, and Helen Muffley. Many thanks to Ben Scofield for several years of collaboration and support during the limnological study as well as the STEM education study. Special thanks to Michael George for assisting in the data collection and construction of field equipment for the limnological study. Lastly, thank you to my youth interns. Your dedication to the educational programming and countless hours in the field assisting in the data collection for the limnological study was greatly appreciated.

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Dedication

I dedicate this dissertation to my friends, family, and educators for their encouragement and support. Special thanks to my parents for their continued support of my professional and educational endeavors and for instilling in me the value of an education. Lastly, I am indebted to my sister, Lauren, for the example she continues to provide.

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Statement of Contribution

The research studies presented in this dissertation were conducted in collaboration with the Coeur d'Alene Tribe through a community-university partnership. As a graduate student under the Integrative Graduate Education and Research Traineeship (IGERT) Program, I was required to complete one dissertation chapter in collaboration with at least one other graduated student enrolled in this program. Therefore, due to the collaborative nature of the community-university partnership in addition to the requirements of the IGERT Program, chapters 2-4 reflect the involvement of several contributors. Chapter 2 adheres to my graduate program requirement through the collaboration with fellow IGERT student, Courtney Cooper. Contributions also extend to our affiliated graduate advisers, Dr. Anne Kern and Dr. Chloe Wardropper as well as two collaborators from our dissertation research, Dr. Chris Meyer and Andy Helky. Courtney and I co-wrote the paper and the remaining authorship team provided valuable feedback and approval. Chapter 3 reflect the contribution of two limnologists employed by the Coeur d'Alene Tribe, Dr. Dale Chess and Ben Scofield, who served as primary collaborators for the limnological study. Contributions for Chapter 3 also extends to my graduate committee member, Dr. Frank Wilhelm, who provided constructive feedback which strengthened the scientific integrity of each chapter. Lastly, Chapter 4 also reflects a collaborative study with the Coeur d'Alene Tribe and includes the contribution of Dr. Anne Kern and Dr. Chris Meyer. The contribution acknowledged in chapters 2-4 reflects the ethical and participatory nature of collaborative, interdisciplinary research and strengthens the authenticity of each study disseminated in this dissertation.

Chapter 1: Introduction

In the western United States (US) there are over 160,000 abandoned mines resulting from a century of hard rock mining and milling activities (Lewis et al., 2017). Federal Indian policy influenced by the Doctrine of Discovery[1] and Manifest Destiny[2] has caused the majority of abandoned mines in the western US to be located on or near Native American reservation territories (Chief et al., 2016; Lewis et al., 2017; Royster, 1993). The proximity of Native American reservations to soil and water contaminated by hazardous waste, such as toxic metals (i.e., Pb, As, Cd), from historical mining activities has caused environmental and public health disparities among Native American communities (Doyle et al., 2018; Lewis et al., 2017). Furthermore, Native American exposure to such hazardous waste is heightened by their traditional practices of gathering local foods, religious ceremonies, and recreational activities (Bergstrand et al., 2015; Chief et a., 2016; Doyle et al., 2018). Collectively, these actions threaten the food and water security as well as the cultural well-being of Tribal communities (Chief et al., 2016).

The complexity and persistence of toxic metal contamination caused by historical mining activities continue to challenge mitigation efforts by Native American tribal communities for generations to come (Chief et al., 2016; Lewis et al., 2017). Currently, tribes are challenged with a variety of issues ranging from the sheer volume of waste, to understanding the biogeochemical cycling and mobility of metals within aquatic and terrestrial systems, and funding scientific research and hazardous waste management (Doyle et al., 2018; Lewis et al., 2017). This reality has instigated collaborative partnerships between Native American communities and universities to support Tribal efforts to mitigate toxic metal contamination issues through a variety of disciplinary approaches (Cummins et al., 2010; Doyle et al., 2018; Gittelsohn et al., 2018; Hunter et al., 2015; Ward et al., 2008).

Ward et al. (2008) describes, The Big Sky Model, a community-university partnership that relied upon participatory methodologies to support Native American Tribes and other rural communities mitigate toxic metal contamination in northern Montana. The partnership resulted in the development and design of a participatory framework for place-based science education which guided high school and Tribal college students in understanding the physical, chemical, and public health

[1] An international legal principle that justified the settlement of land occupied by Indigenous communities by European nations (Miller, 2011).

[2] A concept adopted and implemented by the United States government to permit westward expansion and settlement of land occupied by Native American Tribes to spread the religious beliefs and governance practices reflective of western, European culture and society (Miller, 2011).

issues impacting their land and community (Ward et al., 2008). Building off the participatory processes reflected in the Big Sky Model, The Navajo Birth Cohort Study (Hunter et al., 2015) exemplifies a collaborative research partnership between the Navajo Nation and a local university to address complex environmental health issues related to historical uranium mining and milling activities. The goal of the collaborative partnership and affiliated study was formed to understand the relationship between exposure to uranium and birth defects among the Navajo Nation (Hunter et al., 2015). However, neither study fully embraced the Tribal community or culture, which could have been achieved through the recognition of ethical participatory approaches during study development and implementation.

Participatory action research (PAR) (Hall, 1992) grounded in the fundamental principles of Indigenous research methodologies (IRM) (Kovach, 2010) have been found to advance the ethical nature of collaborative research partnerships between universities and Indigenous communities (Bang & Medin, 2010; Brayboy & Deyhle, 2000; Peltier 2018; Smith, 2013). University of British Columbia researchers draw from both participatory approaches while working with an Indigenous community negatively affected by toxic metal contamination in Guatemala (Caxaj, 2015). This community-university collaboration informed a knowledge translation strategy that used traditional storytelling as a means to communicate environmental health information among the community (Caxaj, 2015). Through the acknowledgment of PAR and IRM approaches, researchers involved in the partnership described in Caxaj (2015) were able to: 1) acknowledge community voices and goals and 2) enhance scientific literacy among the community membership.

A community-university partnership focused on water resource management was established in 2005 between the Crow Reservation in western Montana, University of Montana, and the Little Bighorn Tribal College. This partnership was formed to support the Crow Reservation address water quality issues by providing necessary expertise and data (Cummins et al., 2010). This partnership prompted the Crow Water Project and the Apsaálooke (Crow) Water and Wastewater Authority to build Tribal community capacity and address the community’s water quality issues as a sovereign nation (Cummins et al., 2010; Doyle et al., 2018). Collectively, these community-university studies reflect the need for ethical collaboration and an interdisciplinary research approach (Repko, 2012; Tobi & Kampen, 2018) that support sustainable outcomes for Tribal communities that have been negatively affected by toxic metal contamination from historical mining activities.

Reflecting these efforts and lessons learned, I used a PAR methodological approach (Hall, 1992) grounded in the guiding principles of IRM (four Rs: relationship, respect, responsibility, reciprocity) (Kovach, 2010) to form an authentic community-university partnership with the Coeur d’Alene Tribe, a mining impacted Native American community of northern Idaho, USA. The objective of the partnership was to support the Tribal community's capacity to mitigate water quality issues resulting from historical mining contamination. In collaboration with aquatic ecologists and educators employed by the Tribe, we developed an interdisciplinary research framework which drew from disciplinary approaches in community engagement, aquatic ecology, and science, technology, engineering, and mathematics (STEM) education to support the water quality mitigation goals of the Tribal community. The disciplinary approaches acknowledged in the framework informed my doctoral dissertation research which included a STEM education study and limnological study. Together, the studies included in this dissertation explore how an interdisciplinary research framework can support the Tribal community's capacity to mitigate complex water quality issues caused by toxic metal contamination resulting from historical mining activities.

Context: Interdisciplinary Research Collaboration with the Coeur d'Alene Tribe

I am a female scientist, raised and educated under a western Eurocentric lens in a middle-class suburban household. Formally educated in natural resource management, my desire to embark on an interdisciplinary dissertation in partnership with a Native American tribe was inspired by a number of professional and cultural experiences in the scientific monitoring and management of water resources. These experiences provided me with a sincere interest in supporting water resource management goals of Native Americans through a multidisciplinary approach. The National Science Foundation's (NSF) Integrative Graduate Education and Research Traineeship (IGERT) Program in combination with a willing Native American tribe provided me the opportunity to pursue these research interests.

In 2015, I initiated a community-university research partnership with the Coeur d'Alene Tribe during my first year as a graduate student in the Water Resources Graduate Program/NSF IGERT Program at the University of Idaho. Graduate students affiliated with the Water Resources Graduate Program/NSF IGERT Program engage in integrated, cross-cultural research to address complex water resources issues in the Columbia River Basin, USA (Boll, 2014). The overriding research initiative for this joint program is that the complexity of issues involving water resources and communities cannot be addressed in disciplinary isolation, but instead requires interdisciplinary approaches and community engagement (Cosens et al., 2011). The Columbia River Basin is a transboundary basin governed by the US and Canada under the Columbia River Treaty of 1964 (Cosens et al., 2018). This region exemplifies complex environmental issues due to the combined effects of climate change, population growth, and anthropogenic activities (i.e., hydroelectric dams) (Cosens et al., 2018). My dissertation research focused on the Coeur d'Alene Basin, a sub-basin of the Columbia River Basin, and draws from training and course content provided by the Water Resources Graduate Program/NSF IGERT Program.

Study Location and Community Partner

As a socio-politically diverse region, the Coeur d'Alene Basin, USA (Figure 1.1) is defined by a rich history in metals extraction (National Research Council, 2005; U.S. Census Bureau, 2010). Geographically, the Basin is nested within the greater Spokane River Watershed and drains a catchment 5,225 km^2 in size (USGS, 2013). The catchment encompasses several subwatersheds including the Upper Coeur d'Alene River, South Fork Coeur d'Alene River, Coeur d'Alene Lake, and the Lower St. Joe River (USGS, 2013). The waters of the Coeur d'Alene Basin flow west from the Idaho-Montana border before reaching the dam controlled, 129 km^2 Coeur d'Alene Lake, which drains into the Spokane River and ultimately connects to the Columbia River that empties into the Pacific Ocean (Woods & Beckwith, 1997).

The Coeur d'Alene Tribe has occupied the Basin and surrounding territories since time immemorial (Frey & Stensgar, 2012; Sprague, 1999). Upon the discovery of precious metals in the mid-nineteenth century, thousands of non-Indigenous settlers migrated to the natural resource-rich region and drastically altered the social and ecological landscape of the Basin through the development of extractive industries (i.e., mining and timber) (Frey & Stensgar, 2012; Sprague, 1999). The Treaty of 1873, finalized by the Executive Order of 1891, established the boundaries of the Coeur d'Alene Indian Reservation (Woodworth-Ney, 2004). Reservation boundaries displaced the Tribe from the shorelines of Coeur d'Alene Lake and the Coeur d'Alene River to maximize the economic potential of the region for the benefit of European settlers (Woodworth-Ney, 2004). These actions compromised Tribal authority over ecosystem governance (Frey & Stensgar, 2012). By the mid-twentieth century, the mismanagement of mining practices greatly reduced the Tribe's access to culturally significant foods such as water potato and a variety of freshwater fish (Frey & Stensgar, 2012).

Decreasing profit margins within the mining industry, as well as increasing public health and environmental concerns, such as elevated blood lead levels among residents, led the US Environmental Protection Agency (EPA) to declare the Bunker Hill Mining and Metallurgical Complex a Superfund Site in 1983 (Mix, 2016). The declaration marked the beginning of a long and contentious clean-up effort intended to address social and ecological damages resulting from decades of unregulated disposal of mine waste (Mix, 2016). Initial clean-up efforts began in an area commonly known as "the box" (Figure 1.1), which encompasses a 54 km^2 rectangular area containing the former Bunker Hill smelter and other related infrastructure as well as residential areas (National Research Council, 2005). Today, the persistence of these hazards continues to negatively affect human health and environmental quality throughout the Basin and challenges mitigation efforts conducted by federal, tribal, state, and local agencies (BEIPC, 2019; IDEQ & CdAT, 1996). For the

Coeur d'Alene Tribe, the contaminated waters in the Basin have compromised their cultural well-being by limiting community member access to adequate sources of traditional foods and recreational practices.

Interdisciplinary Research Framework

Over the past ten years, the Coeur d'Alene Tribe Department of Education (DoEd) as well as the Lake Management Department (LMD) have engaged in a variety of efforts to manage contamination (i.e., metals and nutrients) that have impinged on-and negatively affected their ancestral lands and thus their way of life. The DoEd has organized several educational programs that blend cultural resources with STEM education for K-12 youth. The DoEd culturally-relevant educational programming involves the local environment and community members to educate youth about a variety of STEM topics relevant to their "place". The Summer Youth Internship Program exemplified this goal as an educational program aimed to enhance the environmental literacy and STEM leadership capacity among Tribal members. The program pairs Tribal youths (ages 14-18) with a Natural Resource Department employee for a six-week summer internship to provide the youths with practical real-world experiences as they work with natural resource professionals in STEM-related fields.

While the LMD has expressed interest in participating in the internship program, the skills needed to perform the complex monitoring and analysis tasks inhibit the potential involvement of interns. The LMD is responsible for monitoring and managing water resources within the Coeur d'Alene Tribe reservation territory (see Figure 1.1 for boundary) on behalf of the Tribal community. The quality of these water resources are continuously threatened by toxic metals and nutrients from the Coeur d'Alene River. Therefore, aquatic ecologists, employed by this program, monitor the biogeochemical cycling of metals and nutrients within the lower reaches of the Coeur d'Alene River and the southern half of the lake ecosystem. This information is shared with restoration specialists to inform future mitigation, remediation, and restoration efforts. Recently, the LMD has focused on monitoring the cycling of metals and nutrients in the aquatic food web. The role of aquatic macrophytes in the distribution and translocation of metals and nutrients currently presents a data gap in understanding this process. In addition to these scientific goals, the LMD is also seeking pedagogical methods to translate their monitoring and management tasks to participants in the Summer Youth Internship Program. Limited resources have prohibited the LMD from achieving both goals.

I established a community-university partnership with the Coeur d'Alene Tribe to address the research needs expressed by the DoEd and LMD employees through an interdisciplinary framework drawing from disciplinary approaches in community-engagement, aquatic ecology, and STEM education. The disciplinary approaches in the framework established an ethical community-university partnership between the Coeur d'Alene Tribe and myself (*Chapter 2*), informed a limnological study to examine macrophyte phenology in three temperate lakes (*Chapter 3*), and guided a STEM education study to assess the impact of a culturally-relevant STEM education program and affiliated internship on Tribal youth interest in the STEM fields (*Chapter 4*). These outcomes are intended to support the Tribal community's capacity to mitigate water quality issues through ethical collaboration, increase access and availability of scientific data, and community youth interest and leadership in STEM (Figure 1.2). The role of this interdisciplinary framework in supporting the community mitigation goals is appraised in relation to the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind* (Pillars) (e.g., Guardianship, Membership, Stewardship, Scholarship, Spirituality) (CdAT STEP, 2016). The Pillars articulate the personal, collaborative, and spiritual behaviors, beliefs, and core values of a Coeur d'Alene Tribal member (*Chapter 5*). Spirituality was recently added as a fifth pillar by the Tribe but was not included in this assessment as this pillar was not fully defined during the completion of this dissertation.

Chapter 2: Participatory Research Approaches about Water and Society in Mining-Impacted Regions

Participatory research, such as PAR, complements traditional research across many disciplines (Cornwall & Jewkes, 1995; Minkler, 2005; Wilmsen et al., 2012). For partnerships between mining impacted communities and university researchers, participatory approaches are used to develop research that is equitable and inclusive of the community's cultures and norms while adhering to the rigorous standards for scientific research (Hacker, 2013). Promoting community voices and goals through authentic community-university partnerships guided by participatory research approaches has been shown to expand data accessibility and scientific literacy for marginalized communities grappling with complex water resources issues stemming from historical mining activities (Gray, 2018; Ramirez-Andreotta et al., 2016).

In collaboration with Courtney Cooper, a fellow graduate student in the Water Resources Graduate Program/NSF IGERT Program, we evaluated the development and implementation of our community-university partnerships used to conduct interdisciplinary research about water and society. The two partnering communities are located in socio-politically diverse regions within the mining impacted, Coeur d'Alene Basin. As described in this chapter, my dissertation research is in partnership with the Coeur d'Alene Tribe, while Courtney's dissertation research is in partnership with non-Indigenous, rural communities in the Silver Valley (Figure 1.1). The resulting research studies for each partnership diverged due to the proximity of each community to the superfund clean-up site (i.e., 'the box' see Figure 1.1) as well as the socio-pollical values of each community. While our community-university partnerships involved different communities and research topics, both partnerships were guided by participatory research approaches (i.e., PAR, IRM) to promote scientific literacy and data accessibility within partnered communities.

In this chapter, we first discuss key social and biophysical dynamics in the Basin, which, includes a rural Tribal community and several other rural communities that were established to support natural resource extraction. We then reflect critically on the challenges and opportunities for participatory research approaches through an analysis of the two research partnerships. Our reflection is supported by qualitative findings from five semi-structured interviews with partnership personnel. We conclude by providing recommendations for administering participatory research about water and society. Therefore, this chapter offers a guide towards building community capacity in complex water systems research through community-university partnerships.

Chapters 3: Variations in Aquatic Macrophyte Phenology Across three Temperate Lakes in the Coeur d'Alene Basin

Bioaccumulation and cycling of metals, specifically those found to be toxic at low concentrations (i.e., Pb, As, Cd), by aquatic macrophytes is a concern for water resource managers worldwide (Jackson, 1998; Weis & Weis, 2004). Macrophytes are both sinks and sources for metals due to their ability to accumulate metals from contaminated sediments and then release these elements back into the environment upon senescence (Jackson, 1998; Jackson et al., 1994; Weis & Weis, 2004). When bioavailable in the water column, metals can disrupt food web dynamics and cause public health disparities (Chen & Folt, 2000; Harada, 1995; Schaller et al., 2011). Therefore, examining growth patterns, specifically the timing and duration of submerged macrophyte senescence is essential for water resource managers challenged with the task of monitoring and managing legacy mining contamination such as in the Coeur d'Alene Basin. Addressing this need, I collaborated with aquatic ecologists employed by the Coeur d'Alene Tribe LMD to determine the phenology of submerged macrophytes in temperate lakes located in the Basin through a limnological study.

The limnological study was completed between May 1 and November 15, 2017. The primary objective of this study was to determine the timing and duration of submerged macrophyte senescence. The secondary objective was to investigate the feasibility of using a consumer-grade hydroacoustic system to measure seasonal changes associated with the submerged aquatic macrophyte community. I measured macrophyte biomass, sonar biovolume, and collected water quality data from two contaminated lakes in the lower Coeur d'Alene River Basin (Thompson Lake and Black Lake) and one non-contaminated reference site (lower half of Coeur d'Alene Lake known as Chatcolet Lake). Samples for the analysis of biomass were physically collected using a rake. The collection of hydroacoustic sonar data via BioBase software was administered to further analyze macrophyte phenology by recording biovolume, or the percentage of volume occupied by plant biomass in the water column (Valley, 2016). Water quality was examined through water column profiles using a Hydrolab model DS5 sonde.

Length of growing season as informed by growing degree days as well as species composition and richness varied per lake location due to differences in hydrologic connectivity and other ecological factors. However, the timing and duration of submerged macrophyte senescence at each lake location was greatly influenced by the characteristics of the dominant macrophyte species. For example, Thompson Lake reflected a prolonged and indistinct period of senescence due to the dominance of the macrophyte community by *Myriophyllum spicatum*. The collection of sonar biovolume was initially found to be an efficient and cost-effective sampling method, but differences in species composition per lake location as well as operator error diminished the usefulness of this method. The results from this study are expected to improve the Tribe's knowledge of macrophyte phenology within the Basin and inform future monitoring efforts aimed to understand the dynamics of metals and nutrients associated with submerged macrophytes in lake ecosystems.

Chapter 4: Supporting Native American Community Leadership through Culturally-Relevant STEM Education

Leadership in the STEM fields among members of a Native American community greatly enhances a tribe's ability to address complex environmental issues as a sovereign nation (Aikenhead & Michell, 2011; McCarty & Lee, 2014). Culturally-relevant STEM educational approaches drawn from the local environment (i.e., place) and community culture have been found to heighten interest of Native American youth in STEM fields (Bang & Medin, 2010). In the context of legacy mining contamination, these educational approaches can increase the capacity of Native American communities to address persistent environmental issues, independent of the federal government (Ward et al., 2008).

The Coeur d'Alene Tribe has recognized community youth leadership in STEM as an approach to strengthen their ability to mitigate complex water resources issues caused by legacy mining contamination. My interest in exploring how a culturally-relevant STEM education program could encourage Native students to develop youth leadership in the STEM fields was the impetus for this study. In partnership with the Coeur d'Alene Tribe DoEd and LMD, I developed a culturally-relevant STEM education program to heighten Tribal youth interest in STEM. The STEM education program consisted of a six-week STEM education learning opportunity affiliated with the LMD and the DoEd-Summer Youth Internship Program for Coeur d'Alene Tribal youth (ages 14-18). The culturally-relevant STEM program included instructional activities to teach youth interns about key science concepts all with an eye on culturally significance issues in the Coeur d'Alene Basin. In parallel with this learning opportunity, interns provided support for other water resources monitoring tasks associated with the Coeur d'Alene Tribe LMD and the limnological study (*Chapter 3*). Thus, the objective of the STEM education program was three-fold: to educate Tribal youth interns about water quality stressors impacting the Basin; to encourage youth to explore the cultural connection to their aboriginal territory; and to recruit youth to enter the Tribal Department of Natural Resources work-force. I explored the impact of this program and affiliated internship on youth interest in STEM and associated career fields through a qualitative research study guided by a case study research approach. Qualitative findings suggest the culturally-relevant content affiliated with the STEM education program and associated internship heightened the interns' interest and engagement in STEM content, as well as enhanced the interns' desire to become leaders for the Tribal community.

Chapter 5: Conclusion and Recommendations

The collection of work included in this dissertation merges disciplinary approaches in community-engagement, aquatic ecology, and STEM education to support the Coeur d'Alene Tribe water quality mitigation goals. Chapter 2 demonstrates the value of community-university partnerships guided by participatory processes when conducting research about mining impacted water systems. Chapter 3 provides further understanding of submerged macrophyte phenology which is intended to inform future research on the role of macrophytes in the fate and transport of metals and nutrients in temperate lakes. And Chapter 5 confirms the need to combine culture and place to strengthening Native American youth interest in the STEM fields. The integration of each study affiliated with this dissertation assists both the agency and members of the Coeur d'Alene Tribe in the process for self-determination. Supporting this outcome, I explore the effectiveness of this interdisciplinary framework in supporting the Tribal community's capacity in addressing their water quality issues through the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind*. Following this section, a discussion on the importance of collaborative, interdisciplinary research in water resource management is presented. Lastly, recommendations are listed for Chapters 2-4 to offer suggestions to further improve social, ecological, and pedagogical understanding towards addressing water quality issues influenced by legacy mining contamination.

Literature Cited

Aikenhead, G., & Michell, H. (2011). *Bridging cultures: Indigenous and scientific ways of knowing nature.* Pearson Education.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education, 94*(6), 1008–1026.

Basin Environmental Improvement Project Commission (BEIPC). (2019). Coeur d'Alene Basin Commission site. Retrieved from http://www.basincommission.com/

Bergstrand, K., Mayer, B., Brumback, B., & Zhang, Y. (2015). Assessing the relationship between social vulnerability and community resilience to hazards. *Social Indicators Research*, *122*(2), 391–409.

Boll, J. (2014). *Adaptation to change in water resources: Science to inform decision-making across disciplines, cultures and scales*. Retrieved from http://www.igert.org/projects/300.html

Brayboy, B. M., & Deyhle, D. (2000). Insider-outsider: researchers in American Indian communities. *Theory into practice, 39*(3), 163–169.

Caxaj, C. S. (2015). Indigenous storytelling and participatory action research: Allies toward decolonization? Reflections from the Peoples' International Health Tribunal. *Global Qualitative Nursing Research*, *2*, 2333393615580764.

Chen, C. Y., & Folt, C. L. (2000). Bioaccumulation and diminution of arsenic and lead in a freshwater food web. *Environmental Science & Technology, 34*(18), 3878-3884.

Chief, K., Meadow, A., & Whyte, K. (2016). Engaging southwestern tribes in sustainable water resources topics and management. *Water*, *8*(8), 350.

Coeur d'Alene Tribe (CdAT) State Tribal Education Partnership (STEP) (2016). Coeur d'Alene Tribe five pillars to strengthen heart and mind: Five pillars. Prepared for the Coeur d'Alene Tribe.

Cornwall, A., & Jewkes, R. (1995). What is participatory research? *Social Science & Medicine*, *41*(12), 1667–1676.

Cosens, B., Fiedler, F., Boll, J., Higgins, L., Johnson, G., Kennedy, B., … Wilson, P. (2011). Interdisciplinary methods in water resources. *Interdisciplinary Methods in Water Resources ISSUES IN INTEGRATIVE STUDIES*, *143*(29), 118–143.

Cosens, B., McKinney, M., Paisley, R., & Wolf, A. T. (2018). Reconciliation of development and ecosystems: The ecology of governance in the International Columbia River Basin. *Regional Environmental Change*, *18*(6), 1679–1692.

Cummins, C., Doyle, J., Kindness, L., Lefthand, M. J., Don't Walk, U. B., Bends, A., … Ford, T. E. (2010). Community-based participatory research in Indian country: Improving health through water quality research and awareness. *Family & Community Health*, *33*(3), 166.

Doyle, J., Kindness, L., Realbird, J., Eggers, M., & Camper, A. (2018). Challenges and opportunities for tribal waters: Addressing disparities in safe public drinking water on the Crow Reservation in Montana, USA. *International Journal of Environmental Research and Public Health*, *15*(4), 567.

Frey, R., & Stensgar, E. (2012). *Landscape traveled by Coyote and Crane: The world of the Schitsu'umsh*. University of Washington Press.

Gittelsohn, J., Belcourt, A., Magarati, M., Booth-Laforce, C., Duran, B., Mishra, S. I., … Jernigan, V. B. B. (2018). Building capacity for productive Indigenous community-university partnerships. *Prevention Science : The Official Journal of the Society for Prevention Research*, 1–11.

Gray, K. (2018). From content knowledge to community change: A review of representations of environmental health literacy. *International Journal of Environmental Research and Public Health*, *15*(3), 466.

Hacker, K. (2013). *Community-based participatory research*. Wiley and Sons.

Hall, B. L. (1992). From margins to center? The development and purpose of participatory research. *The American Sociologist*, *23*(4), 15–28.

Harada, M. (1995). Minamata disease: Methylmercury poisoning in Japan caused by environmental pollution. *Critical Reviews in Toxicology*, *25*(1), 1–24.

Hunter, C. M., Lewis, J., Peter, D., Begay, M.-G., & Ragin-Wilson, A. (2015). The Navajo birth cohort study.(DIRECT FROM ATSDR). *Journal of Environmental Health*, *78*(2), 42–45.

Idaho Department of Environmental Quality (IDEQ) & Coeur d'Alene Tribe (CdAT). (1996). *Coeur d'Alene Lake Management Plan*. Retrieved from https://www.cdatribe-nsn.gov/wp-content/uploads/2018/10/LMP09.pdf

Jackson, L. J. (1998). Paradigms of metal accumulation in rooted aquatic vascular plants. *Science of the Total Environment*, *219*(2–3), 223–231.

Jackson, Leland J, Rasmussen, J. B., & Kalff, J. (1994). A mass-balance analysis of trace metals in two weedbeds. *Water, Air, & Soil Pollution*, *75*(1), 107–119.

Kovach, M. (2010). *Indigenous methodologies: Characteristics, conversations, and contexts*. University of Toronto Press.

Lewis, J., Hoover, J., & MacKenzie, D. (2017). Mining and environmental health disparities in Native American communities. *Current Environmental Health Reports*, *4*(2), 130–141.

McCarty, T. L., & Lee, T. S. (2014). Revitalizing pedagogy and Indigenous education sovereignty. *Harvard Educational Review*, *84*(1), 101–125.

Miller, R. J. (2011). American Indians, the doctrine of discovery, and manifest destiny. *Wyo. L. Rev.*, *11*, 329.

Minkler, M. (2005). Community-based research partnerships: Challenges and opportunities. *Journal of Urban Health*, *82*(2), ii3–ii12.

Mix, M. C. (2016). *Leaded: The poisoning of Idaho's Silver Valley*. Oregon State University Press.

National Research Council. (2005). *Superfund and mining megasites: Lessons from the Coeur d'Alene River Basin*. National Academies Press.

Peltier, C. (2018). An application of two-eyed seeing: Indigenous research methods with participatory action research. *International Journal of Qualitative Methods, 17*(1), 1609406918812346.

Ramirez-Andreotta, M. D., Lothrop, N., Wilkinson, S. T., Root, R. A., Artiola, J. F., Klimecki, W., & Loh, M. (2016). Analyzing patterns of community interest at a legacy mining waste site to assess and inform environmental health literacy efforts. *Journal of Environmental Studies and Sciences*, *6*(3), 543–555.

Repko, A. F. (2012). *Interdisciplinary research: Process and theory*. London, United Kingdom: Sage Publications.

Royster, J. V. (1993). Mineral Development in Indian Country: The Evolution of Tribal Control Over Mineral Resources. *Tulsa LJ*, *29*, 541.

Schaller, J., Brackhage, C., Mkandawire, M., & Dudel, E. G. (2011). Metal/metalloid accumulation/remobilization during aquatic litter decomposition in freshwater: A review. *Science of the Total Environment*, *409*(23), 4891–4898.

Smith, L. T. (2013). *Decolonizing methodologies: Research and indigenous peoples*. Zed Books Ltd.

Sprague, R. (1999). *An anthropological summary of the dependence of the Coeur d'Alene Tribe upon Coeur d'Alene Lake.* Moscow, ID.

Tobi, H., & Kampen, J. K. (2018). Research design: the methodology for interdisciplinary research framework. *Quality & quantity*, *52*(3), 1209-1225.

U.S. Census Bureau. (2010). American community survey, profile of general population and housing characteristics: 2010 demographic profile data. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

United States Geological Survey (USGS). (2013). Watershed boundary dataset. Retrieved from https://www.usgs.gov/core-science-systems/ngp/national-hydrography/watershed-boundary-dataset?qt-science_support_page_related_con=4#qt-science_support_page_related_con.

Valley, R. D. (2016). Case Study Spatial and temporal variation of aquatic plant abundance: Quantifying change. *J. Aquat. Plant Manage*, *54*, 95–101.

Ward, T. J., Vanek, D., Marra, N., Holian, A., Adams, E., Jones, D., & Knuth, R. (2008a). The big sky model: A regional collaboration for participatory research on environmental health in the rural West. *Journal of Higher Education Outreach and Engagement*, *12*(3), 103.

Weis, J. S., & Weis, P. (2004). Metal uptake, transport and release by wetland plants: Implications for phytoremediation and restoration. *Environment International*.

Wilmsen, C., Elmendorf, W. F., Fisher, L., Ross, J., Sarathy, B., & Wells, G. (2012). *Partnerships for empowerment: Participatory research for community-based natural resource management*. Routledge.

Woods, P. F., & Beckwith, M. A. (1997). *Nutrient and trace-element enrichment of Coeur d'Alene Lake, Idaho* (Vol. 2485). US Government Printing Office.

Woodworth-Ney, L. (2004). *Mapping identity: The creation of the Coeur D'Alene Indian Reservation, 1805-1902*. Univ Pr of Colorado.

Figures

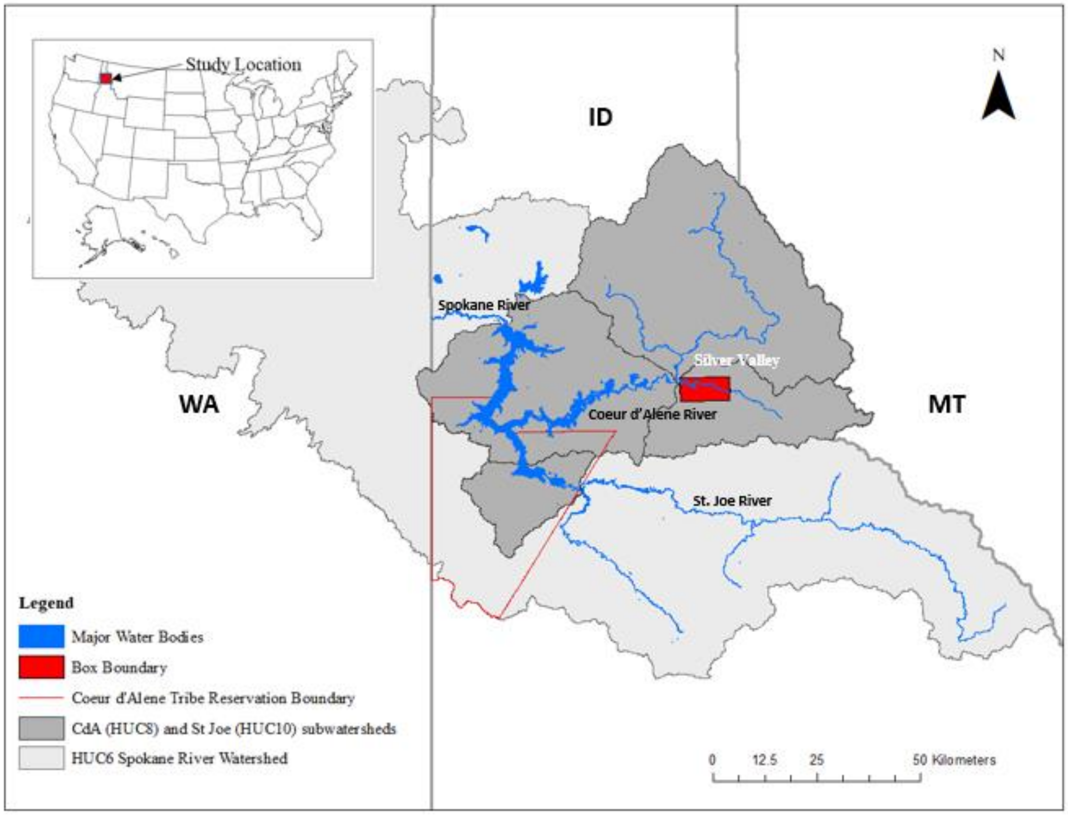

Figure 1.1 Map of the Coeur d'Alene (CdA) Basin, USA including the Spokane River watershed boundary, subwatersheds and major water features of the Basin, primary jurisdictional boundaries of the “Box”, and the Coeur d’Alene Tribe reservation territory. Map image developed in ESRI ArcGIS 10.6.1.
HUC= Hydrologic Unit Code.

Source: USGS Watershed Boundary Dataset; Alta Engineering and Science; Coeur d'Alene Tribe of Indians (accessed at Koordinates.com).

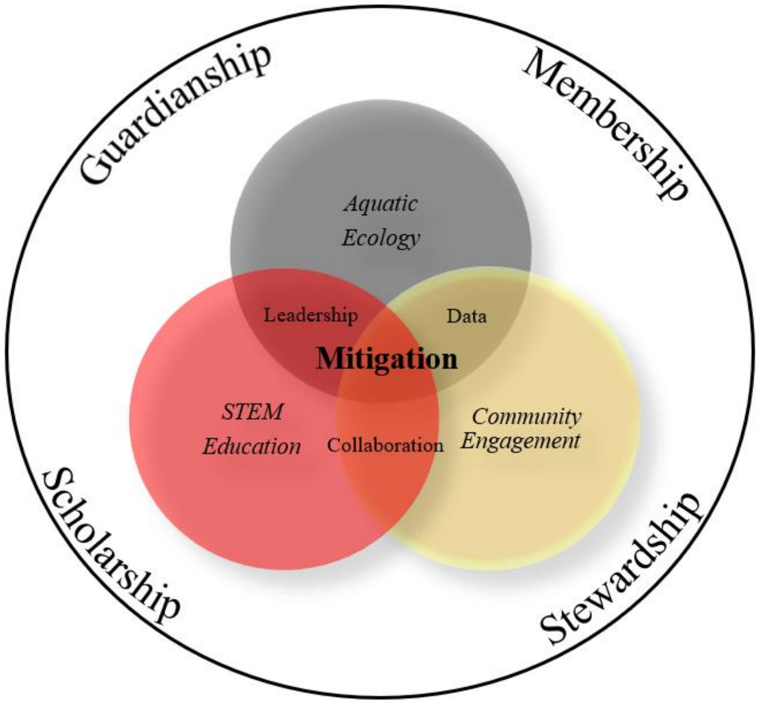

Figure 1.2 Conceptual diagram highlighting the interdisciplinary framework (e.g., aquatic ecology, community-engagement, STEM education), individual objectives of the disciplinary approaches acknowledged in the framework (e.g., leadership, data, collaboration), and overarching objective of the community-university partnership (e.g., mitigation). The outer layer of the diagram highlights the four core values (e.g., membership, stewardship, scholarship, guardianship) from the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind* that were used to assess the effectiveness of this interdisciplinary framework in meeting the community mitigation goals.

Chapter 2: Participatory Research Approaches about Water and Society in Mining-Impacted Regions

Abstract

Given power imbalances and cultural differences, inquiry about how to design equitable and inclusive interdisciplinary research about water and society must also address complex questions about hydrosocial relations. Participatory research facilitates such approaches through a focus on capacity building, promoting data accessibility, and attention to community goals. To demonstrate challenges and opportunities for participatory research, we describe hydrosocial dynamics experienced by Tribal and non-Tribal rural communities residing in a mining-impact region in northern Idaho. We then compare two community-university partnerships in the region. We find that participatory research frameworks, provide a robust set of examples and practices for conducting more equitable and inclusive research. Our experiences demonstrate that recommendations for conducting participatory research should be professionalized within interdisciplinary research frameworks about water and society in order to work towards balancing power in hydrosocial relations.

Introduction

Emerging research from hydrosocial scholars regarding the relation between water and society have focused on the varied characteristics of how societies govern themselves in response to the need to control and manage water (Linton & Budds, 2014). Reflection on how to design more equitable and inclusive interdisciplinary research is needed to address traditional power imbalances identified by hydrosocial researchers (Jepson et al., 2017; Wutich et al., 2019). In addition, research findings from such approaches can be used to inform models in sociohydrology that are more reflective of a reality in which values, norms, and behavioral responses influence governance outcomes (Roobavannan et al., 2018). A range of methods and methodologies allow water scholars to grapple with questions of inclusivity and equitability. Researchers have used these methods to integrate different forms of knowledge and knowledge production systems in efforts to diffuse and contextualize power (e.g., Berry et al., 2018; Wutich et al., 2019). We refer to these approaches as participatory research (e.g., Cornwall & Jewkes, 1995; Ferreira & Gendron, 2011; Hall, 1992; Mackenzie et al., 2012).

While participatory research approaches have emerged across domains, a Web of Science search for “participatory research” and “water” produced only 485 results as of early 2020; suggesting a need for continued conceptual development. A primary reason for the growing popularity of participatory research is the recognition of social context and relationships matters and community partnerships have value (Leung et al., 2004; McMillian, 2012; Wilmsen et al., 2012; Wilson, 2008). Participatory research aims to guide research that addresses systemic power imbalances through capacity building to promote community voices and goals, improve data accessibility, and enhance scientific literacy (Finn & O’Fallon 2015; Marques et al., 2018). Participatory research is often conducted through partnerships between university researchers and communities where participants are actively involved in the research process (e.g., Caxaj, 2015; Datta et al., 2014; Martenson et al., 2012). Participatory approaches, while time intensive, can guide research in more equitable and inclusive directions that are sensitive to local contexts and meet rigorous standards for scientific research (Hacker, 2013). Recommendations and best practices for conducting equitable and inclusive participatory research are important to research related to water and society. These recommendations should be tailored across contexts to account for different kinds of power imbalances.

In this paper, we compare two participatory research partnerships related to environmental contamination, water, and society in different hydrosocial settings within the same mining-impacted region of northern Idaho, USA. In addition to a rapidly growing urban center, the region includes a rural Tribal community and other rural communities that were established to support natural resource extraction. First, we provide a description of the region, followed by a summary of both partnerships, and the participatory approaches employed. Then we reflect and compare the application of participatory research approaches between the two research partnerships by analyzing three primary research elements of the partnerships. The elements include: (1) establishing a research agenda; (2) promoting community voice and goals, data accessibility, and literacy; and (3) maintaining ethical partnerships.

The reflection is guided by our perceptions and experiences as members of the partnership, as well as the researchers. Structuring the comparison around the three primary research elements provided a way to compare participatory research approaches between the two partnerships even though they were guided by different participatory research frameworks. One of the partnerships, the Tribal partnership, formed between the Coeur d'Alene Tribe and university researchers. The other partnership, the Silver Valley partnership, formed between university researchers, community members in an area known as the Silver Valley, and the local health district. Our analysis is based on formal conversations conducted with five key partnership members during the spring and summer 2019. The research design was reviewed by the University of Idaho's Institutional Review Board for the use of human subjects (please refer Appendix A for IRB approval and Appendix B for interview questions). Interview participants were given pseudonyms to ensure confidentiality. The findings from our partnership comparison informed a set of recommendations for conducting participatory research about water and society in rural and Indigenous communities.

Hydrosocial Territories

Understanding the construction of water and society by taking a narrative approach, is a shared practice across both hydro-sociology and hydrosocial research frameworks (Hommes et al. 2019; Wesselink et al., 2017). Narratives also provide an entry point for selecting equitable and inclusive participatory research approaches (Datta et al., 2014). One way to understand complex narratives about water and society is by describing characteristics of hydrosocial territories. Hydrosocial territories are "socially, naturally and politically constituted spaces that are (re)created through the interactions amongst human practices, water flows, hydraulic technologies, biophysical elements, socio-economic structures and cultural-political institutions" (Boelens et al., 2016). We use this definition of hydrosocial territories to frame our overview of mining impacts in the study region in order to show the complexity of efforts to manage mine waste contamination and to briefly map and characterize complex jurisdictional boundaries that influenced the development of the two community-university partnerships.

Geographically, the study region is located in the Coeur d'Alene Basin, USA, which spans a mining-impacted drainage area of 5,225 km^2 (USGS, 2013). The drainage area is nested within the greater Spokane River Watershed and is composed of the Upper Coeur d'Alene River, South Fork Coeur d'Alene River, Coeur d'Alene Lake, and the Lower St. Joe River subwatersheds (USGS, 2013) (Figure 2.1). Within this drainage area, the Coeur d'Alene River flows west from the Idaho-Montana state line for approximately 85 kilometers before reaching the dam-controlled Coeur d'Alene Lake (Restoration Partnership, 2018). About 109 million metric tons of mine tailings were produced through mining activities in the Silver Valley and an estimated 60% of these materials washed into the mainstem and adjacent floodplain of the Coeur d'Alene River (NRC, 2005). In 1983, the region was listed as a Superfund site on the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act or CERCLA (NRC, 2005).

Since then, the US Environmental Protection Agency (US EPA) has conducted extensive Superfund remediation (under CERCLA), at the Bunker Hill Superfund Site (BHSS) in the Silver Valley (NRC, 2005). The most intensive Superfund remediation activities have occurred in a 21 km^2 area known as 'the Box,' which once contained a lead smelter and extensive mining infrastructure. In addition, a large portion of the region was listed on CERCLA's National Priorities List, which initiated a Natural Resource Damage Assessment and Recovery (NRDAR) process that continues to prompt restoration and remediation activities within the boundaries of the Institutional Control Program. The region remains heavily contaminated at abandoned mine sites and in the mainstem, tributary streams, and floodplain of the Coeur d'Alene River where the mine waste was directly discharged and is now distributed by annual high flow events (Bookstrom et al., 2013; Gustavason, 2007; Langman et al., 2018). A 2009 settlement with ASARCO Mining and Smelting Company for $436 million provides resources for continuing restoration and remediation activities within the boundaries of the Institutional Controls Program (Restoration Partnership, 2018).

The hydrosocial territories within the study region are socio-politically divided by county boundaries (NRC, 2005; U.S. Census Bureau, 2010). The Coeur d'Alene Tribe's reservation boundaries overlap with Benewah County, the Silver Valley is in Shoshone County, and the growing city of Coeur d'Alene is located in Kootenai County (Table 2.1). The socio-demographic characteristics in Benewah and Shoshone County are similar, their populations are poorer, more rural, and less educated relative to Kootenai County, and most other counties in Idaho. Over 20% of Shoshone County's population under the age of 65 is on disability. Benewah County contains the smallest population, with 8.5% of its population being American Indian and Alaskan Native. Kootenai County, Idaho's third largest county, reflects a growing population and a socio-economic status that either exceeds or is similar to average for Idaho. Coeur d'Alene Lake is a primary reason for growth in Kootenai County as shoreline development, featuring multiple resorts and residential development, has increased in recent years (Criscione, 2018). Investigating the nature of the hydrosocial relations experienced by the Tribe as well as rural communities in the Silver Valley following the collapse of the mining industry provides insight about the different ways that Shoshone and Benewah County have arrived in similar socio-demographically underprivileged positions relative to Kootenai County and the rest of Idaho.

Differing hydrosocial relations between the Silver Valley communities and the Tribal communities are tied to a complex governance structure related to addressing mine waste in the region. Events in the 1970's, including a downturn in the global economy, a public health crisis, and new environmental regulations, brought an end to primary mining activities in the Silver Valley (Mix, 2016). Blood lead screenings in the 1970's revealed a public health crisis, 99% of Silver Valley area children had a blood lead level greater than 40 micrograms of Pb per deciliter of blood (µg/dL), with the highest recorded at 164 µg/dL (Idaho Department of Health and Welfare, 1976; von Lindern et al., 2003). The Superfund cleanup in the Silver Valley has included remediation of 7,153 properties and removal of primary mining infrastructure. Today, social and economic conditions are slowly improving as economic redevelopment activities progress and childhood blood lead levels near national averages (Helkey, 2018).

Remediation activities, such as source control and water treatment remedies, are a major focus of management in the Silver Valley (BEIPC, 2019). The local health district manages the lead health intervention program and assists in leading the Institutional Controls Program, two programs that support continued efforts to protect human health and the existing environmental remedy (Panhandle Health District, 2018). Local control of these programs has allowed the district to develop programs that are more effective in protecting health in the tightknit communities of the Silver Valley. The Health District continually adjusts their risk communication strategies to better reach people in their service area. For instance, in 2018, they posted new warning signs at popular recreation areas in order to better communicate remaining health risks from primary contact with Pb contamination (Helkey, 2018).

Although the socio-economic situation in Benewah County appears similar to that of Shoshone County and the Silver Valley, the hydrosocial narrative of the Coeur d'Alene Tribe is quite different. The Coeur d'Alene Tribe has been and continues to be disproportionately impacted by hazardous waste as a result of Federal Indian policy guided by the ideals of the Doctrine of Discovery[3] and Manifest Destiny[4] (Royster, 1993). The Coeur d'Alene Tribe is a sovereign nation

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[3] The Doctrine of Discovery was an international legal principle that justified the settlement of non- European territories inhabited by Indigenous communities by European nations (Miller, 2011).

[4] Influenced by the Doctrine of Discovery, Manifest Destiny was a concept implemented by the American government to give reason for the westward expansion and conquest of Native

that has occupied the region since time immemorial (Frey & Stensgar, 2012). Mining activities in the Silver Valley were a primary driver for European settlements and a source of disruption and severe hardship within the Coeur d'Alene Tribal community (Mix, 2016). To maximize the economic potential of the region, the Coeur d'Alene Indian Reservation boundary was finalized under the executive order of 1891, which subsequently reduced Tribal authority over ecosystem governance (Woodworth-Ney, 2004). Therefore, mining challenged the Coeur d'Alene Tribe's ability to self-govern by transforming the social and ecological landscape. Today, metal contamination jeopardizes the well-being of the Tribal community by limiting their access to culturally significant foods and other recreational activities. For example, contaminated wetlands throughout the lower reaches of the Coeur d'Alene River have compromised flora and fauna that is culturally and spiritually significant to the Tribe such as water potato (*Sagittaria latifolia*), a traditional food source for the community (Campbell et al., 1997). Collectively, contaminated resources threaten the cultural values and subsistence practices of the Tribe, thereby affecting their self-determination.

Mitigation efforts administered by the Tribe reflect a holistic perspective focused on improving ecosystem health from a seventh-generation perspective (LMP, 2009). The Tribe prioritizes restoring damaged ecological and cultural resources (i.e., water potato) through mitigation, remediation, and restoration methods. These methods are informed by scientific monitoring and management efforts administered by scientists employed by the Tribe and the State of Idaho (LMP, 2009). Scientific data is a critical component for the preservation of place and acknowledgement of tribal sovereignty for Native Nations (McCarty & Lee, 2014). The Tribe's inherent right to govern (i.e., sovereignty) within their reservation boundaries as well as aboriginal territories, which expand beyond the catchment boundaries, has supported these efforts.

Research related to water and society that focuses on community capacity building must consider the governing structures of the existing hydrosocial territories. The diversity of priorities and stakeholder groups and years of contentious collaboration have led to the establishment of several carefully planned collaborative institutions in the region. These primarily include the Basin Environmental Improvement Project Commission (BEIPC) and the Restoration Partnership (Table 2.2). Together, these collaborative bodies set joint priorities and resolve conflicts between groups. BEIPC, the older of these entities, was established by the Idaho Legislature under the Basin Environmental Improvement Act of 2001 (section 39-8105) to coordinate environmental remediation, natural resource restoration, and related measures to address water quality and heavy metal

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American Tribal territories to spread the religious and governance practices reflective of the American society (Miller, 2011).

contamination (State of Idaho, 2002). BEIPC’s purpose and function are outlined by a Memorandum of Agreement between seven primary governments including the federal government, Coeur d’Alene Tribe, States (Idaho and Washington), and the three counties (Benewah, Shoshone, Kootenai) (State of Idaho, 2002).

The Restoration Partnership is a product of years of planning and a series of lawsuits. Partners, called Natural Resource Trustees in CERCLA terms, include the Tribe, State of Idaho, and Federal government. A series of lawsuits between Trustees and mining companies, including the 2009 settlement with ASARCO Mining and Smelting Company, provides the Trustees with resources for conducting restoration and remediation activities within the boundaries of the Institutional Controls Program (Restoration Partnership, 2018). In 2018, a final Restoration Plan, aligned with Environmental Impact Statement related to recovering damaged natural resources through NRDAR, was finalized with a goal of restoring, rehabilitating, replacing, or acquiring the equivalent of the natural resources and the services they provide injured by mine water contamination (CdA Natural Resource Trustees, 2018). The two partnerships described in this paper aimed to contribute to both the research, and to practices that benefit the participants within these existing collaborations.

Partnerships in the Study Region

Prior to beginning participatory research, researchers should consider how their personal location contributes to knowledge production within the hydrosocial territory (Dei, 1999). The two research partnerships described in this paper were associated with doctoral students’ dissertation research and began in the spring of 2016. Both students were National Science Foundation’s Integrative Graduate Education and Research Traineeship (NSF-IGERT) fellows. The IGERT program provides students (i.e., trainees) with an interdisciplinary water resources education that promotes socially responsible practices in research and the development of innovative problem-solving approaches (e.g., Cosens et al., 2011). Trainees received training on topics such as science communication, Tribal sovereignty, conflict mediation, and values. The two doctoral students, also the lead authors of this chapter, led the design and implementation of the research, providing a suitable opportunity for comparison between projects. Neither student had prior experience working or living in the region and the projects conducted within the partnerships were conceived as primary deliverables for the students’ dissertations. Both partnerships included research designs that relied on primary data collection and projects aimed at capacity building by promoting community voice and goals, increasing access to scientific data, and improving scientific literacy of local citizens. Table 2.3 provides an overview of the projects conducted through both partnerships. In addition to working towards community capacity building goals, the final deliverables from these projects contribute to more generalizable research about water and society.

The Tribal partnership explored how an interdisciplinary research framework can support the Tribal community's capacity to mitigate water quality issues caused by historical mining contamination. The doctoral student connected with the Tribal partnership had training and a disciplinary background in science, informal education, and management. The Silver Valley partnership assessed risk perceptions and behavioral responses to lead contamination among residents and community leaders. This assessment helped to inform the health district's risk communication strategies. The student's training and background in the Silver Valley Partnership focused in law, policy, and management.

Coeur d'Alene Tribe (Tribal) Partnership Overview

The Tribal partnership and collaborative research commenced informally during the summer of 2015, while the doctoral student served as an intern for the Tribe's Department of Education (DoEd) and Lake Management Department (LMD). Primary research ideas stemmed from conversations during the student's summer internship experience. These conversations informed an interdisciplinary research framework which included disciplinary approaches in community engagement, aquatic ecology, and science, technology, engineering, and mathematics (STEM) education. The disciplinary approaches acknowledged in the framework informed multiple studies to support the Tribal community's existing water quality mitigation goals. The researcher consulted with educators and ecologists from the Tribe throughout all phases of the studies.

The studies conducted through the partnership included a limnological study and a culturally-relevant STEM education study involving Coeur d'Alene Tribal youth. The limnological study was conducted with the Tribe's LMD and explored submerged macrophyte phenology in three temperate lakes. The results from this study are intended to inform future research on the role of macrophytes in the fate and transport of metals and nutrients in lake ecosystems. The LMD and the Tribe's DoEd collaborated with the graduate student to develop and implement a culturally-relevant STEM education program and affiliated internship for Tribal youth. The associated study entailed the evaluation of the STEM education program on Tribal youth interest in the STEM fields.

Silver Valley Partnership Overview

The partnership with the health district began during conversations with health district employees at quarterly BEIPC meetings and other community events. These conversations inspired the development of a research project to better understand residents' behavioral responses (e.g., avoiding contaminated areas) to lead contamination. The health district's interest in the partnership objective developed from concerns that people were not taking adequate steps to avoid lead contamination, particularly while recreating in local rivers and working outside. The objectives and research design implemented in the Silver Valley partnership were co-developed between health district employees and university researchers. An initial study, about residents' behavioral responses contributed a social science perspective to the existing data and research studies about blood lead levels in children and physical data about contamination in the environment (e.g., Spalinger, 2007). A follow-up study focused on how community leaders prioritize economic development and issues related to environmental health, including regional water quality impairments.

As the partnership formed, the health district was also implementing a new risk communication campaign that involved posting updated signage at public recreation access points. As a result, the researchers and health district employees developed and tested a college-level curriculum focused on a critical illustration of the rationale behind the new risk communication strategies. The team also worked together to establish a science and technology fair in the Silver Valley, now in its third year, the event attracts around 200 industry representatives, non-profit groups, agency personnel, and students.

Theoretical Frames

For both partnerships explored in this paper, Participatory Action Research (PAR) provided guidance for understanding and developing relationships, focusing on valuing community voices and ensuring that participants are not data points. The Tribal partnership also drew from Indigenous Research Methodologies (IRM). These frames guide research development and help researchers to recognize elements of ethical research. The elements include: (1) establishing a research agenda; (2) promoting community voice and goals, data accessibility, and literacy; and (3) maintaining ethical partnerships (Figure 2.2). Ultimately, PAR and IRM help to take on questions summarized in Chambers (1998): Whose categories and concepts count? Whose values and criteria? Whose preferences and priorities? Whose analysis and planning? Whose action? Whose monitoring and evaluation? (p. 284). These questions often arise in current opinions about how best to conduct research about water and society (Wutich et al., 2019).

Participatory Action Research

PAR aims to facilitate more equitable and inclusive research by placing the research process in the hands of the community (Cornwall & Jewkes 1995; Curwood et al., 2012). The main premise behind PAR, often credited to Kurt Lewin, is that models making causal inferences about human behavior are more likely to reflect the local context when the "human beings in question participate in building and testing them" (Argyris & Schön, 1989, p. 613). This idea is critical in participatory research. PAR offers guidance for engaging community partners throughout the research process (Figure 2.2). Community partners aid in articulating research goals and assist in research design and implementation (Hacker, 2013). Ideally, as a partnership develops, the decision-making power shifts as community partners take on more control of the research. Throughout the partnership, researchers ensure a project remains responsive to community voices and goals by employing iterative cycles of inquiry, action, and reflection (Mackenzie et al., 2012). When community partners control partnership activities, research outcomes are more likely to persist (Schensul et al., 2008). The success of PAR approaches depends on the strength of partnership, skills of researchers, and the ability to sustain research outcomes (Greenwood et al., 2018).

Indigenous Research Methodologies

In Indigenous communities, the guidance of PAR on its own does not provide adequate guidance for forming equitable and inclusive partnerships. Over the past twenty years, Indigenous scholars have advocated for the use of IRM facilitated through PAR to form ethical, trusting, and lasting relationships with Indigenous communities (Bang & Medin, 2010; Brayboy & Deyhle, 2000; Kovach, 2010; Peltier 2018; Smith, 2013; Wilson et al., 2015). IRM diverges from PAR in that at the onset, emphasis is placed on building the partnerships with Indigenous principles: relationship, respect, responsibility, and reciprocity (i.e., the four Rs) (Kovach, 2010). As articulated in Wilson (2001) IRM, offers a fundamentally different paradigm because knowledge is not owned by an individual entity:

> "an Indigenous paradigm comes from the fundamental belief that knowledge is relational. Knowledge is shared with all of creation. It is not just interpersonal relationships, not just with the research subjects I may be working with, but it is a relationship with all of creation. It is with the cosmos, it is with the animals, with the plants, with the earth that we share this knowledge. It goes beyond the idea of individual knowledge to the concept of relation knowledge" (p. 176-177).

Among Indigenous communities, relational knowledge includes water not as just a physical substance but as an important link across all relations, an entity that connects, nourishes, and stewards (Wilson & Inkster, 2018). Grounded in the Indigenous principles of the four Rs, IRM offer an approach to inquiry that recognizes the importance of community control in sustained capacity building (Evans et al., 2009). Applying principles for building relationships and respect helps to initiate partnerships, while responsibility and reciprocity are appropriate for promoting community goals and maintaining trust (Kovach, 2010). IRM, through its prioritization of relational knowledge, asks the researcher to reflect on whether they are fulfilling the role and obligations of relationship, which should improve the reality of the place where you work (Wilson, 2001). While not without challenges, methods like PAR can have constructive applications in Indigenous communities because the framework factors in relational knowledge (Datta et al., 2015). However, in order for the framework to be effective, Indigenous scholar emphasize that research must have empathy for their participants and aim to be accountable to the community (Smith, 2013; Wilson, 2008; Wilson et al., 2015).

Comparing Elements of Participatory Research

In this section we compare how PAR and IRM guided the partnership development (establishing, promoting, and maintaining) (Figure 2.2). By focusing on these three elements we reflect on similarities and differences between the partnerships even though they were guided by different participatory research frameworks. Reflecting on these three elements is important, regardless of the participatory research frame.

Establishing Inclusive and Equitable Research Agendas

Initially, university researchers attended events hosted by community partners without discussing specific research agendas. Participation in events included volunteering at education programs and attending culturally significant events such as community dinners and outdoor recreational activities. Attending events without a specific research agenda allowed researchers to learn about the complex hydrosocial territories and provided time for cultural and social recognition (Kovach, 2010). Research questions in both partnerships originated from ideas that aligned with existing programs, scientific reports and data, as well as community goals. However, formal community needs assessment was not conducted in either partnership as recommended in PAR (Hacker, 2013). Both the health district and the Tribe already had goals and ideas in place regarding approaches for conducting scientific research investigations.

The doctoral student formed an authentic relationship with the Tribe by attending events and interning with the Tribe's LMD and participating in a culturally relevant STEM camp affiliated with the Tribe's DoEd. These experiences provided the doctoral student with an opportunity to learn about the community and culture as well as existing programs and research needs. A community partner with the Tribal partnership highlights the importance of positioning research alongside community goals and programs by urging researchers to "start the relationship early and let the Tribe's needs guide you" (Sam, March 2019). Taking the time to form a relationship with the partner, allowed the researchers to recognize existing efforts as well as community voices and goals in each study.

In the Silver Valley partnership, informal interviews and participant observation were essential for establishing research projects that aligned with community goals. Initial conversations with community leaders improved the researchers' understanding of health issues and community goals. Conversations focused on identifying different perspectives about healthy living environments in the Silver Valley rather than focusing on a specific research question. The participatory approach was reinforced by a health district employee who suggested that "it's important to constantly check in with the people who are in the thick of it to understand the small bits of information that mold ideas and dictate decision making," adding that researchers should "attend community social events to become a familiar face" (Cindy, June 2019). In both cases, university researchers provided space for community partners to share their stories, interests, and experiences.

Promoting Community Voice, Data Accessibility, and Literacy

Once the partnerships formed, it was important for university researchers to continue building trusting relationships, learning about community goals, and understanding existing research infrastructure and projects (Hacker, 2013; Kovach, 2010). Both the limnological study and the study about behavioral responses to lead contamination exemplify how partnerships can improve access to scientific data and advance community goals. The Silver Valley partnership supports a need to better protect human health through improved risk communication while the Tribal partnership provided scientific data that will help recover culturally-important, injured resources. The projects that formed within the two partnerships took these directions because of the goals of their community partners. However, because the researchers and community partners formed relationships prior to beginning research, the studies also developed around the doctoral students' background, strengths, and expertise. Working on projects, based on both community goals and the students' expertise helped to ensure more sustainable projects.

The limnological study with the Tribe filled an ecological research gap within the LMD. In addition to providing scientific data, educational programming was a primary outcome. The STEM education study assessed the impact of a six-week STEM education program and affiliated internship on Tribal youth interest in STEM. This informal educational opportunity relied on the local environment and cultural knowledge to educate Native American youth on the environmental hazards impacting their local waterways. The results of this study indicate that an increase in youth relationship to place and comprehension of STEM strengthened their interest in pursuing a career path in STEM fields for the Tribe. The Silver Valley partnerships provided the health district with support for improving their risk communication strategies, including funding for research from two small pilot grants. Participating in community outreach activities was also important in the Silver Valley partnership. Members established and organized an annual educational science and technology fair in the Silver Valley. At the fair, college students and local primary school students interacted with education and outreach groups, industries, and non-profits to learn about health and environmental contamination. The fair expands the health district's outreach capacity and provides an opportunity for community engagement.

Open communication within the partnerships allowed university researchers to alter research designs when necessary in order to redirect the research to meet capacity building goals. For instance, during conversations conducted with the Tribe a community partner emphasized that, "it is key to be upfront and open, what it is the University is getting from it and what the Tribe or community is getting from it" (Julie, March 2019). Interviews associated with the Silver Valley partnership reinforced the importance of open communication. An interviewee stated that "if you (the researcher) are trying to do some research that could help the community, then you absolutely have to involve them. Otherwise, you might be missing the point in terms of what you come up with" (Sarah, June 2019). In the two partnerships, open communication allowed the research studies to align with the goals of the community partners. These examples are central to the rationale behind conducting research through practice described in relational knowledge paradigms and through participatory research approaches (Datta et al., 2014; Wilson, 2001).

Maintaining Ethical Partnerships

Maintaining trusting relationships through the duration of a partnership requires commitment between partners and frequent reflection (Kovach, 2010; Hacker, 2013). Partnership personnel must remain dynamic and flexible in order to adjust to changing circumstances (McMillian, 2012; Wallerstein & Duran, 2006). To mitigate impending change, Indigenous scholars advocate for community participants to provide the 'final say' in the development, implementation, and dissemination of research (Kovach, 2010). However, transitioning between personnel and projects can present issues because building trusting relationships requires an investment of time and resources (Christopher et al., 2008).

The doctoral student and affiliated Tribal partner worked to sustain the partnership by broadening access to a place-based science education program and integrating activities into informal and formal curricula. Currently, the education program provides "a groundwork for other informal curriculums...It is something that was easy to follow for other resource managers" as expressed by a DoEd employee affiliated with the Tribal partnership (Julie, March 2019). An aquatic ecologist with the LMD thought the data affiliated with limnological study was "very helpful in assisting [LMD scientists] to understand the role of macrophytes (aquatic plants) in contaminated aquatic environments" (Tom, March 2019). Developing datasets and other materials that community partners can use is a recommended method in PAR as data sharing promotes community capacity building (Datta et al., 2014).

The Silver Valley partnership relied on techniques from PAR to sustain knowledge developed through the research studies. For example, prior to conducting a survey of residents within the Silver Valley, the researchers pre-tested the instrument with residents at events and reviewed preliminary results with health district partners. Pre-testing the tool provided an opportunity for reflection, which allowed the survey instrument to become more reflective of community goals. Further, the survey was distributed through the drop-off, pick-up method, which is a recommended method in PAR practices as it capitalizes on the social exchange theory, allowing researchers to briefly interact with community members who participate in data collection (Trentelman et al., 2016). The health district will be able to use the data, as well as project deliverables, to improve their risk communication strategies.

Continually planning for and applying to future opportunities was integral to maintaining relationships in the Silver Valley partnership. After initial data collection, the University researchers and an employee from the Health District attended a workshop together at the Socio-Environmental Synthesis Center (SESYNC) to collaboratively develop curriculum to teach both the lay public and college students about the health risks of lead contamination. In late phases of the Silver Valley partnership, the University researchers helped to secure additional funding and mentor another doctoral student to continue working towards partnership goals. In addition, the final project in the partnership was designed primarily as a reflective study for the doctoral student. The project assessed environmental health (e.g., good water quality) and economic development. Results from this study contribute to broader discussions about future decision-making and policies in the Basin.

Recommendations for Participatory Research about Water and Society

Guidance from participatory research approaches outlined in PAR and IRM ensured that outcomes produced by the two partnerships were more inclusive and equitable. However, explicit and implicit barriers to participatory research remain. As argued by other participatory research scholars, participatory research offered great value in eliciting local knowledge to assess local needs and boost the accessibility of science in decision-making by prioritizing capacity building (Wilk & Johnson, 2013; Wutich et al., 2019). Eliciting local knowledge and needs is a critical input for developing models in sociohydrology (Roobavannan et al., 2018).

As is often the case in participatory research, explicit limitations related to factors such as the researchers' positions as students, time, and resources created challenges through the projects (Chambers, 1997; MacKenzie, 2012). Because these limitations were made transparent from the onset of the projects, the researchers were able to form lasting relationships within the communities and lower explicit barriers that may be experienced in future partnerships between the university and community partners

In addition to explicit limitations of time and resources, participatory research is also limited by implicit limitations. Wilk and Johnson (2013) succinctly summarize these arguments in their description of how participatory research is subject to idealistic conceptions that, "fail to acknowledge and address the plurality of standpoints, uneven power dynamics, conflicting stakes, and distributive inequalities" (p. 697). While true, this critique also applies to traditional research more generally. In the partnerships explored here, participatory methods provided a space where partners could share knowledge and develop relationships through common projects. Eliciting different perspectives was important for developing more equitable and inclusive projects.

Both partnerships promoted capacity building through collaborative research studies that produced scientific data as well as education and outreach programs. These results would not have been achieved without the guidance of participatory research. Several lessons emerged within each element of partnership development. These lessons helped promote capacity building within partnerships and include identifying: (1) established programs, goals, and personnel, (2) respectful levels of community engagement, and (3) partnership limitations.

Established Programs, Goals, and Personnel

Both partnerships formed around established programs, goals, and personnel. Previous experience and existing relationships reduced some early challenges in establishing the partnerships. Working with established partners allowed the research studies to better align with other ongoing projects and goals in the region. In both partnerships, community partners goals prioritized reducing existing health and economic disparities in the region. Understanding the hydrosocial dynamics was particularly important to developing research studies within each partnership. In addition, it allowed university researchers to build on the existing community of practice, limiting the possibilities of research fatigue, and redundancy.

Respectful Levels of Community Engagement

The university researchers within both partnerships found participatory methods essential for identifying a respectful level of community engagement. For the partnership with the Tribe, researchers found guidance from IRM was particularly useful in building ethical relationships during the first year of the partnership. Establishing trusting relationships lowered other barriers to participatory research by decreasing the additional resources needed to engage communities. Learning about community goals and issues prior to initiating research provided the time needed to define realistic goals and objectives for the research projects. Although not always the case, both partnering entities had specific research interests and needs. These needs guided the projects that developed from the partnerships.

Partnership Limitations to Sustaining Community Capacity Building

Finally, identifying an appropriate balance between development of disciplinary depth and community capacity building is important. Balancing structural constraints within partnerships is an essential component of participatory research (Flicker et al., 2007; Halbe et al., 2018; Long et al., 2016). Researchers must acknowledge these constraints and provide extra time to complete projects that align with their values and the values of the partnered community. This issue is an intractable tradeoff that develops when researchers decide to conduct participatory research.

These lessons learned are relatively simple and yet are supported by an extensive collection of research about participatory process. Deciding whether participatory research is “successful” or burden by idealistic conceptions is ultimately subjective and, in some ways, even detracts from the goals of conducting participatory research. For the two partnerships explored here, the doctoral students were encouraged by mentors and through the guidance of participatory research to create an open forum for exchanging ideas in which there was no hierarchy. Once an open forum for exchange emerges, it is more possible to understand how governance may shift to account for existing power imbalances. Research about water and society requires place-based studies to back new approaches to novel models in sociohydrology (Roobavannan et al., 2018). Prioritizing equitable and inclusive participatory research helps to ensure that research about water and society better reflect the complex realities of hydrosocial territories.

Conclusion

We demonstrated the application of participatory research frameworks through two partnerships involving Tribal and non-Tribal rural communities residing in a mining-impacted region. Inquiry about how to design more equitable and inclusive interdisciplinary research about water and society must address power imbalances, cultural differences, and complex questions about hydrosocial relations. Participatory research does not make these difficult questions related to these issues disappear, rather they make these questions explicit and provide an opportunity for researchers and community members to work together to balance power. Researchers conducting participatory research should utilize participatory frameworks to guide research that are sensitive to local contexts and meets rigorous standards for scientific research. Participatory research frameworks such as PAR and IRM facilitate ethical research that prioritizes capacity building through equitable partnerships that acknowledge and embrace relational knowledge. We argue a core set of recommendations for conducting participatory research should be professionalized within emerging interdisciplinary research about water and society.

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Literature Cited

Argyris, C., & Schön, D. A. (1989). Participatory action research and action science compared: A commentary. *American behavioral scientist, 32*(5), 612–623.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education, 94*(6), 1008–1026.

Basin Environmental Improvement Project Commission (BEIPC). (2019). Coeur d'Alene Basin Commission site. Retrieved from http://www.basincommission.com/

Berry, K. A., Jackson, S., Saito, L., & Forline, L. (2018). Reconceptualising water quality governance to incorporate knowledge and values: Case studies from Australian and Brazilian Indigenous communities. *Water Alternatives, 11*(1): 40-60

Boelens, R., Hoogesteger, J., Swyngedouw, E., Vos, J., & Wester, P. (2016). *Hydrosocial territories: a political ecology perspective*. Taylor & Francis.

Bookstrom, A. A., Box, S. E., Fouseck, R. S., Wallis, J. C., Kayser, H. Z., & Jackson, B. L. (2013). *Baseline, historic and background rates of deposition of lead-rich sediments on the floodplain of the Coeur D'Alene River, Idaho* 2004-1211, Version 1.1. US Department of the Interior, US Geological Survey.

Brayboy, B. M., & Deyhle, D. (2000). Insider-outsider: researchers in American Indian communities. *Theory into practice, 39*(3), 163–169.

Campbell, J. K., Audet, D. J., McDonald, T. L., Kern, J., Strickland, D., & Cernera, P. J. (1997). Heavy metal concentrations in *Sagittaria spp*. tubers (water potato) in the Coeur d'Alene Basin, Idaho. Spokane, WA: US Fish and Wildlife Service.

Caxaj, C. S. (2015). Indigenous storytelling and participatory action research: Allies toward decolonization? Reflections from the Peoples' International Health Tribunal. *Global Qualitative Nursing Research, 2*, 2333393615580764.

Chambers, R. (1997). *Whose reality counts* (Vol. 25). Intermediate technology publications.

Chambers, R. (1998). Beyond "Whose reality counts?" New methods we now need? *Studies in Cultures, Organizations and Societies, 4*(2), 279–301.

Christopher, S., Watts, V., McCormick, A. K. H. G., & Young, S. (2008). Building and maintaining trust in a community-based participatory research partnership. *American Journal of Public Health, 98*(8), 1398–1406.

Coeur d'Alene Lake Management Plan (LMP). (2009). Coeur d'Alene Tribe and Idaho Department of Environmental Quality. Retrieved from https://www.deq.idaho.gov/media/468377-_water_data_reports_surface_water_water_bodies_cda_lake_mgmt_plan_final_2009.pdf

Cornwall, A., & Jewkes, R. (1995). What is participatory research? *Social Science & Medicine, 41*(12), 1667–1676.

Coeur d'Alene Basin (CdA) Natural Resource Trustees. (2018). Coeur d'Alene Basin restoration plan. Retrieved from https://www.restorationpartnership.org/pdf/Coeur%20d'Alene%20Basin%20Restoration%20Plan%20May%202018.pdf

Cosens, B., Fiedler, F., Boll, J., Higgins, L., Johnson, B. K., Strand, E., Wilson, P., Laflin, M., Szostak, R., & Repko, A. (2011). Interdisciplinary methods in water resources. *Issues in Interdisciplinary Studies*.

Criscione, W. (2018). In north Idaho, leaders brace for rapid population growth. *Inlander*. Retrieved from https://www.inlander.com/spokane/in-north-idaho-leaders-brace-for-rapid-population-growth/Content?oid=7619376

Curwood, S. E., Munger, F., Mitchell, T., Mackeigan, M., & Farrar, A. (2012). Building effective community-university partnerships: Are universities truly ready? *Michigan Journal of Community Service Learning, 17*(2), 15–26.

Datta, R., Khyang, N. U., Prue Khyang, H. K., Prue Kheyang, H. A., Ching Khyang, M., & Chapola, J. (2015). Participatory action research and researcher's responsibilities: an experience with an Indigenous community. *International Journal of Social Research Methodology, 18*(6), 581–599.

Dei, G. J. S. (1999). Know and politics of social change: The implication of anti-racism. *British Journal of Sociology of Education*, *20*, 395–409.10.1080/01425699995335

Evans, M., Hole, R., Berg, L. D., Hutchinson, P., & Sookraj, D. (2009). Common insights, differing methodologies: Toward a fusion of indigenous methodologies, participatory action research, and white studies in an urban aboriginal research agenda. *Qualitative Inquiry, 15*(5), 893–910.

Ferreira, M. P., & Gendron, F. (2011). Community-based participatory research with traditional and indigenous communities of the Americas: Historical context and future directions. *International Journal of Critical Pedagogy, 3*(3), 153-168

Finn, S., & O'Fallon, L. (2015). The emergence of environmental health literacy—from its roots to its future potential. *Environmental health perspectives*, *125*(4), 495–501.

Flicker, S., Travers, R., Guta, A., McDonald, S., & Meagher, A. (2007). Ethical Dilemmas in Community-Based Participatory Research: Recommendations for Institutional Review Boards. *J Urban Health, 84*(4), 478–493.

Frey, R., & Stensgar, E. (2012). *Landscape traveled by Coyote and Crane: The world of the Schitsu'umsh*. University of Washington Press.

Greenwood, M., De Leeuw, S., Lindsay, N. M., and Reading, C. (2018). *Determinants of Indigenous peoples' health*, second edition. Canadian Scholars' Press.

Gustavson, K. E., et al. (2007). *Superfund and mining megasites*. ACS Publications.

Hacker, K. (2013). *Community-based participatory research*. Wiley and Sons.

Halbe, J., Pahl-Wostl, C., & Adamowski, J. (2018). A methodological framework to support the initiation, design and institutionalization of participatory modeling processes in water resources management. *Journal of Hydrology, 556*, 701–716.

Hall, B. L. (1992). From margins to center? The development and purpose of participatory research. *The American Sociologist*, 23(4), 15–28.

Helkey, A. (2018). *Getting the Lead out- 30 years of remediation and education in the Silver Valley*. Presented at the Institutional Controls in the Bunker Hill Superfund Site, Kellogg, Idaho. Retrieved from https://static1.squarespace.com/static/585aee335016e1541642dc0c/t/5b86c97df950b7278c23dc62/1535560095766/Getting+the+Lead+Out.pdf

Hommes, L., Boelens, R., Harris, L. M., & Veldwisch, G. J. (2019). *Rural–urban water struggles: urbanizing hydrosocial territories and evolving connections, discourses and identities*. Taylor & Francis.

Idaho Department of Health and Welfare. (1976). Shoshone Lead health project (Work Summary). Kellogg, Idaho.

Jepson, W., Budds, J., Eichelberger, L., Harris, L., Norman, E., O'Reilly, K., Pearson, A., Shah, S., Shinn, J., & Staddon, C. (2017). Advancing human capabilities for water security: A relational approach. *Water Security, 1*.

Kovach, M. (2010). *Indigenous methodologies: Characteristics, conversations, and contexts*. University of Toronto Press.

Langman, J., Torso, K., & Moberly, J. (2018). Seasonal and basinal influences on the formation and transport of dissolved trace metal forms in a mining-impacted riverine environment. *Hydrology, 5*(3), 35.

Leung, M. W., Yen, I. H., & Minkler, M. (2004). Community based participatory research: a promising approach for increasing epidemiology's relevance in the 21st century. *International journal of epidemiology, 33*(3), 499–506.

Linton, J., & Budds, J. (2014). The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water. *Geoforum, 57*, 170–180.

Long, J. W., Ballard, H. L., Fisher, L. A., & Belsky, J. M. (2016). Questions that won't go away in participatory research. *Society & natural resources, 29*(2), 250–263.

Mackenzie, J., Tan, P.-L., Hoverman, S., & Baldwin, C. (2012). The value and limitations of participatory action research methodology. *Journal of hydrology*, *474*, 11–21.

Marques, B., McIntosh, J., & Campays, P. (2018). Participatory design for under-represented communities: A collaborative design-led research approach for place-making. In *Handbook of research on civic engagement and social change in contemporary society* (pp. 1–15). IGI Global.

Martenson, D. M., Newman, D. A., & Zak, D. M. (2012). Building community-university partnerships by listening, learning, and responding. *Journal of Extension*, *49*(5).

McCarty, T. L., & Lee, T. S. (2014). Revitalizing pedagogy and Indigenous education sovereignty. *Harvard Educational Review, 84*(1), 101–125.

Mcmillan, J. (2012). Boundary workers and their importance to community-university partnerships. *Metropolitan Universities*, *22*(2), 106–120.

Miller, R. J. (2011). American Indians, the doctrine of discovery, and manifest destiny. *Wyo. L. Rev.*, *11*, 329.

Mix, M. C. (2016). *Leaded: The poisoning of Idaho's Silver Valley*. Oregon State University Press.

National Research Council (NRC). (2005). *Superfund and mining megasites: Lessons from the Coeur d'Alene River Basin*. National Academies Press.

Panhandle Health District. (2018). Community health assessment. Retrieved from http://panhandlehealthdistrict.org/wp-content/uploads/2019/06/CHA-2018-final.pdf

Peltier, C. (2018). An application of two-eyed seeing: Indigenous research methods with participatory action research. *International Journal of Qualitative Methods, 17*(1), 1609406918812346.

Repko, A. F. (2008). *Interdisciplinary research: Process and theory*. Sage.

Restoration Partnership. (2018). Coeur d'Alene Basin restoration partnership (EIS Alternative 2), 1–69. The Coeur d'Alene Basin Natural Resource Trustees. Retrieved from https://www.restorationpartnership.org/pdf/Coeur%20d'Alene%20Basin%20Restoration%20Plan%20May%202018.pdf.

Roobavannan, M., van Emmerik, T. H. M., Elshafei, Y., Kandasamy, J., Sanderson, M. R., Vigneswaran, S., Pande, S., & Sivapalan, M. (2018). Norms and values in sociohydrological models. *Hydrology and Earth System Sciences, 22*(2), 1337–1349.

Royster, J. V. (1993). Mineral development in Indian country: The evolution of Tribal control over mineral resources. *Tulsa LJ, 29*, 541.

Schensul, J. J., Berg, M. J., & Williamson, K. M. (2008). Challenging hegemonies: Advancing collaboration in community-based participatory action research. *Collaborative Anthropologies*, *1*(1), 102–137.

Smith, L. T. (2013). *Decolonizing methodologies: Research and indigenous peoples*. Zed Books Ltd.

Spalinger, S. M., von Braun, M. C., Petrosyan, V., & von Lindern, I. H. (2007). Northern Idaho house dust and soil lead levels compared to the Bunker Hill Superfund site. *Environmental monitoring and assessment, 130*(1–3), 57–72.

State of Idaho. (2002). *Memorandum of agreement for the Basin Environmental Improvement Project Commission*. Retrieved from http://www.basincommission.com/wp-content/uploads/2018/05/BEIPC-MOA.pdf

Trentelman, C. K., Petersen, K. A., Irwin, J., Ruiz, N., & Szalay, C. S. (2016). The case for personal interaction: drop-off/pick-up methodology for survey research. *Journal of Rural Social Sciences, 31*(3), 68.

U.S. Census Bureau. (2010). American community survey, profile of general population and housing characteristics: 2010 demographic profile data. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

United States Geological Survey (USGS). (2013). Watershed boundary dataset. Retrieved from https://www.usgs.gov/core-science-systems/ngp/national-hydrography/watershed-boundary-dataset?qt-science_support_page_related_con=4#qt-science_support_page_related_con

von Lindern, I., Spalinger, S., Petroysan, V., & von Braun, M. (2003). Assessing remedial effectiveness through the blood lead: soil/dust lead relationship at the Bunker Hill Superfund Site in the Silver Valley of Idaho. *Science of the total environment, 303*(1–2), 139–170.

Wallerstein, N. B., & Duran, B. (2006). Using community-based participatory research to address health disparities. *Health promotion practice,* **7**(3), 312–323.

Wesselink, A., Kooy, M., & Warner, J. (2017). Socio-hydrology and hydrosocial analysis: toward dialogues across disciplines. *Wiley Interdisciplinary Reviews: Water*, *4*(2), e1196.

Wilk, J., & Jonsson, A. C. (2013). From Water Poverty to Water Prosperity—A More Participatory Approach to Studying Local Water Resources Management. *Water Resources Management*, *27*(3), 695–713. https://doi.org/10.1007/s11269-012-0209-8

Wilmsen, C., Elmendorf, W. F., Fisher, L., Ross, J., Sarathy, B., & Wells, G. (2012). *Partnerships for empowerment: participatory research for community-based natural resource management*. Routledge.

Wilson, S. (2001). What is an Indigenous research methodology? *Canadian journal of native education, 25*(2), 175–179.

Wilson, N. J., & Inkster, J. (2018). Respecting water: Indigenous water governance, ontologies, and the politics of kinship on the ground. *Environment and Planning E: Nature and Space*, *1*(4), 516–538.

Wilson, N. J., Walter, M. T., & Waterhouse, J. (2015). Indigenous knowledge of hydrologic change in the Yukon River Basin: A case study of Ruby, Alaska. *Arctic*, *68*(1), 93–106.

Woodworth-Ney, L. (2004). *Mapping identity: The creation of the Coeur D'Alene Indian Reservation, 1805-1902*. Univ Pr of Colorado.

Wutich, A., Cardenas, J.-C., Lele, S., Pahl-Wostl, C., Rauschmayer, F., Schleyer, C., Suhardiman, D., Tallis, H., & Zwarteveen, M. (2019). Opportunities and challenges for inclusively framing water research. *Rethinking Environmentalism: Linking Justice, Sustainability, and Diversity*, *23*, 251.

Tables

Table 2.1 Select Socio-Economic Characteristics of Counties in the Study Region.

Demographic		Benewah County	Shoshone County	Kootenai County	State of Idaho
Population					
	Total	9,226	12,796	161,505	1,787,065
	Population density (per km^2)	31.1	12.7	288.3	49.2
Race					
	White	86.6%	94%	94.5%	93.0%
	American Indian and Alaskan Native	8.5%	1.8%	1.3%	1.7%
Education					
	High school graduate or higher	88.3%	85.6%	92.5%	90.6%
	Bachelor's degree or higher	15.1%	11.6%	24.9%	26.9%
Health					
	Disability, under the age of 65	13.2%	20.3%	9.1%	9.3%
Income & Poverty					
	Mean household income	$46,507	$39,091	$54,457	$53,089
	Persons in poverty	14.7%	18.8%	10.3%	11.8%

Table 2.2 Primary Partners Included in Collaborative Groups Related to Mining Impacts.

Basin Environmental Improvement Project Commission Partners	Restoration Partnership Trustees
Coeur d'Alene Tribe	Coeur d'Alene Tribe
State of Idaho, Idaho Department of Environmental Quality	State of Idaho, Idaho Department of Environmental Quality
Federal Environmental Protection Agency	Federal Department of Interior, Fish and Wildlife Service
State of Washington, State of Washington Department of Environmental Quality	Federal Department of Interior, Bureau of Land Management
Benewah County	Federal Department of Agriculture, Forest Service
Shoshone County	State of Idaho, Idaho Department of Fish and Game
Kootenai County	
Panhandle Health District	
Citizens Coordinating Council	

Table 2.3 Primary partnership projects.

Partnership Project Titles	Summary	Capacity Building Goals
Silver Valley		
Behavioral responses to Pb contamination in a mining-impacted area	Community survey of resident's perceptions and behavioral responses to lead contamination. Supported by pilot grant program.	• Data accessibility • Community engagement • Resource generation
Can we have healthy living environments in mining-impacted communities?	Case studies-based curriculum development about the Health District's risk communication strategy.	• Policy recommendations • Risk communication strategies • Curriculum development
A Q methodology approach to identifying environmental health and economic development perspectives	Interviews and card sorting activity (Q method) to understand how leaders view tradeoffs between environmental health and economic development.	• Policy recommendations • Data accessibility
Silver Valley science and technology fair	An annual event to exchange information between community members, environmental managers, university students, and researchers.	• Community engagement • Information dissemination
Tribe		
Variations in aquatic macrophyte phenology across three temperate lakes	Phenology assessed through the collection of water quality parameters, biomass and biovolume.	• Data accessibility • Sampling methods • Community engagement
Supporting Native American Community Leadership through Culturally-Relevant STEM Education	Culturally-relevant STEM programming to further youth interest in STEM. Impact of study was evaluated through a case study research approach.	• Literacy • Community engagement • Curriculum development and instruction

Figures

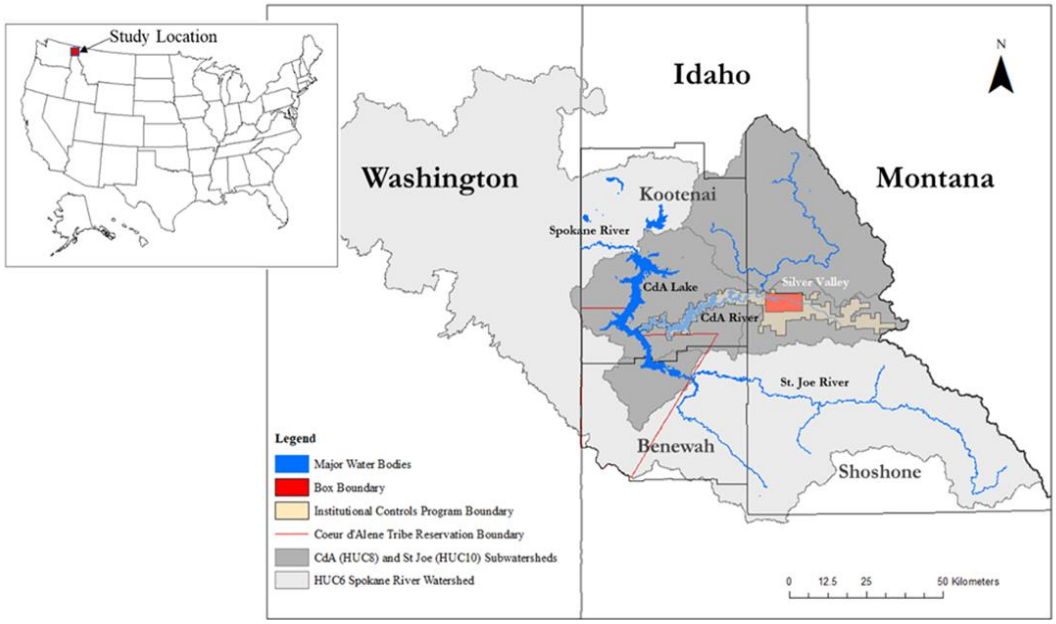

Figure 2.1 Map illustrating the hydrosocial territories of the study region, which includes three counties (Benewah, Kootenai, Shoshone), jurisdictional boundaries of the Superfund Site, as well as geographical boundaries for the Spokane River Watershed, Coeur d'Alene (CdA) Basin which is composed of the CdA and St. Joe subwatersheds.

Map image developed in ESRI ArcGIS 10.6.1.

HUC= Hydrologic Unit Code.

Source: USGS Watershed Boundary Dataset, Alta Science and Engineering, Coeur d'Alene Tribe of Indians (accessed at Koordinates.com).

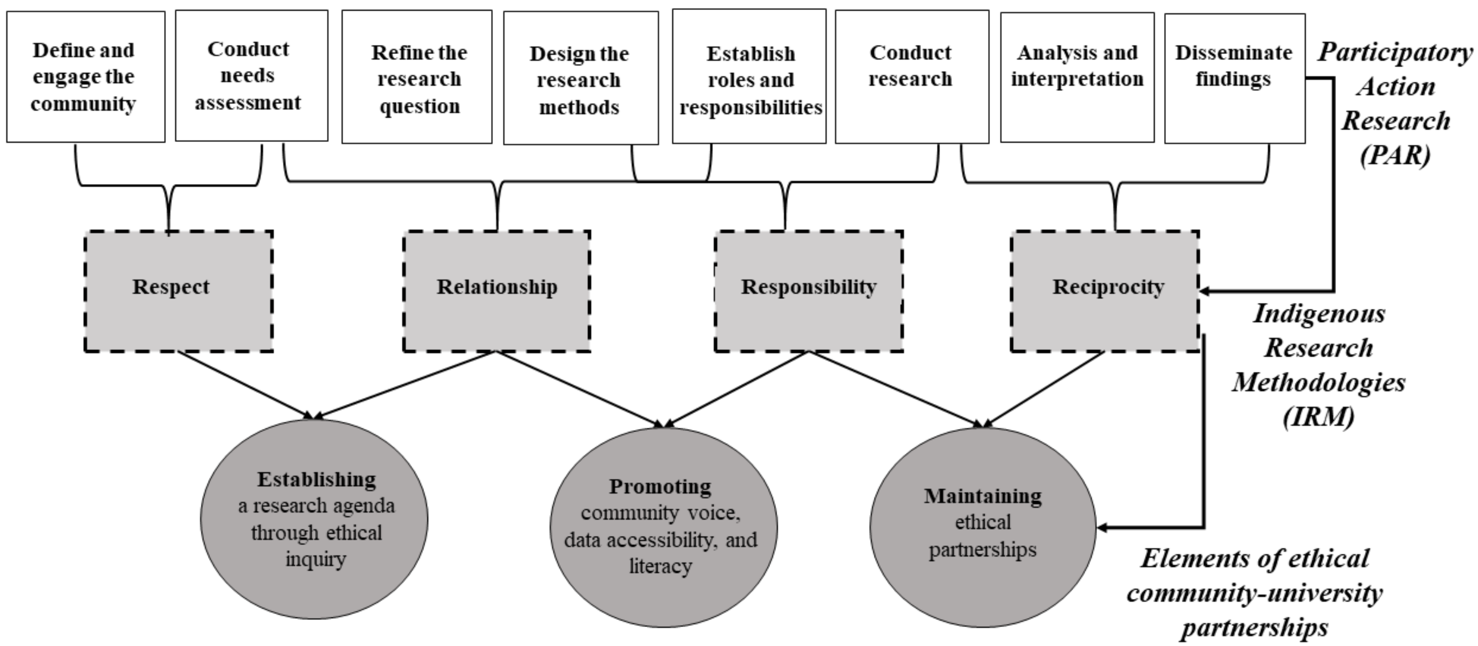

Figure 2.2 Conceptual diagram illustrating the three partnership elements and the iterative cycles of inquiry, action, and reflection employed in participatory research approaches.

Chapter 3: Variations in Aquatic Macrophyte Phenology Across Three Temperate Lakes in the Coeur d'Alene Basin

Torso, K., Scofield, B. D., & Chess, D. W. (2020). Variations in aquatic macrophyte phenology across three temperate lakes in the Coeur d'Alene Basin. *Aquatic Botany*, *162*, 103209.[5]

Abstract

We studied the phenology of submerged macrophytes in three temperate lakes in 2017 to determine the timing and duration of macrophyte senescence and to investigate the feasibility of using sonar to measure seasonal changes in macrophyte biovolume. Phenology was examined with macrophyte biomass, sonar biovolume, and water quality data. Our results indicated that Black and Thompson lakes had longer growing seasons and higher species richness than Chatcolet Lake likely due to differences in hydrologic connectivity. Macrophyte senescence was more distinct in Black and Chatcolet lakes than in Thompson Lake. The prolonged and indistinct senescence in Thompson Lake was likely due to the dominance of the macrophyte community by *Myriophyllum spicatum*. Biovolume results revealed complex spatial patterns in macrophyte senescence at Chatcolet Lake. Macrophyte biovolume was positively correlated with biomass at all sites. Spearman's rank correlation was highest at Chatcolet Lake ($\rho = 0.75$, $p < 0.001$) followed by Black Lake ($\rho = 0.59$, $p < 0.001$) and Thompson Lake ($\rho = 0.49$, $p < 0.001$). The relationship between biovolume and biomass was non-linear and variation in the relationship was attributed to site-specific differences such as species composition in addition to sampling error. Sonar biovolume provided a convenient and nondestructive method to measure seasonal changes in macrophyte biovolume.

[5] Please see Appendix C for Elsevier statement of approval for author's use of their published articles in dissertation/thesis.

Introduction

Aquatic macrophytes are an important component of shallow lentic ecosystems because they provide numerous ecological services such as: fixing carbon, habitat and food to resident organisms, linking nutrient cycling between sediments and open water, favoring clear water states over algal turbid states through stabilization of sediments, nutrients, and algal allelopathy (Jeppesen et al., 1998). The role of macrophytes in cycling elements from bottom sediments to the open water is of particular interest in the Coeur d'Alene Basin given that large portions of the Basin have been contaminated with mine tailings including high concentrations of lead, zinc, arsenic, and cadmium (Bookstrom et al., 2013; National Research Council, 2005). Macrophytes are known to absorb metals from contaminated sediments during the growing season and then release them back into the environment upon senescence (Jackson, 1998; Weis & Weis, 2004).

Examining growth patterns, especially senescence of macrophyte communities in the Basin is important to understand ecosystem-wide patterns of metal cycling. As such, the primary objective of this study was to determine the timing and duration of submerged macrophyte senescence among three temperate lakes in the Basin. The secondary objective of this study was to investigate the feasibility of using a consumer-grade hydroacoustic system (sonar) to measure seasonal change in macrophytes. Traditional macrophyte sampling techniques such as biomass or percentage cover can be time consuming as well as destructive and require expensive laboratory work (Radomski & Holbrook, 2015; Valley et al., 2015). The collection of biovolume via sonar technology is a relatively new method to examine macrophyte variability (Duarte, 1987; Howell & Richardson, 2019; Valley et al., 2015), and if applicable in the Basin, could provide an efficient way to measure variability in macrophyte biomass across large areas.

Methods and Materials

Study Location

The Coeur d'Alene Basin, USA (Figure 3.1) is centrally located in the northern Idaho panhandle and encompasses several subwatersheds including the Upper Coeur d'Alene River, South Fork Coeur d'Alene River, Coeur d'Alene Lake, and the Lower St. Joe River (USGS, 2013). Collectively, these subwatersheds drain an area 5,225 km^2 in size (USGS, 2013). The drainage basin extends west from the Idaho-Montana border before reaching the Spokane River, which drains the 129 km^2 Coeur d'Alene Lake (Woods & Beckwith, 1997).

We collected data at Thompson Lake, Black Lake, and Chatcolet Lake. Thompson and Black lakes are eutrophic based on water column characteristics (Table 3.1). Both lakes are in the floodplain of the metals contaminated Coeur d'Alene River (Bookstrom et al., 2013) and are connected to the river by dredged channels and a vast wetland complex. Thompson and Black lakes have maximum depths of ~7 m and ~6 m, respectively, and are often thermally stratified between late May and early October. Seasonal pumping of adjacent converted wetlands into Black Lake has increased nutrient concentrations and decreased water quality through eutrophication (Kann & Falter, 1987). Chatcolet Lake is located in the southern half of Coeur d'Alene Lake and was chosen as a non-metals contaminated reference site. It has a maximum depth of ~13 m, is mesotrophic, and thermally stratified from June to early October (Table 3.1) (CDA Tribe & Avista Corporation, 2017).

Sampling Regime and Experimental Design

This study examined the phenology of aquatic macrophyte communities from May 1, 2017 to November 15, 2017. Phenology was assessed using submerged macrophyte biomass, biovolume generated from hydroacoustic sonar surveys, and water quality measurements collected twice per month. Survey sites at Black, Chatcolet, and Thompson lakes were 3.3, 2.8, and 1.6 ha in size, respectively. Macrophyte biomass samples were collected from a 50 m point intercept grid (Madsen & Wersal, 2017) overlain on the sample sites. Grid points were located in the field using a Lowrance Point-1 GPSr with 3 m horizontal accuracy. At each point, a biomass sample was collected using the rake twirl method (Johnson & Newman, 2011). Species present, dominant species, and water depth were noted before placing the sample in a plastic bag for laboratory analysis. Depth of water was determined by 0.25 m increments marked on the exterior of the rake handle. A total of 406 biomass samples were collected.

Macrophyte biovolume has been measured with sonar previously (Duarte, 1987; Radomski & Holbrook, 2015; Valley & Drake, 2005) and in this study, we used a consumer- grade sonar system. Sonar data was recorded using a Lowrance HDS-7 Gen 2 with a transom mounted 200 kHz transducer with a 20° beam angle using the BioBase configuration as recommended by Navico (2014). Sonar data was collected along transects perpendicular to shore and traversed the biomass grids to achieve ~25 m spacing between sonar paths. After collection, the sonar data was uploaded to the BioBase website for processing. Biovolume, or the percent of water column occupied by plant biomass, was calculated by dividing plant height by water column depth and was estimated across a five-meter grid spanning the sampling area (Navico, 2014). After processing by BioBase, an ASCII text file was downloaded with latitude, longitude, and biovolume estimates for each sampling event. To minimize false detections, biovolume was not estimated at sonar depths < 0.73 m and when plant detections had lengths < 5% of the water column depth (Valley et al., 2015). Sonar was recorded within a day of when biomass samples were collected at each site.

Because biomass and biovolume measurements could not be taken simultaneously, an assessment of positional sampling error was made. Sonar transects were similar between sampling events, but not identical. Overall mean GPS accuracy when navigating to biomass sampling points was 5.2 ± 3.1 m (mean ± standard deviation), which was approximately 2 m greater than the manufacturer specified accuracy of the GPS receiver. Overall mean matchup distances from pairwise biomass points and biovolume estimates was 1.3 ± 0.5 m. Thus, we feel confident that the biovolume and biomass estimates are representative for each sampling site.

Water Quality and Degree Days

Vertical profiles of water temperature, pH, dissolved oxygen, specific conductance, and photosynthetic active radiation (PAR) at 0.5 m increments were measured and recorded with a Hach Hydrolab DS5 multi-sensor sonde. A standard 20 cm diam. Secchi disk was used to assess water transparency. Water temperatures in each lake were also recorded at hourly intervals with HOBO Water Temp Pro v2 sensors deployed in approximately 1.0 m of water. These temperature data were used to calculate cumulative growing degree days (GDD), which represent an accumulation of "heat units" (Zalom & Goodell,1983). Heat units are accumulated when the mean of the minimum and maximum daily temperature fall between the lower and upper bounds of an acceptable temperature for growth of a specific organism (Zalom & Goodell, 1983). For this study, GDD values were calculated with the “pollen” package in R (Nowosad, 2018) using minimum (15 °C) and maximum (35 °C) growth thresholds for *Myriophyllum spicatum* as reported by Smith and Barko (1990).

Analysis of Macrophyte Biomass

Macrophytes collected for the analysis of biomass were processed following method 10400 D Population Estimates as described by APHA et al. (2012). Macrophytes were first rinsed to remove all sediment and then placed in a salad spinner to remove excess water. Samples were then sorted by species using the keys of Hamel et al. (2001) and Crow and Hellquist (2005a, 2005b). Please note that *Elodea nuttallii* is occasionally found in Coeur d’Alene Lake, however, we denote all *Elodea* spp. as *Elodea canadensis* (Lamb, 2006). Similarly, we have referred to all *Myriophyllum* spp. as *M. spicatum*. However, most *Myriophyllum* spp. encountered in Chatcolet Lake is hybrid watermilfoil comprised of a cross between *M. spicatum* and *M. sibiricum* (Thum, 2016). Black and Thompson lakes had mostly *M. spicatum*, but some hybrid watermilfoil was also present (Thum, 2016).

Once macrophytes were sorted by species, wet mass was determined to the nearest hundredth of a gram with an electronic balance. Sorted plants were then air dried for 4-6 hours. Following this initial drying, samples were transferred to a 105 °C drying oven (Lindberg/Blue M G01350A) and dried until a constant mass was reached. Dried samples were allowed to cool in a desiccator for 15 minutes before the final dry mass was determined.

Statistical Analysis

Statistical analysis and figures were produced using R statistical software version 3.6.1 (R Core Team, 2019). Time series figures of macrophyte biomass and biovolume were constructed with the "Tidyverse" (Wickham, 2017), "cowplot" (Wilke, 2019), and "rgdal" (Bivand et al., 2019) packages. Light extinction coefficients (K_d) were calculated using equation 1 Wetzel (2001):

$$\text{Equation: } K_d\ (\eta\ m^{-1}) = [\text{In}(I_{z1}) - \text{In}(I_{z2})] / (Z_2 - Z_1) \qquad (1)$$

Where, I_{z1} was light intensity at depth interval n and Z_n was depth interval n (m^{-1}). Differences in light extinction as well as Secchi depth between sites and by sampling event were tested using a repeated measures analysis of variance (RMANOVA) and least squares mean (LSM) pairwise comparisons by site using the emmeans (Lenth, 2020) and nlme (Pinheiro et al, 2019) packages.

Differences in species composition between sites were assessed using non-metric multidimensional scaling (NMDS) ordination (Gotelli & Ellison, 2018). Rare macrophyte species that were < 1% of total sample size were removed prior to ordination. Removed species included *Elatine triandra*, *Equisetem fluvatile*, *Najas* sp., *Potamogeton amplifolius*, *Schoenoplectus tabernaemontani*, *Sagittaria latifolia*, and *S. rigida*. The ordination was calculated using species presence/absence data and the Jaccard dissimilarity index (McCune et al., 2002). The NMDS ellipses show a 95% confidence level drawn around the centroid of the site scores. Differences in species richness were assessed using species accumulation curves (SAC) calculated by Kindt's exact method (Oksanen, 2019). The ordination and SAC plots were produced with the "vegan", "ggvegan" (Oksanen, 2019), and "ggplot2" (Wickham, 2016) packages. The relative abundance of macrophytes was calculated by dividing the summed biomass from all sampling events for a particular species by the sum of all species combined and then multiplied by 100 to obtain the percentage (McCune et al., 2002).

To compare macrophyte biomass and sonar biovolume, individual biomass samples were matched up to BioBase biovolume grid estimates by using the ESRI ArcGIS 10.3 Spatial Join tool. Within this tool we set the search radius to 5 m and joined a given biomass sample to the closest biovolume estimate for each sampling event. However, technical issues with the sonar technology prevented the collection of biovolume data within individual sampling points on 6 sampling events over the 7-month sampling period. Prior to statistical analysis, the sampling events containing no biovolume data were removed from the raw data to create a balanced data-set.

The relationship between biomass and biovolume was assessed using linear regression and an ANOVA from the "car" package (Fox & Weisberg, 2011). We also used the ratio of biomass to biovolume from pairwise matchups to compare the relationship between these measures across sites. Differences in ratios between sites over time were tested with a RMANOVA followed by pairwise comparisons of LSM by site. Both biomass and biovolume data were natural log + 1 transformed prior to analysis to satisfy normality and homoscedasticity assumptions. The relationship between biomass and biovolume was also assessed using a Spearman's rank correlation and plotting the data with a smoothed loess line.

Results

Dissolved Oxygen and pH

We highlight mean dissolved oxygen and pH recorded between 0.5 m and 2 m from each lake because this range in depth reflects the depths at which macrophyte biomass and biovolume were collected and the parameters of dissolved oxygen and pH were selected because they are good indicators of photosynthetic activity (Jeppesen et al, 1998). At Black Lake, dissolved oxygen saturation was highest on June 27 at 141% and lowest on October 3 at 78%. Dissolved oxygen saturation at Chatcolet Lake was highest on July 27 at 127% and lowest on September 6 at 87%. At Thompson Lake, dissolved oxygen minimum and maximum saturations occurred at the same time as Black Lake reaching a high of 105% on June 27 and a low of 68% on October 3%. At Black, Chatcolet, and Thompson lakes, pH values were 8.9, 9.0, and 7.4, respectively, when dissolved oxygen saturations were at the lake-specific maximum. Additional water quality parameters are summarized in Tables 3.2-3.4.

Temperature and Growing Degree Days

On May 1, water temperature at all lake sites was below 15 °C (Figure 3.2A), and little to no plant growth was observed (Figure 3.2B). However, as water temperature increased above 15 °C, heat units accumulated, and plant growth occurred. Black and Thompson lakes both reached 15 °C on May 5, while Chatcolet Lake reached 15 °C on May 23. Cumulative GDD for the 2017 growing season at Black, Chatcolet, and Thompson lakes were estimated to be 804, 704, and 780, respectively. Heat units ceased to accumulate and GDD curves plateaued on October 1, October 16, and September 30, for Black, Chatcolet, and Thompson lakes, respectively (Figure 3.2B). Using the period when heat units accumulated for GDD, the growing season lengths for 2017 were 5.0, 4.5, and 4.9 months for Black, Chatcolet, and Thompson lakes, respectively.

Water Clarity

Light extinction coefficients (K_d) per site indicated greater light availability at Chatcolet Lake as opposed to Black and Thompson lakes, but differences between sites were not significant (RMANOVA between subjects p = 0.971). However, pairwise comparisons of LSM by site indicated the overall mean K_d at Chatcolet Lake (0.78 m^{-1}) was significantly less than the mean K_d at Thompson (0.95 m^{-1}) and Black (0.99 m^{-1}) lakes (Table 3.5). The overall mean K_d at Black and Thompson lakes did not significantly differ (Table 3.5).

The seasonal patterns in K_d and Secchi depths were complex (Figure 3.3A-B). Results from the RMANOVA indicated K_d significantly increased over the growing season (RMANOVA within subjects $p = 0.033$) at all sites, while Secchi depths generally decreased, but did not significantly differ by sampling event (RMANOVA between subjects $p = 0.737$) or site (RMANOVA within subjects $p = 0.095$). Secchi depth at Chatcolet was greatest on August 9 at 4.8 m. The Secchi depth in Thompson Lake was greatest on July 7 at 4.4 m. Secchi depths at Black Lake indicated two clear periods during the growing season, the first on May 16 at 4.1 m and a second on September 5 at 3.9 m. Between these clearer water periods there was a substantial cyanobacterial bloom at Black Lake that resulted in a harmful algal bloom health advisory being issued on June 28 (PHD et al., 2017). The cyanobacterial bloom was predominantly comprised of *Dolichospermum* sp. (PHD et al, 2017). Changes in water clarity at Black Lake, due to the cyanobacterial bloom, significantly contrasted with Thompson Lake as indicated by pairwise comparisons of LSM by site (Table 3.6).

Macrophyte Biomass

Initial increases in macrophyte biomass in Black and Thompson lakes occurred between June 1 and June 13 (Figure 3.4). The initial increase in biomass at Chatcolet Lake was between June 14 and June 28. Biomass at Black Lake peaked earliest on June 27 at 94 g/m^2 ± 110 (mean ± standard deviation) and was dominated by *Potamogeton richardsonii*. Total peak biomass at Black Lake was 7× and 6× lower than total biomass at Chatcolet and Thompson lakes, respectively. Total biomass at Black Lake declined after June 27 to 8 g/m^2 ± 25 by August 8. This senescing period at Black Lake spanned 1.4 months. However, after this senescing period, total biomass at Black Lake increased slightly to 18 g/m^2 ± 32 between September and October.

Peak total biomass in Chatcolet Lake occurred on July 27 at 1871 g/m^2 ± 2039 and was dominated by *E. canadensis*. Chatcolet Lake had the highest peak biomass of all sites being 65× and 3× higher than total biomass at Black and Thompson lakes, respectively. Total biomass declined to 51 g/m^2 ± 117 by September 6. This senescing period at Chatcolet Lake spanned 1.4 months. Thompson Lake had no distinct peak in biomass which generally increased over the course of the growing season. Total biomass reached 888 g/m^2 ± 1227on October 3 and was dominated by *M. spicatum*. This contrasted sharply with the total biomass in Black Lake (18 g/m^2 ± 32) and Chatcolet Lake (2 g/m^2 ± 4) at the same time. After October 20, total biomass declined at Thompson Lake which coincided with qualitative field observations of senescence in *M. spicatum* (auto-fragmentation) and *Brasenia schreberi* (development of winter buds).

Species Composition and Richness

The species composition of macrophytes varied by site (Figure 3.5 A) and was most distinct between Black and Thompson lakes. Species distinguishing Black Lake from Thompson Lake included *P. richardsonii* (64%), *Nitella* spp. (0.1%), and *P. zosteriformis* (1.6%) (Table 3.7), while distinct species at Thompson Lake included *B. schreberi* (12%), *Utricularia vulgaris* (0.1%), and *P.*

robbinsii (2.6%). The macrophyte community at Chatcolet Lake was mainly composed of *E. canadensis* (96%) followed by *M. spicatum* and *Ceratophyllum demersum* with a relative total dry mass of 2.0% for both species.

Thompson and Black lakes had higher species richness than Chatcolet Lake. Species richness derived from species accumulation curves (SAC) was similar between Thompson and Black lakes, with respective values of 15 and 14.6 at 84 sites sampled (Figure 3.5 B). Chatcolet Lake had the lowest species richness value of 9.8 at 84 sites sampled.

Sonar Biovolume

Biovolume per lake (Figure 3.6) showed complexity in spatial structure of aquatic macrophyte beds but reflected similar patterns in plant phenology as described by dry mass (Figure 3.4). A peak in biovolume of 29% ± 24 (mean ± standard deviation) at Black Lake occurred on June 23 after which it declined until August 8 reaching a mean of 2% ± 6.

Mean biovolume at Chatcolet peaked on August 9 (70% ± 21) and declined to under 11% ± 16 by October 4. Growth and senescence across the macrophyte bed at Chatcolet Lake was not temporally or spatially uniform (Figure 3.6). Distinct growth and senescence patterns occurred along particular depth contours at Chatcolet Lake. On June 28, biovolume was greatest between depths of 1.5 m and 1.8 m. Along the same depth contour, biovolume dropped noticeably by August 23 and senescence seemed to radiate towards deeper and shallower water.

Similar to the total dry mass (Figure 3.4), mean biovolume at Thompson Lake was consistent through the growing season with less distinct peak and senescence compared to the other lakes. Nearly half of the sonar site at Thompson Lake straddled the max depth of plant colonization which was estimated to be ~3.5 m. Max depth of colonization was not as well defined at Black and Chatcolet lakes because most of the sonar survey areas at those sites reflected a greater uniformity in depth and shallower than the max depth of macrophyte colonization. Max depth of colonization at Black and Chatcolet lakes was estimated to be 3.1 m and > 4.2 m, respectively.

Macrophyte Biomass vs. Sonar Biovolume

The percentages of pairwise matchups that had no measurable biomass, but biovolume estimates > 0% varied between sites. (Figure 3.7). This percentage was greatest at Black Lake followed by Chatcolet and Thompson lakes with respective values of 32%, 12%, and 12%. The ratio between biomass and biovolume significantly differed by site (RMANOVA between subjects p = 0.001) and by sampling event (RMANOVA within subjects p = 0.006). The ratio between pairwise biomass and biovolume matchups at Black Lake was significantly lower than the ratios at Chatcolet and Thompson lakes (Table 3.8). Biomass to biovolume ratio medians at Black, Chatcolet, and Thompson lakes were 0.024:1, 4.0:1, and 3.6:1, respectively.

All regression models between biovolume and biomass were positive and significant. Black Lake had the weakest model fit ($F_{1,134}$= 64.5, $p < 0.001$, $R^2 = 0.33$). The fit at Thompson Lake was marginally better ($F_{1,75} = 66.8$, $p < 0.001$, $R^2 = 0.47$) and Chatcolet Lake had the best fit ($F_{1,147} = 174$, $p < 0.001$, $R^2 = 0.54$). Spearman's rank correlations (ρ) showed similar associations between biovolume and biomass relative to regression and ANOVA results. All correlations were significant and positive between biovolume and biomass (Figure 3.8). As indicated by the loess smoothed lines, the relationship between biovolume and biomass was nonlinear and varied between sites (Figure 3.8).

Discussion

Influence of Ecological Factors on Species Composition and Richness

Differences in light availability and temperature likely contributed to the observed contrasts in species composition among the lakes. The growing season at Chatcolet Lake was approximately three weeks behind the other sites. In addition to a shorter and later growing season, Chatcolet Lake generally had higher water clarity as indicated by mean K_d, Secchi depths, and maximum depth of macrophyte colonization. Contrasts in physical and chemical conditions at Thompson and Black lakes relative to Chatcolet Lake were also due to differences in connectivity to adjacent rivers. Thompson and Black lakes are located in the floodplain of the Coeur d'Alene River and are relatively isolated due to artificial levees that confine the lower river corridor. Floodplain lakes with less hydrologic connectivity can warm faster than lakes with greater connectivity because in-flowing river waters tend to be cooler than lake surface waters during spring snowmelt runoff (Knowlton & Jones, 2003). Reduced hydrologic connectivity likely increases the rate of warming in both Black and Thompson lakes relative to Chatcolet Lake. Chatcolet Lake is more interconnected to the seasonally cooler, lower St. Joe River due to fewer artificial levees. Cold water from the St. Joe River during spring runoff likely created the early season lag in warming at Chatcolet Lake.

Variability in annual water year characteristics likely produces growing seasons of differing lengths from year to year. Inter-annual variability in runoff conditions is likely an important factor in determining phenological milestones for macrophyte development especially in highly connected systems. Predicting macrophyte senescence would benefit from observation of multiple growing seasons (Hampton et al., 2019) given the annual variability in runoff conditions from the Coeur d'Alene and St. Joe rivers (CDA Tribe & Avista Corporation, 2017). For example, the 2015 water year reflected a severe drought causing the Coeur d'Alene River annual mean flow rate (60 m^3s^{-1}) to fall below the annual mean average of 78 m^3s^{-1}(USGS, 2019). In contrast, the annual mean flow rate in the 2017 water year (104 $m^3s\text{-}^1$) was above average (USGS, 2019).

Macrophyte Phenology

Macrophyte phenological cycles are dependent on the duration of the growing season (Grace & Wetzel, 1978; Nichols & Shaw, 1986; Smith & Barko, 1990; Spencer & Ksander, 2001). Phenology of the macrophyte communities was also likely driven by the characteristics of the dominant species because most biomass was attributable to a single species at all sites. The relatively stable biomass observed at Thompson Lake was likely due to the dominance of *M. spicatum*, which can form dense canopies and have high levels of overwintering biomass (Grace & Wetzel, 1978).

In contrast to Thompson Lake, Black and Chatcolet lakes had shorter and more distinct periods of plant senescence. The dominant species at Black Lake was *P. richardsonii* and in some lakes, the presence of *P. richardsonii* has been associated with increased nutrients, turbidity, and disturbance (Kissoon et al., 2013; Radomski & Perleberg, 2012). The dominance of *P. richardsonii* likely reflects the eutrophic nature of Black Lake because of nutrient overloading to the lake (Kann & Falter, 1987).

Elodea canadensis was the dominant species at Chatcolet Lake most likely because of its resilience to lake level fluctuations (Zehnsdorf et al., 2015) and moderate levels of eutrophication (Nichols & Shaw, 1986). This species typically generates one peak in biomass caused by increased temperature and light availability (Engel, 1988). In addition to light and temperature-triggered senescence, we suspect that invertebrate herbivory may have contributed to the complex spatial changes observed in biovolume at Chatcolet (Estell, 2019). Macrophyte senescence can be hastened by herbivory especially in lakes with increasing algal turbidity (Hidding et al., 2016).

Sonar biovolume measurements provide a convenient and nondestructive method to monitor (Wood et al., 2012) these heterogeneous changes in the fine scale spatial distribution of macrophytes. Understanding macrophyte senescence patterns in the Coeur d'Alene Basin is important because it has important implications for the redistribution of the widespread metals contamination of sediments including Pb, As, Cd, and Zn (Bookstrom et al., 2013; National Research Council, 2005). Macrophytes have the capacity to incorporate sediment-associated metals into their tissue and then release them back to the environment during senescence (Jackson, 1998; Weis & Weis, 2004). Knowing when macrophyte senescence happens at contaminated sites with large vegetated areas will allow others to look for subsequent increases in water column metal concentrations that may affect the exposure of organisms to metals at these sites.

Macrophyte Sampling Methods: Biomass vs. Biovolume

Reasonable estimates of macrophyte biomass have been derived from sonar-based measurements such as plant height and biovolume (Duarte, 1987; Sabol et al., 2009). In the current study, the relationship between biovolume and biomass varied per site and the variation was likely due to differences in species composition and the vertical structure of the studied macrophyte patches. Structural characteristics particular to the dominant species of each site coupled with growth differences likely contributed to the observed variation. The loess lines (Figure 3.8) indicate there is a non-linear relationship between biovolume and biomass that varied across study sites. Similarly, Howell and Richardson (2019) used generalized additive models (GAM) to display non-linear relationships between *Hydrilla* biomass and sonar biovolume. They also noted that when biovolume reached 100%, predictions in biomass became much more variable (Howell & Richardson, 2019). Our results are consistent with this, showing an asymptote in the loess line between biovolume and biomass when biovolume values were > 60%.

We speculate that the relationship between biovolume and biomass may improve as macrophytes elongate early in the growing season, but once macrophytes reach the water surface they may grow outward depending on species characteristics, which may increase the biomass to biovolume ratio. However, we are unable to detect this because biomass is located in the noise exclusion zone of the sonar and would result in a false detection (Valley et al., 2015). The higher biomass to biovolume ratio observed at Thompson and Chatcolet lakes seem to confirm this. *Myriophyllum spicatum* in particular, which dominated the macrophyte community at Thompson Lake, was observed at the water surface with a dense canopy later in the growing season. As is widely known, this characteristic in *M. spicatum* contributes to its nuisance status throughout its introduced range (Nichols & Shaw, 1986). As has been described by others, these site-specific differences should be considered if employing sonar biovolume measurements as a surrogate for empirical measures of biomass (Duarte, 1987; Wood et al., 2012; Howell & Richardson, 2019).

Sampling error that comes with matching up discrete biomass samples with biovolume estimates undoubtedly contributed to the observed variation in the current study. Navigation via GPS led to positional accuracy of approximately 5 m in the current study. Incidentally, this distance is the approximate length of the sampling vessel and given the patchiness inherent in macrophyte communities, this could have led to substantial mismatches between biomass and biovolume estimates. These mismatches were apparent in the current study when there was measurable biomass recorded at a point but no biovolume estimate or vice versa. While these findings do not discredit the use of sonar systems, researchers should be aware of their limitations (Radomski & Holbrook, 2015) and consider site-specific conditions such as community composition that can lead to differences in biovolume versus biomass relationships when designing and interpreting survey results (Wood et al., 2012; Howell & Richardson, 2019).

Conclusion

Differences in light availability, water temperature, and hydrologic connectivity likely contributed to contrasts in macrophyte biomass, biovolume, and species composition across sites. Timing of maximum biomass and senescence differed substantially between sites and was likely driven by the characteristics of the dominant species as well as site-specific ecological factors. Biovolume time series indicated unique fine scale spatial differences in senescence that would be difficult to observe with traditional macrophyte sampling techniques. Macrophyte biovolume had a significant positive correlation with macrophyte biomass across all sites. Variation in the strengths of relationship between biovolume and biomass was attributed to site-specific differences in species composition as well as sampling error associated with matching up discrete biomass samples with biovolume estimates. Despite these limitations, sonar biovolume measurements provided a convenient way to measure seasonal changes in macrophytes.

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Literature Cited

APHA, AWWA, & WEF. (2012). *Standard methods for the examination of water and wastewater*. Washington, DC, USA: American Public Health Association (APHA).

Bivand, R., Keitt, T., & Rowlingson, B. (2019). rgdal: Bindings for the 'geospatial' data abstraction library. R package version 1.3-9. Retrieved from https://CRAN.R-project.org/package=rgdal

Bookstrom, A. A., Box, S. E., Fouseck, R. S., Wallis, J. C., Kayser, H. Z., & Jackson, B. L. (2013). *Baseline, historic and background rates of deposition of lead-rich sediments on the floodplain of the Coeur D'Alene River, Idaho*. Spokane, WA: US Geological Service.

Carlson, R.E. (1977). A trophic state index for lakes. *Limnol Oceanogr, 22*:361-369.

Coeur d'Alene Tribe (CDA) Tribe, Avista Corporation. (2017). Coeur d'Alene Reservation five-year synthesis, 2011 – 2015 Monitoring Data. 4(e) Condition No. 5. Spokane River Hydroelectric Project. FERC Project No. 2545. Plummer, Idaho.

Crow, G. E., & Hellquist, C. B. (2005a). *Aquatic and wetland plants of Northeastern North America, volume I: A revised and enlarged edition of Norman C. Fassett's A manual of aquatic plants, volume I: Pteridophytes, Gymnosperms, and Angeiosperms: Dicotyledons* (Vol. 1). Univ of Wisconsin Press.

Crow, G. E., & Hellquist, C. B. (2005b). *Aquatic and wetland plants of Northeastern North America, volume II: A revised and enlarged edition of Norman C. Fassett's A manual of aquatic plants*, volume II: *Angiosperms: Monocotyledons* (Vol. 2). Univ of Wisconsin Press.

Duarte, C. M. (1987). Use of echosounder tracings to estimate the aboveground biomass of submerged plants in lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *44*(4), 732–735.

Engel, S. (1988). The role and interactions of submersed macrophytes in a shallow Wisconsin lake. *Journal of Freshwater Ecology*, *4*(3), 329–341.

Estell, S. (2019). *The growth, diet, and consumption of a lentic caddisfly, Nectopsyche albida, in Coeur d'Alene Lake, Idaho* [master's thesis]. [Moscow (ID)]: University of Idaho.

Fox, J., & Weisberg, S. (2011). *An {R} companion to applied regression, second edition.* Thousand Oaks, CA: Sage.

Gotelli, N. J., & Ellison, A. M. (2018). *Primer of ecological statistics*. Sinauer Associates Publishers.

Grace, J. B., & Wetzel, R. G. (1978). The production biology of Eurasian watermilfoil (*Myriophyllum spicatum L.*): A review. *J. Aquat. Plant Manage*, *16*, 1–11.

Hamel, K., Parsons, J., Boule, M., Feldman, S., Wertz, I., & Zempke, L. (2001, June). *An aquatic plant identification manual for Washington's freshwater plants. Publication 01-10-032.* Retrieved from https://fortress.wa.gov/ecy/publications/SummaryPages/0110032.html

Hampton, S. E., Scheuerell, M. D., Church, M. J., & Melack, J. M. (2019). Long-term perspectives in aquatic research. *Limnology and Oceanography*, *64*(S1), S2–S10.

Hidding, B., Bakker, E. S., Hootsmans, M. J., & Hilt, S. (2016). Synergy between shading and herbivory triggers macrophyte loss and regime shifts in aquatic systems. *Oikos*, *125*(10), 1489–1495.

Howell, A. W., & Richardson, R. J. (2019). Correlation of consumer grade hydroacoustic signature to submersed plant biomass. *Aquatic Botany*, *155*, 45–51.

Jackson, L. J. (1998). Paradigms of metal accumulation in rooted aquatic vascular plants. *Science of the Total Environment*, *219*(2–3), 223–231.

Jeppesen, E., Sondergaard. M., Sondergaard. M., Christofferson. K. (1998). *The structuring role of submerged macrophytes in lakes*. Vol. 131. Springer Science & Business Media.

Johnson, J. A., & Newman, R. (2011). A comparison of two methods for sampling biomass of aquatic plants. *Journal of Aquatic Plant Management*, *49*(1), 1–8.

Kann, J., & Falter, C. M. (1987). Development of toxic blue-green algal blooms in Black Lake, Kootenai County, Idaho. *Lake and Reservoir Management*, *3*(1), 99–108.

Kissoon, L. T. T., Jacob, D. L., Hanson, M. A., Herwig, B. R., Bowe, S. E., & Otte, M. L. (2013). Macrophytes in shallow lakes: Relationships with water, sediment and watershed characteristics. *Aquatic Botany*, *109*, 39–48.

Knowlton, M. F., & Jones, J. R. (2003). Connectivity influences temporal variation of limnological conditions in Missouri River scour lakes. *Lake and Reservoir Management*, *19*(2), 160–170.

Lamb, D. S. (2006). *Project completion report: Baseline Coeur d'Alene Lake aquatic vegetation survey*. Prepared for Avista Utilities by the Coeur d'Alene Tribe Lake Management Department. Plummer, ID.

Lenth, R. (2020). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.4.4. Retrieved from https://CRAN.R-project.org/package=emmeans

Madsen, J. D., & Wersal, R. M. (2017). A review of aquatic plant monitoring and assessment methods. *J. Aquat. Plant Manage.*, 13.

McCune, B., Grace, J., & Urban, D. (2002). *Analysis of ecological communities.* MjM Software Design.

National Research Council. (2005). *Superfund and mining megasites: Lessons from the Coeur d'Alene River Basin*. National Academies Press.

Navico. (2014, December). *Biobase user reference guide*. Retrieved from https://www.cibiobase.com/

Nichols, S. A., & Shaw, B. H. (1986). Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum*, *Potamogeton crispus* and *Elodea canadensis*. *Hydrobiologia*, *131*(1), 3–21.

Nowosad, J. (2018). pollen: Analysis of aerobiological data. R package version 0.71.0. Retrieved from https://cran.r-project.org/web/packages/pollen/pollen.pdf

Oksanen, J. (2019). Vegan: ecological diversity, 12. Retrieved from https://cran.r-project.org/web/packages/vegan/vignettes/diversity-vegan.pdf

Panhandle Health District (PHD), Coeur d'Alene Tribe (CdAT), and Idaho Department of Environmental Quality (IDEQ). (2017). Health advisory issued for Black Lake. Retrieved from http://www.deq.idaho.gov/media/60180258/black-lake-hab-advisory-0617.pdf

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., & R Core Team. (2019). _nlme: Linear and nonlinear mixed effects models_. R package version 3.1-140, <URL: https://CRAN.R-project.org/package=nlme>.

R Core Team. (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org/

Radomski, P., & Holbrook, B.V. (2015). A comparison of two hydroacoustic methods for estimating submerged macrophyte distribution and abundance: A cautionary note. *Journal of Aquatic Plant Management, 53*:151–159.

Radomski, P., & Perleberg, D. (2012). Application of a versatile aquatic macrophyte integrity index for Minnesota lakes. *Ecological Indicators*, *20*, 252–268.

Sabol, B. M., Kannenberg, J., Skogerboe, J., & others. (2009). Integrating acoustic mapping into operational aquatic plant management: A case study in Wisconsin. *J. Aquat. Plant Manage*, *47*, 44–52.

Smith, C. S., & Barko, J. W. (1990). Ecology of Eurasian watermilfoil. *Journal of Aquatic Plant Management*, *28*(2), 55–64.

Spencer, D. F., & Ksander, G. G. (2001). Field evaluation of degree-day based equations for predicting sprouting of hydrilla (Hydrilla verticillata) turions and tubers. *Journal of Freshwater Ecology*, *16*(3), 479–486.

Thum, R. A. (2016). Genetic analysis of invasive Eurasian Watermilfoil in Idaho Waters. Retrieved from Montana State University website: https://static1.squarespace.com/static/564b8c9ae4b0459b2b8187a3/t/58878905bf629adf62568c40/1485277445888/Thum+2016+Genetic+analysis+of+invasive+EWM+in+Idaho+waters_FINAL_12172016.pdf

United States Geological Survey (USGS). (2013). Watershed boundary dataset. Retrieved from https://www.usgs.gov/core-science-systems/ngp/national-hydrography/watershed-boundary-dataset?qt-science_support_page_related_con=4#qt-science_support_page_related_con

United States Geological Survey (USGS). (2019). National Water Information System data available on the World Wide Web. Station 12413860 Water Years 2005-2018. Retrieved from https://waterdata.usgs.gov/usa/nwis/uv?site_no=12413860

Valley, R.D., & Drake, M.T. (2005). Accuracy and precision of hydroacoustic estimates of aquatic vegetation and the repeatability of whole-lake surveys: Field tests with a commercial echosounder. Minnesota Department of Natural Resources Investig. Rep. 527, St. Paul, MN.

Valley, R. D., Johnson, M. B., Dustin, D. L., Jones, K. D., Lauenstein, M. R., & Nawrocki, J. (2015). Combining hydroacoustic and point-intercept survey methods to assess aquatic plant species abundance patterns and community dominance. *Journal of Aquatic Plant Management*, *53*, 121–129.

Weis, J. S., & Weis, P. (2004). Metal uptake, transport and release by wetland plants: Implications for phytoremediation and restoration. *Environment International*.

Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems*. San Francisco, CA: Gulf Professional Publishing.

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. New York: Springer-Verlag.

Wickham, H. (2017). tidyverse: Easily install and load the 'Tidyverse'. R package version 1.2.1. Retrieved from https://CRAN.R-project.org/package=tidyverse

Wilke, C.O. (2019). cowplot: Streamlined plot theme and plot annotations for 'ggplot2'. R package version 0.9.4. Retrieved from https://CRAN.R-project.org/package=cowplot

Wood, K. A., Stillman, R. A., Clarke, R. T., Daunt, F., & O’Hare, M. T. (2012). Measuring submerged macrophyte standing crop in shallow rivers: A test of methodology. *Aquatic Botany*, *102*, 28–33.

Woods, P. F., & Beckwith, M. A. (1997). *Nutrient and trace-element enrichment of Coeur d’Alene Lake, Idaho* (Vol. 2485). US Government Printing Office.

Zalom, F. G., Goodell, P. B., 1983. *Degree days: The calculation and use of heat units in pest management*. University of California, Division of Agriculture and Natural Resources, Davis, CA.

Zehnsdorf, A., Hussner, A., Eismann, F., Rönicke, H., & Melzer, A. (2015). Management options of invasive Elodea nuttallii and Elodea canadensis. *Limnologica-Ecology and Management of Inland Waters*, *51*, 110–117.

Tables

Table 3.1 Trophic status classification for Black, Thompson, and Chatcolet lakes determined by the trophic state index (TSI) (Carlson, 1977), associated parameters (Secchi depth, total phosphorus, and chlorophyll *a*) and lake attributes (i.e., water color, productivity). Parameters and attributes were gathered from previous studies (see reference column) at each lake.

Site	TSI	Secchi Depth (m)*	Total Phosphorus (µg/L)	Chlorophyll a (µg/L)	Attributes	Trophic classification	Reference
Black Lake	50-70	2.3*	38	11.8	Brown, gray water color; highly productive	Eutrophic	(Kann & Falter 1987)
Thompson Lake	50-70	3.0*	25	7.5	Brown, green water color; highly productive	Eutrophic	(Torso K, University of Idaho, June 2018, unpublished Data)
Chatcolet Lake	40-50	2.9*	20	5	Green, brown water color; moderately productive	Mesotrophic	(CDA Tribe and Avista Corporation 2017)

*Average Secchi depth collected by Torso et al., 2017. These values are affiliated with Figure 3.3B.

Table 3.2 Black Lake water quality data sampled at 1 m in depth between May and October 2017.

Sampling Event (Month, Day)	Temperature (C)	pH	Specific Conductance (µS/cm)	Photosynthetic Active Radiation ($\mu mol/s/m^2$)	Dissolved Oxygen (mg/L)
May 1	11.0	7.7	74	102	9.6
May 16	14.0	7.9	73	347	9.7
June 1	21.4	7.5	78	226	9.2
June 13	19.2	8.7	66	229	11.1
June 27	22.8	9.0	70	1230	11.3
July 12	24.7	9.5	93	144	0.0
July 27	24.5	8.4	89	160	8.0
Aug 8	24.5	7.9	80	218	7.8
Aug 22	21.6	7.6	79	1124	8.1
Sept 5	20.5	7.7	81	293	7.9
Sept 26	15.4	7.3	84	910	8.0
Oct 3	14.3	7.1	85	989	7.4
Oct 20	10.1	7.4	83	99	9.5
Oct 31	8.9	8.1	89	203	10.6

Table 3.3 Chatcolet Lake water quality data sampled at 1 m in depth between May and November 2017.

Sampling Event (Month, Day)	Temperature (C)	pH	Specific Conductance (µS/cm)	Photosynthetic Active Radiation (µmol/s/m²)	Dissolved Oxygen (mg/L)
May 3	7.8	7.5	42	1201	11.4
May 18	8.5	7.5	38	2126	10.4
June 2	13.0	7.5	31	1683	10.4
June 14	13.4	7.8	28	1120	10.5
June 28	19.6	8.0	33	1684	9.7
July 14	24.7	8.9	49	2059	9.8
July 27	24.3	9.1	54	148	9.5
Aug 9	24.4	9.2	49	1018	9.0
Aug 23	21.9	8.7	50	1228	8.6
Sept 6	20.4	7.6	51	653	7.4
Sept 25	14.9	7.4	52	227	8.4
Oct 4	14.0	7.5	52	1084	8.7
Oct 17	10.3	7.3	51	549	10.2
Nov 1	8.3	7.6	56	108	10.2

Table 3.4 Thompson Lake water quality data sampled at 1 m in depth between May and October 2017.

Sampling Event (Month, Day)	Temperature (C)	pH	Specific Conductance (μS/cm)	Photosynthetic Active Radiation (μmol/s/m²)	Dissolved Oxygen (mg/L)
May 1	11.6	7.3	37	142	8.6
May 16	14.6	7.7	39	1622	9.5
June 1	21.6	7.3	40	164	8.3
June 13	18.7	7.5	34	173	9.0
June 27	22.8	7.4	36	186	8.3
July 12	25.3	7.1	50	1340	7.6
July 27	24.5	7.1	55	1193	7.3
Aug 8	24.7	7.0	50	967	6.1
Aug 22	21.6	7.0	51	1121	7.2
Sept 5	20.6	7.0	52	154	7.3
Sept 26	15.9	7.0	51	89	7.0
Oct 3	13.7	6.8	50	632	6.6
Oct 20	9.4	7.0	49	47	8.1
Oct 31	9.0	7.5	54	160	9.0

Table 3.5 Least squares mean (LSM) pairwise comparisons of light extinction (K_d m^{-1}) by site.

	Black Lake	**Chatcolet Lake**	**Thompson Lake**
Black Lake	1	0.0	0.0
Chatcolet Lake	0.004	1	0.0
Thompson Lake	0.795	0.016	1

Table 3.6 Least squares mean (LSM) pairwise comparisons of Secchi depths (m) by site.

	Black Lake	**Chatcolet Lake**	**Thompson Lake**
Black Lake	1	0.0	0.0
Chatcolet Lake	0.004	1	0.0
Thompson Lake	0.795	0.016	1

Table 3.7 Aquatic macrophyte species, NMDS codes, and the relative abundance (%) per lake location captured between May and November 2017. Data displayed in table was generated from the biomass dataset (g/m^2).

Taxa	NMDS Code	Black Lake (%)	Chatcolet Lake (%)	Thompson Lake (%)
Brasenia schreberi	Brasen	< 1	0	12
Ceratophyllum demersum	Cerato	3.5	1.6	4.0
Elatine triandra	Elatin	< 1	0	0
Eleocharis parvula	Eleoch	< 1	< 1	0
Elodea canadensis	Elodea	11	96	< 1
Filamentous algae	Filame	4.4	< 1	< 1
Fontinalis sp.	Fontin	0	< 1	< 1
Myriophyllum spicatum	Myriop	4.9	2	76
Najas sp.	Najass	0	< 1	0
Nitella sp.	Nitell	< 1	0	0
Potamogeton amplifolius	Pampli	0	0	< 1
Potamogeton epihydrus	Pepihy	< 1	0	< 1
Potamogeton pusillus	Ppusil	2.3	< 1	4.1
Potamogeton richardsonii	Pricha	64	< 1	< 1
Potamogeton robbinsii	Probbi	0	0	2.6
Potamogeton zosteriformis	Pzoste	1.6	0	< 1
Ranunculus aquatilis	Ranunc	0	< 1	0
Sagittaria latifolia	Slatif	< 1	0	0
Sagittaria rigida	Srigida	< 1	0	0
Sagittaria spp.	Sagitt	< 1	< 1	< 1
Schoenoplectus tabernaemontani	Schtab	< 1	0	0
Utricularia vulgaris	Utricu	0	0	< 1
Vallisneria americana	Vallis	5.1	0	< 1

Table 3.8 Least squares mean (LSM) pairwise comparisons of biomass vs. biovolume ratios by lake.

	Black Lake	Chatcolet Lake	Thompson Lake
Black Lake	1	0.0	0.0
Chatcolet Lake	0.004	1	0.0
Thompson Lake	0.795	0.016	1

Figures

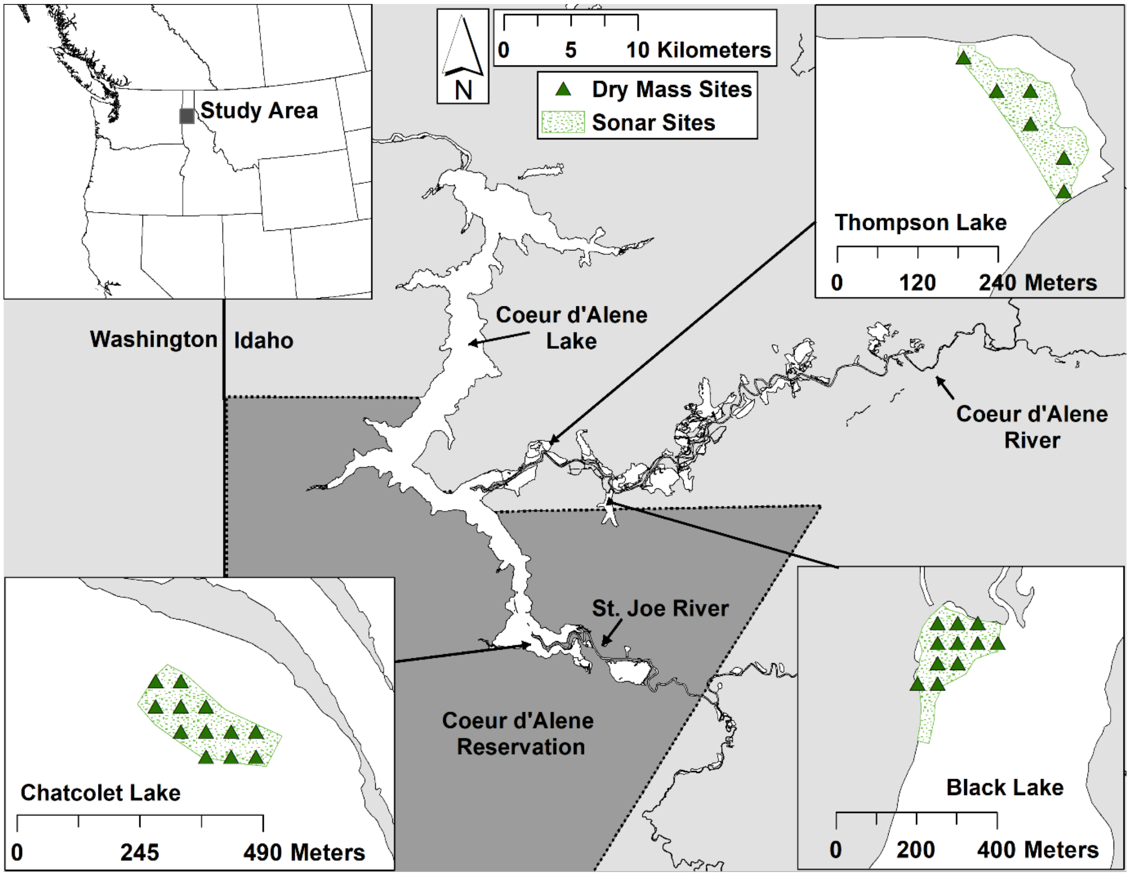


Figure 3.1 Map of Coeur d'Alene Basin, associated waters within the State of Idaho, USA, and the Coeur d'Alene Tribe's Reservation boundary. Map layers were referenced from USGS Watershed Boundary Layer and the Coeur d'Alene Tribe GIS Department. The image was created in ESRI ArcGIS 10.3.

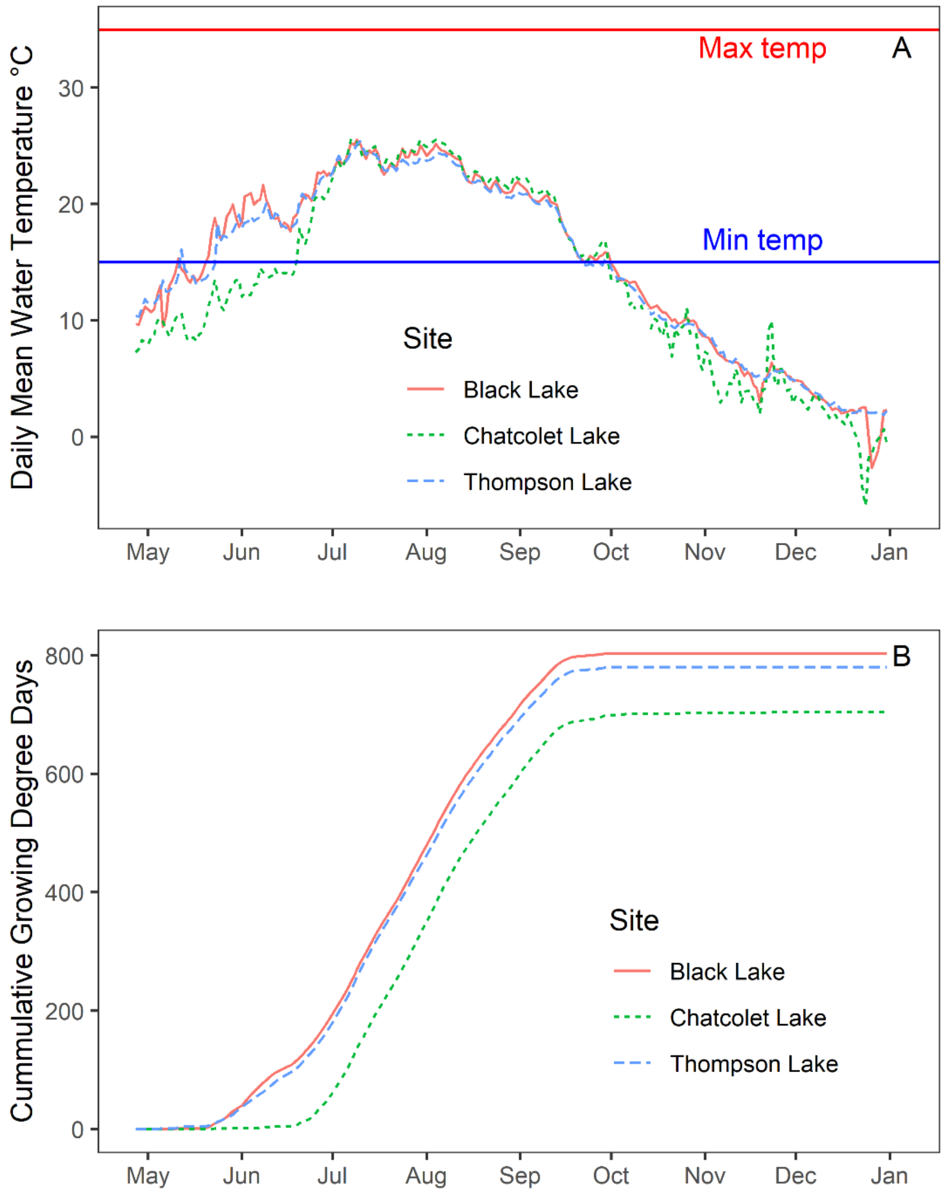


Figure 3.2A-B Daily mean water temperature (°C) (A) and cumulative GDD (B) as a function of time in 2017 at three study lakes in the Coeur d'Alene Lake Basin, Idaho. The horizontal minimum and maximum lines represent water temperatures between which *Myriophyllum spicatum* can actively grow.

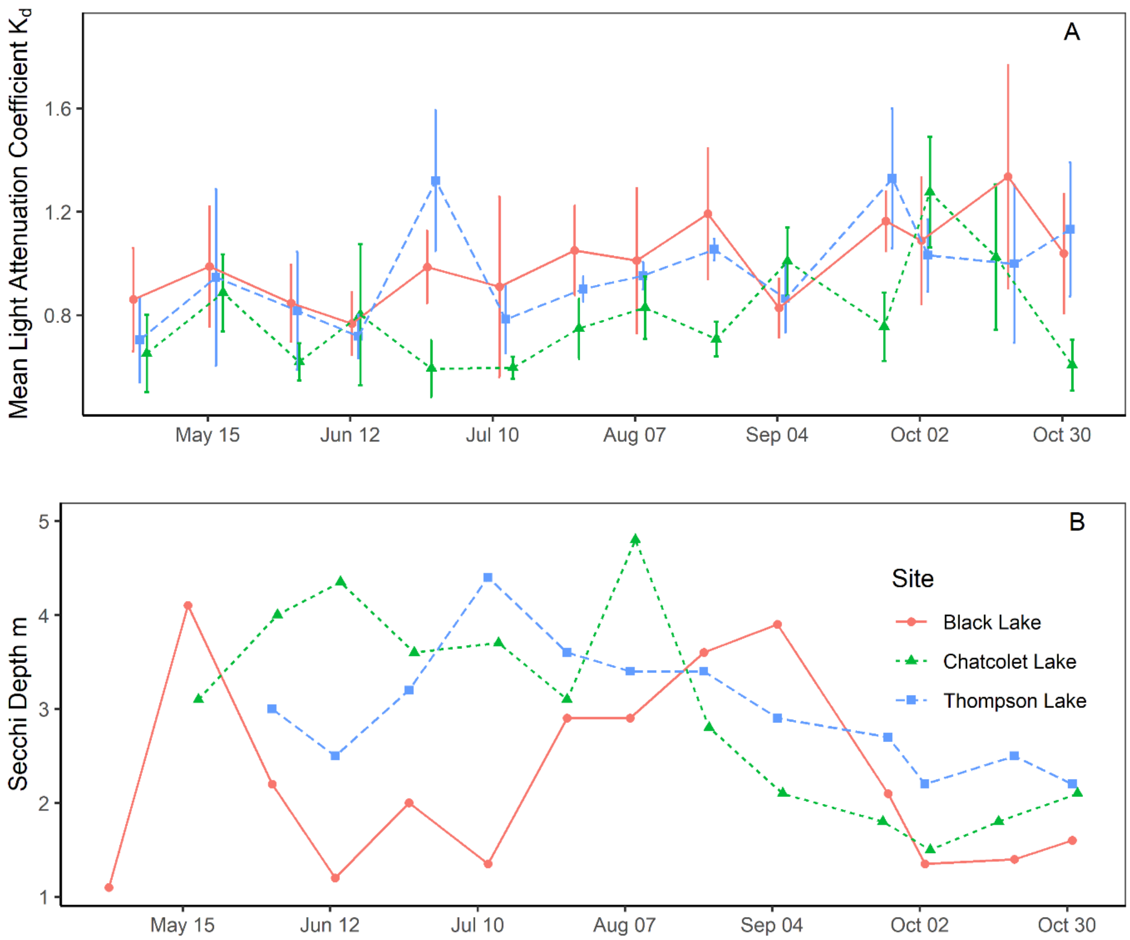


Figure 3.3A-B Relationships of (A) mean light attenuation coefficients (K_d) ±1 standard deviation and (B) secchi depth as a function of time in 2017 at each sampling site in three lakes in the Coeur d'Alene Basin, USA.

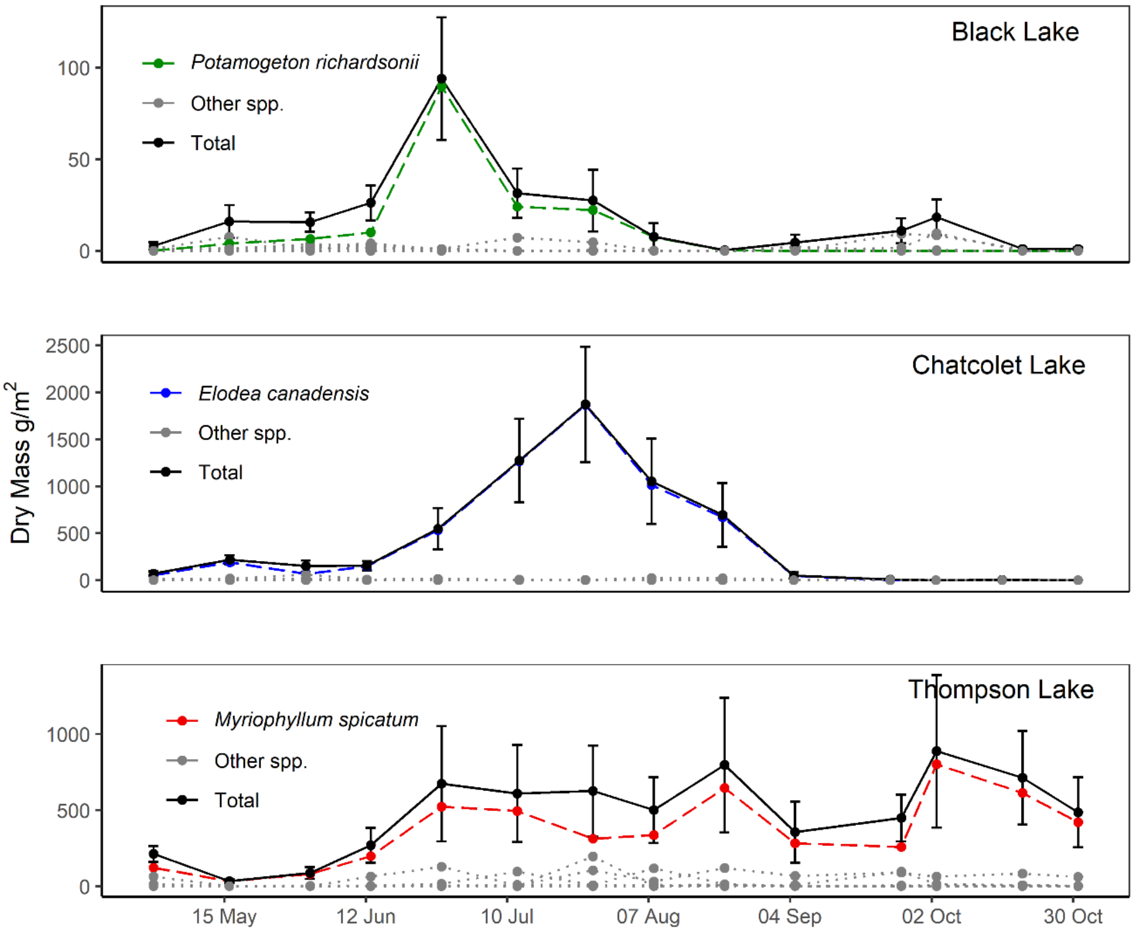


Figure 3.4 Mean biomass for dominant macrophyte species, other present species, and total biomass per lake location calculated from the dry mass dataset (g/m^2) by sampling date. Error bars represent the standard error of mean biomass (g/m^2).

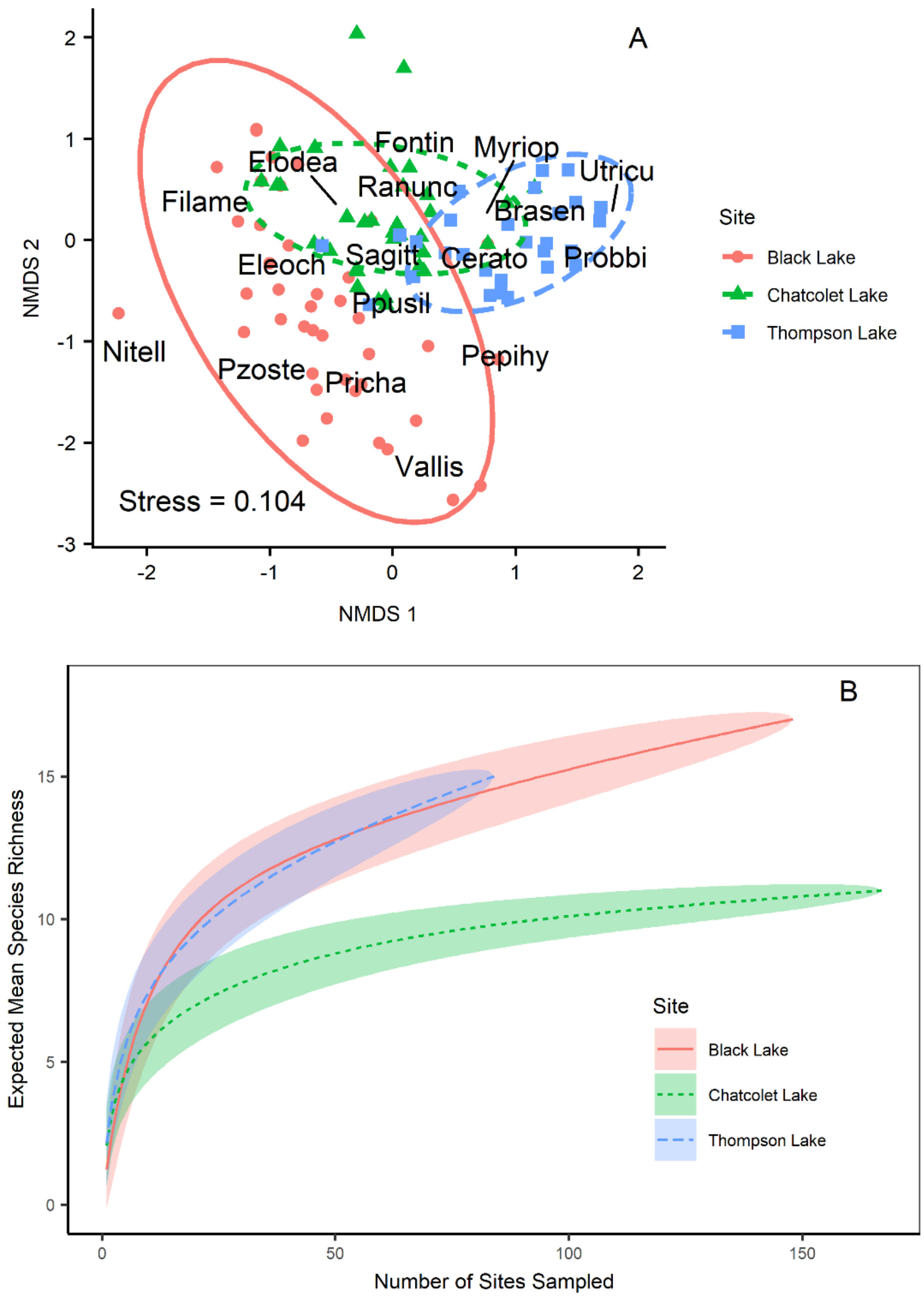
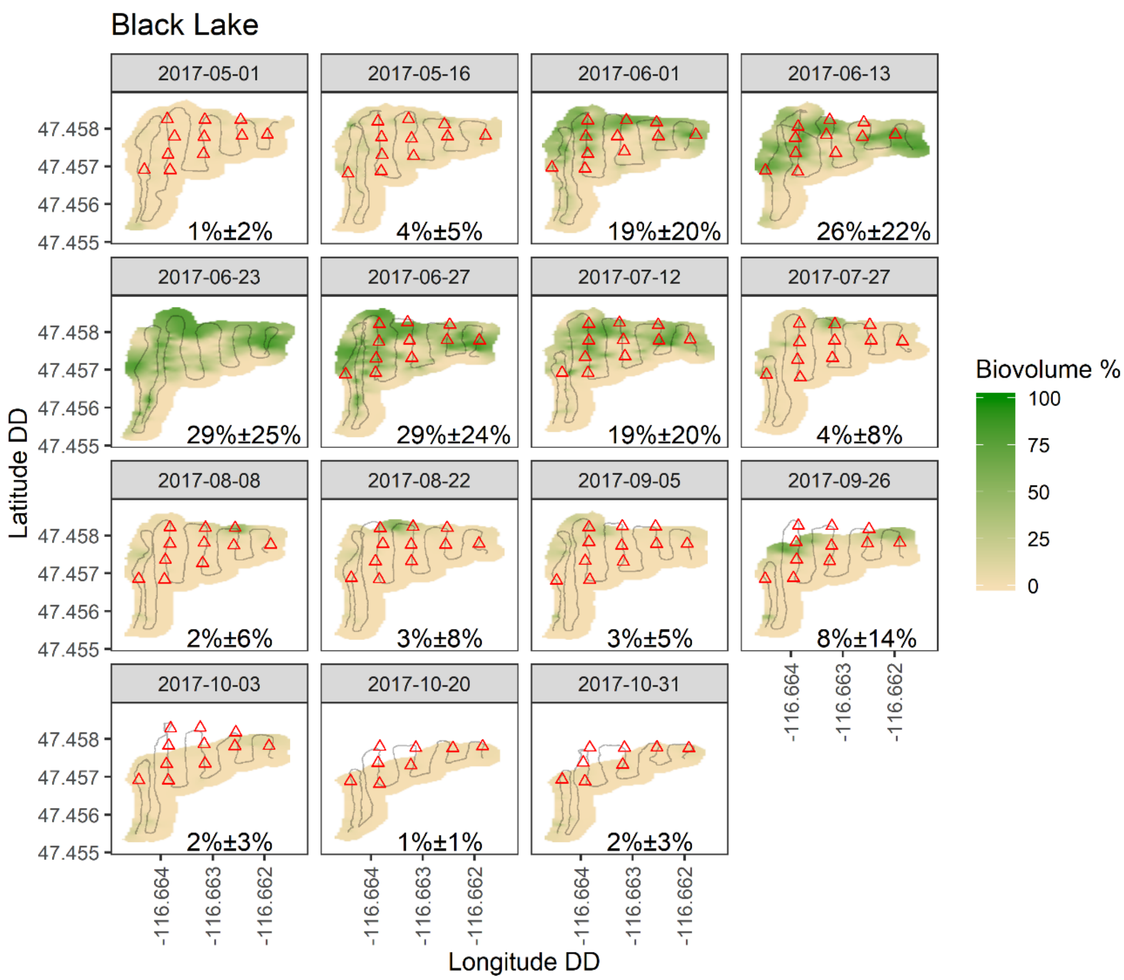
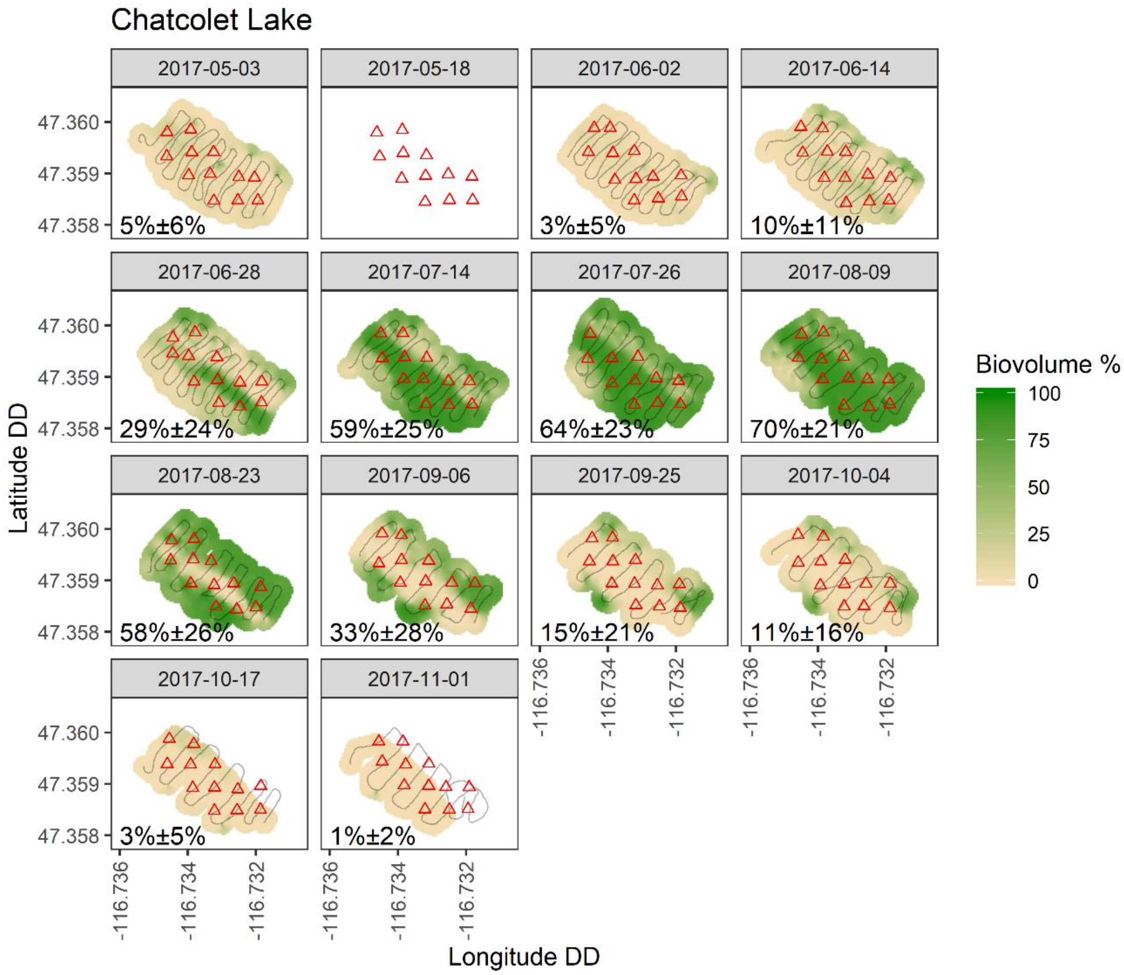


Figure 3.5A-B Non-metric multidimensional scaling (NMDS) ordination (A) displaying differences in species composition per lake location. Species accumulation curve (SAC) (B) of mean species richness per lake location. The shaded confidence interval represents one standard deviation above and below the estimated richness. Both plots were produced from presence/absence data taken from the dry mass dataset.


Black Lake
2017-05-01
2017-05-16
2017-06-01
2017-06-13
1%±2%
4%±5%
19%±20%
26%±22%
2017-06-23
2017-06-27
2017-07-12
2017-07-27
29%±25%
29%±24%
19%±20%
4%±8%
2017-08-08
2017-08-22
2017-09-05
2017-09-26
2%±6%
3%±8%
3%±5%
8%±14%
2017-10-03
2017-10-20
2017-10-31
2%±3%
1%±1%
2%±3%
47.458
47.457
47.456
47.455
Latitude DD
-116.664
-116.663
-116.662
Longitude DD
Biovolume %
100
75
50
25
0


Chatcolet Lake
2017-05-03
2017-05-18
2017-06-02
2017-06-14
5%±6%
3%±5%
10%±11%
2017-06-28
2017-07-14
2017-07-26
2017-08-09
29%±24%
59%±25%
64%±23%
70%±21%
2017-08-23
2017-09-06
2017-09-25
2017-10-04
58%±26%
33%±28%
15%±21%
11%±16%
2017-10-17
2017-11-01
3%±5%
1%±2%
47.360
47.359
47.358
-116.736
-116.734
-116.732
Latitude DD
Longitude DD
Biovolume %
100
75
50
25
0

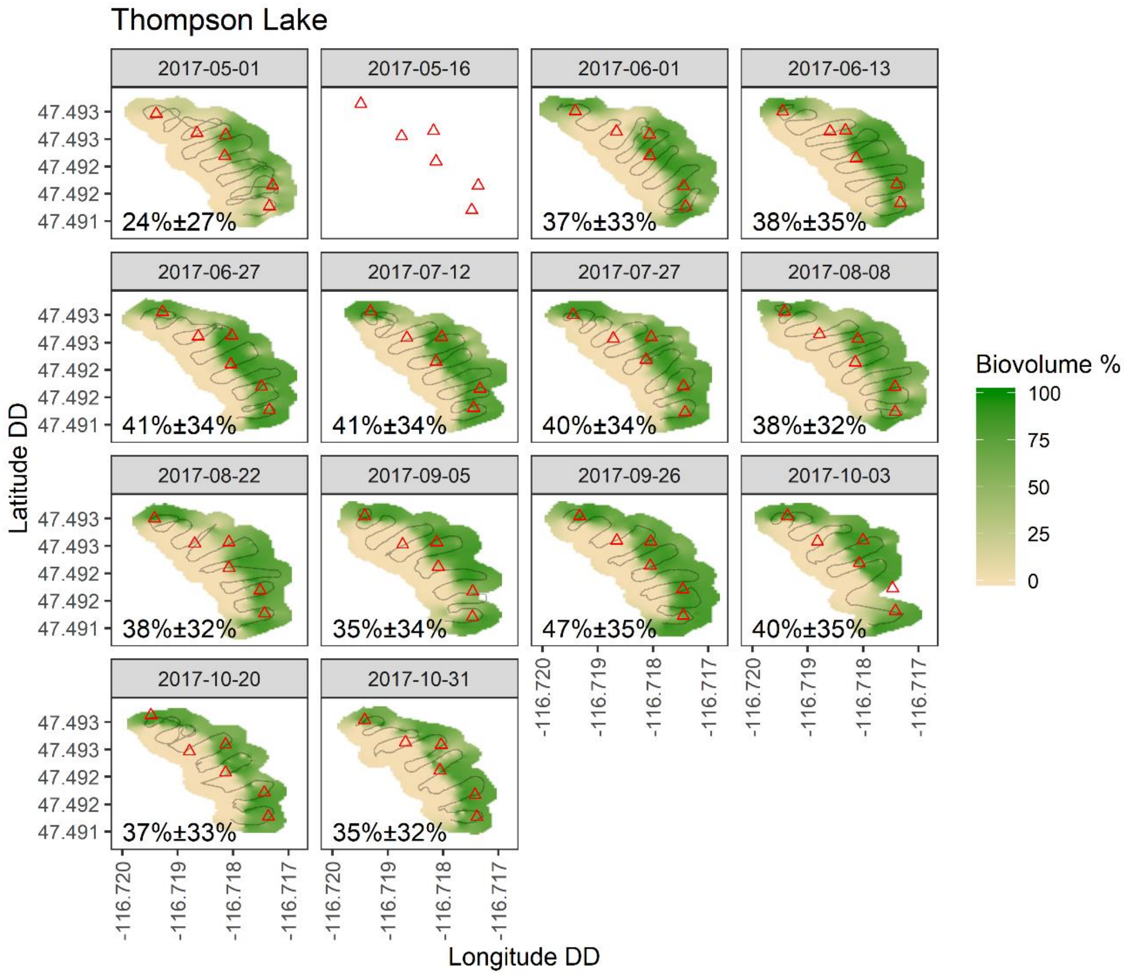


Figure 3.6 Spatial time series of sonar biovolume per sampling event at Black , Chatcolet , and Thompson lakes. Sampling date format represents calendar "Year-Month-Day". Biovolume mean ± standard deviation is shown for each sampling event within the figures. Within each plot, the line represents the sonar and the triangle represents the biomass sample.

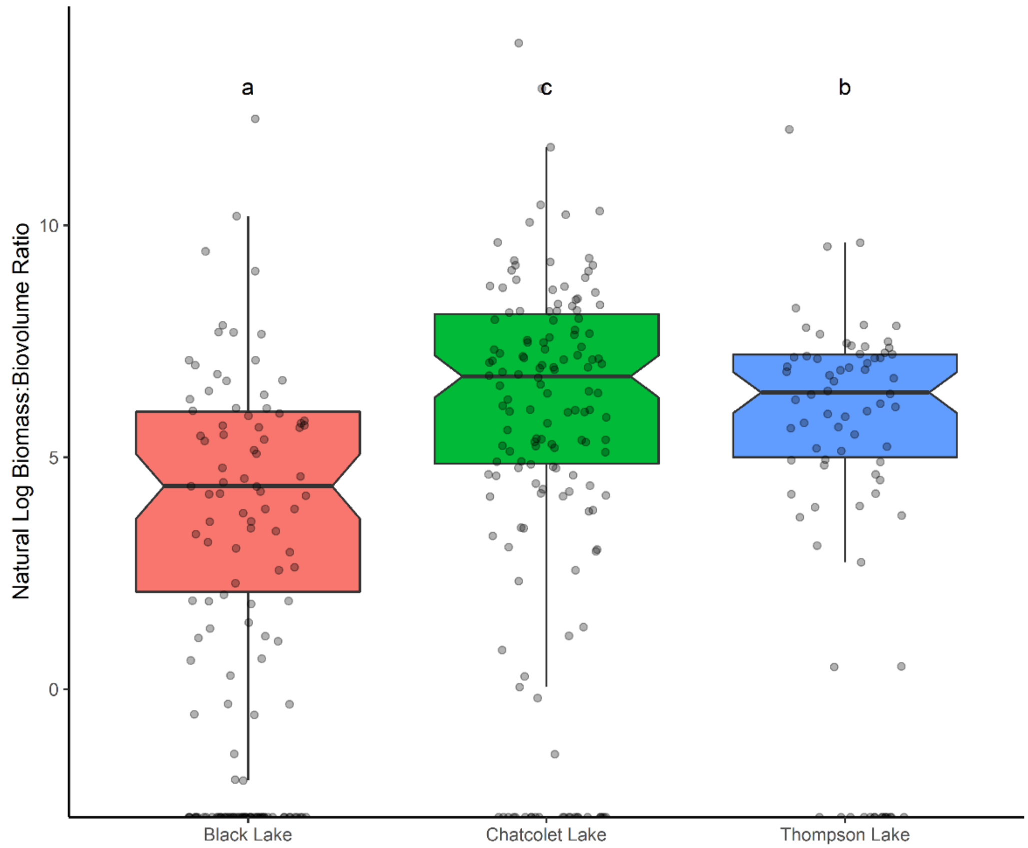


Figure 3.7 The ratio of biomass to biovolume from pairwise matchups by lake. The ratio of biomass to biovolume was transformed with the natural logarithm prior to plotting. The bottom of the box shows the 25th percentile, the top of the box show the 75th percentile, and the bar in between is the median. The whiskers show ± 1.5 × the interquartile range. The “jittered” points show the individual ratios from pairwise matchups. The letters above boxplots indicate significant differences as determined by pairwise comparisons of least squares means by lake ($p < 0.001$).

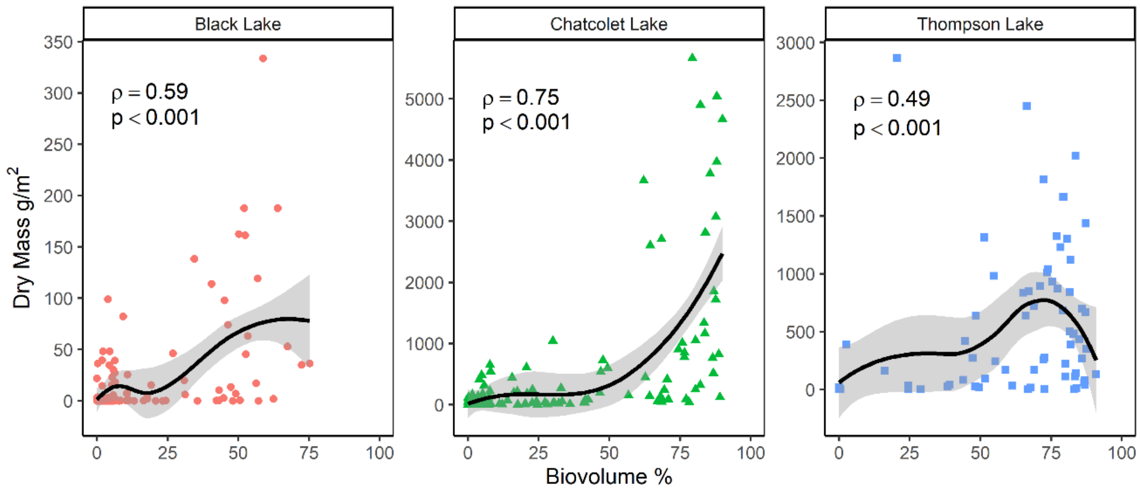


Figure 3.8 Total biomass of macrophytes (dry mass g/m^2) as a function of biovolume (%) by lake. The shaded region around the loess line represents a 95% confidence interval.

Chapter 4: Supporting Native American Community Leadership through Culturally-Relevant STEM Education

Abstract

The Coeur d'Alene Basin, USA is heavily contaminated with toxic metals (i.e., Pb, As) from the mismanagement of historic mining practices. Toxic metal contamination has profoundly impacted the Coeur d'Alene Tribe by disrupting their connection with their homeland and way of life. I employed participatory action research methodologies acknowledging the fundamental characteristics of Indigenous research to cultivate a collaborative research partnership between the Tribe and myself, a University of Idaho graduate student researcher. The community-university partnership informed a science, technology, engineering, and mathematics (STEM) education program in affiliation with an existing summer internship to support the Tribe's efforts to mitigate their contaminated water resources by enhancing youth leadership in STEM. I report on my understanding to enhance Tribal youth interest in STEM through a culturally-relevant STEM program and affiliated internship experience. Findings show the educational activities and practical experience facilitated youth comprehension of STEM content and desire to become a leader in the community and an advocate for their place.

Introduction

The leaching of toxic metals (i.e., Pb, As) from historic mining activities has resulted in environmental and public health disparities worldwide. In the western United States, the majority of abandoned mines and associated contamination are located in close proximity to Native American land (Lewis et al., 2017). Native American communities maintain a unique relationship with the environment that embodies a physical, cultural, economic, and spiritual connection (Berkes, 2012). This complex dependency on the land, in combination with a low socioeconomic status, has caused Native American communities to become vulnerable to environmental hazards (Bergstrand et al., 2015; Lewis et al., 2017). Thus, a greater vulnerability to environmental hazards has challenged the capacity of Native American communities to mitigate these issues as a sovereign nation (Bergstrand et al., 2015; Doyle et al., 2018).

Leaders, among the community membership, in science, technology, engineering, and mathematics (STEM) can greatly enhance a Native American Tribe's capacity to cope with environmental change, independent of the federal government (Aikenhead & Michell, 2011; McCarty & Lee, 2014). Despite this call, Native Americans are falling behind in STEM fields, both academically and professionally (Smith et al., 2014). This underrepresentation is due to a failure to acknowledge Indigenous epistemologies within the Western-dominated science curriculum as taught in K-12 schools (Aikenhead & Michell, 2011; Cajete, 1999; Iseke & Desmoulins, 2015). These and other reasons have led to research in informal and formal STEM educational efforts that integrate Indigenous and Western epistemologies using the local environment (e.g., place) and the community to develop culturally-relevant pedagogies to increase Native American youth interest in STEM (Bang & Medin, 2010; Stevens et al., 2016). Thus, culturally-relevant STEM education represents an effective place-based educational strategy to increase Native American youth engagement in STEM endeavors. In the context of historic mining contamination, these educational approaches enhance the capacity of Native American communities to address persistent environmental issues as sovereign nations (Ward et al., 2008).

Community-based research partnerships between university researchers and Native American communities are a particularly inclusive approach in facilitating culturally-relevant STEM education opportunities (Bang & Medin, 2010; Stevens et al., 2016). Kovach (2010) advocates for the integration of participatory action research (PAR) and Indigenous research methodologies (IRM) to advance the ethical nature of collaborative research partnerships between universities and Indigenous communities. Facilitating community-university partnerships through IRM and PAR invites communities to be collaborators rather than research subjects (Battiste, 2008; Evans et al., 2009; Peltier, 2018). Therefore, IRM facilitated by PAR methodologies are understood to be an ethical and effective form of inquiry among Indigenous scholars (Evans et al., 2009; Hermes, 1998; Hudson & Taylor-Henley, 2001; Kovach, 2010; Peltier, 2018; Smith, 1999). Drawing from methodologies in participatory research, PAR is a collaborative process specifically used to develop opportunities in research, education, and action with community partners and associated agencies (Hall, 1992). IRM enhances the PAR methodology by providing researchers with guidance for building relationships through respect, responsibility, and reciprocity (e.g. four Rs) (Peltier, 2018). By integrating PAR and IRM when partnering with Native American communities grappling with complex environmental issues from an education perspective, researchers: 1) acknowledge the voices and goals of the partnered community and 2) enhance the scientific literacy among the community (Caxaj, 2015).

Reflecting these approaches, a cross-cultural collaboration facilitated by PAR and IRM methodologies began in 2015 between the Coeur d'Alene Tribe and myself, a University of Idaho graduate student researcher to address complex water resource issues related to historical mining activities. This community-university research partnership resulted in the development and implementation of a culturally-relevant STEM education program in affiliation with an existing summer internship experience. The overarching objective of this program and affiliated internship was to support the Tribal community's capacity to mitigate persistent environmental hazards impacting their water resources by increasing community youth leadership in STEM. I explored the impact of this program and internship experience on Tribal youth interest in the STEM fields and associated leadership desires through a qualitative research study guided by a case study research approach.

Community-University Partnership

Study Location

Nested within the Spokane River Watershed, the Coeur d'Alene Basin of northern Idaho, USA is composed of several subwatersheds that drain an area 5,225 km^2 in size (USGS, 2013) (see Figure 4.1). Centrally located in the Basin, the Coeur d'Alene River, St. Joe River, and Lake Coeur d'Alene have been home to the Coeur d'Alene Tribe of Indians since time immemorial (Frey & Stensgar, 2012). Thousands of European settlers migrated to the Basin and drastically altered the landscape through mining extractive industries upon the discovery of precious metals in the mi-nineteenth century (Woodworth-Ney, 2004). Capitalizing on the natural resource rich region, large scale mining operations were established through the Bunker Hill and Sullivan mines in 1885 (Snow, 2017). The spread of toxic metal contamination from the mismanagement of mine waste materials quickly led to environmental and public health decline, leading the US Environmental Protection Agency to declare the Bunker Hill Mining and Metallurgical Complex a Superfund Site in 1983 (Snow, 2017). Clean-up efforts initially began in a 54 km^2 rectangular area, commonly known as "the box," which contains the former Bunker Hill smelter, other mining related infrastructure, and residential land (NRC, 2005). Meanwhile, the Tribe's unique connection to the land heightened their vulnerability to a drastically altered landscape. As such, this transformation greatly diminished the capacity of this Tribal community to cope with these persistent environmental issues as a sovereign nation.

Coeur d'Alene Tribe Hazardous Waste Mitigation Goals

The Tribe has recognized community youth leadership in STEM as an approach to strengthen their ability to mitigate complex water resource issues caused by legacy mining contamination. Over the past 10 years, the Coeur d'Alene Tribe Department of Education has supported several informal culturally-relevant summer programs for K-12 youth. One educational program aimed to enhance the STEM workforce 'pipeline' among Tribal members is the Summer Youth Internship Program. This program employs Tribal youth (ages 14-18) within the Tribe's Natural Resources Department for a 6-week summer internship.

Most recently, the Coeur d'Alene Tribe Lake Management Department has become involved in the Summer Youth Internship Program. However, the depth and breadth of scientific knowledge needed to assist with the fieldwork conducted by this department has conflicted with the lack of content knowledge and ability of interns involved with the program. Thus, the Department of Education and Lake Management Department sought pedagogical methods to translate the complex information to Tribal members employed in the Summer Youth Internship Program.

The need to enhance the capabilities expressed by the Tribe, in combination with my interest in studying culturally-relevant STEM education for Native American youth, initiated the community-university partnership. Collectively, this partnership informed a STEM education program affiliated with the Lake Management Department's involvement in the Summer Youth Internship Program. The STEM education program entailed a place-based watershed science learning opportunity that drew from the Tribal culture and local environment to enhance Tribal youth interns' connection to place and interest in STEM. The impact of this education program and internship experience on advancing Tribal youth leadership in STEM was measured by the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Min*d (CdAT STEP, 2016).

Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind Framework

The *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind*, known as the "Pillars", is a set of core values developed by the Coeur d'Alene Tribe Department of Education to focus essential learning outcomes and education for Coeur d'Alene Tribal youth and invoke Tribal leadership[6] (CdAT STEP, 2016). The Pillars: Membership, Scholarship, Stewardship, Guardianship, and Spirituality provide a structure to guide educational endeavors conducted by the Tribe. Membership are those "deeds" that make one "responsible, accountable, and informed citizen in all spheres of relationships" (CdAT STEP, 2016). Scholarship are those "dispositions" that allow one to engage in a "life-long, holistic learning with ideas rooted in tribal values, self-determination, self-government, and sovereignty" (CdAT STEP, 2016). Stewardship are those "behaviors" that affords one to be "a caretaker of all spheres of life; people, place, landscape and the cosmos" (CdAT STEP, 2016). While Guardianship are those "actions" that will "protect and defend our tribal sovereignty and ways of knowing and being; watching over and guarding our culture, history, language, and spirituality" (CdAT STEP, 2016). The aim of the Tribal leadership and Department of Education is for Tribal youth and citizens to embody the Pillars in all they do and believe. Spirituality was recently added by the Tribe as a fifth pillar. However, this pillar was not fully defined during the time period of this study and therefore was not included in the analysis.

Materials and Methods

Establishing an Ethical Partnership

The partnership began during the summer of 2015 while I was a graduate student intern with a National Science Foundation (NSF) culturally-relevant STEM education camp titled, "Back to the Earth" (BTTE). BTTE was a collaborative effort between University of Idaho researchers and Coeur d'Alene and Spokane Tribe(s) employees, members, and youth (Howard, 2017). The informal STEM education camp provided me with an opportunity to learn about the Coeur d'Alene Tribe's cultural values and research needs while affording an opportunity to develop an authentic relationship with Tribal youth and leaders. Following my involvement with BTTE, I used a participatory action research (PAR) methodological approach (Hall, 1992) grounded in the fundamental characteristics of IRM (i.e., four Rs) (Kovach, 2010) to initiate a community-university partnership between the Coeur d'Alene Tribe Department of Education and Lake Management Department and myself. Once I established the partnership, I employed this blended methodological approach through a series of in-person meetings between myself and employees from the Department of Education and Lake Management Department. During these initial project meetings, I shared my educational research

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[6] Membership, Scholarship, Stewardship, Guardianship, and Spirituality are now referred to as "core values" by the Coeur d'Alene Tribe. However, at the time of this research study, these terms were known as the "Pillars" among the Tribal community and therefore, are referred to as the "Pillars" within this article.

goals with Tribal employees (including staff from the Department of Education and Lake Management Department) and community members and they shared theirs which happened to align with mine. Ultimately, we established the viability and genuine intent of the research needs, a STEM education program that would involve Tribal employees and community members. I then proposed my community-university partnership and education program to the Coeur d'Alene Tribe Culture Committee and Natural Resources Committee. Upon receiving the Tribe's approval for the research partnership and associated program, I co-developed a two-year STEM education program in affiliation with the Summer Youth Internship Program with a collaborative team, conducted over the summer of 2016 and 2017. These crucial meetings allowed me, a non-Indigenous graduate student researcher raised and educated under a Western epistemology, to gain the Tribe's blessing and respect for the partnership.

Promoting Research Goals: Study Development, Design, and Implementation

This study explored how a culturally-relevant STEM education program affiliated with an existing Summer Youth Internship Program for Coeur d'Alene Tribal youth (ages 14-18), called "interns," could encourage Native students to develop youth leadership in the STEM fields. The STEM education program involved instructional activities to engage and teach the interns about key science and cultural issues about the Coeur d'Alene Basin. In parallel with the learning opportunities, the interns provided support for other water resource monitoring tasks conducted by the Coeur d'Alene Tribe Lake Management Department. Six specific content units aim to teach and enhance the interns' connection to place, comprehension of STEM content, and recognition of the Pillars composed the STEM education activities (Figure 4.2). The overarching objective of the STEM education program was three-fold: i) teach interns about water quality stressors impacting the Basin, ii) encourage interns to recognize their cultural connection to their aboriginal territory, and iii) recruit interns to work for the Tribal Department of Natural Resources. The goal, as emphasized by the community partners, was to support Tribal youth scientific literacy and leadership capacity in STEM.

Study Participants

The study participants encompassed members of the Coeur d'Alene Tribal community, including agency staff and youth, as well as myself. The Tribal community and agency staff guided me in the development, design, and instruction of culturally-relevant activities. In partnership with the Coeur d'Alene Tribe, I co-developed and instructed the STEM education program. In addition to these practical elements, I collected, analyzed, and disseminated all qualitative data related to this study. A summary of participant demographic and professional information is listed under Table 4.1. Pseudonyms were given to assure participant confidentially. An extended version of each case is referenced under Appendix D.

Qualitative Data Collection and Analysis

A case study research approach represents the primary qualitative method in collecting and analyzing data associated with this study. Creswell and Poth (2017) define case study research as a methodology or "qualitative approach in which the investigator explores a real-life, contemporary bounded system (case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information" (p. 97). As a result, this approach provides a thorough understanding of a case or issue through multiple types of analyses such as holistic investigation or analysis of themes (Yin, 2009).

Guided by a case study research approach, the qualitative data included pre and post-study surveys and interviews from participating youth interns and staff. The cases were informed by themes and supportive quotes from interview transcripts, surveys, and as well as researcher observations made over the two-year study to develop the participant cases. The individual cases culminated into a collective case narrative. This type of case study was selected because it allows researchers to address an issue, in this case STEM education for Native American youth, through multiple perspectives (Creswell & Poth, 2017). Therefore, I relied upon multiple cases to analyze the impact of this informal STEM education program and affiliated internship on Native American youth 1) connection to place, 2) interest in the STEM fields, and 3) STEM leadership capacity. The analysis of themes informed the general meaning of the study as outlined in the study findings and discussion. Please see Appendix A for IRB approval, Appendix E for interview questions, and Appendix F for surveys.

STEM Education Program Overview

Each educational unit and instructional activity are described below. Descriptions of the units summarize the culturally-relevant activities in relationship to the Pillars. Educational units were scaffolded over the two-year program to expand the learning and understanding of each subject and topic.

Unit 1- Orientation to Place

Prior to the formal internship, youth interns explored the cultural heritage and natural history of the Coeur d'Alene people on a driving tour of the lower Coeur d'Alene Basin with Coeur d'Alene Tribe Lake Management Department personnel. To further their relationship to place and provide a cultural context for this research project, the tour highlighted culturally significant and historically relevant locations throughout the Basin. This unit emphasized the pillar of Membership.

Unit 2- Impact of Toxic Metal Contamination on the Coeur d'Alene Basin

I provided a presentation on complex water resources issues resulting from historical mining activities in the Coeur d'Alene Basin. Following this presentation, the interns participated in the activity titled, “How to Read a Scientific Article” (modified from University of Idaho Waters of the West Program and The Lands Council, 2015). For this activity, interns read one scientific article related to the negative impact of toxic metal contamination in the Coeur d’Alene Basin (e.g. Sprenke et al., 2000). Once they read the article, we defined each section of the article and the information within. This unit emphasized the pillars of Scholarship and Stewardship.

Unit 3- Limnology

Interns were given a primer on the field of limnology, the primary discipline within which the Coeur d’Alene Tribe Lake Management Department conduct scientific research related to metal contamination. I opened this unit with a presentation on this specific discipline of ecology and the role of freshwater lakes in the biogeochemical cycling of metals. After the presentation, interns engaged in a literature review on the role of lakes in metal cycling and distribution. Concluding the literature review, interns provided a brief oral presentation of their findings to the group. This unit emphasized the pillars of Scholarship and Stewardship.

Unit 4- Remediation/Restoration

The Coeur d’Alene Tribe Lake Management Department employees provided an oral presentation to introduce the interns to the terms “remediation” and “restoration” in relationship to toxic metal contamination. Following this presentation, the Tribal employees led the interns on a driving tour of the Basin, highlighting the various mitigation and remediation work conducted by the Tribe. This unit emphasized the pillars of Guardianship and Stewardship.

Unit 5- Relationship to Place

The interns assisted community members with a variety of activities related to traditional foods and recreation in affiliation with an annual event that celebrates the culture of the Tribe. These cultural activities specifically exposed the interns to their Tribe’s traditional practices conducted along the shores of Coeur d’Alene Lake. This unit emphasized the pillars of Membership and Guardianship.

Unit 6- STEM Career Field(s)

The interns created a research poster summarizing their internship experience. The interns' presented the poster at the annual STEM career brunch. All STEM related staff members employed by the Tribe, in addition to the interns involved with the Summer Youth Internship Program attended the brunch. Following their presentation, the interns were provided the opportunity to network and connect with Tribal staff members. This unit emphasized the pillars of Scholarship and Stewardship.

Discussion and Findings

Two major themes emerged from the qualitative data indicating a positive impact of the internship experience and STEM educational program on interns' interest in STEM and associated career fields. The first theme indicated a relationship between the interns' connection to place as measured by the four Rs of IRM, which facilitated their comprehension of STEM. Meanwhile the second theme demonstrated the interns' desire to become a leader in STEM for their community as measured by the Pillars (Figure 4.3).

Theme 1: Connection to Place (four Rs– Relationship, Respect, Responsibility, Reciprocity) and Comprehension of STEM

Entering year one, the interns were aware of the water quality issues affecting their local environment and community, but they could not communicate how or why these issues negatively affect the social and ecological function of the Basin. Tess reflects this finding in her response, "Before the internship, I only had a general understanding of environmental issues. I know now why we don't have any places for water potatoes (cultural food)" (Tess, Post2). To enhance their understanding of these complex environmental issues, the STEM education program began with a series of activities aimed to strengthen their relationship, respect, and responsibility for their place. These activities included a tour of the Basin to orient the interns to their place, field trips to archaeological locations within the Tribe's aboriginal territory, and cultural activities (i.e., canoeing, pit baking, harvesting camas). The result of this approach on the interns' relationship to place and awareness of complex environmental issues is summarized in Tess's response, "All encompassing, Plummer is just a town. I knew before we had more territory, but the internship gave more relationship to place. Switching schools, I lost some of the connection. The internship provided community and knowledge about the area" (Tess, Post2).

Exposure to culturally significant locations and activities fostered a sense of place and provided an experiential learning environment that created a foundation for the interns to understand the STEM content and field experiences offered by the STEM education program and affiliated internship. This level of comprehension was demonstrated by the youth interns' definition of toxic metals captured in the year two exit survey:

> "Toxic metals are metals dissolved in water and are contamination in the water, killing living things surrounding it" (Tim, Post2). And
>
> "Toxic metals are something to avoid, elements that harm the environment (people, animals, lakes) in large quantities" (Tess, Post2).

In turn, this knowledge helped Tim and Tess further their awareness of the issues negatively impacting the Coeur d'Alene Basin and enhanced their desire to reciprocate their interests back to the

Tribe. While the interns' have shared this desire since the beginning of the internship, their exposure to a variety of STEM fields and career options during the internship and associated activities offered by the education program helped them define a career path. As such, Tess would like to pursue a career related to "restoration, remediation, mitigation in the Hazardous Waste Management Program (Department al program within the Coeur d'Alene Tribe)" (Tess, Post2). To achieve this goal, she would like to earn an undergraduate degree in the biophysical sciences and "well, obviously masters or, yeah doctorate" (Tess, Post2). As for Tim, he repeatedly stated he wanted to apply his interests in math to a career path focused in the biophysical sciences and water resource management. This finding is supported by Jane's description:

> [I had an] opportunity to hear Tim speak at the native youth program last spring in Washington, D.C. We invited Tim because he spent four years with the Summer Youth Internship Program. A joy listening about his first two years in the Summer Youth Internship program because he found out what he did not want to do. He wanted to be a math teacher, he then wanted to enter a science field due to internship experience. Learning his voice, relationship/respect for homeland. He wants to be able to have a voice when he completes university (Jane, Post2).

One's perception of place is defined through a variety of factors related to the physical ecosystem, culture, and community (Briggs et al., 2019). As described in the case descriptions above, the youth interns' perception of place is defined by their culture and community. This perception influenced their relationship to place which facilitated their sense of respect and responsibility to preserve their natural environment. While each intern's perception of place may differ, it is imperative to recognize this central theme to further their connection to place and engagement in STEM. A greater recognition of place offered by the internship and STEM education program caused both interns to express their interest in reciprocating this knowledge back to the Tribe in a STEM related role.

Theme Two: STEM Leadership (Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind)

Over their two-year involvement with this STEM education program and affiliation internship, Tess and Tim were able to apply their interests in the Tribal community and the STEM fields to acquire a greater understanding of their place. A greater understanding of place furthered their connection to the STEM content and recognition of the Pillars. In turn, their recognition of the Pillars caused both interns to express a desire to become leaders in STEM for their Tribal community and advocates for their place. Reflecting upon this outcome, Jane thought the STEM education program and internship was a positive experience and "had an impact on youth and an impact on our community" (Jane, Post2). Furthermore, she expressed it was "so exciting to see why we have summer internships, we wanted student interns to become a member of their community, become stewards of natural resources and people. Its working, my dream, why we established internships" (Jane, Post2). The positive impact of the STEM education program and practical internship experience on the interns' recognition of each pillar in the context of leadership is described below.

Membership (*t'u'lschint*)

Membership was addressed through a variety of cultural activities, supervised by Sam that involved pit baking, a canoe journey, and an archaeology lesson at historically significant locations. These activities were specifically addressed to further the interns' cultural connection to place and Tribal community. The interns' recognition of their Tribal membership was especially evident while assisting with the annual pit bake and canoe journey. As summarized from Sam's personal observations, both interns were proudly supporting their Tribe in each activity. His observations are further supported by Tim's response to his favorite cultural aspect of the internship: "Pit baking. I like to learn about my past as a Tribal member" (Tim, Post1). These cultural activities offered by the STEM education program were specifically addressed to further the interns' leadership in culturally significant events and locations.

Scholarship (*snmiypnqwiln*)

Prompted by their sense of membership and relationship to place, Scholarship was demonstrated by the interns' ability to articulate how toxic metal contamination was negatively affecting the water quality of the Basin from a Western and Indigenous perspective. This ability was observed at a variety of education and outreach events held for the Tribal community, staff, and general public. The interns were also able to utilize their 'Scholarship' gained from the internship and education activities to enhance their understanding of scientific theories, concepts, and practices discussed in the mainstream school system:

> During science class I can really apply some of the stuff we are working on. In class, I am taking chemistry and biology. Having the hands-on experience was helpful to understand the material and enhanced my interest in STEM because I have something to relate it to. I understand how it happens, the why behind chemical equations (Tess, Post2).

Ultimately, 'Scholarship' gained during their involvement in the summer internship and education program activities benefited the interns' leadership in science communication and comprehension.

Stewardship (*'ats' qhnt' wesh*)

The interns' recognition of their Tribal membership in combination with Scholarship or knowledge of their place prompted a deeper connection to the local environment and a sense of Stewardship for the Basin. Therefore, "Stewardship was addressed from the nature of the internship" (Sam, Post2). Both interns expressed a desire to steward the land by passing on their knowledge gained from their two-year involvement in the STEM education program and affiliated internship. This desire is expressed in Tess's statement, "I would like to help build awareness of the problems we face in the Coeur d'Alene Lake ecosystem" (Tess, Post1). Similarly, Tim wishes to "pass on his cultural experience to my community" (Tim, Post2).

Guardianship (*hngwa' Yqn; hnshat' qn*)

Collectively, Tess and Tim's recognition of Membership, Scholarship, and Stewardship culminated into a sense of Guardianship for their place and community. Specifically, Tess would like to protect her place and community through a career related to environmental "restoration, remediation, mitigation" (Tess, Post2). As for Tim, he would like to pursue the position of "water resources program manager or water quality specialist" (Tim, Post2) within the Lake Management Department to sustain the water resources from a seventh-generation perspective. Therefore, both interns' wish to apply their sense of guardianship as an employee for the Coeur d'Alene Tribe in a STEM-related role.

The intern's recognition of the Pillars was also displayed in their year two research poster as described under Unit 6. In this poster, the interns related the practical experience gained from their six-week internship as well as the theoretical knowledge acquired from the STEM education program to the Pillars. A map of the contaminated area is displayed at the center of the poster to symbolize the reason behind their involvement in the STEM education program and internship: to assist their community mitigate metal contamination as a leader in STEM. Their experience, objective of the internship and education program, and their leadership desires were further expressed to the Department of Natural Resources while presenting their research poster at the end of the 2017 internship.

Study Limitations

While the qualitative data indicates the positive impact of this study on Native American youth interest in STEM, I identify time, funding, and the number of participants as three limiting factors. Restricted amount of time and funding, in addition to the small number of youth participants, may challenge the longevity and credibility of these results. Similar limitations are described by Mabh (2019). Addressing these limitations, the Tribe is actively pursuing additional funding sources to increase the number of youths involved in the STEM education program and internship. Lake Management Department staff received an additional grant to hire Tess, Tim, and two other youths for 2018 and 2019 Summer Youth Internship Program. However, the permanency of these efforts is dependent on the longevity of funding, which presents a second limiting factor in retaining youth interest in STEM. Reflective of these results, future research on culturally-relevant STEM education for Native American youth led by university research teams should consider strategies and approaches in transitioning this educational opportunity into a permanent program managed by the Tribe.

Conclusion

Native American community members in STEM leadership roles represent an important and perhaps powerful cohort of professionals that must navigate between Western and Indigenous epistemological frameworks to best meet the needs of the Tribal community (Bang & Medin, 2010; Smith et al., 2014). Informal STEM education efforts acknowledging culturally-relevant pedagogy can assist Tribal youth to navigate these epistemological frameworks and further their connection to the role of STEM in their community. These educational efforts enhance Tribal youth interest in the STEM career fields. Therefore, youth member leadership in STEM remains a critical component for the preservation of place and acknowledgement of Tribal sovereignty for Native Nations.

Guided by a place-based perspective grounded in equity and cultural-relevance, culturally-significant content appeared to enhance the potential for STEM leadership capacity within the Coeur d'Alene Tribe. The results indicate a positive impact of this two-year STEM education program and affiliated internship on youth interns' understanding and ultimate connection to place, comprehension of STEM content, and interest in pursuing a STEM career offered by their Tribe. However, the longevity of the study results is dependent on time and available funding.

Moving forward, the research findings from this study contribute to the field(s) of place-based education, culturally-relevant STEM education, participatory action research methodologies, and Indigenous research scholarship. This contribution allows for better understanding of how culturally-relevant STEM education for Native American youth can support tribal community capacity in mitigating complex environmental change as a sovereign nation. To maintain the longevity of these efforts, future community-based research studies providing culturally-relevant STEM education for Native American youth should consider strategies in transitioning this temporary informal learning opportunity into a permanent program managed by the partnered tribe.

Acknowledgements

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Literature Cited

Aikenhead, G., & Michell, H. (2011). *Bridging cultures: Indigenous and scientific ways of knowing nature*. Pearson Education.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education*, *94*(6), 1008–1026.

Battiste, M. (2008). Research ethics for protecting Indigenous knowledge and heritage: Institutional and researcher responsibilities. *Handbook of Critical and Indigenous Methodologies*, 497–510.

Bergstrand, K., Mayer, B., Brumback, B., & Zhang, Y. (2015). Assessing the relationship between social vulnerability and community resilience to hazards. *Social Indicators Research*, *122*(2), 391–409.

Berkes, F. (2012). *Sacred ecology*. Routledge.

Briggs, L., Krasny, M., & Stedman, R. C. (2019). Exploring youth development through an environmental education program for rural indigenous women. *The Journal of Environmental Education*, *50*(1), 37–51.

Cajete, G. (1999). *Igniting the sparkle: An Indigenous science education model*. Skyland, NC: Kivaki Press.

Caxaj, C. S. (2015). Indigenous storytelling and participatory action research: Allies toward decolonization? Reflections from the peoples' international health tribunal. *Global Qualitative Nursing Research*, *2*, 2333393615580764.

Coeur d'Alene Tribe (CdAT) State Tribal Education Partnership (STEP) (2016). *Coeur d'Alene Tribe five pillars to strengthen heart and mind*: Five pillars. Prepared for the Coeur d'Alene Tribe.

Creswell, J. W., & Poth, C. N. (2017). *Qualitative inquiry and research design: Choosing among five approaches*. Sage Publications.

Doyle, J., Kindness, L., Realbird, J., Eggers, M., & Camper, A. (2018). Challenges and opportunities for Tribal waters: Addressing disparities in safe public drinking water on the Crow Reservation in Montana, USA. *International Journal of Environmental Research and Public Health*, *15*(4), 567.

Evans, M., Hole, R., Berg, L. D., Hutchinson, P., & Sookraj, D. (2009). Common insights, differing methodologies: Toward a fusion of indigenous methodologies, participatory action research, and white studies in an urban aboriginal research agenda. *Qualitative Inquiry*, *15*(5), 893–910.

Frey, R., & Stensgar, E. (2012). *Landscape traveled by Coyote and Crane: The world of the Schitsu'umsh*. University of Washington Press.

Hall, B. L. (1992). From margins to center? The development and purpose of participatory research. *The American Sociologist*, *23*(4), 15–28.

Hermes, M. (1998). Research methods as a situated response: Towards a First Nations' methodology. *International Journal of Qualitative Studies in Education*, *11*(1), 155–168.

Howard, M. A. (2017). *Roles of community and land in STEM education for Native American youth* (Unpublished doctoral dissertation). University of Idaho, Moscow, Idaho.

Hudson, P., & Taylor-Henley, S. (2001). Beyond the rhetoric: Implementing a culturally appropriate research project in First Nations communities. *American Indian Culture and Research Journal*, *25*(2), 93–105.

Iseke, J. M., & Desmoulins, L. (2015). A two-way street: Indigenous knowledge and science take a ride. *Journal of American Indian Education*, *54*(3), 31–53.

Kovach, M. (2010). *Indigenous methodologies: Characteristics, conversations, and contexts*. University of Toronto Press.

Lewis, J., Hoover, J., & MacKenzie, D. (2017). Mining and environmental health disparities in Native American communities. *Current Environmental Health Reports*, *4*(2), 130–141.

Mbah, M. (2019). Can local knowledge make the difference? Rethinking universities' community engagement and prospect for sustainable community development. *The Journal of Environmental Education*, *50*(1), 11–22.

McCarty, T., & Lee, T. (2014). Critical culturally sustaining/revitalizing pedagogy and Indigenous education sovereignty. *Harvard Educational Review*, *84*(1), 101–124.

National Research Council (NRC). (2005). *Superfund and mining megasites: Lessons from the Coeur d'Alene River Basin*. National Academies Press.

Peltier, C. (2018). An application of two-eyed seeing: Indigenous research methods with participatory action research. *International Journal of Qualitative Methods*, *17*(1), 1609406918812346.

Smith, L.T. (1999). *Decolonizing methodologies: Research and Indigenous peoples*. Zed Books Limited.

Smith, J. L., Cech, E., Metz, A., Huntoon, M., & Moyer, C. (2014). Giving back or giving up: Native American student experiences in science and engineering. *Cultural Diversity and Ethnic Minority Psychology*, *20*(3), 413.

Snow, B. D. (2017). *Living with lead: an environmental history of Idaho's Coeur d'Alenes, 1885-2011*. University of Pittsburgh Press.

Sprenke, K., Rember, W., Bender, S., Hoffmann, M., Rabbi, F., & Chamberlain, V. (2000). Toxic metal contamination in the lateral lakes of the Coeur d'Alene River valley, Idaho. *Environmental Geology*, *39*(6), 575–586.

Stevens, S., Andrade, R., & Page, M. (2016). Motivating young native American students to pursue STEM learning through a culturally relevant science program. *Journal of Science Education and Technology*, *25*(6), 947–960.

United States Geological Survey (USGS). (2013). Watershed boundary dataset. Retrieved from https://www.usgs.gov/core-science-systems/ngp/national-hydrography/watershed-boundary-dataset?qt-science_support_page_related_con=4#qt-science_support_page_related_con

University of Idaho Waters of the West Program and The Lands Council. (2015). *4. Scientific articles [The Confluence Project: Watershed Science Curriculum]*.

Ward, T. J., Vanek, D., Marra, N., Holian, A., Adams, E., Jones, D., & Knuth, R. (2008). The big sky model: A regional collaboration for participatory research on environmental health in the rural West. *Journal of Higher Education Outreach and Engagement*, *12*(3), 103.

Woodworth-Ney, L. (2004). *Mapping identity: The creation of the Coeur D'Alene Indian Reservation, 1805-1902*. Univ Pr of Colorado.

Yin, R. K. (2009). *In L. Bickman & DJ Rog (Eds.), Case study research: Design and methods*. Sage Publications.

Tables

Table 4.1 Study participant descriptions.

Participant	Job description	Membership	Role in Study
Tess	Intern	Community member	Youth intern for two-year study
Tim	Intern	Community member	Youth intern for two-year study
Sam	Director of Natural Resources for Coeur d'Alene Tribe	Community member	Program developer and instructor for two-year study
Lauren	Restoration Specialist for Coeur d'Alene Tribe Lake Management Department	Non-community member	Program developer and instructor for two-year study
Chris	Director of Coeur d'Alene Department of Education	Community Member	Program and study advisor.
Kathleen	University of Idaho graduate student researcher	Non-community member	Program developer and instructor. Designed and implemented STEM education study.

Figures

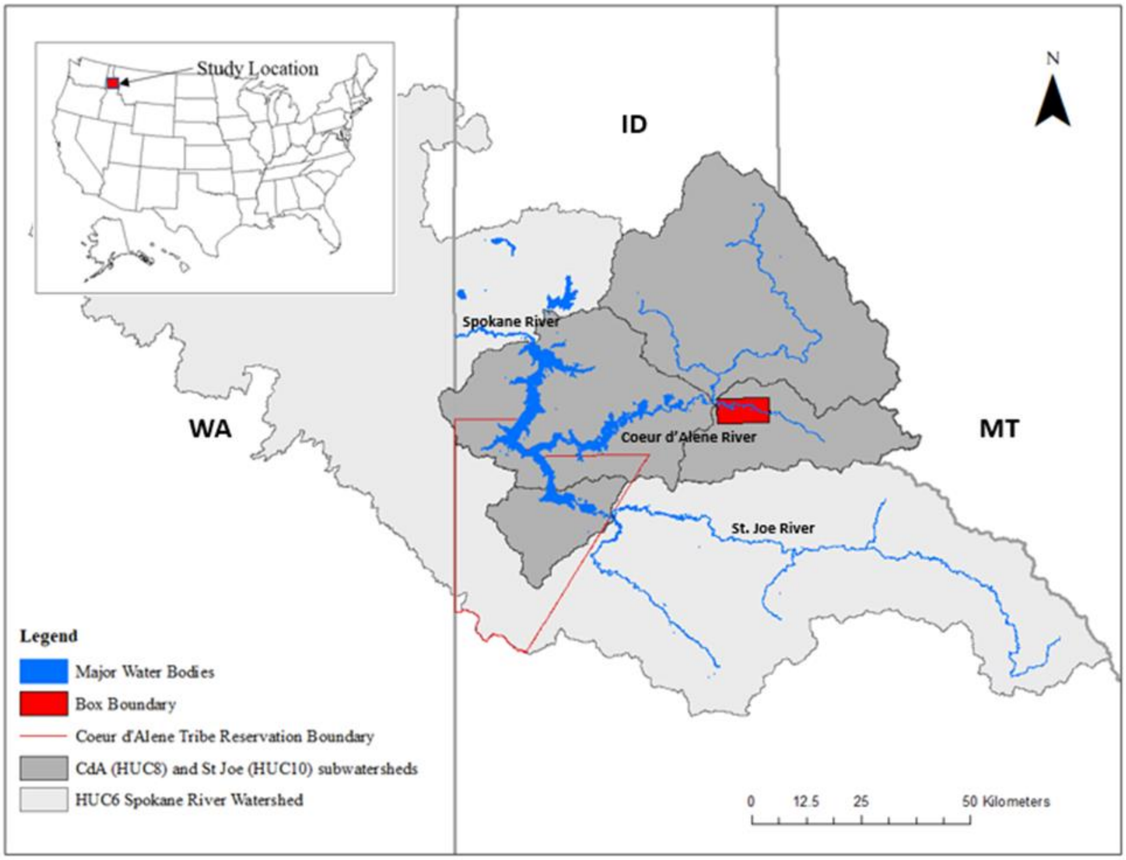

Figure 4.1 Map of the Coeur d'Alene Basin, USA including the Spokane River watershed boundary, subwatersheds and major water features of the Basin, primary jurisdictional boundaries of the “Box”, and the Coeur d’Alene Tribe reservation territory. Map image developed in ESRI ArcGIS 10.6.1. HUC= Hydrologic Unit Code.

Source: USGS Watershed Boundary Dataset; Alta Engineering and Science; Coeur d'Alene Tribe of Indians (accessed at Koordinates.com).

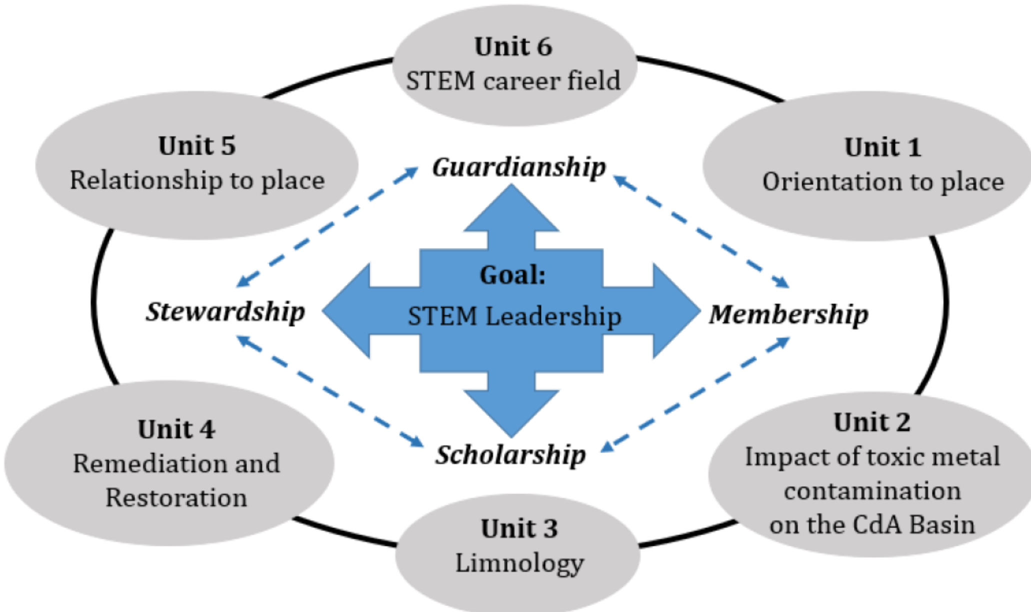

Figure 4.2 Conceptual diagram of STEM education program in relationship to the Pillars (Guardianship, Membership, Scholarship, Stewardship).

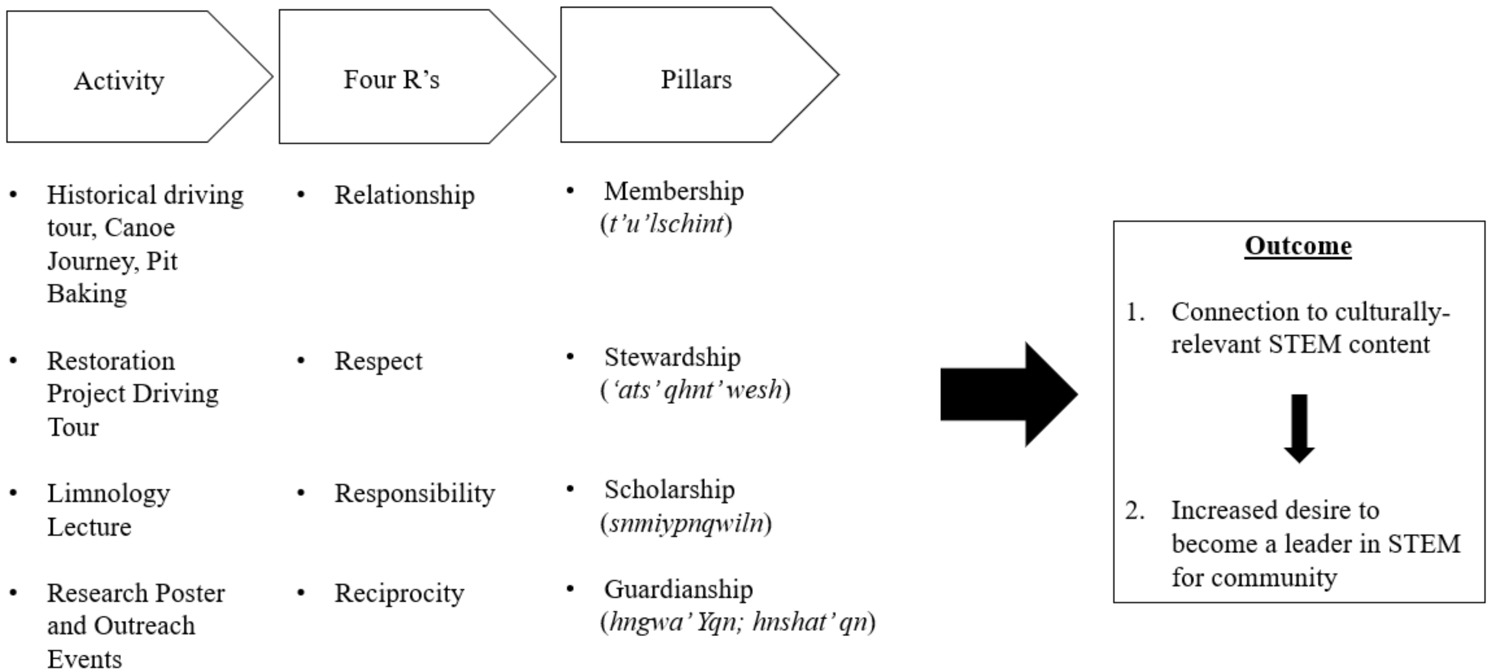

Figure 4.3 Conceptual diagram illustrating the education study outcome as related to the education activities and Indigenous principles: four Rs and Pillars.

Chapter 5: Conclusions and Recommendations

Despite widespread efforts to manage water quality issues through scientific monitoring and educational efforts, toxic metal contamination caused by historical mining activities remain a primary source of water quality impairment in the Coeur d'Alene Basin (CdA Basin Natural Restoration Trustees 2018; National Research Council, 2005). For the Coeur d'Alene Tribe, water quality impairment continues to threaten the cultural, physical, and spiritual well-being of the community (CdA Basin Natural Restoration Trustees 2018; Frey & Stensgar, 2012). This dissertation addressed these complex issues through an interdisciplinary research framework acknowledging approaches in 1) community engagement, 2) aquatic ecology, and 3) science, technology, engineering, and mathematics (STEM) education. I specifically addressed each approach by 1) engaging with the Tribal community through an authentic research partnership guided by ethical participatory research methodologies, 2) examining submerged macrophyte phenology through a formal limnological study in collaboration with scientists employed by the Tribe, and 3) developing and instructing a culturally-relevant STEM educational program alongside educators and scientists employed by the Tribe for community youth. Therefore, the research framework presented in this dissertation integrates three approaches drawing from disciplinary principles in participatory methodologies, ecology, and education to support the Tribal community water quality mitigation goals.

The collection of studies in this dissertation demonstrates the value of conducting interdisciplinary research in mining impacted water systems together with a community-university partnership guided in participatory methodologies. The integration of each study offers a framework to support the organization and members of the Coeur d'Alene Tribe. I explored the effectiveness of this interdisciplinary framework in supporting the partnered community through the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind* ~ Membership, Scholarship, Stewardship, Guardianship, Spirituality (CdAT STEP, 2016). My analysis included empirical data supported by semi-structured interviews with community partners (please see Appendix A for IRB approval and Appendix B for interview questions) as well as my personal observations. Spirituality was not included in my analysis because it was not fully defined during the time period of my dissertation research. Thus, the analysis reflects only four of the five pillars: Membership, Scholarship, Stewardship, and Guardianship.

t'u'lschint: Membership

"Capable, decent, moral, 'a good person', a good citizen in your family, tribal, local and world community. A responsible, accountable and informed citizen in all spheres of relationship" (CdAT STEP, 2016).

An educator employed by the Tribe and partner in the STEM education program and affiliated study defined membership as “a group of people or the Tribal memberships themselves, but when you talk about the lake, you also talk about the creeks, streams, and the rivers that go into it, so that is membership in itself” (Julie, spring 2019). The STEM education study described in *Chapter 4* acknowledged the pillar of Membership through a culturally-relevant education program and affiliated internship that recognized Tribal culture, place, and the STEM fields. The combined educational opportunities provided a theoretical and practical perspective on water resource management that furthered youth relationship to place and interest in the STEM fields. Study results indicated a greater connection to place, which enhanced youth interest and desire to pursue a STEM career for their Tribe. Greater leadership in STEM among Tribal members will assist the community in mitigating water quality issues related to toxic metal contamination as a sovereign nation. This outcome is further summarized by an interview response with a senior leader of the Tribal community and partner in the education study:

> Currently, the Tribe is lacking in community member leadership in STEM. While non-Tribal STEM employees are greatly assisting the scientific research and reputation of the Tribe as a leader in the mitigation of mining contamination in the Basin, Tribal leaders with a background in STEM can utilize their expertise in both STEM and traditional knowledge to make the best decision for their community” (Sam, spring 2019).

***snmiypnqwiln*: Scholarship**

“Life-long, holistic learning with ideas rooted in tribal values, self-determination, self-government and sovereignty that produces deep knowledge to understand the world and meaningful application within the community” (CdAT STEP, 2016).

The pillar of Scholarship is recognized in both the content covered in the STEM education program (*Chapter 4*) as well as the primary data collected during the limnological study (*Chapters 3*). The theoretical and practical opportunities acknowledged in the STEM education program provided, “a place-based scholarship” (Sam, spring 2019) and furthered the scientific literacy of Tribal youth. The limnological study furthered data accessibility to inform future research on the role of macrophytes in metal distribution in the Basin. This outcome is further supported by the interview response, “The STEM education program enhanced the intellectual capacity of the community by enhancing member interest in STEM. The macrophyte study provided needed data to enhance the Tribe’s efforts in mitigating contamination and recognition of Tribal sovereignty in the Basin” (Sam, spring 2019). Collectively, greater data accessibility and scientific literacy among the community is intended to further the Tribe’s theoretical understanding of the fate and transport of toxic metals, which will support future mitigation efforts towards managing such pollutants within an aquatic ecosystem.

***'ats' qhnt' wesh*: Stewardship**

"A caretaker of all spheres of life; people, place, landscape and the cosmos; to manage with integrity, accountability, reciprocity, and social awareness—looking at each other from the heart." (CdAT STEP, 2016).

The outcome of scientific literacy and data accessibility provided by each study will support the ability of the Tribe to care or "steward" their water resources. Supporting this finding, youth expressed an interest to improve water quality issues through the remediation of contaminated sediments at the conclusion of the STEM education program (*Chapter 4*). Furthermore, a scientist employed by the Tribe and partner in the limnological study expressed the study results "filled a big data gap, which will help prioritize future mitigation strategies" (Tom, spring 2019). Therefore, these findings demonstrate the impact of the STEM education program on the community members' desire to take care of their local environment, while the limnological study provided needed scientific data to inform future research and management strategies.

***hngwa' Yqn; hnshat' qn*: Guardianship**

"A sense of responsibility to protect and defend our tribal sovereignty and ways of knowing and being; watching over and guarding our culture, history, language and spirituality." (CdAT STEP, 2016).

The pillar of Guardianship is addressed by the utility of the scientific data and educational products. The scientific data collected from the limnological study furthered Tribal scientists' understanding of submerged macrophyte phenology, which will inform future research on the role of macrophytes in the cycling of metals within a lake ecosystem. The theoretical foundation provided from the STEM education program enhanced "youth stewardship, membership, and guardianship for the Basin…This was achieved by strengthening their relationship to place and in turn their interest in STEM" (Sam, spring 2019). Supporting this reflection, youth expressed a sense of guardianship for their place and community by stating their desire to pursue a career in STEM to protect the Basin for their community and future generations in their interview and survey responses at the conclusion of the program. To increase the longevity of STEM education study results, the education program and affiliated practical experience has been integrated into a permanent internship program to reach a greater number of Tribal youths. As described by Sam (spring 2019), "the curriculum will be modeled off of the STEM education program affiliated with the Lake Management Department because this is the only education program under the Summer Youth Internship that caused youth interns to express their interest in pursuing a STEM career within the Tribe." In turn, these efforts are intended to support the Tribes efforts in protecting their water resources for future generations.

Interdisciplinary Research in Water Resource Management

Addressing the complexity of water quality issues related to mine waste contamination transcends disciplinary knowledge in the biophysical and social sciences as well as the epistemological foundations of local communities. An interdisciplinary research methodology provides researchers with an opportunity for integration and collaboration across multiple scales, disciplines, and cultures to address complex issues through sustainable decision making (Pahl-Wostl et al., 2008). For Native American tribes grappling with water quality issues influenced by toxic metal contamination, an interdisciplinary research methodology is complementary towards an Indigenous epistemology, which reflects a holistic, systematic ontology (Wilson et al., 2019). Community-university partnerships facilitated through participatory action research (PAR) (Hall, 1992) and Indigenous research methodologies (IRM) (Kovach, 2010) enable capacity building by promoting community voices and goals, improving data accessibility, and enhancing scientific literacy (Chief, 2018; Chief et al., 2016). Therefore, addressing water quality issues through interdisciplinary approaches guided by participatory processes can lead to more equitable and sustainable research outcomes for the partnered community.

Reflecting these recommendations from previous studies, this dissertation in collaboration with the Coeur d'Alene Tribe addressed complex water quality issues caused by toxic metal contamination through interdisciplinary approaches that encouraged the integration of multiple disciplines and collaborative decisions making. Participatory approaches (i.e., PAR and IRM) were employed to establish a community-university research partnership, promote community voices and goals, and maintain an ethical relationship. Stemming from the partnership foundation, the limnological study and educational program enabled capacity building by improving data accessibility and scientific literacy. Results reflect the positive impact of each study in supporting the community partner to mitigate their contaminated waterways. However, the longevity of study results may be limited by the availability of future resources. Addressing this limitation, recommendations for chapters 2-5 are provided below.

Recommendations

Chapter 2

- Researchers should recognize culturally appropriate participatory research methodologies for partnered communities. For example, Indigenous research methodologies (IRM) are used to support Indigenous communities, specifically those communities that have a significant historical impact from colonization and are striving towards decolonization through self-determination.

- Expanding upon existing Institutional Review Board (IRB) protocols and trainings, the office of the IRB should develop workshops and associated curriculum for university researchers interested in partnering with a community or agency for future research, prior to approaching the desired partner.

Chapter 3

- A multi-year assessment of macrophyte phenology would benefit researcher understanding of potential variability in inter-annual and annual macrophyte phenological characteristics (Hampton et al., 2019). Specifically, researchers should further investigate the effect of lake regulation and hydrologic connectivity with adjacent water bodies on macrophyte growth within the chain lakes of the lower Coeur d'Alene River floodplain.
- Researchers should closely examine methods to reduce Biobase sonar sampling error caused by weather (e.g., wind) and boat operator error.
- Researchers should consider expanding the statistical analysis outlined in this chapter by employing the spatial statistical method of Kriging through R statistical software package "gstat" (Gräler et al., 2016). This method can be used to extrapolate phenology results across the littoral zones of the study location.
- Researchers should use the phenology results, specifically the time period of macrophyte senescence to inform future research on metal and nutrient association with submerged macrophyte in temperate lakes within the Coeur d'Alene Basin.

Chapter 4

- Non-Indigenous collaborators should rely on the four Rs of IRM to ethically support the educational sovereignty in Native American communities.
- The Coeur d'Alene Tribe Department of Education as well as local school administrators are encouraged to adapt the informal STEM education program to a formal mainstream science curriculum for elementary and high school aged Coeur d'Alene Tribal youth. These efforts are intended to support the educational sovereignty goals of the Coeur d'Alene Tribe.

These recommendations offer suggestions to extend the social, ecological, and pedagogical understanding towards addressing water quality issues resulting from mining contamination. The integration of each disciplinary approach promotes sustainable decision making among the Tribal community membership. Therefore, this dissertation demonstrates the application of an interdisciplinary research methodology, guided by an ethical participatory research approach, to support a Native American community reach their water resource management goals. Broadly, the research presented in this dissertation contribute to the field(s) of interdisciplinary research, participatory research, and Indigenous research scholarship. This contribution allows for better understanding of how interdisciplinary research facilitated through a community-based perspective can support a Native American tribe's capacity to mitigate complex water resource issues as a sovereign nation.

Literature Cited

Chen, M., Ding, S., Lin, J., Fu, Z., Tang, W., Fan, X., … Wang, Y. (2019). Seasonal changes of lead mobility in sediments in algae- and macrophyte-dominated zones of the lake. *Science of The Total Environment*, *660*, 484–492.

Chief, K. (2018). Emerging voices of tribal perspectives in water resources. *Journal of Contemporary Water Research & Education*, *163*(1), 1–5.

Chief, K., Meadow, A., & Whyte, K. (2016). Engaging southwestern tribes in sustainable water resources topics and management. *Water*, *8*(8), 350.

Coeur d'Alene Basin (CdA) Natural Resource Trustees. (2018). Coeur d'Alene Basin restoration plan. Retrieved from: https://www.restorationpartnership.org/pdf/Coeur%20d'Alene%20Basin%20Restoration%20Plan%20May%202018.pdf

Coeur d'Alene Tribe (CdAT) State Tribal Education Partnership (STEP) (2016). Coeur d'Alene Tribe five pillars to strengthen heart and mind: Five pillars. Prepared for the Coeur d'Alene Tribe.

Frey, R., & Stensgar, E. (2012). *Landscape traveled by Coyote and Crane: The World of the Schitsu'umsh*. Pullman, WA: University of Washington Press.

Gräler, B., Pebesma, E., & Heuvelink, G. (2016). Spatio-Temporal interpolation using gstat. *The R Journal*, *8*(1), 204-218

Hall, B. L. (1992). From margins to center? The development and purpose of participatory research. *The American Sociologist*, *23*(4), 15–28.

Hampton, S. E., Scheuerell, M. D., Church, M. J., & Melack, J. M. (2019). Long-term perspectives in aquatic research. *Limnology and Oceanography*, *64*(S1), S2–S10.

Kovach, M. (2010). *Indigenous methodologies: Characteristics, conversations, and contexts*. University of Toronto Press.

National Research Council. (2005). *Superfund and mining megasites: Lessons from the Coeur d'Alene River Basin* [National Research Council]. National Academies Press.

Pahl-Wostl, C., Tàbara, D., Bouwen, R., Craps, M., Dewulf, A., Mostert, E., … Taillieu, T. (2008). The importance of social learning and culture for sustainable water management. *Ecological Economics*, *64*(3), 484–495.

Wilson, N. J., Harris, L. M., Joseph-Rear, A., Beaumont, J., & Satterfield, T. (2019). Water is medicine: Reimagining water security through Tr'ondëk Hwëch'in Relationships to treated and traditional water sources in Yukon, Canada. *Water*, *11*(3).

Appendix A - IRB Approval Letter

University of Idaho
Office of Research Assurances
Institutional Review Board
875 Perimeter Drive, MS 3010
Moscow ID 83844-3010
Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

To: Anne Mary Kern

Cc: Kathleen Torso

From: Sharon Stoll
Chair, University of Idaho Institutional Review Board

Date: December 05, 2018
Title: Holistic Investigation of Heavy Metal Mobility in the lower Coeur d'Alene River.

Project: 16-112
Approved: 12/05/2018
Expires: 12/27/2019

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the above-referenced non-exempt study is approved for another year in accordance with 45 CFR 46.111. The approval period is listed above and includes the additional exit interviews. Research that has been approved by the IRB may be subject to further appropriate review and approval or disapproval by officials of the Institution.

This study may be conducted according to the protocol described in the application. Research that has been approved by the IRB may be subject to further appropriate review and approval or disapproval by officials of the Institution. Every effort should be made to ensure that the project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice. As Principal Investigator, you are responsible for ensuring compliance with all applicable FERPA regulations, University of Idaho policies, state and federal regulations.

Federal regulations require researchers to follow specific procedures in a timely manner. For the protection of all concerned, the IRB calls your attention to the following obligations that you have as Principal Investigator of this study.

1. For any changes to the study (except to protect the safety of participants), an Amendment Application must be submitted to the IRB. The Amendment Application must be reviewed and approved before any changes can take place.

2. Any unanticipated/adverse events or problems occurring as a result of

participation in this study must be reported immediately to the IRB.

3. Principal investigators are responsible for ensuring that informed consent is properly documented in accordance with 45 CFR 46.116.

4. A Continuing Renewal Application must be submitted and approved by the IRB prior to the expiration date else automatic termination of this study will occur. If the study expires, all research activities associated with the study must cease and a new application must be approved before any work can continue.

5. Please complete the Continuing Renewal/Closure form in VERAS when the project is completed.

6. Forms can be found at https://veras.uidaho.edu.

Appendix B- Exit Interview Questions

(Estimated time: 25-30 minutes)

1. Did my interdisciplinary study support the Tribal community and/or agency goals?

2. In your opinion, how did this community-university partnership assist the Tribe's efforts in mitigating mining contamination?

3. In what ways did this dissertation study advance the *Coeur d'Alene Tribe Five Pillars to Strengthening Heart and Mind* (Pillars) within the Tribal community and agency?

    a. STEM education study

    b. Limnological study

4. In the context of the Pillars, how did this study support the Tribe's efforts in self-governing complex water resource issues related to mining contamination?

    a. STEM education study

    b. Limnological study

5. After observing my dissertation study, would you support additional research partnerships between the Coeur d'Alene Tribe and the University of Idaho in the future? Why or why not?

Appendix C- Publication Agreement

Elsevier provides a blanket statement of permission for all authors to use their published articles in their dissertation/thesis.

Statement: "Please note that, as the author of this Elsevier article, you retain the right to include it in a thesis or dissertation, provided it is not published commercially. Permission is not required, but please ensure that you reference the journal as the original source."

Appendix D- STEM Education Study Case Study Narratives

Tess

Tess is a High School junior and an enrolled Coeur d'Alene Tribal member. She is the granddaughter of a prominent Coeur d'Alene Tribal Leader. Her family's selfless dedication to their place and the Coeur d'Alene Tribe has shaped Tess's relationship to the Basin. As such, Tess describes the Coeur d'Alene Basin as "a place of comfort and relaxation. My family likes to spend a lot of time around the water. We gather to celebrate since my family is from the Basin we have a lot of history which holds this area close to me." The Basin represents her "whole life, culture, recreation, everything revolves around the Lake."

Tess's avid interest in her community, place, the STEM fields, and natural resource management prompted her involvement with the Summer Youth Internship Program and affiliated STEM learning opportunity. As one of two youth interns for the Lake Management Summer Youth Internship Program, Tess demonstrated a sincere interest in the management and restoration of the Coeur d'Alene Basin. Specifically, Tess would like to dedicate her interests "to the Tribe by getting more involved and communicating with more people…I would like to help build awareness of the problems we face in the Coeur d'Alene Lake ecosystem." This sense of responsibility for her "place" is demonstrated through her desire to pursue a career in the STEM fields under the Coeur d'Alene Tribe Lake Management Department.

Tim

Tim is a member of the Coeur d'Alene Tribe and has lived on the reservation his entire life. At 18 years old, Tim is a senior in high school and attends the local public school on the Coeur d'Alene Reservation. He is involved in a variety of sports and enjoys hunting and finishing around the Coeur d'Alene Basin with his family. Tim has gained a sense of respect for the Coeur d'Alene Basin and the Tribal community from his family which has shaped his relationship to place. As such, he considers the Coeur d'Alene Basin to be "a part of my culture, my life...it's where we originate from."

Tim has a passion for mathematics and would like to apply this interest to a career in accounting, engineering, or biology. Most importantly, he wants to pursue his professional career as an employee of the Coeur d'Alene Tribe. Tim has been working towards these professional goals through formal and informal educational experiences offered through the Coeur d'Alene Tribe. However, he is still searching for a career to focus his interests.

This professional search prompted Tim's initial desire to be a part of the Lake Management Summer Youth Internship Program and affiliated STEM education learning opportunity. Tim was involved in the internship and affiliated STEM education program for two years and worked alongside Tess for the duration of the STEM study. The STEM content covered in the summer learning opportunities and affiliated field work helped Tim discover a variety of STEM careers (e.g. engineering, limnology, ecology, and chemistry) in which he could apply his interests in mathematics. This realization helped him connect to the STEM content and affiliated practical experience.

Sam

Sam is a Coeur d'Alene Tribal member and has been an employee of the Coeur d'Alene Tribe Lake Management Department in the Cultural Resources Protection Program for the past 5 years. He currently serves as the Director of the Natural Resources for Coeur d'Alene Tribe. An advocate for the protection of the Coeur d'Alene Tribe's cultural resources, Sam believes place serves an important role in the preservation of culture. He defines place as "something anyone can recognize, the physical place" and in terms of Coeur d'Alene Tribal culture, can also be interpreted as "alive." Thus, Sam's perception of place is maintained through a physical and spiritual connection to the land.

Sam was able to reciprocate his connection to place and knowledge of the Coeur d'Alene culture as a collaborator in this two-year study. Specifically, Sam assisted in the development and instruction of culturally-relevant content in the STEM education learning opportunities. The incorporation of culture, facilitated through Sam's involvement with the program, was critical for the youth interns' development in the four Rs and furthermore comprehension of the STEM content. As previously stated, Sam believes cultural education supplies the desire to steward the land and the STEM education "provides the why." Sam's involvement in the development and implementation of this study provided the cultural foundation that connected the students to their place which allowed them to comprehend the STEM content.

Sam expressed that the *Coeur d'Alene Tribe Five Pillars to Strengthen Heart and Mind* (Pillars) "are fairly new to be verbalized but are correct to represent their culture." He personally believes spirituality is the most important pillar and is central to this theoretical framework. However, due to recent adoption of these terms by the Tribe, he expressed they are difficult to measure and define.

Regarding the Pillars, he did believe all pillars were addressed in the internship and affiliated learning opportunities. Specifically, Sam thought "stewardship was addressed from the nature of the internship" and scholarship was addressed due to the interns' exposure to "highly educational content." He could not provide a specific example of how guardianship was addressed but expressed the interns understood the term. In turn, Sam directly observed the intern's development in the pillar of membership over the two-year study. At the beginning of the internship, Sam observed the interns just "talking about Tribal membership." By the end of the internship, the interns' sense of membership sparked their interest to be an employee of the Lake Management Department. These observations made by Sam over the course of the two-year study reflects the positive impact the internship and affiliated STEM education program had on the interns' desire to be a leader for their Tribal community.

Lauren

Lauren has been an employee of the Coeur d'Alene Tribe Lake Management Department for the past 13 years. Currently, she serves as the Program Manager and Restoration Coordinator for the Hazardous Waste Management Program, a subdivision of the Lake Management Department. The mission of the Hazardous Waste Management Program is to protect the natural resources within the Coeur d'Alene Tribe's aboriginal territory that have been injured by toxic heavy metal contamination from past mining and smelting activities in the Coeur d'Alene Basin. The Lake Management program is involved with a variety of projects to assist in the remediation and restoration efforts of the damaged natural resources. As the Program Manager and Restoration Coordinator, Lauren ensures the Tribe is represented and involved in the work mentioned above and serves on multiple committees (e.g., Restoration Partnership, Basin Environmental Improvement Project Commission, Coeur d'Alene Chamber of Commerce Natural Resources Committee, and the National Tribal Waste Response Assistance Steering Committee) combating the issue of heavy metal contamination in the Coeur d'Alene Basin.

Her knowledge and respect for the Coeur d'Alene Tribal culture and homeland has developed from her interactions with the community. Over the past 13 years she has worked for the Tribe, she expressed that "they have embraced me into their culture" and "have opened their arms for me to partake in their traditional cultural activities like gathering water potato, attending storytelling classes, and attending the Cultural Event nights." While this trusting relationship took time to evolve, they embraced her and other non-Tribal staff members "to carry on their fight." Thus, her dedication for the preservation of Tribal culture and remediation and restoration of the natural resources facilitated her involvement in the STEM education study.

Lauren acted as a co-collaborator in the Lake Management Summer Youth Internship Program and affiliated STEM education learning opportunity. Specifically, Lauren assisted in the development and instruction of several key lessons affiliated with the characterization, remediation, and restoration of injured natural resources in the Coeur d'Alene Basin. Her empathy for the Tribal community and Coeur d'Alene Basin was demonstrated through her involvement in this study and attributed to the youth interns' development in the pillars of stewardship and guardianship.

To continue the youth interns' interest and employment in STEM for the Tribe, Lauren has advocated for an additional internship opportunity for the youth interns after the completion of the

STEM education study. This additional opportunity will help maintain their interest in the STEM career fields and development in the Pillars. This extension reflects her avid encouragement for the involvement of Tribal members in STEM leadership roles for the Coeur d'Alene Tribe.

Chris

Chris is a Coeur d'Alene Tribal member and defines the term culture as "one's place, one's identity with place, it's their history with that place, one's whole being…I see culture as internal." Born and educated on the Coeur d'Alene Reservation, Chris has developed a deep connection and love for her place and the Tribal community. This connection was influenced by her interactions with the natural environment and connection with Tribal elders. These connections have developed her perception of place, which is tied to the people of the Coeur d'Alene Tribe.

Chris has applied her connection to place and community to the education of Tribal youth. Chris entered the field of education as a k-12 educator in the local Tribal School. After receiving her doctorate in Education, she has served as a primary staff member in the Coeur d'Alene Tribe Department of Education for the past 18 years. She currently serves as the Director of Education for the Coeur d'Alene Tribe. During her time with the Department of Education, Chris has strived to implement the framework of the Pillars to develop leaders of the Tribal community. The implementation of this framework was demonstrated in the STEM education learning opportunity. Serving as a lead collaborator in the development of this study, Chris assisted in the development of the STEM education program and affiliated activities. Through her guidance, the framework of the Pillars was implemented to measure the leadership development of Tribal youth in STEM.

Reflecting upon the STEM education study, Chris felt that the Summer Youth Internship and affiliated STEM program addressed each pillar and furthered the youth intern's connection to place and interest in STEM. Chris witnessed this development after hearing both interns speak about their past experience with the internship opportunity. Both interns were able to articulate western STEM concepts as related to their Tribal community and culture. The content covered during the internship provided the interns with an opportunity to develop a voice and a relationship for their homeland which facilitated their growth as members of the community and stewards for their place

Appendix E- STEM Education Study Interview Questions

Adult Participant

1. Tell me about the term culture and what it means to you? *(relationship)*
    a. Specifically, the culture of the Coeur d'Alene Tribe.
2. What is your perception of place? *(relationship)*
3. Did the internship and affiliated STEM education program help the interns develop a relationship to their place? *(relationship)*
4. Did the internship and affiliated STEM education program enhance the intern's respect and familiarity with the Coeur d'Alene Basin? *(respect)*
5. Tell me about the Pillars of Coeur d'Alene leadership? *(responsibility)*
    a. Do you think each pillar was addressed during this internship?
    b. How can we address each pillar within the internship?
6. Did the internship provide opportunities for students to "give back" (reciprocity) their newly gained skills and understandings to the community? *(reciprocity)*
    a. If so, in what ways?
7. Do you think this internship prepared the youth for a career readiness in the Tribal STEM workforce? *(responsibility)*
8. How well did this STEM education learning and internship opportunity serve the community? *(reciprocity)*
9. On a scale of 1-10 (1=negative, 10=positive) how would you rate this program?
    a. Reaching youth?
    b. Teaching science content?
    c. Teaching about the place?
10. Is there anything else you want to tell me?

Youth Intern Participant

1. What is your perception of place? *(relationship)*
2. Tell me about the Coeur d'Alene Basin. *(respect)*
3. What does culture mean to you? *(responsibility)*
4. What career would you like to pursue? *(responsibility)*
    a. How will you achieve this career?
    b. What educational and professional preparation will you need to pursue?
5. Tell me about the environmental quality of Coeur d'Alene Basin. *(respect)*
    a. What about the toxic metals?
    b. On a scale of 1-10 (1=poor, 10=good), how would you rate the environmental quality of the Coeur d'Alene Basin? *(respect)*
6. How would you communicate or disseminate your knowledge about the environmental issues to your family and friends? *(reciprocity)*
    a. Elders
    b. Adults
    c. Youth
7. How did the internship impact your relationship to place? *(relationship)*
    a. Do you have suggestions improved?
8. Tell me about the Pillars of leadership for the Coeur d'Alene Tribe. *(responsibility)*
    a. What has the impact been on you after being involved in the internship?
9. Can you apply this internship experience in the future? *(responsibility)*
    a. Tell me how.
10. On a scale of 1-10 (1=negative, 10=positive) how would rate your experience in the summer youth STEM program? Can you say more?
11. Is there anything else you want to tell me?

Appendix F- STEM Education Study Surveys

2016 Pre-Survey

Scale (1=least; 4=greatest)

1. How well do you identify with the science, engineering, technology, and mathematics (STEM) career field(s)? (Circle one)

1 2 3 4

2. Do you recognize your cultural norms and values within the STEM career field? (Circle one)

1 2 3 4

3. Rate your current knowledge of heavy metal contamination in the Coeur d'Alene (CdA) Basin. (Circle one)

1 2 3 4

4. How often do you visit the CdA River Basin? (Circle one)

1 2 3 4

5. Rate your current interest to pursue a career in the STEM field. (Circle one)

1 2 3 4

6. Describe the CdA Basin in three words?

7. What does the CdA Basin (i.e. River, Lake, etc.) mean to you? How to do you utilize the Basin?

8. What does the CdA Basin mean to your family and elders?

9. Why is the CdA Basin important to the CdA Tribe?

10. Define heavy metals and describe their impact on the environment.

11. What do you hope to learn from the summer internship?

12. What do you expect to gain from this experience?

13. What sparked your initial interest in the STEM field?

14. If you are interested in pursuing a career in the STEM field(s), which emphasis are you most interested in and why?

15. How would you like to apply your interest in the STEM career field(s) in order to support the CdA Tribe?

2016 Post-Survey

Scale (1=least; 4=greatest)

1. How well do you identify with the science, engineering, technology, and mathematics (STEM) career field(s)? (Circle one)

1 2 3 4

2. Do you recognize your cultural norms and values within the STEM career field? (Circle one)

1 2 3 4

3. Rate your current knowledge of heavy metal contamination in the Coeur d'Alene (CdA) Basin. (Circle one)

1 2 3 4

4. Rate your current interest to pursue a career in the STEM field. (Circle one)

1 2 3 4

5. Describe the CdA Basin in three words?

6. What does the CdA Basin (i.e. River, Lake, etc.) mean to you?

7. Why is the CdA Basin important to the Coeur d'Alene Tribe?

8. Define heavy metals and describe their impact on the environment.

9. What did you not expect to learn from this experience?

10. What you learn from the summer internship?

11. What sparked your interest in the STEM field(s) from this internship?

12. After completing this internship, what position within the Lake Management Department would you most like to pursue?

13. How would you like to apply your interest in the STEM career field(s) in order to support the CdA Tribe?

14. Would you participate in this internship with the Lake Management Department next year?

15. What lesson/field work experience did you like the most and the least? Why?

16. List any additional STEM and/or cultural topics you would like to see incorporated into the internship next year.

2017 Pre-Survey

Scale (1=least; 4=greatest)

1. How well do you identify with the Science Engineering Technology and Math (STEM) career field? (Circle one)

1 2 3 4

2. Do you recognize your cultural norms and values within the STEM career field? (Circle one)

1 2 3 4

3. Rate your current knowledge of heavy metal contamination in the CdA Basin. (Circle one)

1 2 3 4

4. How often do you visit the Coeur d'Alene River Basin? (Circle one)

1 2 3 4

5. Rate your current interest to pursue a career in the STEM field. (Circle one)

1 2 3 4

6. Describe the CdA Basin in three words?

7. What does the CdA Basin (i.e. River, Lake, etc.) mean to you? How to do you utilize the Basin?

8. Define heavy metals and describe their impact to the environment.

9. What do you hope to learn from the summer internship?

10. If you are interested in pursuing a career in the STEM field, which emphasis are you most interested in and why?

11. How would you like to apply your interest in the STEM career field in order to support the CdA Tribe?

2017 Post-Survey

Scale (1=least; 4=greatest)

1. How well do you identify with the Science Engineering Technology and Math (STEM) career field? (Circle one)

1 2 3 4

2. Do you recognize your cultural norms and values within the STEM career field? (Circle one)

1 2 3 4

3. Rate your current knowledge of heavy metal contamination in the CdA Basin. (Circle one)

1 2 3 4

4. Rate your current interest to pursue a career in the STEM field. (Circle one)

1 2 3 4

5. Describe the CdA Basin in three words?

6. What does the CdA Basin (i.e. River, Lake, etc.) mean to you?

7. Why is the CdA Basin important to the Coeur d'Alene Tribe?

8. Define heavy metals and describe their impact to the environment.

9. What did you not expect to learn from this experience?

10. What did you learn from the summer internship?

11. After completing this internship, what position within the Lake Management Department would you most like to pursue?

12. How would you like to apply your interest in the STEM career field in order to support the CdA Tribe?

13. Would you participate in this internship with the Lake Management Department next year?

14. What lesson/field work experience did you like the most and the least? Why?

15. List any additional STEM and/or cultural topics you would like to see incorporated into the internship next year.