Adaptive Epistemologies:
Scientific Practice and Environmental Restoration
in a Changing Climate

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Authorization to Submit Dissertation

This dissertation of Shana Lee Hirsch, submitted for the degree of Doctorate of Philosophy with a Major in Water Resources: Law, Management, & Policy and titled "Adaptive Epistemologies: Scientific Practice and Environmental Restoration in a Changing Climate," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

The role of scientific knowledge production in adaptation and change in socio-ecological systems has been under-conceptualized. While gathering data and increasing knowledge will undoubtedly help facilitate decision-making, adaptation within epistemic communities themselves also requires attention. This research explores how scientific practices and the knowledge infrastructures, institutions and organizations that support them are adapting to meet emerging societal goals and shifting environmental conditions. In this ethnographic study, I examine how salmon habitat restorationists in the Columbia River Basin, USA, are dealing with the uncertainty and complexity that climate change is introducing to their epistemic work. I historically situate the development of the field of ecological restoration, analyze how science relates to legal and political goals for salmon habitat restoration, and conceptualize how scientific practice adapts to the uncertainty and indeterminacy that results from climate change. To do this, I engage theoretical concepts from the field of science, technology, and society (STS) with environmental governance and management theory. By examining scientific practice, knowledge infrastructures, and institutions and organizations, I develop a conceptual framework for "adaptive epistemologies," in which scientists alter the way they produce knowledge using the strategies of emergence, acclimation, and anticipation. I argue that we need to consider adaptation to environmental change more closely in scientific work itself, including how collective goals relate to knowledge production, thereby facilitating or hindering adaptation. This can be developed by extending the notion of collective empiricism to call for transdisciplinary engagements between disparate disciplines and fields.

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Finally, this is an ethnographic work, and it would not have been possible without the many individuals throughout the Columbia River Basin who gave up precious hours of their workday (or days off), invited me into their offices and field sites, and shared their hopes, dreams, and fears about the restoration of salmon to the Columbia River Basin. I feel humbled and inspired to have had the opportunity to speak to such a diverse group of dedicated people, many of whom have devoted decades of their lives and their entire careers to the goal of salmon recovery. I hope that their dedication and effort comes through in their words and work that is depicted in this dissertation.

Dedication

To my Dad,
who has taught me how to do so many things.
He might not believe in climate change,
but he has always believed in me.

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Chapter 1: Introduction

Overview

Until I physically attempted to traverse the length and breadth of the Columbia River and its tributaries, I had no way to conceptualize its vastness. Depending on where you are heading, driving across the Columbia River Basin on an interstate highway takes a day or more. If you are travelling into the mountain headwaters, you should be prepared to drive for several more hours on gravel roads. While this requires some dedication on the part of the driver, the salmon that have migrated back to those remote streams make my road trip seem trivial in comparison. Some of these fish have travelled hundreds of miles and passed over eight major dams—in each direction—to get there. Whether they are hatchery or wild fish, they connect these remote streams to the ocean by bringing back marine nutrients in their flesh.

The complexity of their lives, and of the environmental and social makeup of the entire Columbia River Basin, often seems overwhelming. Yet people throughout the basin have been working for decades to understand it. And now, ecological restoration is attempting to reverse the environmental degradation that has brought these salmon species close to extinction. Restoration of salmon habitat has more support today than it ever has, and over the past few decades, a large economy, or even "industry" has emerged to support this restoration effort. Parallel to this, an epistemic community of restorationists has developed to support this work through ecological monitoring and scientific application of environmental management tools. Currently, however, another layer of complexity is being introduced: climate change.

Climate change can already be seen and felt in the Columbia River Basin. The winter of 2014-2015 brought a "snow drought" to the—usually white—peaks of the Cascades and the Northern Rockies. The first six months of 2015 were the warmest ever recorded, and the wildfire season was the most severe the region had experienced in modern history (Blunden and Arndt, 2016; Vano et al., 2015; NIFC, 2017). "Climate change is something that we have been living through essentially for the last 50 years," one land manger observed, “you can already see these trends in the weather stations and at the flow-gauging stations” (R 20).

Scientists corroborate the changing climate that Pacific Northwest residents are witness to. Across the Columbia River Basin, rivers and streams are warmer than ever before (Mote et al., 2013; 2016). Most watersheds are experiencing a shift from high-elevation precipitation in the form of snow to rain, which is raising water temperatures to levels dangerous to salmon (Mantua, et al., 2010). The changes in snowfall and precipitation in the mountains are, in turn, affecting the hydrograph of the rivers and impacting fish migration, spawning, and rearing (Rieman and Isaak, 2010). In 2015, hundreds of thousands of salmon perished in a massive die-off due to low river flows and fatally-high temperatures (NW Council, 2015). Environmental change is becoming increasingly apparent, and ecological restorationists working to restore endangered salmon habitat in the basin are having to adapt their scientific work and management practices in order to meet changing conditions. Yet these environmental changes are adding a new layer of complexity and uncertainty to ecological restoration of salmon habitat (Beechie et al., 2012). While policy makers, scientists and engineers all recognize that ecological restoration is critical for maintaining biodiversity and mitigating the impacts from climate change, it is still unclear whether, and how, salmon can be recovered and their habitat restored to the Columbia River Basin.

The scientific effort to understand, manage, and restore habitats has never been straightforward. Defining seemingly simple concepts such as “natural” or “desirable” ecological states has always proven to be problematic. Coming to a consensus on the best way to value and regulate nature while maintaining multiple uses is even more difficult. The meaning of restoration, at its core, is suffused with the idea that it is desirable to return an ecosystem to a historic state of some form, yet restorationists have increasingly been questioning whether this “historic fidelity” is even possible (Light et al., 2013; Hobbs et al., 2013). The uncertainty introduced by climate change challenges restorationists working to measure and identify ecological thresholds and create management goals (Suding and Leger, 2012; Hobbs et al., 2013). Common scientific and management tools such as ecosystem equilibrium models and historic range of variability are no longer reasonable metrics for success because historic conditions no longer exist

(Seastedt et al., 2008). In response to these challenges, adaptive management and planning are often called for, yet it is unclear exactly what this recommendation entails in terms of scientific practice or management actions (Keith et al., 2011). Restoration ecologists have also pointed out that it is difficult to manage for change when many of the practices and policies in place today were developed based on assumptions of a stable climate and model of ecological equilibrium (West, 2009). Because of these issues, the urgent desire for solutions within the restoration community is often coupled with a sense that there is not enough time to employ the scientific method. In the field of ecological restoration, anticipating the future is becoming an increasing preoccupation.

To deal with this conceptual shift, new "paradigms" have been called for (Choi, 2000). New theoretical concepts have been introduced, such as "hybrid ecosystems," which recognize the need to orient towards a future ecological state (Choi, 2004; Hobbs et al., 2009), or "novel ecosystems" that contain species combinations that have not previously occurred (Hobbs, 2006). Assisted migration—moving species outside of their home range in order to help mitigate loss of biodiversity—may even be necessary (Corlett, 2016; Hobbs et al., 2009; Dunwiddie et al., 2009). The idea of protected areas for conservation worldwide has even been called into question as particular species and ecosystems are tied to places that may no longer support them (Heller and Zavaleta, 2009; Hansen et al., 2010). The effects of climate change have also led some key voices in the field to claim that traditional restoration goals are now "unachievable" (Zedler et al., 2012; Hobbs et al., 2013). This may, indeed, be the case for some Columbia River salmonids, as water temperatures and flows shift drastically, making it difficult for them to survive in some of their historic range (Mantua et al., 2010).

While theoretical advances in the field of ecological restoration have been crucial in coming to terms with the fact that there will likely be a "no-analog" future (Williams and Jackson, 2007), exactly how they are negotiated by ecologists and practitioners is not well understood. Even though climate change raises fundamental theoretical and practical issues for riparian and instream habitat restoration in the region, many restoration practitioners still worry that future climate change scenarios are rarely incorporated into restoration planning. Instead, restorationists working in the field often make decisions on a day-to-day basis, experimenting with and altering the river landscape as they try to restore salmon habitat, manage for future climatic change, and deal with high levels of scientific uncertainty and indeterminacy. How will the field of ecological restoration tackle these issues and create practical solutions to adapt to climate change? How does the field anticipate the future, and shift from looking to the past for guidance? And, more broadly, how does a scientific field *itself* adapt to climate change?

The Context of the Columbia River Basin

The Columbia River Basin encompasses a diverse landscape roughly the size of France. The headwaters of the Columbia River begin in the Rockies and the Cascade Mountains, draining dozens of sub-basins and major tributaries including the Snake, Salmon, Clark Fork, Willamette, and Yakima Rivers in the US, and the Kootenay and Okanagan Rivers in British Columbia. Almost all of the precipitation that falls on Idaho, and Oregon and Washington east of the Cascades, as well as large areas of Montana and British Columbia, drains through the system, reaching the Pacific after funneling through Portland and a 47-mile-long estuarine system at its mouth. Restoring salmon and their habitat to this immense and diverse region is no easy task.

The scale of the Columbia River Basin (over 250K sq. mi.) and the complex life cycle of salmonids make the effort to restore endangered fish populations highly intricate. The Columbia River is the fourth-largest river by discharge in North America; it crosses through seven state boundaries and numerous sovereign tribal nations, and constitutes a major international transboundary river. Straddling the border of the United States and Canada, The Columbia River Basin is not only ecologically complex, but also the site of international diplomacy through the Columbia River Treaty, which includes negotiation over water rights for hydropower generation and flood regulation to protect major US cities as well as communities along the river in British Columbia. While the Columbia River Treaty between the United States and Canada does not mandate consideration or coordination of issues related to ecological integrity, this topic continues to emerge in transboundary talks (Cosens and Williams, 2012). Adding function as a “third prong” to the treaty was even recommended by the US Entity in the Treaty Review process (US Entitity Treaty Review, 2013). Any salmon restoration effort within the Columbia River Basin must therefore be coordinated across State, Federal, and Tribal boundaries, as well as between public and private land owners, making management and monitoring along the river continuum a complex problem. Until recently, there has been little watershed or basin-wide coordination or monitoring of restoration efforts (Katz et al., 2007).

To add to this ecological and social complexity, many salmon species also migrate throughout the northern Pacific Ocean, and this spatial and jurisdictional complexity along the river continuum and into the ocean has made any attempt to restore salmon throughout their entire habitat and life history wildly complex. Regulation, recovery, and restoration of salmon species must therefore be organized between international marine waters. In the United States, the National Oceanic and Atmospheric Administration Fisheries Service (NOAA), along with state fish and wildlife agencies and coordinated intertribal bodies such as the Columbia River Inter-Tribal Fish Commission (CRITFC) are major players tasked with implementing the restoration effort. Meanwhile, organizations such as the Northwest Power and Conservation Council (NW Council) help coordinate and distribute habitat restoration funding for hydropower mitigation efforts by the Bonneville Power Administration (BPA). Individual consulting and engineering firms, tribal natural resource departments, and community groups also play an important role in the recovery effort.

The Columbia River and its tributaries were transformed during the first half of the Twentieth Century, as large-scale hydropower and irrigation projects sought to put the power of the river to work (White, 1995). This transformation required a profound simplification of natural complexity (Hirt and Sowards, 2012). During this period, nature was altered on a massive scale, and the scientific and natural resource institutions and organizations that were set in place to support this transformation still influence the material possibilities in the basin today, as hatchery science and fish passage technologies became the preferred ways to tackle salmon decline (Taylor, 1999). Habitat loss due to hydroelectric infrastructure, agriculture, forestry, and municipal development have all been major factors in declining populations of salmonids in the basin, yet habitat protection was not considered a priority until the late twentieth century. Despite this, it is now widely recognized that habitat restoration *is* critical to promoting salmon survival, particularly in rearing and spawning phases of their life-cycle (Stanford et al., 2006).

Hydroelectric dams on the Columbia River and its tributaries provide over half of the electricity-generating capacity for the Pacific Northwest region of the United States (NW Council, 2013). Mainly constructed during the dam-building era beginning with the New Deal in the 1930s on into the 1970s the thirty-one dams have transformed the material relationships in the region in complex and contentious ways. While the economy of the Pacific Northwest may have benefited from this inexpensive, renewable, and mostly state-owned energy source, these dams, along with development and exploitation of the rich natural resources of the Pacific Northwest, have irrevocably altered the ecosystem and devastated the anadromous fish populations that call it home.

As a direct result of this habitat loss due to hydropower development, there are currently thirteen salmonid species that are listed under the Endangered Species Act (ESA) as either endangered or threatened. Salmonids—both salmon and trout—have complex life cycles, which can entail adult migration of up to hundreds of miles upstream from the ocean to spawn in tributaries. Juvenile fish then return to the ocean after spending the beginning of their life in freshwater. They migrate throughout the North Pacific for two to six years while they grow to adult fish. While the dams were originally thought to impact salmon mainly by creating barriers to upstream migration, there is now a better understanding of their multiple impacts. These impacts from dams include decreasing juvenile survival as they migrate downstream to the ocean through higher water temperatures, longer downstream migration times, fluctuations in oxygen levels, and mortality through contact with dam infrastructure (Dauble et al., 2003). Although it is difficult to know exactly how much is spent across the region, is estimated that at least $300 million USD per year is spent on habitat restoration in the Columbia River Basin (Katz et al., 2007; Bernhardt et al., 2005; Rieman et al., 2015). In 2016, the NW Council alone allocated $274.2 on recovery, with $117.9 million going directly to habitat restoration and protection (NW Council, 2017). Many still wonder if this is enough, if it is too late, or if restoring habitat is actually making a difference in populations that are still declining (Katz et al., 2007).

Uncertainty within and between social and ecological dynamics is only magnified when climate change is over-layed onto the spatially and politically complex management regimes within the basin. As more precipitation falls in the form of rain rather than snow, water temperatures are increasing, summer flows are decreasing, rivers are becoming "flashier" with storm water, and wildfire risk and intensity is increasing year on year (Nolin et al., 2012). Researchers have found that changes in both precipitation and temperature are already impacting the hydrologic regime of the basin, and these changes are only intensifying (Mote et al., 2013; Mote et al., 2003). Climatic changes are expected to shift the spring peak flows earlier in the season, while at the same time decreasing late-summer flows (Mote et al., 2013; Mote et al., 2003). Yet snowmelt-driven summer flows are what allow many salmon populations to migrate to headwaters during the spawning phase of their life-cycle. Meanwhile, the increasing water temperatures in lower elevations are also negatively impacting salmon survival and spawning, making healthy, cooler, higher elevation, headwater stream habitats even more critical "climate refugia" (Mantua et al., 2010).

For those tasked with restoring salmon habitat in the Columbia River Basin, the scope and scale of this "wicked" problem can be overwhelming. Yet despite these difficulties, the restoration of salmon habitat in the Columbia River Basin is progressing. The Columbia River Basin is fairly unique in terms of the scope and scale of restoration in that it is driven by mandates from the ESA and Tribal Treaty Rights. As such, it is relatively well funded compared to restoration efforts in other river systems. While the sole purpose of the ESA is to prevent extinction at "whatever the cost," it is also important to recognize that the loss of fisheries has fundamentally impacted the treaty rights of Native American tribes in the region. Due to the impacts of hydropower development, they have suffered the loss of a fundamental First Food along with fishing sites of irreplaceable cultural and spiritual significance (Pearson, 2012; Barber, 2005). A growing demand for and recognition of Tribal treaty rights and environmental equity (Cosens, 2012) is adding to the call for mitigation and habitat restoration from both legal and environmental justice standpoint.

Yet despite the mandates and the money, the restoration of salmon and their habitat to the Columbia River Basin is still a herculean task. In a sense, people in the Pacific Northwest are trying to do something that has never been done before: to maintain a highly regulated river system that supports a hydro-industrial complex while at the same time maintaining anadromous fish. Restoring salmon to the Columbia River

Basin—“fixing” all of the problems caused by an industrial hydro-system—is, in a sense, a kind of mega-experiment on a massive scale. Yet this large-scale experiment was never meant to be one, and as such, there is no overarching experimental design. As the restoration effort has evolved, the epistemic community of restoration specialists has adapted as new problems and information arises, and we are only just discovering what it means to manage such a task.

Conceptualizing Adaptive Epistemologies: Adaptation of a Field

Natural resource crises often transcend science, and these crises result from much larger political and economic forces. Yet even in these situations, the value of nature, the role of expertise, and implications of uncertainty and ignorance influence how scenarios play out in practice (Bocking, 2004). While scientists do need to communicate effectively to managers, studies on the sociology and history of science demonstrate that the dynamic between science and policy is more complex than simply communicating science clearly to policy-makers who will then use it. Science and politics cannot be separated, and this becomes especially evident in the Columbia River Basin, where science is increasingly being fought over in courts over the past several decades (Blumm and Paulsen, 2013; Doremus and Tarlock, 2005).

Ecological restoration of salmon habitat in the Columbia River Basin offers a unique case study of an epistemic community at a critical time of uncertainty, adaptation, and change. Restoration in the Columbia River Basin is an example of a collective effort run by expert systems of specialists who work to fulfill the needs of society and its institutions by producing knowledge. But, science is also a form of work, and within these larger systems lie the daily practices of scientists and practitioners in the field or in the lab as they go about their work modeling ecosystems, monitoring streams and rivers, and prioritizing and planning for a climate-changed future. The transformation—or adaptation—of the science of ecological restoration will have important and measurable impacts on the ways in which natural resource managers and scientists respond to climate change, including the ways that law and science relate to facilitate alternative futures and the way that a climate-altered nature is valued and imagined.

Science is always changing, and epistemic cultures that embrace and recognize change as inherent are more likely to be able to anticipate and adapt to exogenous changes, both environmental and social. Expert systems increasingly constitute what has been called a “knowledge society” (Knorr-Cetina, 1999), and organize our material and social worlds in particular ways (Giddens, 1990). The ways in which knowledge itself is produced, and how this knowledge production can adapt to environmental change is therefore an important social dynamic to understand. Yet, while knowledge and learning are considered key components of adaptive socio-ecological systems (SESs), these relationships have not been explored or articulated in detail. The goal of this research is to explore how scientific practices and the infrastructures, institutions and organizations that support them are adapting to meet emerging societal goals and shifting environmental conditions. In this ethnographic study of salmon habitat restorationists in the Columbia River Basin, I historically situate the development of the field of ecological restoration, analyze how science relates to legal and political goals for salmon habitat restoration, and conceptualize how scientific practice adapts to the uncertainty and indeterminacy that results from climate change. To do this, I engage theoretical concepts from the field of science, technology, and society (STS) with environmental governance and management theory.

By examining knowledge production and scientific work itself, I aim to advance knowledge on adaptive governance and resource management. Adaptive management is based on the contention that as science is conducted and management conditions change, new information will become available and actions may need to be adjusted. Despite its seemingly simple formula, adaptive management has been difficult to fully implement in practice (Blumm and Paulsen, 2013; Volkman and McConnaha, 1993; Ruhl and Fischmann, 2011; Doremus, 2001; Benson and Stone, 2013; Craig and Ruhl, 2014). While the cycle of adaptive management recognizes science and knowledge production as critical elements, there has been little examination of how scientists themselves deal with and adapt to changing management goals as they produce knowledge. This study seeks to understand how knowledge production is or is not adaptive, and normatively consider what it would mean to facilitate or support adaptation in science. What follows is a case study aimed at answering these questions: *How do scientists and environmental* *managers adapt both epistemological and management practices to accommodate environmental change and uncertainty? How do scientists and environmental managers deal with climate change in their practice? How do the relationships between science, law, and natural resource management shift when confronting the need to adapt?*

Scholars have highlighted the science-policy interface as a problematic area for effective response to climate change, and they have called for better communication at this boundary in order to support more sustainable transitions (Cash et al, 2003). Although there are many questions that need to be answered in order to address pressing problems in environmental and natural resource management, and there is no doubt that scientists play a pivotal role in finding solutions, these solutions can often be more a matter of careful attention to politics than simply providing more data (Bocking, 2004). STS provides a challenge to the idea that more, better, or clearer science will solve environmental management problems: it urges us to look for the basis of these problems in different locations, especially in the production of knowledge itself. To address complex environmental issues, we need to understand how knowledge about environmental issues is produced, exchanged, and used by society. This requires interrogating the practice of science, the institutions and infrastructures that facilitate this practice, and the cultures and virtues from which this practice emerges.

This study employs an interdisciplinary perspective of scientific and epistemic work, and explores conceptual implications using concepts from historiography of science, philosophy of science, social theory, and STS. Literature that addresses the science-policy interface from an environmental management perspective is often focused on reducing uncertainty by doing "more" or "better" science or seeking to "bridge the gap" in communication between scientists and policy-makers or managers. This type of work usually conceptualizes the science-policy interface as consisting of divided domains and unidirectional flows of information from science to policy or management. In contrast, STS is concerned with understanding how science is constructed—not only the construction of knowledge, but also the construction of methods, epistemologies, and institutions (Sismondo, 2010). With its roots in social constructivism, but with ongoing theoretical and empirical development that moves well beyond this base, STS has essentially two broad channels of inquiry: studying the sociology of the scientific community itself, and studying the sociology of the scientific community's relationship to the rest of society (Yearley, 2004). Of course, these two fields of study overlap, and in order to understand how the scientific community relates to society, it is necessary to understand the sociology of science and its actors (Yearley, 2004). In turn, understanding the controversies between science and law, policy, and environmental management requires an understanding of how scientists interact with, create, perform, and disseminate this knowledge to policy-makers and the public. This often occurs in a co-productive way, in which science and the institutions and organizations that support it influence each other in an iterative way (Jasanoff, 2004). Case studies of scientific practice are some of the most recognized works of STS literature, and some of these even focus on controversies surrounding environmental management (Yearley, 2008). These studies seek to clarify how scientists produce knowledge in the field or in the lab (Latour and Woolgar, 1979; Callon, 1986; Knorr-Cetina, 1999; Kohler, 2002). Work in STS has demonstrated that controversies over knowledge, its production, and exchange are usually settled through power struggles that are cultural, social, political, or legal in nature.

In the following chapters, I bring disciplines from STS and environmental governance and management into conversation in order to make what are often invisible or ignored dynamics of adaptation and change in scientific work into view. I develop a conceptual framework for "adaptive epistemologies," in which scientists alter the way they produce knowledge using the strategies of emergence, acclimation, and anticipation to adapt to environmental change. In philosophy, epistemology is the study of knowledge and justified belief. It asks questions about where knowledge comes from, how it is structured, and how it is justified. I use the term epistemologies more broadly, to refer to the production and dissemination of knowledge. In using the term "adaptive epistemologies," I draw from these meanings, yet this study does not employ the term in the strict philosophical sense. Instead, I use it relative to the social nature of epistemology, or "social epistemology," which acknowledges the social, historical, and cultural context of epistemological work (Solomon, 2008). In the context of social epistemology, the production of knowledge is done not only by individuals, but it is also a social activity. Social epistemology itself is a diverse and multidisciplinary field, but its focus on the "normative tools" for evaluating what scientists do, and "normative goals"

(Fuller, 1993) for intervention in knowledge production fit well with the aims of this work—to understand what scientists do to deal with environmental change in the applied field of restoration ecology.

In the following chapters, I examine how ecological restorationists are adapting to climate change in order to develop the concept of "adaptive epistemologies." To do this, I draw from multiple disciplines to examine several sites of knowledge production and scientific work, including: scientific practices, knowledge infrastructures, and institutions and organizations. By examining these different sites, the diverse strategies that restorationists are using to deal with change at multiple scales and sites of knowledge production become visible. These strategies include emergence, acclimation, and anticipation. *We need to consider adaptation to environmental change more closely in science, including consideration of how collective goals relate to knowledge production, thereby facilitating or hindering adaptation. I argue that inter- (and trans-) disciplinarity provide a productive space for exploring these complex problems and can foster more adaptive epistemologies.*

Waiting for certainty from science is not only impossible, but infeasible. Delays in making decisions and taking action can have devastating results on biodiversity (Dietz and Stern, 1998). The normative aim of this work is to enable both environmental managers and scientists to be more effective when dealing with climate change in the Columbia River Basin, as well as globally. In addition to contributing to theoretical work on adaptation in environmental management and social studies of science, I hope that the conceptual framework of adaptive epistemologies will be of value to people who are dealing with the immediate effects of climate change in their own work. While conducting the fieldwork for this study, ecologists, managers, and policy-makers all expressed a need to understand the changes occurring throughout the basin, and they wanted to know how climate change might likely affect their science and their practice. But, what I heard most often, was a need for practical advice and tools for incorporating climate change into their work. While the specifics of how this might be done are not the main objective of this research, the framework of adaptive epistemologies was created with users in mind. I want to give scientists, mangers, and policy-makers a conceptual space to think about where they might focus their own efforts in strategizing for climate change in the context of knowledge production, and I hope that reflecting on the strategies described in “adaptive epistemologies” will provide a place to begin their own exploration for dealing with climate change in their work.

Outline of the Chapters

The effects of climate change in the Columbia River Basin and the Pacific Northwest are apparent, and they are growing. From drought, wildfire, to flooding, participants in this project, as well as the wider community of people concerned with restoring salmon to the rivers and streams of the region have been trying to figure out what to do. Yet while *un*certainty about what to do seems to be growing exponentially, certainty that environmental conditions are changing is also growing. Those working on salmon habitat restoration can see the ways that environmental conditions are shifting, and it is affecting their work. This puts restoration practitioners in a key location for instituting adaptive changes in the short term. They are taking action and shifting their practices through facilitating the emergence of alternatives, acclimating their methods to move forward in their work, and anticipating the future.

In the following chapters, I explain these strategies and use empirical examples to describe how restorationists use them to deal with change. Throughout the dissertation, I engage with a set of cross-disciplinary concepts from STS, philosophy of science, social theory, and adaptation in socio-ecological systems. The result is a contribution to our understanding of the role that scientists—and knowledge itself—plays in adaptive change.

Chapter Two, “A Science for the Columbia River,” begins by historically situating the development of salmon science and ecological restoration in the Columbia River Basin. I use archival sources from the University of Washington Special Collections, which contain materials from the Fisheries College, one of the oldest in the world—founded in 1919. The key archive that was used for this research is the Harlan B. Holmes papers, which contains the daily work journals of a fisheries scientist as he documented experiments and travelled throughout the basin during the 1920s-50s. During this time, he and many others were busy developing a scientific infrastructure for salmon science in the basin. Holmes travelled throughout the Columbia River Basin collecting data on salmon decline and recovery, and his journals give a personal and historical account of scientific work that provides a conceptual baseline and sets up the idea of change in science.

In Chapter Three, “Climate Change and Adaptation,” I introduce the different kinds of changes that the Columbia River Basin has experienced. These include changes that Tribes have been dealing with for over a century, including institutional, cultural, economic and political changes, in addition to the drastic ecological transformation of the river into what historian Richard White (1994) has called an “organic machine.” Tribal treaty rights and the ESA signal a shift in the status quo of management of the river for development, and now climate change is offering a new challenge. This challenge has been met by scientists working to restore salmon and their habitat in different ways, which I describe as strategies that contribute to adaptive epistemologies.

In Chapter Four, “Investigating Adaptive Epistemologies,” I define and explain the concepts from science studies that will be used to explore these adaptive strategies. These include scientific practices, knowledge infrastructures, and institutions and organizations. In addressing the co-production of science and the institutions and organizations with in the Columbia River Basin, I outline the importance of the social and legal context. Institutions and organizations are also underpinned by supporting “knowledge infrastructures” that enable knowledge to be produced in particular ways, including the metrics used to measure success. I then move on to describe how restorationists are embedding new epistemic cultures and virtues in their work by adopting adaptive strategies through their practices.

In Chapter Five, “Emergence,” I describe the strategy of emergence, in which an evolving collective empiricism embraces multiple types of restoration efforts, including improvisation and experimentation. Restorationists are becoming more willing to employ novel restoration strategies that at times seem at odds. I highlight how this is a strategy for dealing with uncertainty and the emergent mess of natural systems, or what Taylor (1995) calls “unruly complexity.” I illustrate this strategy through the example of beaver restoration, where unfamiliar concepts and methods are tolerated in order to “see what happens,” and foster emergence of new restoration tools for dealing with climatic change. Because multiple cultures will contain multiple surfaces of emergence, an epistemic community that embraces multiple disciplinary cultures is more likely to have more solutions emerge.

In Chapter Six, “Acclimation,” I explore how restorationists use the strategy of “acclimation” to describe a process of adjustment in which restorationists are forced to use a pragmatic approach to knowing as well as trained judgment to make decisions in the face of uncertainty. I use the example of ecological monitoring to describe explore this strategy in practice, and how it influences the knowledge infrastructures that are created. By using the strategy of acclimation, restorationists adjust their practices in a relatively short time period. This requires developing knowledge infrastructures that take the future, or “the long-now” into account, as well as changing their practices to incorporate more “trained judgment.”

Chapter Seven, “Anticipation,” introduces the strategy of anticipation through modeling. I define the strategy of anticipation as a re-orientation toward the future by using scientific practices and knowledge infrastructures to facilitate the exploration of these possible futures. Anticipation represents a shift in restoration-thinking to the future, and helps overcome epistemic indeterminacy. Models allow restorationists to anticipate and explore potential futures, and the strategy creates openings for technoscientific interventions. Anticipation represents a shift in restoration-thinking: instead of looking to the past for baselines to restore *to,* restorationists are orienting their work to the future through a new, anticipatory epistemic culture.

In Chapter Eight, I conclude that teasing apart what are often cited as key components of adaptive socio-ecological systems: learning and knowledge, deserves attention. Science is a collective effort and an important tool that society needs to address environmental and social change. The strategies of adaptive epistemologies highlight the roles that knowledge production plays in adaptive change. This is part of an evolving collective empiricism where collective modes of working contrast with competitive modes, and experimentation, improvisation, and interdisciplinarity are embraced, so that novel strategies can emerge. By becoming aware of the dynamic nature of knowledge production, we can open a new space for intentionality and adaptation within science itself. This can be developed by extending the notion of collective empiricism to call for transdisciplinary engagements between disparate disciplines and fields.

This project is an interdisciplinary endeavor, and as such it covers a lot of ground. In doing so, I hope to give enough information to be able build a depth of understanding about these fields, but inevitably, some details must be left out. I hope that, in trying to satisfy many readers, I don’t end up satisfying none, but I will take that risk in the hopes that it will spark a new, transdisciplinary conversation. I hope that the “adaptive epistemologies” framework can provide insights for not only scholars who study scientific practice, but also those that work in the field of natural resource management or ecological restoration and are seeking to encourage strategies for adaptation.

Chapter 2: A Science for the Columbia River

Establishing Salmon Science

In the summer of 1923, Harlan Holmes embarked on his second field season as a biologist for the US Department of Commerce Bureau of Fisheries. His work would eventually take him throughout the Columbia River Basin, traveling by train, bus, ferry, canoe, and whatever rides he could hitch from cannery owners and fellow scientists. In later years, he brought his own car for this journey, but this meant that many of his field days were spent as a shade-tree mechanic, trying to keep it running as he drove around remote areas of Washington, Oregon, and Idaho. His task was to survey the Columbia River Basin: to find places where salmon still thrived, where they were no longer present, and locate places to build hatcheries and field stations for scientific work. He was a fisheries scientist, and as a trained biologist, he wanted to measure fish, mark fish, and count fish in order to understand what their life-cycles entailed and how changes in the environment affected the different species. He was also a conservationist, and the declining salmon populations worried him. He saw this as an issue to be remedied, and he brought science as his tool in this effort. His career, from 1920s into the 1960s, working for both the Department of Commerce and the US Fish and Wildlife Service, spanned a time when the "salmon crisis" was beginning to be recognized, and to figure out the best way to remedy these problems, science was being called upon. In this way, he was a forerunner to the restorationists that are working on salmon conservation today, and his field notes—stuffed with jottings, plans, photos, and fish scale samples—describe his scientific practices and his conservation ethic as he went about his work[1].

In the early Twentieth Century, the Columbia River was dominated by large canneries. Fish wheels unceasingly scooped vast quantities of fish from the river (Taylor, 1999). In his first two field seasons, Holmes travelled throughout the Lower and Mid-Columbia from cannery to cannery, trying to enroll workers into his "marking" work. Holmes wanted to set up a monitoring program in order to mark fish so that he could simply understand where they were coming from and where they were going. At this

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[1] The Harlan Holmes Papers are located in: University of Washington Libraries Special Collections, Harlan Holmes Papers, Acc. 2614-001.

time, little was known about salmon life-cycles, and there was little understanding about distinct populations, runs, or “races.” He also wanted to know exactly how many fish actually survived the canneries’ fish-wheels on their way up the Columbia. Holmes was one of the early fisheries biologists tasked with figuring all this out.

The first step in his plan was to find cannery workers and fishers who would join his scientific enterprise to mark and measure fish. At this time, there was very little documentation about the fish that were being caught. On his way to the field, he stopped and bought twenty-five yard sticks to put in canneries: “such places are particularly in need of measuring sticks,” he wrote (Holmes, June 17, 1922). In addition to setting up measuring stations, he developed his own traps to catch fish at particular points along the river, scooping them up and putting them into ponds or tanks that he created on site. There was almost no infrastructure to support Holmes’ work, and so he built his field-labs from scratch. He had to set up a “home” for science (Geissler and Kelly, 2016). Many of his days were spent moving equipment or constructing traps and ponds. He also spent a lot of time negotiating with hatchery and cannery owners in order to secure places to establish his longer-term experiments.

Having found some locations to conduct his science, he set to work scooping up fish. But this didn’t always go according to plan. In fact, he didn’t have much of a plan to go by, as he was conducting novel experiments that hadn’t been done before. He didn’t have any expert or any textbook to consult. Instead, he tried different methods, adapting them as he went. Holmes often lacked equipment, and this too, he improvised along the way. For example, on May 22nd, 1923, Holmes spent the day catching fish for marking near Lake Quinault, just north of the Columbia River Basin. He recorded in his journal:

> Made a circular net about 4 ft in diameter and took it down to the trap at the outlet of the lake where we easily caught several hundred fine looking fish about 3 ½ inches long. Brought them back to the hatchery in a milk can, pouring water continuously on the way (Holmes, May 22, 1923).

But the next day he found his previous day’s work lost:

> May 23: Got up around 6 this morning to catch more fish. Went to the hatchery and found about half of those placed there last night, dead. I caught a few more and transported them carefully from the boat house to the hatchery, a distance of a

> few hundred feet. We spent most of the morning operating a short seine and caught several thousand fish, the most of which were placed in live tanks but a few were taken to the hatchery. I marked a few about noon. It was noticed that many scales were removed in handling and a couple of them died soon. Losses in the hatchery were large even with the most carefully handled fish (Holmes, May 23, 1923).

His field station at Lake Quinault, just outside the basin on the coast of Washington, seemed plagued with problems, and eventually he determined that many of the fish there had been infected with a parasite that rendered his experiment useless. Soon after this incident, he abandoned the project for the season.

Further inland, on the main-stem of the Columbia, he also faced issues with keeping fish alive in adverse conditions, with little knowledge about how to do so, and almost no infrastructure to support his field stations. As he traveled to visit his various field stations, he would leave others in charge. Returning to a field station in Quinault, he found many of his marked fish dead or dying. The person that he had left in charge didn't seem to realize that the food he was feeding the fish was rotten:

> Mr. Larsen seems to see nothing wrong with food which to me seems badly spoiled. This liver, which left Portland Monday and was brought to the hatchery Thursday P.M., was placed in cold running water and ground when needed. The last was ground on Friday morning and kept in a bucket immersed in running cold water. By Sunday the ground liver had a distinct odor and today it not only had a strong odor but showed evidence of forming gas. Had new food not arrived this old food would have been used tomorrow (Holmes, June 12, 1923).

Lack of trained personnel with expertise to support his scientific work was endemic. Holmes struggled with getting all of his workforce to use rigorous methods and take reliable measurements. "I am impressed by the unreliability of certain figures," he wrote in reference to one employees reporting, "Such approximations as this would be worse than worthless even if listed as such" (Holmes, June 12, 1923). Yet, while these difficulties plagued his field-stations, he was forced to forge quickly ahead for lack of time: the marking methods he was developing required him to complete his work before incoming fish runs crossed over with the outgoing, ocean-going fish. Despite setbacks and failed experiments, Holmes worked to refine his methods and by the end of his field season in 1923, he and his team had marked 101,000 fish, recording:

> the extra 1000 to cover losses resulting from overcrowding and lack of sufficient flowing water on May 18, and what loss there has been immediately following marking. This likely more than doubly covers the loss prior to liberating (Holmes, June 12, 1923).

While Holmes' early work for the Bureau of Fisheries may seem crude and lacking rigor, he was building upon previous biological knowledge and practicing his work according to the norms of a field biologist of his discipline in his time.

Science as Historically Situated

Holmes' work in the 1920s, although still recognizable, relevant, and even useful to scientists today, was also different in important ways. Scientific practice is conducted within the context of cultural values and norms of a specific time and place. The cultural imaginary of the Columbia River Basin and the salmon within it that were the objects of Holmes' scientific work were different scientific objects than what they are today. This is not because the fish or the River or the water are fundamentally different, but instead, it is because the science that exists today is situated in a very different time and place. New ways to manage nature emerge from scientific practice. As knowledge about the River is produced, the ways in which we view scientific objects has also changed. Similarly, the scientific virtues that were emphasized during the time of Holmes' field work are different than those today, and although the technologies that Holmes employed were also different, the institutions and organizations that supported and constrained his work have also evolved. Regardless of these differences, the scientific work in the Columbia River Basin of Holmes' day influences what is done today. This is what Pickering (1995) refers to as the "irredeemable historicity of scientific knowledge" (p. 33). The practices of scientists in the past established the basis for the knowledge and the knowledge infrastructures that exist in the present. Historicity, as well as change, are therefore essential features of epistemic communities and scientific practice.

STS and social studies of science situate scientific practice within the cultural values of a time and place, and in doing so highlight changes in the ways in which scientific work is pursued and applied to natural resource management (Bocking, 2004; Yearley, 2008). Kuhn's (1962) groundbreaking work on the nature of scientific "paradigms" first described how scientific truths are located within a particular epistemic community and are subject to change and contestation through time. This work helped to launch a field focused on historically situating science, and it brings with it a valuable lens for understanding how science changes. As such, historically situating ecological restoration in the Columbia River Basin is a good starting point for answering questions about how restorationists are adapting their scientific work to deal with climate change.

Ecological science has had a contested relationship with natural resource management and uncovering these conflicts also helps show how change occurs. What follows in this chapter is a brief history of restoration ecology and ecological restoration, including the major themes that developed in early ecological science and how they have influenced the development of the field. After giving a broad overview of the evolution of ecological restoration, I will shift to explore how the field has developed in the Columbia River Basin. This will provide a basis from which to view the strategies for dealing with climate change in later chapters.

Roots of Ecological Restoration

The Emergence of the Field

The history of ecological restoration as a field of study has been a contested one. Restorationists, ecologists, and philosophers vigorously debate the purpose, goals, values, and meaning of restoration and its normative relationship to management, science, and the public (Bradshaw, 1987; Jordan III et al., 1987; Higgs, 2003). Further, Worster (1987), Kingsland (2005), and other historians of ecology have explored how conflicting ideas about the best way to manage the natural world are evident from within the roots of ecological science itself, and form the basis for ongoing conflicts and divergences.

In Worster's (1987) wide-ranging history of ecological science, *Nature's Economy,* he identifies two threads that run throughout the development of ecology as a scientific discipline. He named them the "Arcadian" and the "imperial" ideals. The Arcadian ideal views nature as holistic, a whole, a community, or a system. It is romantic in the sense that it views relationship with nature as an ideal, where the opposite lies in the alienation and detachment of the industrialized world (Worster, 1987). In contrast, the imperial ideal focuses on reason and, in doing so, tries to classify and understand nature so that it can be understood and controlled (Worster, 1987). According to Worster (1987), both of these ideals are rooted in enlightenment philosophies that were aimed at improving the natural world in order to create a paradise on earth through the scientific endeavor. As such, they consistently reemerge in political and philosophical thought through time, and as they do, they influence the natural sciences and resource management in different ways. For example, early approaches to natural resource management in the US drew on both of these ideals and launched scientific and managerial projects to control national landscapes through increasing legibility, as explorer-scientists worked throughout the nineteenth century to map territory so that it could be efficiently settled and claimed (Worster, 1987; Scott, 1998; Cronon, 1983). From this perspective, the development of the Columbia River Basin and our scientific understanding of it is also embedded within these shifting scientific and natural resource paradigms.

The early goals of process-based restoration were to restore the processes of succession, or to speed them up so that they could return to an equilibrium which had been lost through a disturbance (Bradshaw, 1984). One origin story of restoration finds its roots in Aldo Leopold’s scientific work at the University of Wisconsin Arboretum beginning in the 1930s. There, Leopold worked to restore the tall grass prairie of the Midwest. While this story is often repeated, Allison (2012), finds other possible origins for the restoration enterprise, including indigenous ecologists and hunter-gatherers, who practiced land management through a deep understanding of ecological processes. Or, in early forest restoration in Germany in the 1300s and England in the 1600s (Allison, 2012). Yet an alternative beginning may have been in the late 1700s with the advent of forestry in Europe (Hall, 1997). Regardless of where we begin, restoration has certainly existed for a long time—in one form or another—and humans have worked to repair damaged ecosystems in many different ways, either for the purpose of managing the landscape for productivity or for aesthetic reasons.

In the American West, restoration as a scientific endeavor began in the early 1900s, as land grant institutions tried to restore forests and rangelands to productive conditions. This was partially done through the work of George Perkins Marsh and John Wesley Powell, who saw the west as suffering from over-exploitation in grazing lands and forests (Hall, 1997; Hall, 2005). Some of this work was carried out through the Forest Service's Great Basin Experiment Station, which was established in 1912 (Hall, 2005). This is a different origin story for restoration than the more common one that attributes it to Leopold. Allison (2012) views the origin story of Leopold as being so strong because it links restoration with a "land ethic" of restoring nature for its own sake, not for exploitation (timber harvest or rangeland use), as in the case of the earlier work by Marsh and Powell. This is interesting in relation to the salmon recovery efforts in the Columbia River Basin, because the restoration that is taking place is—first and foremost—to prevent the extinction of salmon. Yet at the same time, there is the assumption that harvest and fisheries are an important impetus for restoring populations. It is these kinds of nature for society vs. nature for nature's sake dichotomies that begin to break down when teasing apart the purpose and goals of restoration. These debates about the soul and the sources of ecological science extend into ecological restoration and restoration ecology itself.

Debating Restoration Today

Regardless of its exact roots, the field of ecological restoration that we know today grew out of the ecological awareness that was developing in the mid 20th Century. Developments within the Ecological Society of America in the 1970s and 1980s helped to launch both the disciplines of conservation biology and ecological restoration. The field of ecological restoration has since developed into its own discipline, with journals, societies, conferences: all of the markers of a fully-fledged epistemic community. The Society for Ecological Restoration (2004) defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability." While this definition seems straightforward, each of the words within it has been debated at length, and some restorationists still disagree with parts. Further, "restoration ecology" is often differentiated as the science of ecological restoration

(Jordan et al., 1987), while the broader field of “ecological restoration” includes not only scientists, but also managers, lay-people, and practitioners. Some see restoration ecology as the more “scientific” or “academic” endeavor of the two. Debate differentiating between these restoration endeavors has certainly been carried out in the two main journals of the field: *Restoration Ecology* and *Ecological Restoration*. Many practitioners and scientists span both worlds, however, and a division is difficult to maintain between the science and its application. As restoration science has increasingly engaged the public in restoration projects, the field has also developed into a more transdisciplinary project, effectively transforming itself to encompass a broader community of practitioners (Gross, 2010). For this reason, I use the term “restorationists” to refer to anyone involved in the greater restoration endeavor, including scientists and practitioners of various sorts.

As the field emerged from multiple disciplines and locations, restorationists, ecologists, and philosophers have vigorously debated the purpose, goals, values, and meaning of ecological restoration and its relationship to management, science, and the public. Throughout the development of the field, there have also been voices that have warned about “dangers” that could derail the restoration enterprise entirely. These warnings include fears of creating an overly technological restoration that would have unintended, negative effects on society as humans become convinced they could “fix” any ecological damage they can cause (Higgs, 2003). These debates continue today, and are often found between those who ascribe to a more engineering-based restoration on one side and those that prefer a more process-based approach.

The origin stories for the field of restoration also influence the approaches and goals of restorationists today. While the school of thought that evolved from Leopold and others in the Midwest was aimed at restoring processes to degraded lands, a more engineering-based restoration developed in western government agencies and land grant institutions. This engineering-based perspective views restoration as a way to reclaim highly degraded land, often where all ecological processes have been completely altered or no longer exist (Allison, 2012). Often these landscapes, need complete reclamation, and can use a pragmatic approach to the establishment of “any ecosystem” instead of none at all (Allison, 2012). These two strands of thinking merged in the founding of the Society for Ecological Restoration in 1988, where restoration of ecological processes became the goal of both types of restoration. However, though the goal became similar, the means through which restorationists believe it should be met still differs. Some restorationists aim for "re-setting" the ecological system so that processes can take over and do most of the restoration work. In river restoration, this is often achieved by removing barriers such as culverts, connecting river channels to floodplains, introducing large woody debris, or reintroducing beavers to alter a watershed. In contrast, the engineering-based approach relies more on regrading streams and modifying channels using heavy equipment, or introducing groundwater through piping systems. Again, the goal may be to restore processes, but how they are restored, and how much initial and continued human intervention is needed to restore these processes varies, and is a point of debate (Palmer et al., 2014).

In 1987, Bradshaw famously asserted that ecological restoration was the "acid test for ecology," believing that it should form the experimental basis for the discipline of ecology itself. Bradshaw (1987) recognized the difficult relationship between management and science in ecological restoration early on, and he worried that its ecological roots were getting "left behind" as restoration turned to the tools of engineering and management to transform nature. In an early collection of essays, restorationists pondered the relationship between science and ecology and worked to define the burgeoning field by debating and drawing boundaries around what restoration was and was not (Jordan III et al.,1987). Some authors have even called restoration a "big lie" that cannot meet expectations to fix what humans have destroyed, and advocate for preservation as the main focus of conservation efforts (Katz, 1992). These debates have been formative to the field, and they are ongoing.

The Goals and Purpose of Ecological Restoration

Restorationists are also still debating the *purpose* of restoration: Is it to return a landscape to a historical analogue? To mitigate for damage done elsewhere? To test ecological theories, such as succession? To reconnect society to nature? The stakes for defining the future of the field seemed high in the early days, with vocal critics and opinions on all sides. This meant that the epistemic community that formed was not accidental, but thoroughly contested through a social process.

Setting realistic goals for restoration continues to be a major issue (Ehrenfeld, 2000). Despite the field coalescing around the Society for Ecological Restoration and its definitions of purposes and goals, there are still ongoing debates. Should restoration be beholden to attaining a specific, historical ecosystem or aim for achieving a state where ecological processes are reintroduced through rebuilding ecosystem structure and function? This is certainly still a debate within the subfield of river and riparian restoration, where mandates to restore ecosystem processes must be balanced with flood protection for infrastructure, as well as demands for flow regulation for hydropower. It is certainly difficult to separate out the "ecological" from the "engineered" in many parts of the Columbia River Basin that have been so transformed.

The Role of Science in Ecological Restoration

Ecological restoration is often seen as a purely practical matter, where science and technology can offer solutions to pre-determined problems (Nilsson and Aradottir, 2013). Yet a closer look at the values behind restoration goals and priorities demonstrates that is not the case. As debates in the field have murmured on through the years, the political nature of ecological restoration becomes clear (Light and Higgs, 1996). One of these debates concerns whether or not cultural values should be included when considering restoration planning (Higgs, 1994). Higgs (1994) was concerned that an overly "technical" restoration could come to dominate the field, ignoring local community participation and involvement in restoration work. These debates center around a problematic division between society and nature, and some see participatory restoration as a partial solution to this problem (Higgs, 1994; Light and Higgs, 1996). A coincident worry centers around restoration becoming overly commodified, through a neoliberal order (Lave et al., 2010; Lave 2012), thereby potentially forfeiting its democratic potential (Light and Higgs, 1996).

The role of science itself in restoration has also been a subject of fierce debate. Higgs (2005) has wondered whether or not there is a danger of a "scientific authoritarianism" taking over the field and losing sight of other forms of knowledge. Cabin (2007) questions whether science was a useful framework for ecological restoration in the first place, arguing that the complexity of nature and land-management does not match with the culture of science. Instead, he offers a framework for a “trial-and-error” restoration practice or, borrowing from Leopold, an “intelligent tinkering” approach as opposed to a “more rigorous, data-intensive scientific methodology” (Cabin, 2007, p. 1; Cabin, 2011). The “intelligent tinkering” model of practice that he outlines blends what he calls the “attributes of good science (e.g., objectivity, hypothesis testing, and rigor) with attributes of good practice (e.g., technical skill, local knowledge, relentless passion)” (Cabin, 2011, p. 174). He sees value in the legitimacy and financial benefits that a scientific framework can provide, and thinks it is important to consider when “formal science” may be appropriate, but also when it might not (Cabin, 2007). Cabin (2007) believes that there needs to be more professional support and reward for engaging in this kind of “tinkering” and experimentation, and the goals of scientific experimentation can often be at odds with the need to “get things done on the ground” (p. 2). Cabin’s (2007) ideas provoked a fierce debate within the journal *Restoration Ecology,* with exchanges about the role of science in restoration, the definition of science itself, and whether or not the long timeframe needed to demonstrate results was the real issue (see Cabin, 2007a; 2007b; Giardina et al., 2007).

This tension, although present, is not due to a difference between science and “the rest” of restoration, but is instead a dynamic imbedded in the practice of scientific work itself. This tension extends to the work of ecological restorationists in the Columbia River Basin. While some restorationists see this as a science-practice divide in restoration, others view it as a problem of science “driving” restoration. However, as I will describe throughout this study, there are many drivers in this system, and these have feedbacks that both push and pull, resulting in the co-production of science, management, and policy. As I will show, restorationists in the Columbia River Basin are reorienting themselves to solve the practical, “on-the-ground” problem of restoring salmon to the river in a changing climate. Instead of viewing science as separate from the social, by looking at the practices, infrastructures, institutions, and organizations that shape and reproduce science in the basin, by looking at social epistemology, we can see that they are deeply entwined and always changing.

Development of Habitat Restoration in the Columbia River Basin

Clearly, ecological restoration has a contested history and opinions on all sides of these debates contribute to a diverse epistemic community that has varied through time and across contexts. The development of salmon habitat restoration in the Columbia River is no different, as it has emerged with its own debates and issues. Much like ecological restoration more broadly, it reflects the wider science of restoration ecology, as well as the regulatory environment of the region. Many of these developments are reflective of the mandates for salmon recovery that are in place. The metrics used to meet these mandates, and the epistemic communities that they rely on, co-produce restoration and the science that supports it.

Legislation such as the ESA provides an example of what Jasanoff (2004b) has termed the co-production of science and law, whereby science is used to support legal action, and the resulting policies, in turn, create a pivotal role for science. Co-production describes a situated and iterative process, where the "ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it" (Jasanoff, 2004b, p. 2). Co-production has implications for how the environment is managed because knowledge about nature is co-produced along with societal actions to manage the environment and order nature. While there are undoubtedly people that tend towards either *producing* science or *implementing* restoration actions, in this study, many restorationists stand with a foot firmly in both worlds, and through their practices, and the cultures, virtues, and institutions that support them, and they all co-produce restoration in the Columbia River Basin.

Although there have been significant structural and technological changes, the scientific and natural resource paradigms and institutions that were put in place during the development of the Columbia River Basin still influence the scientific work today. As habitat loss and the need to protect riparian landscapes came to be recognized as a driving factor in decreasing salmon runs, scientific priorities in the basin also shifted. But because the infrastructures for hatchery science were already firmly in place, these scientific endeavors continue to dominate the basin. Further, the large scale of the Columbia River Basin, the multiple jurisdictional boundaries within it, and the spatial complexity of salmon life-cycles has meant that the epistemic community has been forced to innovate in order to cope with this large scale. This iterative dynamic between society and nature is echoed in the ways in which science and law are co-produced in the basin, and have contributed to the geographical (Allen, 2003) and techno-scientific profile of salmon restoration and recovery in the Columbia River Basin. A brief history of this place-based restoration will help situate the science that occurs there today.

Coincident with the early ecological restoration efforts in the US West, discussed above, the 1920s to 1930s saw an increasing public awareness of the value of wetlands. This was mainly due to the influence of sportsmans' organizations that were interested in preserving wetlands in the Midwest to serve as habitat for wildfowl. The Migratory Bird Habitat Stamp Act was passed in 1934, and it still contributes to the preservation and recreation of wetlands in the US. During the same era, riparian restoration also began to be recognized as management tool, as trout anglers witnessed declines in fish numbers (White, 1994). Simultaneously to this growing awareness of the importance of freshwater habitats, the dam-building era in the Columbia River Basin was taking off.

The first large dam in the Columbia River Basin that was completely impassible to anadromous fish was the Warm Springs Dam, built on the Malheur River in Oregon in 1919. By 1920 the first comprehensive plans for building dams throughout the region were being drawn up. Between the 1930s and the 1970s, over two dozen large dams were built on the Columbia and its tributaries. These dams were built with a combination of benefits in mind, including hydropower, irrigation, and, after the 1948 flood of Portland, flood control. 1938 saw Bonneville Dam completed. In 1941, the Grand Coulee Dam was finished, and it is still one of the largest dams in the world. In 1957, the Dalles Dam flooded Celilo Falls, one of the most important tribal fishing sites in the region. Dams continued to be built through the 1970s, with major dams on almost all of the main tributaries, including the Hells Canyon Dams, which blocked salmon habitat in the upper Snake River and its tributaries. In fulfillment of the Columbia River Treaty of 1948, Canadian dams were also built for flood control and hydropower. In Idaho, Dworshak Dam, one of the highest in the world, was one of the last dams to be built, in 1973. With the catastrophic failure of Teton Dam in 1976, the dam-building era came to an end, but only after transforming the Columbia River into one of the most regulated rivers in the world.

A River Co-produced

Co-production provides a useful idiom for conceptualizing the relationship between science and institutions, especially legal institutions such as the ESA (Jasanoff and Wynne, 1998). Co-production is a dialectical process, in which processes, as well as cognitive, institutional, material and normative facets of society are interlinked (Jasanoff, 2004). While scientists produce knowledge in terms of epistemic norms and values, the science they produce is nonetheless made to meet the needs of particular societal norms and values that are expressed through legal frameworks.

The story of hydropower development in the Columbia River Basin demonstrates the ways in which natural resource management was developed to meet a need to civilize, subdue, and transform nature for maximum production and economic gain (Cronon, 1983; 1992). This was particularly true in the Western US, and science and technology have been enrolled to forward specific economic and political agendas. “Conservation” was originally aimed at increasing productivity, and engineers sought to improve on nature, either through the creation of a pastoral, promised-land (Fiege, 1999; Worster, 1987; Wilkinson, 1992), or through increasing the production of a nature-machine (Hughes, 2004). According to Worster (1987), ecological science transitioned between 1920 and 1945, moving from a utilitarian to a preservationist perspective. However, even if a more preservationist value of nature began to gain traction within the scientific and management paradigm of the time, the tension between utility and preservation was not resolved, as the Columbia River was purposed for large-scale development of hydropower.

In the Western landscape, preservationist goals were only applied in specific locations, or preserves, while the rest of nature was viewed in terms of economic value and improvement (Alagona, 2013). Preservationist values did not necessarily influence early ecological management and the science it relied upon, and this is illustrated in the large-scale changes that took place throughout the western US during the first half of the Twentieth Century, a time when ecological ideas were emerging in science. The ideology of maximum economic benefit was nurtured in resource agencies such as the US Forest Service and the Bureau of Reclamation (Langston, 1995; Worster, 1987). Progressive era "high-modernism" (Scott, 1998) reflected technological optimism, and the state sought to put nature to work in places such as the Columbia River Basin through large-scale investment in infrastructure and regional planning (White, 1995; Hirt and Sowards, 2012). This required a profound simplification of natural complexity in order to arrive at a more politically popular solution (Hirt and Sowards, 2012).

The Columbia River Basin that exists today has been the result of co-production of ecological science, sociotechnical imaginaries, and the institutions that emerge through shifting societal values. River development in the early twentieth century was able to concentrate on hydropower production partly because the growing field of ecology promised answers and technological fixes to the environmental degradation that would result (Taylor, 1999; Fiege, 1999). Ecological thinking was not always coupled with environmental values (Bocking, 2004). Early ecology was used to address the societal goals of economic development and find ways to have both a fishery *and* a heavily developed river basin. Co-production demonstrates how natural resource management draws on different scientific paradigms as a basis for authority, each with markedly different material consequences. The science that is produced during a particular time is often the science that is deemed useful to fulfill these paradigms.

Hydropower effectively divided the Columbia River Basin into an industrial river in the service of hydropower, flood control, and irrigation in the upstream reaches, leaving fisheries production for the lower river (Allen, 2003). This spatial disparity has had ecological and environmental justice implications, and has also affected the scientific work done in the basin. Before the 1850s, 88 percent of returning salmon were heading upstream to areas above the Bonneville Dam to spawn, but that number has been halved to around 44 percent (Allen, 2003). While the physical presence of the dams blocks access to upstream spawning areas, this spatial disparity is not solely because of the development of dams, but is also due to the technoscientific solutions to the problem.

At the time the dams were built, fisheries biologists recognized the importance of habitat for fish and realized that blocking the river could potentially devastate fish runs.

Yet although habitat was a consideration, habitat restoration as we recognize it today is a more recent development. When the dams were built, habitat—especially in the headwater regions—was not recognized as a priority for mitigation funding. Instead, the mains-stem and lower sub-basins of the Columbia River were the major beneficiaries of mitigation dollars in the form of money for hatchery development. While mitigation from hatcheries focused on fish production in the lower Columbia River, it wasn't until fairly recently that the estuary was even considered eligible for mitigation funds for habitat because habitat below the dams was not considered to be affected by them. In addition, as the impacts from climate change are increasingly felt, the headwaters are being called upon to provide habitat in the form of high-quality cold water refugia.

In 1938, the Mitchell Act was the first major legislation aimed at addressing salmon decline due to dams. The act is emblematic of the way that the river was imagined at the time—as a techno-natural, or "organic" machine—with technological fixes as the main solution (White, 1994). Although legislation such as the Mitchell Act included language to improve stream habitat and even survey the upper tributaries, the main funding package went towards building, sustaining, and researching hatcheries and hatchery production. Meanwhile, the habitat mitigation money went towards building fish ladders, developing screens for irrigation canals, and, rarely, addressing pollution (Allen, 2003). In the end, only 5 percent of Mitchell Act funds went towards this type of "habitat" work (Allen, 2003). Mitigation actions for the damage that dams caused were also implemented in 1946, in the form of the Lower Columbia River Fisheries Development Program and John Day Fisheries Mitigation, yet both focused on hatcheries. The program eventually added a habitat program, which led to stream-clearing, constructing bypass around dams, and screening irrigation ditches. This was too little, too late, as headwaters runs had already been decimated from their previous abundance (Allen, 2003). Today, these types of fish passage projects, while improving habitat access, would not generally be considered "habitat restoration." So, given these challenges, how did this shift to focus on habitat restoration occur, and how did the current science of restoration in the basin emerge?

Emergence of Coordinated Habitat Restoration in the Columbia River Basin

During the 1930s and 1940s, stream restoration was mainly focused on in-channel "improvements" (White, 1994). This meant removal of large-woody debris from streams, a practice that is now regarded as counterproductive to improving salmon habitat. Some work in the Pacific Northwest was also being done in headwater areas to manage streambank erosion through stabilization (White, 1994). The work that Harlan Holmes was doing during this period—tagging fish and trying to understand their life-cycles, measuring the effects of the dams, and surveying their historic territory and run sizes in the upper tributaries—was mainly focused on finding ways to mitigate damage of the dams by creating passage. He would come to spend his later career engineering fish bypass for dams. Fish bypass is still one of the main tactics for mitigating the effects of the dams, especially as some of the most important and far-reaching environmental legislation in the world became law. The laws that were passed during the 1970s continue to influence the science that is done in the Columbia River Basin in important ways.

In 1970, the National Environmental Policy Act (NEPA) was passed, making it necessary for all federal actions to conduct a review of environmental impacts. This includes the Federal dams that operated in the Columbia River Basin. The Clean Water Act of 1977 also set in place regulation for stream temperature and flow within the region. But even more impactful was the Endangered Species Act of 1973. It would result in the eventual listing of thirteen salmonid species throughout the Columbia River Basin as either threatened or endangered. The ESA transformed environmental management, the kinds of mitigation efforts used to recover species, and the scientific work that would be needed for this, including metrics and practices that were needed to meet recovery goals (McEvoy, 1992). Most salmon habitat restoration that occurs within the Columbia River Basin is done because of the ESA.

This period also saw a resurgence of Tribal power in the basin, as tribes throughout the basin reasserted their Treaty Rights. In 1855, the Nez Perce, Umatilla, Warm Springs and Yakama Tribes signed treaties with US government, reserving the right to hunt fish at "usual and accustomed" sites. Many of these customary fishing sites were destroyed through inundation by dam construction. Through a concerted effort and long-fought resistance by the tribes, in 1969, US v. Oregon (302 F Supp. 899) designated tribal fishing sites along the Columbia as well as guaranteed 50 percent of the overall harvest. This development made recovery of salmon even more critical as tribes now have greater rights to demand mitigation and recovery, and environmental justice has finally been put on the table.[2]

During the 1970s, conflict between hydropower and fish was brewing, and in 1980 the Northwest Power and Planning Act was passed with the vision of creating a plan to maintain energy production and a plan for mitigating damage to fish and wildlife. Out of this act, the NW Council would come to drive restoration of salmon and their habitat as they dictate where BPA mitigation money will be spent. While the Northwest Power and Planning Act anticipated that the NW Council would call for actions to mitigate the damage to fish populations from the dams, it was also assumed that because the dams completely block some habitat, this mitigation would be partial. Because of this, much of the mitigation for this lost habitat is done in offsite locations and actions, not in previously accessible habitat. In order to establish areas to improve, restoration prioritization efforts began in the 1980s, as high-quality spawning and rearing areas began to be identified. The first such "Columbia River Fish and Wildlife Program" was produced in 1982, and habitat improvement was a critical element of the mitigation plan (NW Council, 1982).

The ESA also requires fish and wildlife agencies to develop Biological Opinions (BiOps) that determine the ecological impacts from operation of the hydroelectric dams (and all other federal actions) to endangered and threatened migratory species. In the Columbia River Basin, these are conducted by NOAA Fisheries for anadrounous fish and FWS for resident species (e.g. bulltrout). BiOps are based on scientific assessments using the "best available science," but have been at the center of ongoing contention and litigation (the most recent BiOp was remanded in May 2016) for over twenty years. This is one way in which the interface between law and science is key to how fish are restored

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[2] Treaties include: Treaty with the Yakama, 1855; Treaty with the Tribes of Middle Oregon, 1885; Treaty with the Walla Walla, Cayuse, etc., 1855; Treaty with the Nez Perces, 1855; among others in the Columbia River Basin.

and managed in the Columbia River Basin (Blumm and Paulsen, 2013; Doremus and Tarlock, 2005). The BiOps have driven the science that is used to understand the effects of dams, but they have also helped establish the importance of habitat restoration as a key mitigation tactic for offsetting these effects. The first BiOp was in 1992, after the 1991 listing. Since then there have been eight BiOps in total, including two supplementary BiOps. This regulatory background provides the backdrop for the science and the ecological restoration that began to flourish in the late 1980s and early 1990s.

While impacts from dams were driving a need to protect and restore salmon habitat, much of the early riparian habitat monitoring, protection, and restoration that took place in the Pacific Northwest was done in the field of forestry, out of a concern for the impacts of logging. In 1987, *Streamside Management,* one of the first guides to riparian restoration in the region, was published, and some of the first interdisciplinary symposia aimed at riparian restoration science were held. This was partly driven by the regulatory framework of the Northwest Forest Plan, which aimed to make logging practices more accountable to environmental damage. In the early 1990s, an interdisciplinary cross-pollination at the University of Washington began to be cultivated. Researchers from forestry and fisheries departments, as well as engineering, formed a working group called the Center for Streamside Studies. Degradation to water quality through impacts from logging roads and fine sediment was a main concern. Dead wood and large woody debris in streams began to be studied through wood surveys and pool area studies. While large woody debris in streams had been discussed in the literature since 1979 (Keller and Swanson, cited in White, 1996), it only became an important riparian restoration tool in the early 1990s (Naiman et al., 1992).

These studies helped inform early riparian restoration practices in the region. A trend toward process-based restoration began in the 1990s, and landscape and watershed scale approaches were also introduced (White, 1996). Throughout the 1990s, although the focus remained on placing fish screens in irrigation ditches and fish passage to blocked areas, researchers helped shift the focus to process-based restoration. Throughout the 1990s, scientists at NOAA, the University of Washington, and other agencies and universities wrote about and studied the benefits of process-based restoration, the use of remote sensing to prioritize monitor restoration success, as well as the need for large woody debris in streams. Research like this helped shift restoration thinking towards creating and improving riparian habitat through restoring ecological processes. It was an exciting and innovative time for riparian restoration in the region.

But at the same time, Columbia River Tribes were also pushing for a change in focus in the region. In 1995, CRITFC published *Spirit of the Salmon: Wy-Kan-Ush-Mi Wa-Kish-Wit* (CRITFC, 1995), which was a tribal restoration plan that pushed for comprehensive habitat restoration as a key recovery strategy. During this same period, salmonids throughout the Columbia River Basin were being listed, and recovery planning was in full swing. The ESA requires monitoring every five years, so large-scale monitoring programs had to be put in place. Recovery plans, including baselines and benchmarks for populations and habitat areas also had to be developed and updated using the best available science. In 1996, the NW Council created the Independent Scientific Review Panel (ISRB), which would serve to independently review all projects funded by the BPA. When they met in 1996, they recognized the overwhelming skew towards mitigation through hatcheries and the lack of focus on habitat restoration. A National Research Council Report entitled *Upstream*, was published in 1996, and called for the "rehabilitation" of salmon populations, mainly relying on hatchery technology, and only long-term visions of restoration. Then 2005, the ISRB published *Return to the River,* which re-focused on recovery through process-based restoration. While language and funding still favored technological fixes, a shift in restoration had occurred. *Return to the River* introduced an ecosystem-based approach and described what it would mean to mitigate habitat loss and recover salmon through a focus on habitat restoration (Williams et al., 2005). This scientific work, in turn, provided a conceptual framework for the Fish and Wildlife Program of the NW Council, and the recovery planning for the coming decades. Ecological restoration had finally arrived in the Columbia River Basin.

A Changing Restoration Science

Restoration in the Columbia River Basin is, in a sense, a "large-scale experiment" (Gross, 2010). This experiment is, in many ways, very different from the one that Harlan Holmes shaped throughout his career. Yet in other ways his practice seems familiar to the scientific work that is being carried out in the basin today. Holmes' early work was concerned with measurement, with tracing the life-cycles of salmon, and generally understanding and classifying the species and runs. Yet he was also concerned with understanding the broader ecological processes within the Columbia River Basin, and he was particularly interested in establishing a baseline understanding of where salmon habitat was located. This work is similar, in many ways, to the habitat monitoring work that is ongoing today. Yet, instead of measuring and monitoring the habitat of the Columbia River Basin itself, Holmes did the best he could do with a highly qualitative description of what habitats salmon seemed to like and where their habitat had been lost. This was not due to his lack of precision or rigor as a scientist, but due to the kind of work that was being funded at the time—and the scientific methods and metrics of ecological restoration that were yet to be developed.

As Holmes traveled further into the headwaters in the years after his initial fieldwork for the Bureau of Fisheries in 1923, he began talking to people about fish passage around dams. The Bureau of Reclamation was beginning work on the Yakima Project, a massive engineering and irrigation effort that would transform the Yakima Valley into one of the most productive fruit-growing areas in the country. To do this, the Bureau of Reclamation dammed the Keechelus River in 1917. On his field trips, Holmes met with people who were eager to find ways to keep fish coming up the river and spawning in the valley. They also wanted to find ways to develop technology that would keep fish from entering irrigation canals. He met with residents and fishers near Cle Elum, Washington, and discussed fish passage around the dams. People were concerned that the development was impacting one of their cherished resources.

In 1924, Holmes' field season took him further afield. He drove his car up into the Okanagan River Valley of Washington and British Columbia. The Okanagan Sub-basin was, and continues to be one of the most productive spawning areas for salmon in the entire region. He collected scales from salmon in order to determine the differences between fish populations, the main purpose of his research trip. But, in addition to biology, his field diaries are also filled with resident's fears about changes in the abundance of fish runs, as well as the shifts they were beginning to notice in the timing of the runs. In many of the locations he travelled, the effects of development were being both seen and felt: residents were noticing a difference in the rivers. Holmes recorded finding many streams dewatered. For example, while traveling through the Okanagan Valley, he took a side trip to look at Shingle Creek. “It is about like the other creeks in this valley,” he wrote, “not much more than a brook, the greater part taken out for irrigation. There were no fish in sight at the places where I observed it, but I did not go to the mouth” (Holmes, October 19, 1924). Holmes met with similar sights in the Methow Valley of Washington, where he discovered streams that were once rich salmon spawning grounds, but had been diverted for irrigation and agricultural development.

In 1927, Holmes traveled throughout the Salmon and Snake River Basins of Idaho, finding many of the same issues. He “learned at Idaho City in the evening that many Chinooks spawned in Boise River before dams were constructed” (Holmes, August 8, 1927). But locals were particularly angry about Sunbeam Dam. The dam was built in 1910 by a private mining company in order to provide electricity for its operations. Its construction effectively blocked salmon from returning to a large part of the Salmon River sub basin (USFS, 2018). Holmes’ field notes about how locals felt about the dam are particularly telling:

> It is interesting to note that everyone in this part of the country is very much opposed to the dam and is very free about stating that they would like to see it blown out. It is a wonder someone has not done so long before now (Holmes, August 12, 1927).

The locals did get their way in 1934, when the dam was, in fact, “blown out,” at the request of the USFS after the mining company failed to produce a profit and abandoned their operations.

The conversations recorded by Holmes demonstrate that at least some non-tribal communities in the early part of the twentieth century clearly cared about having salmon in their rivers. The quotes also show that they could see how the development of the river was having a detrimental effect on salmon abundance. But Holmes and his colleagues went one step further, and saw the potential for restoration of areas that had recently blocked fish access or dewatered streams. In the upper reaches of the Salmon River, Holmes was particularly interested in documenting where fish were spawning, and he recognized the same type of high-quality habitat that has now been prioritized for restoration almost a century later. He wrote in his 1927 field journal:

> Took my time going down Bear Valley. Looked along the River (a very small stream at the head of the valley) at several places but saw no evidence of salmon or spawning grounds. Took a picture looking toward the head of the valley. The valley is a level and comparatively flat meadow several miles wide in some places. The river windes [sic] its way in a very crooked course through this marshy flat. It must be a wonderful nursery grounds for aquatic life upon which young salmon might feed (Holmes, August 12, 1927).

It would take almost a century before valley floors like this one would be recognized for their critical role in salmon recovery and would be restored to the highly complex, braided streams that form in wide valley bottoms—what are now called "Stage 0," floodplains.

Science and Controversy

Holmes' survey work in the headwaters of the Columbia River Basin was funded by the 1927 Rivers and Harbors Act, which requested the US Army Corps of Engineers to develop a comprehensive plan for the Columbia River Basin. The comprehensive plan, entitled "Columbia River and Minor Tributaries," would include a survey of habitat, but its main purpose was to locate areas where hydropower, irrigation, navigation, and flood control projects should be developed. This comprehensive plan, also known as the "308 Reports," eventually resulted in the transformation of the Columbia River into a series of reservoirs, destroying or blocking much of the habitat that Holmes was busy documenting in the 1920s.

As Holmes' career progressed, he spent less and less time up in the headwaters surveying the areas where fish were spawning, talking to locals, and counting "bluebacks," or Sockeye. Instead, he moved on to work as a biologist for the US Fish and Wildlife Service and carried out most of his studies at the first dam fish meet when traveling up the Columbia: Bonneville. He spent the remainder of his career trying to determine the effects of the dam on juvenile and adult salmon and experimenting with ways to diminish these impacts. He developed fish passage technologies for many of the large dams, as well as numerous screening devices to protect juvenile fish. By the end of his career, he was working almost solely on Bonneville Dam passage experiments. Holmes' scientific work had come to meet the needs of river development, and technological fixes had become the answer to the impacts on salmon. Where he started his career concerned with habitat, the demands of river development shifted his scientific work towards fish passage technology.

Holmes' work also became central to one of the early legal controversies surrounding dam operation. He was especially interested in understanding how the pressure created by dams impacted juvenile fish, and he created novel experiments to enable him to test the effects both in the lab, and through marking and collecting fish above and below the dams. In 1952, he wrote a report entitled: "Loss of Salmon Fingerlings in Passing Bonneville Dam as Determined by--Marking Experiments." Up until this point, it was generally assumed that juvenile fish passed through the dam turbines or over the top of the dams with few problems. This report and especially the statistical methods that Holmes used became critical in establishing whether or not the dams were going to have to admit responsibility for damaging juvenile fish. The paper went through many rounds of reviews, and the US Army Corps of Engineers (Corps) were particularly unimpressed with the conclusion that the dams contributed to large loses of juvenile fish. The Corps attacked Holmes' statistical methods, particularly the chi-square tests, and drafts of the document were sent to respected statisticians across the country to determine whether his conclusions were warranted. Lt. Col. L. W. Correll of the Army Corps of Engineers was adamant that they were not disputing the damage to fish by the dams, but were instead disputing the statistics in the report. He wrote in a letter to Holmes:

> Again, I wish to state, however, that the Corps of Engineers would not object to an adverse report on the effects of the Bonneville Dam on the salmon fishery so long as the adverse findings are based on factual and conclusive data. I believe that the answer to this question is so important and far reaching to the future of all the resources concerned that no answer should be declared or implied until the supporting facts are conclusive (Lt. Col. Correll, October 29, 1952).

As we will see throughout the story of science in the Columbia River Basin, the Colonel was right: the controversy over which “supporting facts” are, in fact, “conclusive” is still the topic of debate and the answer is still “important and far reaching to the future of all the resources concerned.” Although this was just one controversy in which science was enrolled, science would continue to play a key role in determining the impacts of dams to salmon until the present.

Sociotechnical Imaginaries in the Columbia River Basin

Historically, there have been conflicting ideas about how best to manage nature, the Columbia River Basin, and its fisheries. These can be located in the roots of ecological science and changing societal values. Environmental management has drawn from different scientific paradigms as a basis for scientific authority, as demonstrated by the different development trajectories of salmon management within the US and Canada. This points to what Pickering (1995) has called the “irredeemable historicity of scientific knowledge,” where “what counts as scientific knowledge now is a function of the specific historical trajectory that practice has traced out in the past” (p. 33).

Using a historical perspective to examine the development of ecological science has illustrated how societal values and “sociotechnical imaginaries” have influenced the ways in which science has been pursued and applied. While adaptations in scientific practice and knowledge infrastructures occur in response to environmental changes at the global scale, they are also shaped by how society collectively views and manages for the future through “sociotechnical imaginaries” (Jasanoff and Kim, 2009; Jasanoff, 2015). Imaginaries are the “collectively held, institutionally stabilized, and publicly performed visions of desirable futures,” and sociotechnical imaginaries are social formations enabled through science and technology (Jasanoff, 2015a). Environmental management is realized through national scientific and natural resource policy programs that reflect a specific imaginary of the environment and how it should be managed to meet future national needs and interests. Much of the science that is produced at a particular time is created in response to a need, which is based on a particular imaginary of what the future should be.

Holmes' early work on salmon and their habitat in the basin demonstrates how epistemic work is not only historically situated, but is also social. Over the past several decades, a specific kind of restoration science has developed in relation to institutional needs and societal goals. Between the time of Holmes' early work and his later work at Bonneville Dam, sociotechnical and environmental imaginaries have shifted from answering questions about where salmon are, what they did, and what they require to survive to questions such as "how can salmon and dams coexist?" or "what kind of technology can we use to allow them to coexist?" It also demonstrates that scientific practice and the epistemic community that emerges to support that practice can also change. Therefore, the epistemic work and the normative goals and recommendations that are produced through ecological restoration will also shift when encountering environmental change. This change is essential and confirms that science can be adaptive. Ecological restoration, as well as restoration ecology, are aimed at producing knowledge that can intervene in the world. In the following chapters I develop the conceptual framework of adaptive epistemologies in order to observe and understand these changes in the field of ecological restoration in the face of climate change.

Chapter 3: Climate Change and Adaptation

Climate Change Arrives in the Columbia River Basin

Most people that I spoke to as I travelled throughout the Basin all agreed on one thing: climate change has arrived. One restorationist described:

> Back in 2015, that super-hot summer was destructive. It was wild. It was so hot for so long…The whole main channel was 80 degrees or more. And there would just be these clumps of fish trying to survive where a seep of groundwater was coming out. You could *see* that. You could *see* adult sockeye dying...[there were] mass deaths of adult sockeye because they were just too stressed…So you can kind of see how things might end up looking, and it is frightening...That was tough. Trees died. [There were] fires (R16).

For many people in the Pacific Northwest, 2015 was a wake-up call. The winter of 2014-2015 saw record-low snowfall, and the ensuing high temperatures, drought, and low stream-flows of 2015 brought devastation to the environment, and especially to salmon runs. For restorationists, 2015 was a benchmark for how bad things could be in the future, and for many it represented an oracle of sorts. Globally, 2015 was the warmest year on record, with 2014 already breaking the previous record (Blunden and Arndt, 2016). In the Pacific Northwest, the warm temperatures contributed to record low snowpack. In many areas, this equated to zero snowpack, a drastic decline in spring runoff, and drought throughout the region (Mao et al., 2015). On top of this, a hot, dry summer increased fire intensity and frequency throughout the basin (Vano et al., 2015). These high temperatures were deadly to salmon. As salmon made their way up the mainstem in early summer, record-high water temperatures exceeded survivable levels, and mass die-offs ensued (NOAA Fisheries, 2016). NW Council estimates that 250,000 sockeye died in the Columbia River and its tributaries as a result of warm water. This was well over half of some runs (NW Council, 2015). Snake River sockeye were particularly hard-hit, with only a handful returning to spawn.

Meanwhile, the North Pacific was experiencing a sea-surface temperature anomaly that became known as “the blob.” Sea-surface temperatures had been consistently above normal since 2013, creating a “blob” of warm water that extended from the Bering Sea to California (Bond et al., 2015). The “blob,” while likened to the effects of El Nino years, was much more severe, with low returns of ocean-run salmonids throughout the region, and record low returns from 2013-2015 (Pacific Fishery Management Council, 2016). Unlike a typical El Nino, however, “the blob” continued to stick around for longer than expected and was the greatest deviation from normal since the 1980s, and possibly since 1900 (Bond et al., 2015). Critically, for salmon feeding in the ocean, it prevented nutrient up-welling that forms the foundation to the coastal ecosystem by supporting forage fish (Gewin, 2015). The “blob” also played a role in keeping temperatures at record high levels over land (Mote et al., 2016), bringing a double-punch of climate impacts to migrating salmonids. Some scientists believe that rising ocean temperatures may lead to more ocean anomalies, and “the blob” will become the “new normal.”

These shifts have caused fisheries managers to re-think their modeling and management tools, and some have adopted ecosystem-based models for decision-making, instead of relying on past ecological baselines that may no longer exist (Gewin, 2015). According to climate models, the future does indeed look like 2015. Winters are predicted to be warmer and wetter, and summers will be dryer and hotter, resulting in low snowpack, decreased stream flows, and increased water temperatures—all things detrimental to salmonid survival (Nolin et al., 2012). These changes also introduce more stochacisity, or extreme fluctuation, to the system, as precipitation events are expected to become more intense, increasing rain-on snow events, and producing a more extreme hydrograph (Crozier, 2016; Vano et al., 2015). In addition to increasing mortality, these changes could potentially shift the range of salmon species northward as well as shifting the timing of their runs. All of these changes are expected to accelerate in the Columbia River Basin in the next few decades (Roberts et al., 2015). And these changes in the timing and intensity of runoff will not only affect fish; they will also change the seasonality of hydropower production as well (Kao et al., 2015).

Restorationists throughout the basin are trying to grasp, understand, and adjust to this change. As one person said:

> 2015 kind of gave us a little bit of a reality check: Oh, wow! ...It was a really tough summer…It was a stressful. It was like, ‘if this is what it is going to be like,

> it is not going to be fun.' Stream temperatures were just totally lethal. Totally lethal (R16).

Many people are starting to use the 2015 season as a new benchmark, and after living through it, spoke about having had a glimpse into the future.

Restorationists are adapting their work to meet the challenges of climate change in different ways, but for many, 2015 represents a key test in this adaptation. These changes include shifts in work or design practices, such as planting different species that might tolerate future conditions. For instance, one restorationist recalled,

> We had done a restoration project that we finished in late 2015, and then we were planting native species over the winter. Normally that is fine, and the roots are fine. But 2015 was extremely long and dry and hot in the summer so we ended up having to water our plants for the first time ever. We were like, 'well at this point maybe we should start thinking about more drought tolerant species because that is one of the predictions is that precipitation is going to fall as rain and it is going to fall west of the Cascades and then you'll have a wetter winter but a dryer longer summer.' That is what they are predicting. So, 2015 might be what you are considering the new normal when it comes to the future (R26).

This is an example of the kinds of incremental changes that restorationists are making as they deal with climate change. But these adaptations extend to more fundamental changes, including re-thinking the focus of restoration ecology to anticipate the future. Meanwhile, these changes have also emboldened the restoration community, as the public becomes aware of the importance of habitat restoration: if climate change is going to increase water temperatures and fluctuation in the hydrograph, restoration could mitigate these effects by reconnecting cooler groundwater, increasing shade and habitat diversity, and strengthening ecological and physical responses to change (Battin et al., 2007; Beechie et al., 2012). As one practitioner put it: "Everything has changed…I, personally, believe that going back is not a realistic goal." (R34).

Climate Impacts on the Field of Restoration

While ecological restoration is quickly becoming recognized as critical for maintaining biodiversity and mitigating the impacts of climate change, the field itself is also trying to adapt to and anticipate a climate-changed future where there is “no analogue” (Williams and Jackson, 2007). Ecological restoration of fish and wildlife habitat is recognized as a “global priority,” and has been incorporated into the Convention for Biological Diversity (CBD) and the United Nations Environment Program (UNEP) (Aronson and Alexander, 2013), and climate change mitigation and adaptation policy itself increasingly relies on the field of ecological restoration as its scientific justification and base (Baker and Eckerberg, 2013). Yet there is also a general recognition among restorationists that climate change will make restoration more difficult, while it also becomes more important (McDonald, 2013). As restorationists come to terms with the effects of future climate change, how will the past be understood and valued?

Measuring and identifying ecological thresholds and change is challenging for ecological restorationists (Hobbs et al., 2013). Many of the field’s prominent scholars have recognized the need to broaden the scope of the meaning of restoration due to the effects of climate change (Hobbs and Cramer, 2008; Clewell, 2009). Ecosystem equilibrium models and managing for historic range of variability are becoming increasingly anachronistic as historic conditions no longer exist, or are no longer reasonable restoration goals (Seastedt et al., 2008). Instead, new concepts that move away from restoration to a historical reference baseline are becoming increasingly common. Novel ecosystems are ecosystems that contain species combinations that have not previously occurred within a given biome (Hobbs et al., 2006). Similarly, “hybrid ecosystems,” recognize the need to orient towards a future ecological state (Choi, 2000; 2004; Hobbs et al., 2009). Some have proposed using a “dynamic reference” that accounts for changes in both reference and restoration sites (Hiers et al., 2012). Although concepts like novel ecosystems are becoming more widespread, they are not always accepted, and the implications for management are contentious. Nonetheless, these concepts have helped reconceptualize restoration of ecosystems to a state other than a historic analogue.

So, how is the epistemic community dealing with change and uncertainty? For restorationists working on the front lines of climate change in the Columbia River Basin, a sense of urgency is often coupled with a sense that there is not enough time to employ the scientific method. As van Diggelen et al. (2001) lamented, in reference to ecological restoration over a decade ago: “the feeling is often that the situation is so critical that one should act immediately and try to salvage all that can be” (p. 115). Jackson and Hobbs (2009) worry that “we face serious risk that global change will outpace our scientific capacity to prescribe adaptive strategies, let alone implement them” (p. 568).

To counter these issues, environmental managers often call for adaptive management, yet it is still unclear exactly what this recommendation entails. This is often further confused by the lack of acknowledgement of the interaction between social and ecological systems and their combined capacity for adaptation and/or resilience. Management goals for achieving resilience, for instance, would be aimed at building in the ability of a system to recover from and resist a shift into a new state, whereas goals for dealing with climate change adaptation anticipate a shift to a new state (Miller et al., 2007, Harris et al., 2006). For example, Heller and Zavaleta (2009) reviewed 113 papers about conservation management and found that most recommendations for dealing with climate change were not specific enough—70 percent suggested overly general principles such as becoming “more flexible,” and concluded that “climate change adaptation work,” is still largely at the ‘idea’ stage (p. 18). Starzomski (2013) also found that, especially when dealing with novel ecosystems, management techniques generally provide little or no guidance. Further, Bernazzani et al. (2012) reviewed habitat conservation plans and found that, although adaptive management is often referred to, explicit outcomes or actions are not usually included. In terms of “what to do” about climate change, then? Restorationists are left to figure it out.

Theories of Change in Social-Ecological Systems

On the other hand, there is a growing body of literature on the adaptation and resilience of socio-ecological systems (SESs) that conceptualizes change in environmental management and the science that supports it in a different way. This literature also engages with theories of change, and often calls upon knowledge production to help facilitate those changes by providing data, monitoring, and experimental design (Walters and Holling, 1990). The conceptual framework for adaptation and resilience draws not only on ecological concepts but also on SES theory developed by Gunderson and Holling (2002), along with many others. Work on adaptation in SESs has explored how governance and law itself are or are not resilient and adaptive when confronted by climate change (Pahl-Wostl, 2009; Cosens, 2010). The driver of change within SES theory is the emergence of new ideas, problems, and solutions that occurs through cross-scale interactions (Waters and Holling, 1990; Chaffin and Gunderson, 2016). While these cross-scale interactions are understood to occur at multiple scales, it is not clear what these interactions actually look like at the level of scientific practice or how these practices relate across scales. I want to explore whether or not these theoretical concepts and frameworks for adaptation are useful in understanding adaptations within scientific fields. Ecological restoration provides an excellent example of what Gross (2010) calls an "in-situ and in-context mode of knowledge production" (p. 85) and as a case study, it provides an example of how epistemological issues influence nature and the material world.

Adaptation in Social-Ecological Systems

The social-ecological systems (SESs) framework conceptualizes the complex amalgam of human and natural forces that are in constant interaction. SESs are multi-level systems, with subsystems that have their own separate parts and variables, each of which exist and act within different scales. All of these systems and parts may be understood on their own, but because they interact with each other, proponents of the SES concept believe that it is better to look them in a holistic way (Ostrom, 2009). By viewing systems as having multiple scales and parts that interact, we can see how a change in one variable will affect changes on the larger SES (Ostrom, 2009).

In some fields, this systems perspective has transformed the way that natural resource managers view their work. It has especially influenced the way that ecological systems are modeled in that it provides a way for managers to conceptualize the interactions within complex systems (Taylor, 2005). SES literature emphasizes the role of scientific knowledge, data, and modeling in facilitating more adaptive environmental management. Literature on SESs and adaptive environmental management often discusses the need for knowledge to support this adaptation, but the details of this dynamic are unclear. What kinds of knowledge would be adaptive, and what would the knowledge infrastructures, institutions, and organizations that facilitate this adaptation look like? What kinds of practices would signify that this adaptation is occurring? In order to form a base from which to explore adaptation in science, I will outline some of the ways that adaptation is conceptualized in management, governance, and law in SESs.

Adaptive Management

At its most basic, climate adaptation is "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007). In terms of normative goals for management or society, adaptation is the ability of a system to recover from or adjust to a disturbance in a desired way (Nelson et al., 2007; Folke et al., 2005). Adaptive environmental management, first proposed by Walter and Holborn (1976) and then Holling (1978), consequently recognizes and even embraces the uncertainty and unpredictability of ecosystems, and it advances the idea that, in order to be able to adjust to this uncertainty, managers should iteratively revisit and retest assumptions (Walters and Holling, 1990). Adaptive management is conceptualized as a cycle of steps including: defining management goals, developing alternative strategies to achieve them, and implementing these strategies in order to compare them, as in an experiment. Finally, through this process, new knowledge about which strategies will meet these goals is gained, and strategies can then be modified in an iterative way, starting again from the beginning of the cycle. In this way, new knowledge is constantly used to test a hypothesis. This is a basic form of abductive reasoning, a form of reasoning that consists of "inference to the best explanation" (Bromley, 2008, p. 2). Adaptive management is sometimes framed as a large-scale experiment used to test hypotheses about ecological models (Walters and Holling, 1990; Lee, 1999). By using multiple—or shifting—strategies, adaptive management is able to cope with uncertainty by "spreading the risk:" if one of the strategies (or hypotheses) fails, the idea is that others likely will succeed (Keith et al., 2011). Therefore, although uncertainty is recognized as inherent, it is "managed" by incremental increases in relative knowledge and shifting actions as this new knowledge is gained (Walters and Holling, 1990). The aim of adaptive management is to ensure that management decisions are appropriate and continually adjusting to ecological, social, and technoscientific change.

Adaptive management has been practiced by natural resource management agencies for decades. The original framework for adaptive management involved implementing multiple actions at once and determining their success through a comparative experiment (Walters and Holling, 1990). But, in practice, there have been almost no examples in which this strict experimental form of adaptive management has actually been applied to a management issue (Keith et al., 2011). Even when multiple actions are taken, they are rarely separately monitored and then compared in order to determine relative success. Instead, adaptive management is most often conceptualized as a single, on-going experiment (Keith et al., 2011). Some have criticized this kind of adaptive management as being more about trial-and-error (Duncan and Wintle, 2008) or "ad-hoc planning" (Ruhl and Fischmann 2011). Gunderson and Light (2006) refer to this as "passive adaptive management," pointing out its difference to the originally conceived comparative experimental design. Although adaptive management remains a popular framework among managers, it is only one of many tactics available for dealing with uncertainty.

Many agencies working to restore salmon to the Columbia River Basin have adopted an adaptive management approach. In his 1993 book, *Compass and Gyroscope,* Lee, an academic and former board member of the NW Council, advocated for incorporating adaptive management into planning and policy in the region. Adaptive management has since become an important component of recovery planning in the basin, and is a major feature of the strategy for monitoring programs (Bouwes et al., 2016). Yet despite its conceptual value, many also believe that adaptive management in the Columbia River Basin has not delivered on its promises to balance uncertainty while still taking action (Blumm and Paulsen, 2013; Volkman and McConnaha, 1993; Ruhl and Fischmann, 2011; Doremus, 2001). This seeming failure of adaptive management requires a deeper look at how natural resource science and policy adapts to and deals with change.

"Embracing uncertainty" is still a major issue for adaptive management (Keith et al., 2011). One reason for this may be because it requires policy-makers to embrace an unknown outcome—and a potential failure of the action—something that is antithetical to "good" decision-making. Another problem may be that modeling for critical uncertainties themselves is underdeveloped (Keith et al., 2011). Yet, even when these problems are taken into consideration, scientific work, which involves designing an experimental framework and monitoring change can be difficult or impossible when environmental baselines are shifting and cross-scale interactions are complex. Therefore, revisiting adaptation in environmental management from a science studies perspective is warranted, and can provide insight into how scientific practice itself can be adaptive to meet the needs of changing social and environmental factors.

Adaptive Governance and Adaptive Law

There are two other recent iterations of "adaptation" that influence our understanding of change in SESs. These include adaptive governance and adaptive law. These concepts demonstrate how adaptation can be extended to more social and political aspects of SESs and also signal the importance of knowledge infrastructures, institutions and organizations in enabling or constraining these changes.

Adaptive governance is framework for governance that takes change and uncertainty in SESs into account (Chaffin and Gunderson, 2015; Gunderson and Light, 2006). Adaptive governance proposes a way to manage ecosystems through collaborative and iterative planning based on institutional learning (Olsson et al., 2006). It is a way to deal with uncertainty and allows for adaptive management. If institutions are flexible and dynamic, as opposed to static, they have an increased "adaptive capacity," allowing SESs to "reconfigure themselves" without losing their fundamental functions when confronted with change (Folke, et al., 2005). Adaptive governance, therefore, advocates for organizational learning and cross-scale linkages that are more iterative, enabling flexibility and innovation that can address mismatches of scale (Garmestani and Benson, 2013). Building adaptive capacity will therefore require bringing ecological knowledge to bear on the governance of SESs, and in doing so can create "good" governance systems that are democratic, legitimate, and facilitate equity and justice (Cosens 2010; Cosens, 2013).

Recent work on adaptive law builds on theories of adaptive governance and has conceptualized and identified ways that legal institutions can either foster or hinder adaptation and resilience to climate and other social and ecological changes (Garmestani et al., 2013; Cosens, 2010; Cosens et al., 2014; Cosens et al., 2017). In part, this work was initiated in order to better understand how environmental laws like the ESA, which are often characterized as “inflexible,” can adapt to climate change (Gosnell et al., 2017). Many environmental laws, such as the ESA, were developed in the 1960s and 1970s, when a colloquial ecological understanding hinged on a “balance of nature” understanding that could be predicted and managed accordingly (Garmestani et al., 2013; Gunderson, 2013). Adaptive law, therefore considers how the adaptive capacity, processes, and structures within legal institutions themselves, can adapt while still maintaining legitimacy (Cosens et al., 2017; Cosens et al., 2014). In addition to issues of legitimacy, translating a theory of ecological systems into social-ecological systems, and especially law, is difficult because the dynamic nature of SES systems can be at odds with the stability that law assumes to achieve (Ruhl, 2012; Cosens, 2008). Despite these challenges, law has proven to be adaptive in other circumstances, and theoretical work on adaptive law is trying to address these challenges (Cosens et al., 2017).

These frameworks for adaptive management, governance, and law all attempt to address the difficulty of dealing with uncertainty at different scales and locations. Yet, while they each highlight the critical role that knowledge, and science, plays in facilitating adaptation and resilience, they do not examine adaptation within the epistemic community itself. This study takes these concepts as a starting-point for thinking about how SESs can deal with uncertainty and climate change.

Why “Adaptive Epistemologies?”

In advocating for adaptation in SESs, authors often call for increasing knowledge and data collection in order to enhance system sustainability. For example, Ostrom’s (2009) framework for measuring the sustainability of SESs states the importance of increasing “predictability of system dynamics” so that decision-makers can better estimate potential outcomes. While increasing knowledge and highlighting the importance of science are frequently discussed, scientific practice is also discussed in SES literature in other ways. For instance, integrating social and ecological knowledge is a main goal of SES work, yet this interdisciplinary integration has been fraught with difficulty. Theoretical models and predictions have often failed to incorporate social complexity and cultural, political, and economic subtleties often go undiscussed (Ostrom, 2009). To fill this gap, Ostrom (2009) and others have, again, called for more detailed work to be done in order to understand how adaptive institutions can be facilitated, and particularly how "knowledge, deliberation, and learning affect institutional change" (Koontz et al., 2015, p. 147). While these are important factors to consider in facilitating adaptation, it is also important to understand how science itself can be adaptive in order to support these broader goals of SES adaptation.

Adaptive epistemologies, like other adaptive frameworks, acknowledges that knowledge is emergent and ever-changing. I described this adaptation in the way that ecological restorationists in the Columbia River Basin adapted to the extreme conditions of 2015. It can also be seen in the way that the field of ecological restoration more broadly is shifting its conceptual gaze from restoring to past, historic baselines analogues to a no-analogue, climate changed future. In the following chapter, I will outline the theoretical concepts, methods, and conceptual framework for investigating adaptive epistemologies.

Chapter 4: Investigating Adaptive Epistemologies

A New Name for an Old Thing

The River Restoration Northwest Stream Restoration Symposium has been an annual occurrence for seventeen years, and many of the more than four hundred people at the conference have been attending for over a decade. It is a place where old colleagues come together to discuss their projects, students come to learn new skills and network for jobs, engineering firms come to showcase their latest technologies, and the "restoration industry" comes together to share new ideas. This year was no different, and the "new idea" on everyone's mind was "Stage 0."

For decades, river restoration has been centered around the idea that an alluvial stream develops as a single channel, with water reaching flood stage and topping banks every few years. This single-channel framework, or "Channel Evolution Model," is still the most common way to classify and understand past and future changes in streams (Schumm et al., 1984). Restorationists use these stream models for planning restoration of stream structure and function. The model follows the evolution of streams through Stages 1-7 as it evolves due to hydrogeomorphic processes such as incision and aggradation. Another, often controversial, classification system, "Natural Channel Design," or the "Rosgen" system (Rosgen, 1994), has also dominated restoration design and similarly follows a single-channel framework. Rosgen's system has been particularly influential because the uptake of the Rosgen system has been linked to certification programs that have facilitated privatization of the industry in some regions (Lave et al., 2010; Lave, 2012). Regardless of the model used, they have all assumed single-channel rivers and streams to be the norm.

These single-channel models are now being questioned. A new framework, the "Stream Evolution Model" considers the prevalence of single-channel streams to be human-created: a result of land use and an artifact of development that drained wetlands, ditched fields, and development on historic floodplains (Cluer and Thorne, 2013). The Stream Evolution Model adds a "Stage 0" and a "Stage 8" to the evolutionary cycle. These stages represent multi-threaded or "anastomosed" streams in floodplains that are typically inundated by floodwater several times a year (Cluer and Thorne, 2013). Streams like these are now thought to more closely resemble pre-development conditions, including areas influenced by beaver (Bouwes et al., 2016). As more studies are completed, Stage 0 streams have been found to provide more ecological benefits than single-channel streams, including increased habitat diversity and physical resilience, as well as amelioration of high temperatures (Cluer and Thorne, 2013).

“Stage 0” was a big deal at the annual symposium because the idea was forcing restorationists to rethink restoration goals, the engineering methods used to reach those goals, and the metrics for measuring success. To be sure, not everyone is on board with this new concept, and some are skeptical of its utility, but for many it represents a new way to think about their work. One restorationist at the symposium even cited Kuhn (1962): “it’s a ‘paradigm shift’” he stated.

At the conference, talks by some of the pioneers of the concept were followed by preliminary results from projects that had implemented “Stage 0” designs. Practitioners were excited to see the results and assess whether the “Stage 0” would help them in their own projects. To many, it made sense that setting restoration sites back to this earlier stage would garner more ecological response, especially in terms of the goals that were emerging as important for mitigating the effects of climate change: increasing groundwater interaction and a diversity of habitat types all within close proximity. As I will describe in Chapter Five, restoration using beavers and beaver dam analogues (BDAs) is also fast becoming an important tactic, and “Stage 0” describes a “re-beavered” landscape, fitting in well with this larger shift in the field.

But, most importantly, restorationists at the conference were excited because “Stage 0” gave a name to something that they had been working around for a while: restoring floodplain connectivity with natural processes and moving away from more heavily engineered, channel-centric approaches. In one conference talk, a restorationist pointed out that one reason why the earlier, channel-centric approaches dominated may have been that they were easier to “count” (Hogervorst, February, 2018). The success of many restoration projects is measured in relation to recovery goals, which usually include numbers of pools, numbers of structures, or miles restored. The complex, braided streams in a highly dynamic floodplain make quantifying the success of “Stage 0” restoration projects difficult. But putting a “name” to this new restoration goal: “Stage 0,” enables people to use it more easily, and as was pointed out to the conference audience, could lead to the “social acceptance of a new technique” (Hogervorst, February, 2018). These types of changes in theory, practices, and metrics are constantly rippling through epistemic communities, and now some of them are emerging as strategies that restorationists are adopting to deal with climate change.

Science and Change

Ecological restoration provides a provocative case for understanding how scientists deal with change. This is because the very purpose of restoration, the methods and metrics used, and the goals of the field have to shift to cope with climate change. Because ecological restoration and conservation sciences more broadly are applied sciences, restorationists are on the front line for dealing with and adapting to climate change. Scientific practice in the epistemic community of ecological restoration takes on many forms. While some of these practices involve what might commonly come to mind when we think of laboratory or field work—scientists taking measurements, for instance—scientific practices are also on view at conferences like River Restoration Northwest, where people present their ideas, and different epistemic cultures are enacted, negotiated, and performed (Hall, 1997). The practices that make up the scientific work of ecological restoration in the Columbia River Basin are indeed diverse. Throughout the region, there is a vast network of people in fields and offices. They are ecologists, fisheries biologists, hydrologists, engineers, forestry workers, planners, policy-makers, bulldozer operators, summer interns, community volunteers, and fish wranglers. They are measuring, counting, modeling, monitoring, designing, planning, tagging fish, moving dirt, planting trees, and writing policy. All of this work is, to some extent, a form of scientific “practice,” in the sense that as it is done, it “makes” and “remakes” the field of ecological restoration. The actors in this diverse epistemic community are all practicing and performing ecological restoration, even though the things they are doing can be very different. One way to understand how these individuals are dealing with climate change is to look at how they are shifting their practices—simply: what are they doing differently in light of climate change?

Change in the Columbia River Basin is not a new phenomenon. Environmental and social changes have been drastic and ongoing since European settlement, and for millennia before, as Indigenous peoples shaped the landscape. Science, too, has always been changing, and scientists have always been adapting to different drivers of change. Yet, while change is always occurring, formations that create temporary stability in science also exist. Once the foundations of a discipline are laid, they can be modified, but those original foundations must be dealt with and adjusted in order to change (Hacking, 1992). For example, the origin story of ecological restoration and Holmes' work in the first half of the twentieth century demonstrates how those disciplinary foundations influence and co-produce the field today.

Theories of change in science provide some ways to conceptualize these shifts in epistemic communities. In Kuhn (1962)'s *The Structure of Scientific Revolutions,* he shifted the study of science to look at what scientists actually do when they are "doing" science. Instead of a teleological argument that sees science and technology as constantly progressing, he argued that there are periods of "normal science" which are upset by scientific revolutions, or paradigm shifts. According to Kuhn (1962), when scientists in a given field are conducting "normal" science, they share a "paradigm," including the same beliefs, understandings, theoretical frameworks, models, and methods. They go about solving "puzzles" using these shared worldviews and ways of working. Eventually, however, unsolved "puzzles" accumulate into "problems," creating a period of "crisis," which necessitate changes to the paradigm. This crisis is eventually resolved, and a new paradigm is constructed that enables normal science to continue. Kuhn (1962) offers a framework for understanding change in science, but he also explains how different paradigms can exist simultaneously, even if they are at odds with one another, or in his words, "incommensurable."

Instead of change, Hacking (1992) focuses on stabilities in science, and finds that disciplines develop bodies of theory, scientific apparatuses, and methods of analysis that are constantly adjusted to one another to maintain continuity. He uses the analogy of a rope to describe science: there are multiple strands and, while one can break, the rope may still hold (Hacking, 1992). These strands can be theoretical, experimental, or instrumental technologies. So, while some parts of an epistemic endeavor may change, others may stay the same. Instead of a Kuhnian paradigm shift, science may remain stable even if new theory or technology becomes available. Instead of a major shift, scientists may slowly adapt to technological innovation, data needs, or exogenous changes that require new theories or focus.

For ecological restorationists, climate change is one of these shifts, and it is currently underway. Funtowics and Ravetz (1993) argue that, because society needs science to address risk and environmental crisis, science now operates in a “post-normal” state. A “post-normal” science recognizes the complexity of nature and moves beyond a positivist and modernist vision of techno-scientific progress (Funtowics and Ravetz, 1993). Unpredictability, contradiction, and complexity are assumed, and this “enriched awareness of the functions and methods in science” is welcomed (p. 740). Similar to adaptive management, in a “post-normal” science, values are explicit, and uncertainty is recognized and “managed.” Funtowics and Ravetz (1993) argue that a post-normal science has the potential to transform science into a more democratic force by recognizing multiple ways of knowing and addressing risk and the environment in a more just way.

Assumptions and Concepts

In this chapter, I outline the concepts that I will use to locate change in science in the following chapters. They hail from STS, philosophy of science, and social theory more broadly, and include practices, knowledge infrastructures, and institutions and organizations. I want to see if the carefully developed insights from science studies and critical theory can help answer questions about science and environmental management in a climate-changed future. To do this, I take a pragmatist starting point: the Columbia River is a highly altered ecosystem and it is managed as a hydropower-generating machine—it is techno-natural, and the way it is managed reflects this. A pragmatist would ask: what do we want this river to be in the future, and how do we get there? In terms of managing natural resources, the first part of this question is a highly contentious and political. There are many versions of “we” and just as many visions of “the future.” So, how can we even begin, let alone move on to the second part of the question—how to get there?

One answer is to look to law, which—when idealized—can be viewed as a sort of societal consensus of values for what "we," as a society want the river to be in the future. According to this perspective, a shift is happening, whereby the river is coming to be valued not only as a hydroelectric machine but also for its ecology, and especially for its salmon-sustaining abilities. This has been a massive cultural and societal shift, driven by a desire to save a species "at whatever the cost." Coupled with the ongoing struggle and recognition of Tribal Treaty rights, as well as a broader environmental justice movement focused on restoring salmon to the region, there has, no doubt, been a shift in societal values of the Columbia River. Although many streams of culture and power operate to shape these multiple environmental imaginaries, this dissertation focuses on the role of one of these: restoration science. It asks: what role does restoration science have in shaping the way that we manage the river? And, crucially, in light of climate change: how can this science adapt? These questions motivate my interest in how science works, what it does, and how it co-produces and shapes nature. Science is not usually thought of as something that adapts, but by bringing science studies to the world of adaptive management and ecological restoration, I hope to work towards filling this gap.

This is first and foremost a qualitative, ethnographic project. In this study, you will find the perspectives of many ecologists, but I am not an ecologist by training. My background is as a social scientist of natural resources and also of science. While I have worked hard to familiarize myself with riparian and stream ecology, hydrogeomorphology, and applied as well as theoretical concepts in restoration, I am not a natural scientist. What I *can* bring is a social scientist's perspective to these fields. Similarly, although this story pivots on some nuances of statistical data and modeling, which I have a foundational understanding of, I am not an expert in either of these quantitative fields. Instead, I bring the eye and ear of a qualitative researcher, and the ethnographic sensibility of a "thick" description.

Most importantly, despite the crucial perspective of the Native American peoples in the US and Canada who are intrinsically affected by the topic of this work, I am a first-generation immigrant to the United States and the Pacific Northwest, and so will not speak for Indigeous peoples. Instead, my engagement with Indigenous voices is only through relaying perspectives of individuals as honestly as I can from interviews and conversations with tribal members who generously offered their time. These are individual perspectives and do not necessarily represent the opinions of other tribal members.

Finally, this study holds to the assumptions of STS, which have its roots in social constructivism and postmodernism, and are founded on an understanding that knowledge is situated (Haraway, 1991). In the words of Pickering (1995), "scientific knowledge is objective, relative, and historical, all at once" (p. 33). This means that science is "produced and consumed by particular groups of people" (Clarke, 2005, p. xxiv) and located within a particular historical context (Kuhn, 1962). Claims to knowledge are considered inherently political. Despite this, it is also crucial to understand that a major assumption of this, and most STS work, is that *science is important* and it is *different* from other ways of knowing. It is important to the way that we know the world, to the way that we decide to act, and to all of the practical and policy decisions that rely on scientific work. Although knowledge is understood as situated, this does not mean that scientific facts are any less "real." It also does not mean that all knowledge is equal. STS has been rightly criticized for some of its early work that equated all forms of knowledge and expertise by confusing the idea that all knowledge was socially constructed with meaning that all social constructions are sufficient to constitute knowledge (Edwards, 2013). Almost all STS scholars now recognize this relativist folly, and instead consider themselves to embrace a "third wave" of STS scholarship (Collins, 2009). This work is dedicated to recognizing the "truth" within the embodied claims of knowledge production, which are critical to our ability to act in and understand the world. It also acknowledges the way that scientific controversy can exist within scientific consensus (Edwards, 2013). Most of all, this scholarship respects the unique value of scientific evidence and the importance of expert communities to our ability to make decisions and act in the world. I hope that the scientists represented in this work would agree.

Methods

This project was developed in a time, not so long ago, when there was increasing regional and federal funding and support for climate change science and migration and adaptation research. The first two years of this research were spent attending conferences and workshops across the basin, observing the restoration community, and discussing the many issues that they were facing when dealing with climate change in their work. The effects of climate change were being keenly felt, especially in the record-breaking, almost snow-less winter of 2015. In many places salmon returns were at an all-time low, yet still, there was a tentative optimism. Restorationists, for the most part, believed that, with support, our society would be able to adapt to or mitigate the worst effects of climate change and that the federal government would increasingly prioritize this effort.

That bubble burst for many people when Donald Trump was elected president in 2016. The bursting of this bubble also coincided with my first year of conducting in-depth interviews throughout the Columbia River Basin. While the topic of climate change was already politicized in much of the rural West, with President Trump entering the White House, an all-out war was seemingly declared against environmental protection and the science that supports it. The highest office in the nation was openly hostile towards climate change research, mitigation, and adaptation. Many programs that were working on topics related to climate change began having their funding cut. Some scientists were even fired or demoted in an effort to end their research programs. Even in agencies where this wasn’t happening overnight, cuts were being threatened from federal levels in the long-term. As I worked through my interviews with restorationists, morale was low and rage ran palpably under the surface.

This was certainly an interesting time to be conducting a study on how scientists were dealing with climate change. Their main concern often centered on a lack of political support for their work at a fundamental level. Some participant scientists joined marches and protests, openly engaging in advocacy and political action to keep climate science and adaptation on the federal agenda. This unexpected political shift undoubtedly colored the interviews and observations in this study. Most often, this shift was illustrated through expressions of anxiety, sadness, and exhaustion, as people saw their life’s work being swept under the rug, ignored, or literally going to waste in a federal political atmosphere that was openly hostile and toxic to anything associated with climate change. Fortunately, many of the state, tribal, and local agencies and organizations did not feel this effect as acutely, as political support for environmental issues remains high at regional, state, and local levels in most of the Pacific Northwest. Regardless, everyone I spoke to was aware of the political shift, and most people brought it up in interviews. This all points to a fundamental fact of ethnography: that it is a situated method, and although it is possible to illustrate concepts that might be transferrable, it is first and foremost grounded in the time and place that it is conducted.

This research combines the interpretive qualitative methods of grounded theory (Charmaz, 2005), archival and policy analysis, and ethnography, including interviews and participant and nonparticipant observation. Situational analysis was chosen as a method because it can provide insight into controversies over knowledge, which are understood to be highly contextual (Clarke, 2005). This aligns well with Haraway's (1991) "situated knowledges" concept, which contextualizes knowledge historically, and is committed to recognizing the "truth" within embodied claims. This is important because it supports postcolonial perspectives and ensures that actors are not silenced—a particularly important consideration in the study area of the Columbia River Basin where traditional and indigenous knowledge plays a critical role in decision-making and restoration in the region and where colonialism has been—and still is—a powerful force driving access to resources and the way that we know and frame those resources.

The "situation" that was analyzed encompasses both the historical development of the field of salmon habitat restoration and restoration ecology, as well as the current practices of salmon habitat ecologists, habitat restoration managers, and people and institutions involved with developing salmon habitat policy. Because grounded theory, and specifically a "situational analysis" theory/methods framework was used, the data collection and analysis stages of research were iterative (Clarke, 2005; Clarke et al., 2015). Grounded theory approaches are aimed at identifying themes and the sensitizing concepts that point towards and align with those themes (Bowen, 2006). Categories for coding were developed using situational analysis mapping exercises and memos, which are designed to help identify key themes and relationships in the research (Clarke, 2005). In order to capture emerging practices and strategies for dealing with climate change, I paid special attention to those people who are on the "front lines"—actually conducting restoration research and monitoring activities, and therefore making epistemic choices. In a region as large as the Columbia River Basin, a study like this this necessarily encompasses a large number of people. Fortunately, the situational analysis method is designed to help deal with this through situational mapping exercises that help identify key actors that would be potential participants for in-depth interviews. The “situation” is also narrowed by the study’s focus on how actors are dealing with climate change in their scientific practice, therefore eliminating those actors in the basin whose work does not touch on climate change or scientific work. Nevertheless, a large-scale ethnography like this one aims to sample a cross-section of actors from different sectors and locations in order to develop a broad picture, while going in-depth in certain locations to gain a more detailed perspective of the issues.

Through situational mapping, initial participants for in-depth interviews were identified. From this initial group and additional snowball sampling, a total of forty-two individuals were interviewed in thirty-six in-depth, 1-1.5 hour semi-structured and open-ended interviews. These interviews were transcribed and then coded using MAXQDA software. The coding method was, again, informed by grounded theory and situational analysis. These are abductive methods, meaning that potential hypotheses emerge from data as they are collected, interpreted, and analyzed. As concepts emerged in the interviews, the iterative coding process foregrounded themes that could be seen across interviews, and anomalies stood out. As themes emerged, they were integrated into future in-depth interviews, in order to “test” them out with participants and triangulate—validate or dispute—them.

In order to gain a depth of understanding beyond the individual perspectives captured in the interviews, the study also included participatory and non-participatory observation. Participatory fieldwork involved taking part in five major regional conferences and associated conference workshops on ecological restoration and salmon recovery themes. At these conferences, I was able to observe emerging topics of concern and have informal discussions about how people were struggling with and through issues in their field. The field notes and conference materials collected were analyzed as above. I also took part in virtual workshops and webinars that are held regularly among practitioners in the region. I was generously invited to join restorationists in the field, and was shown around several of their restoration sites. I was also able to participate in management site visits where experiments were being conducted or management decisions were being made. These visits were invaluable in contextualizing the issues that participants discussed in interviews, and I was able to further triangulate emerging topics and concepts. Notes from these visits and conferences were also coded and analyzed using MAXQDA software. Finally, historical documents at the University of Washington Special Collections, as well as policy documents from organizations in the basin such as the NW Council and the BPA were also analyzed using the above methods.

Where to Look for Adaptation in Science?

As a conceptual framework, I hope that adaptive epistemologies can serve as a reminder that scientists are constantly adapting to social and environmental change. I expect that the framework will also provide some conceptual space for people engaged in environmental management and scientific work to reflect on the way that climate change is influencing their own practices, or might do so in the future. This is a step away from the promises of modernity—techno-scientific solutions and certainty—that instead looks to the actions of individuals and organizations that are working on habitat restoration today in order to capture the social nature of epistemic work. Therefore, the conceptual framework of adaptive epistemologies considers the role of scientific practices, the knowledge infrastructures that facilitate these practices, and the institutions and organizations that are co-produced by them, in facilitating or hindering adaptation in SESs. By examining these sites, I will be able to explore the ways that ecological restoration is adapting.

Practices

Ever since Kuhn's (1962) groundbreaking work on changing scientific "paradigms" and "revolutions," sociologists have understood science as changing. Practices are constantly re-making the social fabric, or culture, or science. Therefore, science can be understood as performative and temporally emergent through practice (Pickering, 1995). I draw from cultural studies and STS to define both culture and practice. From a performative perspective, I draw from Pickering (1995) to define scientific practice as "the work of cultural extension," or the activities of scientists that make and remake that science (Pickering, 1995, p. 3). Culture and practice are therefore entwined through action. Practices are the actions that perform a particular culture (Pickering, 1992). In defining culture, I draw from the field of cultural studies, which views it as shared social meanings that are constituted through practice and representation (Hall, 1997). Practice is temporal, while culture is not; it is a resource that is used, and a "surface of emergence," or what currently exists from which practice can take place (Pickering, 1995, drawing from Foucault, 1972). Looking at scientific practice is useful when thinking about change in science because it highlights the role of individuals and their actions in either remaking or extending—in other words, *changing*—a particular scientific culture.

Pickering (1995) describes the process of cultural extension in what he terms the "mangle of practice," whereby the goals of scientific work are constantly "accommodated," revised, or "tuned" as scientists encounter "resistances" through practice. This dialectic process of "resistance" and "accommodation" therefore drives practices to change, and thereby culture to also shift. This conception of practice is particularly relevant to understanding change in ecological restoration, because its dialectic nature bears striking resemblance to the emergent qualities of an adaptive socio-ecological system. This temporally emergent aspect of practice is also aligned with pragmatist notions of understanding the world as changing through time as they adjust to current circumstances.

As scientists cope with uncertainty and shifting baselines, they shift their epistemological practices: they find ways to deal with "resistances" to their efforts by adjusting to or "accommodating" them. As in other scientific endeavors, these resistances often occur when temporal and spatial scales that were assumed to be unproblematic suddenly create an obstacle, necessitating a change in practice. From this contradiction new practices emerge. Therefore, practice is a key site where we can observe the adaptation of scientific work. In the Columbia River Basin, restorationists are adapting their work to deal with climate change in several ways, including facilitating the emergence of new practices, acclimating their practices by working to "tame" indeterminacy, and using models to anticipate the future.

Epistemic communities are constituted through an epistemic culture. These epistemic cultures are "cultures that create and warrant knowledge" (Knorr-Cetina, 1999, p. 1). Scientific/epistemic cultures are the ways and norms of working within and achieving expert status in a particular scientific field, and like all cultures, they change.

For example, in Knorr-Cetina's (1999) ethnographic work on epistemic cultures, she goes beyond describing and defining a discipline and instead looks at the "epistemic machinery," or organization of expert systems that are a precursor of knowledge construction. To do this, she looks to the different empirical approaches, collections of instruments, and social mechanisms that make up an epistemic culture. She demonstrates that disciplines are not homogenous and often contain overlapping but distinct epistemic cultures (Knorr-Cetina, 1999).

Ethnographic methods are particularly useful for examining practices and cultures, and researchers in STS have developed a significant literature devoted to studies of scientific practice. Like this one, these studies often use ethnographic methods to examine the performative work that scientists do within laboratories (Latour and Woolgar, 1979; Knorr-Cetina, 1999, Law, 1986), or field sites (Kohler, 2002). Following Knorr-Cetina's ethnographic work, I focus on the way that culture is "deployed in knowledge production" through practices in order to observe strategies that restorationists are using to adapt to environmental change. While Knorr-Cetina was concerned with the epistemic cultures within large-scale experiments and laboratories, other researchers have focused on field science (Geissler and Kelly, 2016; Kohler, 2002). Similarly, the large-scale experiment of restoration in the Columbia River Basin has also developed its own cultures of field science. Different restoration cultures and enterprises have emerged in the Columbia River Basin over the past several decades, and certain metrics have exerted political force as they become institutionalized (Knorr-Cetina, 1999). The epistemic cultures and expert systems that result are therefore unique and situated, but they also change. The historical overview of the disciplines of restoration ecology and ecological restoration in Chapter Two outlined several of these distinct cultural shifts that have happened through time.

Looking more closely at individuals, behind epistemic cultures and practices lie what Daston and Galison (2007) call specific "forms of the scientific self" (p. 4). Daston and Galison's (2007) work on the concept of "objectivity" demonstrates how epistemologies have particular "ethos" that are both "ways of being" and "ways of knowing." Like culture, these virtues are historically situated and change through time. While they are only one aspect of a culture, they play an important role in epistemic work. Epistemic virtues and norms like truth, objectivity, replicability, or creativity become important for scientists to engender at distinct historical moments.

Epistemic virtues differ from simply being a "virtuous" scientist, in the sense of having competence or expertise. Instead, they refer to "normative codes of conduct…bound up with a way of being in the world" (Daston and Galison, 2007, p. 40). For instance, Daston and Galison (2007) find that epistemic virtues such as "truth-to-nature," "mechanical objectivity," and "trained judgment" evolve through time. While these virtues can deem a scientist "virtuous," they change, and they play distinct and different roles in knowledge making in different periods. During different periods of history, scientists performed different virtues, and possessing them was viewed as an important part of the scientific endeavor (Daston and Galison, 2007).

These changing norms related to what is been deemed "good" and "bad" science can be found in the ways that participants discuss their own—and other peoples'—restoration work and scientific practice. Epistemic cultures in restoration value increased experimentation in the face of uncertainty, and are underpinned by epistemic virtues of efficiency, or "pragmatic efficacy" (Daston and Galison, 2007). The epistemic virtues within restoration ecology are also shifting to focus on anticipation as a virtue. This has been found in other epistemic communities that shift to look to the future, as a moral injunction to anticipate the future while doing scientific work emerges (Adams, 2009). Each virtue has its own practices, which can often be at odds. For instance, the epistemic virtues of precision and replicability are often contradictions (Daston and Galison, 2007). Similarly, a need to experiment and adapt restoration practices in the Columbia River Basin is in tension with the certainty demanded by the ESA—where species must be recovered at "whatever the cost." Disciplinary principles and virtues within engineering, for instance, also come in to conflict with restorationists seeking to exploit natural, ecological processes. As climate change takes effect in the Basin, epistemic virtues are also changing, and as certainty becomes a less plausible goal, anticipation and experimentation become more desirable epistemic qualities. The scientific practices, the cultures they emerge from, and the virtues that scientists deem important are all things that can be observed through the actions and words of scientists as they negotiate their work. Through these observations, change can be qualitatively described, making them a focus for understanding how scientists are adapting.

Knowledge Infrastructures

Studies in the sub-field of knowledge infrastructures examine the structures that support scientific work. While knowledge infrastructures include institutions, organizations, and norms, they also include material structures like buildings, wires, and computer networks. Knowledge infrastructures are therefore included as an object of study because they capture not only more abstract things such as metrics, standards, and networks of people, but also the scientific instruments, models, and data networks and repositories that are often invisible (Bowker et al., 2010; Edwards 2010). Knowledge infrastructures support the work that scientists do and influence the way that science is applied (Bowker and Star, 1999). Infrastructures are especially important to consider in this study of adaptation in scientific work because they enable scientific work to occur. As such, they can be designed and maintained in ways that facilitate or hinder adaptation.

Because their materiality and rigidity have legacy effects, their design has consequences for the science that results (Edwards et al., 2013). Yet in the context of environmental management, these infrastructures must be able to adapt to changing socio-ecological conditions and trajectories including climate change. Knowledge infrastructures in place today will shape future scientific capabilities and programs dedicated to salmon recovery in the Columbia River Basin. In order for them to be successful, it is important to understand how knowledge infrastructures can be adaptive in a time of unprecedented environmental change.

Salmon habitat restoration in the Columbia River Basin is supported by a large-scale knowledge infrastructure. While this knowledge infrastructure includes the individuals, their work practices, norms such as standards and routines, as well as the physical spaces and materials such as cyberinfrastructures that support their work. This infrastructure is considered “large” because of its geographic and temporal scale, ambitious goals, large economic investment, and coordination among many actors (Edwards, 2003). Understanding how knowledge infrastructures are changing has been identified as one of the key research challenges for infrastructure studies (Edwards et al., 2013).

Ideally, knowledge infrastructures should support scientific work without needing constant upkeep—therefore they should be relatively stable and reliable (Star and Ruhleder, 1994). However infrastructures are "paradoxical" in the ways that they both support and stifle adaptation and change (Star and Ruhleder, 1994). According to Bowker and Star (1999), this is due to the way they must be able to facilitate work practices across organizations and users by employing standards, while at the same time remaining locally useful and specific. This means that knowledge infrastructures need to be both rigid and flexible, universal yet able to change (Edwards et al., 2010).

This tension becomes especially clear in large-scale infrastructures where sociotechnical systems have a spatially and temporally broad reach (Star and Ruhleder, 1994). While infrastructures are often understood as "geographically dispersed," (Star and Ruhleder, 1996, p. 112), they can nevertheless be built to facilitate the management of a natural resource and promote a specific management paradigm and goal in a specific location. Shared infrastructures are an important "public good" that are ideally oriented toward supporting sustainable research over the long term (Bowker et al., 2010). While the locally situated yet larger-scale, dispersed nature of infrastructures makes them particularly complex, at the same time, this is what makes them more likely to adapt.

Infrastructures can be studied ethnographically by focusing on the techniques that actors use to deal with them and work within them. Bowker (1994) developed the method of "infrastructural inversion," which, instead of ignoring research infrastructures because they are often invisible, focuses on how individuals and groups support and create infrastructures. Some of these tactics include: *infrastructuring* (Pipek and Wulf, 2009)*, standardization, and scaling* (Ribes, 2014). Sustained work, such as *data interoperation* and *infrastructuring* can also be observed at both the individual and organizational level (Ribes, 2017). For example, establishing a basin-wide program of data interoperability is an important way in which restorationists in the Columbia River Basin coordinate and establish a knowledge infrastructure.

By focusing on these dynamics, we can see how restorationists work to design and implement adaptive knowledge infrastructures in a changing climate. In Chapter Six, I use the example of the Pacific Northwest Aquatic Monitoring Program to explore how restorationists are creating adaptive knowledge infrastructures that tack back and forth between the past, present, and future by standardizing data and creating consistency not only across spatial extents, but also across time. I argue that one of the ways that restorationists cope with environmental uncertainty and change is through orienting these infrastructures to what Karasti et al. (2010) refer to as "infrastructure time," by anticipating the future needs and orienting infrastructures to the goal of sustainability and adaptation through change.

Institutions and Organizations

Institutions can be defined as the "enduring regularities of human action in situations structured by rules, norms, and shared strategies" (Crawford and Ostrom, 1995, p. 582), or alternatively, "any form of constraint that humans devise to shape human interaction" (North, 1990, p. 4). Organizations, on the other hand, are "groups of individuals bound by some common purpose to achieve objectives" (North, 1990, p. 5). While organizations are sometimes conceived of as a kind of institution, this study draws its definition from later institutional theorists, who separate the two (Scott1995). Institutions, in this sense, prescribe interactions within organizations (Ostrom, 2005, p. 3). Institutions do not include physical structures, hence the use of knowledge infrastructures as a complementary concept (Pahl-Wostl, 2009). Institutions and organizations are important to consider in the context of adaptive epistemologies because they enable or constrain individual and collective action aimed at adaptation. Researchers have proposed several ways that institutions can be made more adaptive, and this conceptual base provides a useful starting point for exploring how institutions involved in epistemic work can also become adaptive.

Adaptive institutions are those that are flexible enough to deal with multiple and shifting objectives in SESs (Pahl-Wostl, 2009). However, institutions that are adaptive are different than those that simply change. Instead, adaptive institutions are able to adjust and move in a *normative* direction, to meet societal goals (Pahl-Wostl, 2009). Therefore, in an adaptive scenario, institutional goals are important. This means that the intent of an institution or management effort is also important. This intent plays out in scientific practice, in what Pickering (1995) calls the "dance of agency" that occurs between scientists and the natural world as they go about their work. Therefore, institutions and their goals are foundational to determining kinds of scientific work gets done.

Several organizational factors have been identified as contributing to adaptive institutions. Polycentricity and federalism indicate systems of governance that contain overlapping or nested jurisdictions. Polycentric organizations promote interactions across scales and can offer redundancy in the case of a failed effort at one level (Ostrom, 2005). By facilitating experimentation, interactions between scales promote “multi-level learning processes” that allow actors at different scales to learn from one another (Pahl-Wostl, 2009). Seeing success in one location can also help empower local actors to create solutions based on local knowledge (Ostrom, 1990).

In addition to organizational factors such as polycentricity, knowledge and social learning have been identified as key characteristics in an adaptive institutional framework (Koontz et al., 2015). Social learning occurs as people interact with each other and produce relational knowledge about their situation (Schusler et al., 2003). Organizations can facilitate or hinder social learning necessary for adaptation (Pahl-Wostl, 2009). In an adaptive organization, policies are likened to experiments that will be changed if they are not meeting a chosen end (Ostrom, 2005). Much like adaptive management itself, adaptive institutions and organizations facilitate experimentation (Koontz et al., 2009), and adaptive governance by dealing with complexity and uncertainty (Huntjens et al., 2012). An organizational culture that places importance on questioning embedded assumptions will more likely facilitate adaptation of institutions (Pahl-Wostl, 2009).

Although these concepts help us understand what factors might produce adaptation of institutions generally (Koontz et al., 2009), they should be extended to adaptive *knowledge* institutions that would be more prepared to facilitate epistemological work through times of change. Organizations that produce knowledge are particularly well situated to embrace these adaptive institutional structures because they are already attuned to learning and responding to new knowledge as it arises. Restorationists in the Columbia River Basin are already shifting their work due to institutional change, where organizational goals are translated into scientific goals in order to meet the needs of salmon recovery institutions in a changing climate.

Ecological restoration in the Columbia River Basin is supported by specific institutions and organizations that facilitate knowledge production and organize the epistemic community in particular ways. These organizations include large basin-wide organizations and entities such as NOAA, CRTFIC, the NW Council, and BPA, as well as smaller local and regional watershed councils, individual tribal and state natural resource agencies. Institutions include the legal infrastructure and norms that drive salmon recovery and restoration of critical habitat. The most influential of these is the ESA, although other environmental and natural resource laws such as NEPA, the Northwest Forest Plan, agreements such as the Fish Accords, and water quality standards are also important. Organizations that influence science also include fisheries and forestry departments at universities, tribal research departments, and research consulting firms.

Ecological restoration has developed in specific ways in relation to these institutions and organizations. In the early 1990s, salmonids in the Columbia River began to be listed under the ESA. Tribes were some of the first to advocate for listings, and after years with only one or two adults returning to spawn, the Shoshone-Bannock Tribe put forward the first listing proposal for the Snake River Sockeye in 1990. This fundamentally altered the way that restoration would be carried out in the basin. While some restoration was taking place prior to the ESA listings, some restoration was taking place, this was mostly in smaller streams that focused on forestry lands in response to the Northwest Forest Plan. With the first ESA listings in place, the Pacific Coast Salmon Recovery Fund was developed, and states also stepped in with their own recovery programs and regional boards. In many ways, the ESA launched ecological restoration in the Columbia River Basin, and the institutions and organizations in place today owe their creation to this law. As one restorationist put it, the listing of salmonids in the basin "kicked things into a different level and into a higher gear" (R6).

As described in the last chapter, legislation such as the ESA helps demonstrate what Jasanoff (2004) has termed the co-production of science and law—whereby science is used to support legal action, and the resulting policies, in turn, create a pivotal role for science. Organizations co-produce science in straightforward ways, such as allocating funding through policies and institutions. For instance, the BPA delivers most of the funding for habitat restoration in the Columbia River Basin as mitigation for the effects of the dams. In many ways, BPA funding defines what kind of knowledge gets produced. As an organization, with the coordination of the NW Council, BPA not only funds monitoring programs, but also prioritizes projects, metrics, and methods of restoration. Organizations like the BPA also make the research funding structure of restoration ecology unique in the Columbia River Basin. It is generally an "unwritten rule" that grants from other science funding agencies such as the National Science Foundation are almost impossible to get, because it is assumed that the BPA will be funding fisheries-related research in the region. Funding is also spatially determined by the fact that the BPA is only responsible for mitigating the effects of dams, so areas below the Bonneville Dam, such as the estuary, were not recognized as being affected until recently, and now only to the tidal high-water mark. In these ways, institutions and organizations are a determining factor in scientific work in the basin.

Yet, I will argue that institutions and organizations co-produce science in more subtle ways as well. Since the time of the first ESA listings, the epistemic community of ecological restoration in the basin has grown rapidly to meet the mandate to recover salmon. While the ecological complexities and political hurdles to restoration can seem overwhelming, people in the conservation and restoration community nevertheless galvanized around the opportunity that listing afforded. One restorationist who witnessed the rise of the restoration effort in the Columbia River Basin reflected on the uniqueness of this situation:

> "We actually have the opportunity in the Pacific Northwest. We still have wild fish. A lot of people don't have that, like in New England where the Atlantic salmon is Endangered, almost gone in Ireland and Scotland. We actually have an opportunity and I think it is very inspiring." (R9)

To a restoration scientist, recovering salmon to the Columbia River Basin is a once in a lifetime chance to put their scientific practice to work.

Institutions and organizations facilitate and support the practices that are necessary for science to adapt to social and environmental change. They determine the goals and priorities for science, and, in doing so, they depend upon knowledge infrastructures to support those goals. Although epistemic organizations and infrastructures may seem to evolve on their own, they are, in fact, iteratively created, or co-produced, by both society and scientists working toward specific goals. This means that institutions and organizations can also be purposefully developed in ways that facilitate adaptation to change.

Moving Forward

These concepts outline some of the sites to observe change in knowledge production. By looking at the scientific practices of restorationists, the knowledge infrastructures that support those practices, and the institutions and organizations that facilitate or hinder adaptation, we can better understand what an adaptation to environmental change in science looks like. While each of these concepts hails from different disciplinary perspectives, they share two qualities that make them useful in this study: they can all be observed through ethnographic methods and they are all sites where change is negotiated and can be observed. Therefore, by paying attention to how the epistemic community of ecological restoration relates to these concepts, strategies for dealing with change become apparent. The three strategies are by no means the only strategies that restorationists use to deal with change, but they were important themes that serve as a conceptual framework for beginning to consider adaptive scientific practices, knowledge infrastructures, and institutions and organizations. I have called them: emergence, acclimation, and anticipation. The next three chapters describe these strategies for dealing with change by using the concepts above to discuss empirical examples.

Chapter 5: Emergence

Making Room to Breathe

"Did you know that we are losing .3% per year of snow in the Cascades since 1870?" Scott[3] asks. "Since then we have lost half of our snowpack and we have only gone downhill since then. By 2080 there will not be any snow in the Cascades." I'm sitting in a coffee shop in Winthrop in the Methow Valley, North-central Washington. It's a remote, touristy town of a few hundred people. Here, in the off-season between the tourists seeking world-class Nordic skiing and the deluge of summer hikers, the cafe is bustling with locals who all seem to know one another. They stop in on their way to work for a cup of coffee and a 'hello' as they head to their jobs on the ranches and forestlands surrounding the valley. I'm here to talk to a pioneer of beaver reintroduction in the region. He is deeply concerned about the changes that are taking place in this valley, and he is deeply passionate about communicating climate change, or "extreme events"—the term d'art that he uses in a region full of climate change skeptics.

For the past forty years, Scott has been working to restore riparian hydrology by reintroducing beavers. The topic makes him come alive. I want to know how he started down this road—and why beavers? He is humble about his work:

> I don't have any extra intelligence or an extra set of batteries compared to anybody. I don't know anything more than other people, but I do know that innovations require a champion. Some people might say a visionary, but I don't claim to be a visionary. I just claim to be somebody who saw something on the side of the road and picked it up and started carrying it. As a wildlife biologist, I want to try to improve the landscape. It is a passion for me. It has been a passion in my bones forever.

"The Methow Beaver Project" began as a bit of an experiment. Scott saw a chance to make a change and he took it. As a Forest Service Biologist, he was looking for a way to make a more lasting impact on the landscape than the "piecemeal" restoration work that was being done. When the chance came along to try out beaver restoration, he

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[3] Due to requirements of the IRB, this name has been changed.

took it: “When we started, we weren’t sure if it would make a difference at all,” he says. That was back in 2008, and since then, the Methow Beaver Project has grown into a nationally-renowned example of the successful restoration of ecological processes through beaver reintroduction. They have moved dozens of “nuisance” beavers from lowland areas, where they are viewed as destructive to farmland, and relocated them to headwater areas on Forest Service land.

As Scott tells me about the origins of the project, we are interrupted from time to time as he greets a familiar face walking into the coffee shop. In the background, I overhear conversations with the barista. “What do you think of the river?” “Highest I’ve ever seen it.” “I think it’s running at 7500 CFS.”

The River. You can see it from the back porch of the coffee shop. Whole trees with their roots and soil still attached are being flung down its course. The River is the talk of the town today, as it has been for the week I have been here. As I drove up the Columbia River from Wenatchee on my way to the Methow Valley, I saw a vivid change in the Columbia as the crystal-blue of the main-stem began to mix with a chocolate froth. Plumes of milky-brown water and forest debris roared down the Methow River and to its confluence with the Columbia. Logs, sticks, and everything in-between were pulled downward by the heavy flow. I had never seen the Methow like this, in all its melt-water glory. The tumult and debris looked dramatic to my outsider’s eye. The precipitously rising waters appeared to be a disaster unfolding. But as I spoke to the locals, I learned that, while this was considered “high” water, and was close to flood-stage, it was also simply the way the river works. Every few years high waters like these race down from the mountains as the snow melts. Sure, this might tear out a few culverts and cut some deeper turns, but this is what rivers like the Methow, which are driven by snowmelt, are “supposed” to do.

Nevertheless, the River was the talk of the coffee shop. People were excited to see it so high and dynamic as it raced by the back door, carrying whole trees with it. But as dramatic as it looked, it wasn’t something to worry about. Scott picked up on the banter of the coffee shop:

> The river that we are sitting next to should have the opportunity to move all over the valley. As we sit here, the river is coming up and it has been doing some

> exciting things in the last couple of days. We are fighting it as much as we can and trying to keep it confined, but salmon want that river to breathe.

To dramatize, Scott takes a moment to breathe in and out slowly—he is gifted with a dramatic flair. “And,” he continues after a moment, “room to breathe means that it needs the entire floodplain—not riprap to constrain it…Our big hydrograph here is a key feature of the ecosystem function.” Embracing the dynamism of nature is something that ecological restorationists have been advocating for decades. In anticipation of climate change, these practices are expanding to encompass larger scales and more disciplinary perspectives. The epistemic community of restorationists is openly fostering a culture of experimentation where “unruly complexity” is encouraged. This leads to the emergence of new ideas and constitutes a strategy for dealing with environmental change and uncertainty.

Experimentation and Emergence

Back in 2008, Scott’s try-anything attitude helped launch the ‘Beaver Project,’ and it has brought many people in the Methow community together in an effort to restore watershed processes by using beavers as a restoration tool. Even as we finished our coffee next to the surging tumult of Methow River snowmelt, Scott spoke about how the uncertainties of climate change have affected his own work: “When you’re on this roller coaster you want to be like, ‘Whoa! Slow down.’ It's very difficult. It's very difficult to try to get some scientific answers in such volatile systems.” This chapter explores some of the strategies that restorationists are using to seek these scientific answers in such an uncertain environment. This is happening both at the individual and cultural level of practice, and is influencing the culture of collective empiricism of the Columbia River Basin.

There are people like Scott throughout the Columbia River Basin, people who are experimenting with innovative ways to restore the ecosystem processes that were lost as the river and its headwaters were developed and confined. Other restorationists are even working to engineer these processes into places they never existed. As described in previous chapters, process-based and engineering-based restoration have been in tension throughout the evolution of the field, and many people still firmly situate themselves in one "camp" or another. One reason for this divide is that many restorationists view the legacy of engineering "solutions" as a major contributor to the problems that got rivers into trouble in the first place. Engineers constrained and straightened river channels, coinciding with habitat loss. Scott, for instance, juxtaposes his desire to "give the river room to breathe" with the rip-rap that constrains it.

Yet ecological restoration, especially of rivers, owes much of its roots to hydraulic engineering, and designers and engineers play a major role in restoration planning, science, and implementation in the Columbia River Basin. There are also those that think that—while beavers might be a step in the right direction—restoring ecological processes takes a long time. They worry that efforts to restore process may not be enough, or may not happen fast enough to mitigate the effects of climate change that are already taking place. After witnessing the devastating die-offs of 2015, many people are willing to implement innovative measures—engineering *or* process-based—so this type of ecological disaster never happens again.

In practice, many restorationists find themselves pulling from both toolboxes—process-based restoration and more technologically-based engineering solutions to try to try to "hedge" the uncertainty that climate change introduces. These strategies for dealing with uncertainty and adapting to climate change are fostered in epistemic cultures that embrace experimentation and make a gamble, or "hedge," that if enough things are tried, something will work. The collective goal is increasingly to bring fish back by increasing habitat *by any means* necessary. While restorationists often disparage those in opposite camps, the divide is breaking down, as tactics that were once seen as incompatible come together in restoration projects. One example of this is found in the "beaver dam analogue"—an engineered dam structure that mimics a beaver dam and is often intended to entice a beaver to take it up as its own.

These strategies are a way to not only deal with the mess of natural systems, what Taylor (2005) has aptly called "unruly complexity," but which also foster this complexity of interactions so that new concepts and ideas emerge. Ecological processes are not easily generalized and bounded into discrete systems; instead, are replete with intersecting processes that are difficult to predict (Taylor, 2005). But these very properties drive change, just as the "mangle of practice" drives change in culture. Strategies that embrace experimentation and unruly complexity must be supported through epistemic cultures that value these virtues that are being fostered and performed through epistemic practices and institutions. A willingness to experiment with new restoration strategies that may cross the process-engineering divide demonstrates these epistemic virtues and cultural norms, and they can be observed in discourses as individuals appeal to the ethical values of their work, and the way that they make knowledge effective in the world (Daston and Galison, 2007). This points to an evolving collective empiricism which embraces multiple types of restoration efforts, including improvisation and experimentation. This is found in epistemic cultures that foster the emergence of novel solutions to deal with uncertainty and immediacy of climate change effects.

Emergence as a Strategy

Theories of scientific practice and social and cultural change, from Marx to Foucault, philosophy of science, and SES theorists all employ a concept of "emergence." The term "emergence" is used to describe novel concepts or properties that arise out of the interaction between different, more fundamental concepts or properties. For this reason, the term "emergence" was chosen to describe this strategy because it bridges disciplines and has been applied to dynamics at multiple scales of science, from biology and physics to social relations and the production of knowledge. Emergence is one of the key dynamics in conceptual models of SESs and adaptive management. In these conceptual frameworks, emergence of new practices, ideas, and situations is driven by the dialectic nature of co-production. Yet, while emergence within adaptive governance or environmental management is often cited in SES theory, its details have been under-theorized. Therefore, we need more detailed considerations and empirical examples of what exactly drives emergence, what it looks like, and what its effects are.

Work on SESs has detailed the dynamics that give rise to emergence in these systems. Ostrom (1990) documented the emergence that occurs through self-organizing governance systems, and the ways in which they foster innovation in natural resource governance. In addition, Gunderson and Holling's (2002) theory of "panarchy," or the "adaptive cycle of complex systems," describes the dynamics that give rise to emergence in SESs. Panarchy is a theory of cross-scale interactions in which disturbances lead to a reorganization of the SES (Gunderson and Holling, 2002). Understanding these cross-scale interactions in SESs is important in order to facilitate adaptive capacity (Cash et al., 2006). In connecting adaptive governance with panarchy, Chaffin and Gunderson (2015) locate cross-scale interactions of nested temporal and spatial scales, which they identify as sites of "emergence." By studying these cross-scale interactions empirically, then, we should be able to highlight where emergent interactions in an epistemic community are occurring in order to adapt.

From an STS perspective, Pickering (1995) also draws from Foucault (1972) to enlist the concept of emergence in order to understand change. He finds that scientific practices emerge in a dialectic exchange. As scientists work, they come up against "resistances," whereby they must modify their hypothesis, their ideas, or their practice itself in order to carry on. These modifications are called "accommodations," and they lead to the emergence, or adaptation of scientific practice. This dialectic process is conceptually similar to emergence in the adaptive cycle of panarchy, where cross-scale interactions between parts of a system lead to emergence of new practices and cultures.

Social theorists consider culture to be the "surface of emergence" from which humans structure their discourse and actions in epistemic work (Foucault, 1972). By understanding culture in this way, we can see how different cultures will lead to the emergence of different concepts and ideas. For example, an epistemic culture that is techno-scientific is more likely to develop engineering solutions to address environmental problems. Culture as "surface of emergence" also demonstrates how cultural change can lead to new concepts and ideas that might not have been possible under other circumstances. In dealing with uncertainty and change in the field, restorationists are embracing a culture of improvisation and experimentation in which they engage with unruly complexity, as well as diverse disciplinary concepts. Because multiple cultures will contain multiple surfaces of emergence, an epistemic community that embraces multiple disciplinary cultures is more likely to have more concepts, and thereby more solutions emerge. Dealing with the uncertainty of climate change through fostering emergence is therefore becoming a key strategy for dealing with climate change in restoration. Emergence can also be seen in the work of beaver restoration, as restorationists employ novel restoration design strategies and goals. Through the work of beavers, ecosystem processes are set in motion, unpredictability is encouraged, and emergence is thereby encouraged

The Work of Beavers

By employing the tools of paleoecology, researchers have found that beavers and salmon evolved together (Davis and Gibling, 2011). The oldest record of beaver is from about 30 million years ago—the oldest dam from around 3-5 million years ago (Davis and Gibling, 2011). Similar to "Stage 0" restoration, some restorationists believe that restoring beavers is a fundamental way to restore ecological processes to large areas. Beaver restoration advocates like Scott conceptualize restoration on a very long, evolutionary, time-scale. To them, restoration is about restoring the processes that existed before the river was transformed—and that is going to take a long time. As one beaver restorationist put it, "we need to do more than throw some sticks in a crick" (R35). He is referring to the common restoration tactic of engineering log-jams from large woody-debris in the river. He'd like to see beavers doing this instead.

The idea behind using beavers to create wildlife habitat is not new, and efforts to restore beavers to ecosystems have been taking place since the 1930s (Woodruff and Pollock, 2015). These efforts, which are outlined in Heter's (1950) article: "Transplanting Beavers by Airplane and Parachute," in which managers employed novel ways to deliver beavers to the headwaters of the Columbia River Basin for the purposes of creating ponds for waterfowl. Unfortunately, these projects were not monitored, and so it is unclear if they were successful. Since those early efforts, the Columbia River Basin has been continuously developed and settled, and it has been humans—not beavers—that have drastically altered the hydrologic regime. As land was settled, many wetlands were drained, and beavers were either killed for their pelts or because they were seen as a nuisance by causing flooding and property destruction. They were nearly extirpated from the Pacific Northwest by 1900 (Bouwes et al., 2016). The removal of beavers from Pacific Northwest ecosystems succeeded in reducing the places where salmon can spawn, rear, and grow, because beavers are essential ecological engineers, creating diverse habitat through their life histories and behaviors.

Beaver reintroduction is process-based restoration at its most basic: add beavers, and they start the process of flood-plain reconnection by creating biogenic dams. “Biogenic dams” are dams created by living organisms—beavers, dead and living trees, roots, and vegetation, altering the movement of sediment and water, forming networks of pools and channels that are ideal salmon rearing habitat (Pollock et al., 2014). In addition to creating fish habitat, Pollock et al. (2014) monitored the effects of beaver restoration on groundwater, and found that water over a kilometer away was affected, with increasing, and colder, upwelling occurring downstream. Other studies have demonstrated increased steelhead density, survival, and production after beaver dam analogues were installed (Bouwes et al., 2106). Beaver restoration is founded on the idea that creating these biogenic dams will reconnect floodplains and produce salmon-rearing habitat that is diverse and connected to the temperature-mediating abilities of ground water. In the context of climate change, this is critical, especially in areas like the Methow Valley, where water temperatures and flows are a limiting factor in salmon survival. The additional the water storage that beaver dams provide in the headwaters could help compensate for the loss of water storage in the form of high-elevation snow (Lawler, 2009).

Process-based restoration is being recognized as an important way to counteract the effects of climate change, and beaver restoration is one way to achieve this relatively quickly. While many restorationists don’t explicitly incorporate climate change data or mitigation measures into their designs, when asked how they are addressing climate change, they often cite process-based restoration as their strategy. For example, one restorationist explained,

> Our approach is more based on physical process. While there is temperature data that gets considered and we are always looking for groundwater sources and refugia—this is in part a climate adaptation—but, also, we just want to restore natural river processes and connections. I think our underlying philosophy tends to be where we can restore natural river function and reconnect floodplains and groundwater sources, that that will accomplish the goals of preparing for a changing climate. And, if we put the river into its naturally functioning state it will be able to maintain itself and we won't be in a maintenance mode all the time

> taking care of artificial things. It will be in a state that, theoretically, fish are adapted to (R 17).

Beavers are capable of restoring long stretches of stream—something that is costly to do by hand, and often impossible in remote headwater areas. By reintroducing beavers to areas where they no longer live, beaver reintroduction programs are hoping to glean these benefits. The Methow Beaver Project relocated 240 "nuisance" beavers between 2008 and 2014. They were brought to 51 sites, and have had a fairly high success rate of around 60 percent (Woodruff and Pollock, 2015). This high rate of success could be due to the care that the project participants and volunteers take in the relocation process—pre-building partial "artificial lodges," providing forage, and making sure that beavers pairs are compatible (Woodruff and Pollock, 2015). Relocation in other parts of the basin has also been successful, although not always at such a high rate.

Despite its historical roots, beaver restoration for the purposes of salmon recovery is fairly new, and restorationists are only beginning to monitor the results and perfect the methods. The engineering paradigm for restoration is still dominant in many regions and organizations. One restorationist discussed process-based restoration this way:

> Initially, I think, there was a lot of skepticism over restoration work and why we were doing it because people have seen the government agencies tear out wood and straighten streams and riprap streams and they kind of thought, 'Oh. That is how you handle a stream.' So, we have this big, huge paradigm shift that we are working through to get people's eyes and brains retrained on what a healthy functioning River actually looks like…Right now I think we are still in the phase of: 'You want to put wood back in!? You want to take out a levee!?' (R17)

Paradigms don't necessarily shift quickly. Nonetheless, experimenting with "nature's engineers" is facilitating the emergence of new ideas.

Embracing Unruly Complexity, Becoming Interdisciplinary

Due to the success of these projects, beaver restorationists at the Forest Service and other agencies have been hosting workshops to train restorationists in beaver reintroduction throughout the Pacific Northwest. The workshops spread information about how to restore using beavers, but also how to hone these new practices with feedback. "The Beaver Restoration Guidebook" breaks the process of beaver restoration down into simple steps:

1. Identify suitable habitat (often using remote sensing).
2. Assess current beaver population status and distribution.
3. Evaluate individual release locations.
4. Pursue acquisition of beavers.
5. Collect information about beavers captured (or re-captured).
6. Care for beavers temporarily and ensure that beavers are grouped as families or compatible units with both males and females.
7. Prioritize and prepare release locations.
8. Deliver beavers to selected sites.
9. Conduct follow-up monitoring and provide support (Castro et al., 2015).

While this step-by-step process seems fairly straightforward, beavers themselves often behave in unpredictable ways. Woelfle-Erskine (2017) labels beavers, "stochastic transgressors against Manifest Destiny engineering projects" (p. 5), highlighting their transformative abilities, and the way they alter landscapes differently than engineers. Yet they can also become collaborators with restorationists in the transformation of rivers (Woelfle-Erskine, 2017). The "messiness" and unpredictability of beaver reintroduction is a useful strategy for adaptation because it introduces another site for the emergence of new ways to deal with climate change.

According to some restorationists, too many restoration plans are based on ideas about how streams "should" behave: there will be a two-year flood event, a five-year event, etc. A lot of models also assume a steady state, or balance in an ecosystem. The problem is that biogenic dams, such as the ones that beavers construct, are meant to upset this balance. As such, they are difficult to model, but are highly functional in restoring natural processes to a river system. Beaver restorationists have measured positive fish response to the restored wetlands and complex pool systems that beavers create. But, one restorationist pointed out, you aren't necessarily going to be able to see the results of this recovery "in a publishable time frame" (R 36). The long timescale of ecological recovery makes it difficult to measure success in beaver restoration, but short-term changes have been demonstrated.

Yet unpredictability is exactly the dynamic that process-based restorationists want to reintroduce to the river. Beaver restorationists are doing this work because, in just "trying things out," new ways to address the effects of climate change emerge. Scott agrees:

> When we started we weren't sure if we could make a difference at all. We weren't sure if it would have an influence and it didn't start out as a climate change project. But then I got to realize that we are struggling [with lack of water] and the places below the beaver dam continued to run and continue to run. Then it became obvious that this is something that could contribute if we start to lose snowpack.

This is an example of the ways in which restorationists have come to embrace the emergence that occurs with experimentation and unruly complexity in order to hedge their bets against climate change. While the number of monitoring efforts and publications to show efficacy of the method is growing, there is little evidence to "prove" that introducing beavers will mitigate climate effects. Even without this evidence, the epistemic culture is embracing beaver restoration as a way to confront environmental change.

The two philosophies of restoration: process-based and engineering, come together and find in some common ground through beaver dam analogues, or "BDAs," as they are known in the field. These are usually fairly simple structures that are made to mimic a beaver dam, and they have been shown to increase ecological function in much the same way as beavers (Castro et al., 2015). Sometimes, they are drafted into an engineered restoration design. Much like beaver dams, these small-scale alterations can have large-scale and long-term effects. This embrace of natural processes and engineering coincides with the rise of the "Stage 0" restoration strategy in restoration. While BDAs lack much resemblance to the structurally based restoration designs that have been most common until now, many engineering firms are adopting them into their designs. This demonstrates how highly embedded epistemic cultures can shift, and unfamiliar concepts and methods are tolerated in order to see what happens—to foster emergence by allowing multiple cultures, or "surfaces of emergence" to coexist.

Although these cultures may exist in contradiction, they also exist in tandem. This is a common feature of science in general, although it is often overlooked in an aim to synthesize science into distinct epistemic cultures. Daston and Galison's (2007) study of objectivity demonstrates that a plurality of virtues and differing "visions of knowledge" are foundational to science. Although Kuhn (1962) argued that scientific culture formed through unitary conceptual frameworks in the form of paradigms, others have argued (Hacking, 1992) that scientific work is actually conducted through heterogeneous, patchy cultures and practices that are not uniform conceptually, but instead "mutually" adjust to each other.

This is the case in ecological restoration, as demonstrated in the cultures that have formed around process-based and engineering-based ecological restoration. As ecological restoration matured as a field, many of the lines that were "drawn in the sand" seem to be gaining less traction as the new common foe of climate change enters the picture. Process-based and engineering-based restoration are coming together through the concept of BDAs, and other, similar engagements across previously fractured cultures in the ecological restoration community. One restorationist and educator described it this way:

> I think the big change is that we are going from really focusing on channel structure and not paying attention to things like macroinvertebrates or primary productivity. In our program, we have the physical processes class and the ecological processes class, and what we are seeing is that they are coming closer and closer together. Especially when it comes to beaver. They create dams, but they are organisms, so they are engineering organisms. There's this really interesting kind of connection between these disciplines and they are coming much closer together and recognizing that the separation is pretty artificial. I think people are becoming interdisciplinary. (R 11)

This is similar to a trend that Knorr-Cetina (1999) found in the large-scale mega-experiment at CERN. There, a large and long-term collaboration exists on a massive scale, with physicists from around the world working on a common goal. To be sure, there are intense conflicts and rivalries, but the epistemic culture that supports the large-scale mega-experiment is fostered by an epistemic culture that supports experimental ideas and unruly complexity, a strategy that is helping restorationists deal with the uncertainty of climate change.

Conclusion

In this chapter, I have outlined the ways in which fostering emergence is a key strategy that restorationists are using to deal with climate change. Using techniques from both engineering and process-based restoration, multiple cultures are engaged, creating more opportunities for new concepts and practices to emerge. One of these practices is beaver restoration. Although it has been used in the past, incorporating it into the epistemic culture of restoration in the basin is new, and combining beavers with engineering, the novel concept of the "beaver dam analogue" emerged.

Yet, fostering emergence is also a way to embrace unpredictability, which is what river restoration is, in many ways, about—giving the river "room to breathe." The concept of emergence engages with the particular qualities of agency that restoration entails. Restoration is about "doing things" to nature, and then seeing what nature does back. Therefore, thinking about the emergent qualities of ecosystems and human agency is useful in understanding what drives change and adaptation. Interactions between components and scales are a constant within an ecological system. A hydrologic system, such as the Columbia River Basin, can be highly variable. In other words, it is constantly "doing things." No matter how much some humans would like to (and try to) control the actions of the river, they cannot entirely do so. Therefore, the material world has a certain degree of agency that acts on scientists and alters their practice (Pickering, 1995). Appropriately to the problem of climate change, Pickering (1995) uses the example of "the weather," to illustrate the agency of nature, in which "winds, storms, droughts, floods, heat and cold…engage with our bodies as well as our minds" (Pickering, 1995, p. 6). Scientific practices, according to Pickering (1995), are a "continuation and extension of coping with this material agency" (p. 6-7).

This "rebalancing" of agency is particularly helpful for conceptualizing how restorationists deal with climate change in their practices. As scientists and the environment interact through time, scientific practice takes on an emergent quality. As new problems arise, new solutions emerge. Just as in adaptive management of SESs, uncertainty always exists, and this uncertainty is accepted as a dynamic to be fostered, not contained. In addition to the actions of beavers, the river and its ecological processes, the salmon, the ocean, and climate change, all play a role in this emergence through temporal and spatial cross-scale interactions. This emergent sensibility is fundamentally about an openness that allows for tensions between "rational control" and "irrational free-play" (Locke et al., 2007)). This playfulness tests and stretches what restoration design can accomplish. It is not only found in beaver reintroduction, but also in innovative engineering solutions that may lead to unexpected outcomes, and new ideas to emerge. As one restorationist explained in reference to a project with unintended outcomes:

> Nature will always expose the hidden flaws. That is the nature of nature. So, if there is a flaw in an approach sooner or later it will become obvious…Good scientists laid them out and they had a good plan, but they just couldn't execute it. Too many things kept popping up and interfering and fundamental ways. So maybe the lesson is the chaotic unpredictability of climate change (R27).

Daston and Galison (2007) compare the emergence of new epistemic virtues to an avalanche: "at first, a few tumbling rocks, falling branches, and minor snow slides amount to nothing much, but then, when conditions are ripe, individual events, even small ones, can trigger a massive, downward rush" (p. 49). In a similar way, the epistemic virtues that are emerging to cope with climate change are only just beginning to surface, but they are nevertheless present in the way that restorationists in the Columbia River Basin talk about their work.

Different scientific virtues and cultures coexist with one another, and as time passes, more of them accumulate and add to the mix of possibilities (Daston and Galison, 2007). Individual scientists and managers draw from these virtues and cultures in their work, and, for restorationists, this strategy of fostering emergence by allowing multiple cultures to coexist is becoming a way to deal with the unexpected, and with climate change. Epistemic cultures that have evolved along with the field of ecological restoration itself, such as engineering-based and process-based restoration, have ebbed and flowed. Sometimes they have been in confrontation, but these cultures also coexist and support a mix of tactics from which new strategies for dealing with change can emerge.

To be sure, some restorationists are loyal to one "camp" or the other and see the split as embodying important differences in assumptions and even ideologies. Yet at the same time, as I described through the development of ecological restoration in the Columbia River Basin, these virtues and cultures cannot be attributed to individuals alone. Instead, they are developed through a "collective empiricism" that has evolved over time (Daston and Galison, 2007). When restorationists restore natural processes by reintroducing beaver to a watershed, they are drawing from a tradition of process-based restorationists that have worked towards similar goals for decades. Similarly, when restorationists draw on engineering principles to engage in habitat restoration, they too are drawing on a history of environmental engineering that has developed over time. When individuals draw from these epistemic resources, they are drawing from collective histories of conservation work in the basin, with particular cultures. They also represent different ways of seeing nature, different ways of knowing, and different tactics for dealing with change. Yet as climate change becomes more tangible, people are beginning to work towards what they describe as a "common goal,"—restoring salmon to the basin by any means necessary. Beavers, often called "nature's engineers," break down the engineering/ecosystem-process divide as they engineer their own dams throughout the headwaters. "Success" is also re-defined, as learning something—anything—becomes more important than achieving a particular outcome. As one restorationist stated,

> You know, it's not black and white. We don't have "success" and "failure." We are often working in the gray areas. One of the things that I am really pushing is this idea of success where I'm not interested in success, which indicates an endpoint or target, but that, really, it creates oscillations of the system and it has a heartbeat. If you don't have that, and it never changes then it's never going to be ok. (R11)

Enrolling beavers in restoration is becoming more popular as people embrace the "messiness" that process-based restoration involves. Beavers serve as an example of a process-based restoration strategy that is difficult to monitor, measure, or predict. Yet, increasingly, restorationists are willing to give it a try and see if it does have an effect. While Scott is clearly passionate about the Methow Beaver Project, he keeps his eye on the bigger problem of climate change and how to mitigate its effects in the Methow: "We could sell beavers to everybody. But what I want to do is to talk to 1,000 people and I want every one of those people to ask ‘what can I do?’ and take one little step forward. I don't care what it is. I want them to make a little tiny change. 1000 people walking in this direction is a pretty good start. I've got over 1,400 so far.” Not that he’s counting, of course.

Chapter 6: Acclimation

Monitoring Restoration

Restorationists in the Columbia River Basin are not only tasked with restoring ecological function and processes; they also need to determine whether or not these restoration actions are working. Katz's (1992) framing of restoration as the "acid test" for ecology highlights the extent to which experimentation is embedded within the practical matters of restoration design and implementation. But, as previously described, in the Columbia River Basin, salmon habitat restoration is also driven by the ESA's mandate to recover endangered species. Because of this, changes in scientific practice often occur in response to changes in policy. The ESA requires recovery efforts to demonstrate their efficacy through specific metrics and monitoring practices that determine much of the monitoring work in the basin. Yet, monitoring practices must also adapt to environmental changes, which can complicate restorationists' ability to design monitoring protocols that provide information needed to move forward.

While monitoring constitutes a major scientific effort in the Columbia River Basin, monitoring programs have been some of the most problematic, and often neglected, aspects of restoration. Many local and regional restoration projects conduct their own monitoring, and several major, large-scale monitoring programs have also been organized by NOAA, the BPA, and the NW Council. These monitoring programs are often "fish-centric," meaning they are counting "fish in and fish out" of the rivers. Individuals are tracked using PIT (Passive Integrated Transponder) tag arrays, counted in "snorkel surveys" or by electrofishing. Other monitoring programs focus on habitat, water quality, potential productivity, measuring changes in-stream temperature, stream flow, channel morphology, or percent of vegetation shade cover and large woody debris.

What to measure, how to measure it, and especially how to tell if restoration is making a difference are all topics of keen debate in the restoration community. Restorationists throughout the basin hold strong opinions about monitoring, and oftentimes these opinions result in contentious debates at conferences and meetings. Some believe that monitoring efforts have been lacking, while others think that the programs are focusing on measuring the wrong things. Still, others think that monitoring is a waste of money entirely. These conflicts and tensions often center around anxieties about how to deal with the large-scale and ambitious goal of the recovery effort. These concerns are compounded by the uncertainty inherent in drawing baselines and monitoring in the context of climate change.

Yet these problems also stem from the "newness" of ecological restoration as a field, and the lack of standardization, metrics, and methods from which to draw. The best approaches to measuring and monitoring are still being determined. In this chapter, I explore how restorationists are developing robust monitoring strategies to inform restoration design and measure restoration success in a climate-changed future. I develop the strategy of "acclimation" to describe a process of adjustment in which restorationists are forced to use a pragmatic approach to knowing as well as trained judgment to make decisions in the face of uncertainty.

Types of Monitoring

Monitoring in ecological restoration of salmon habitat began with a focus on physical changes to stream morphology caused instream restoration, not with an eye to evaluating restoration of ecological process. Most early monitoring studies were also focused on individual sites and were not meant to be widely applied (Roni, 2005). However, as adaptive management became more embedded in the recovery effort, monitoring became even more important in order to evaluate actions and make adjustments if needed (Roni, 2005). While large-scale monitoring was needed in the Columbia River Basin, it would take decades to create a comprehensive monitoring program. Even now, monitoring for ecological responses to habitat restoration lags far behind monitoring for individual metrics such as number of fish, miles of restored stream, or number of instream structures. But these metrics are focused on short-term benefits, and a more comprehensive and long-term monitoring program that takes a holistic approach to understanding underlying ecological changes has been advocated by restorationists since the 1990s (Roni, 2005; Beechie and Bolton, 1999; Naiman et al., 1998).

Although the purpose of monitoring habitat restoration is to understand how restoration action affects the environment, and by extension fish, restorationists refer to several different monitoring "goals" or approaches. Implementation monitoring focuses on how much restoration is being done "on the ground." Effectiveness monitoring seeks to understand whether or not restoration is working to alter the environment in desirable ways. Baseline monitoring is focused only on characterizing the existing conditions to enable future comparison. Status monitoring looks at the variability of conditions across an area, and trends monitoring looks at changes through time, taking a "pulse" of the environment in order to provide a baseline and quantify changes taking place (MacDonald et al., 1991). Finally, validation monitoring evaluates whether a hypothesis about a restoration's effects was correct (Roni et al., 2005). Each of these monitoring approaches has met with different success rates as the recovery effort has advanced, and usually a combination of monitoring types is used.

Monitoring Programs in the Columbia River Basin

The main source of funding for habitat monitoring in the basin is provided by the BPA in order to understand whether or not their mitigation efforts are working. For this purpose, funding has been directed toward three main monitoring programs: the Integrated Status and Effectiveness Monitoring Program (ISEMP), the Columbia Habitat Monitoring Program (CHaMP), and the Action Effectiveness Monitoring of Tributary Habitat Improvement (AEM). Each of these programs has different purposes, but they all work together. For example, ISEMP develops monitoring protocols and standardized data collection methods that can be used across the Columbia River Basin to determine the effectiveness of habitat restoration actions within CHaMP study areas. An additional, related program to establish Intensively Monitored Watersheds (IMWs) has also been developed. The IMW program is an attempt to understand the effectiveness of restoration at the watershed, or population scale, instead of the more commonly targeted "reach" scale, but it has been challenging to implement due to lack of consistent funding and coordination (Bennett et al., 2016).

Challenges of Monitoring

The words of one frustrated informant sum up many of the problems surrounding monitoring:

> The Northwest Power and Planning Council has spent 66 million dollars in the past decade on monitoring, and they are about to abandon virtually every one of those programs. So, how does one cost-effectively monitor the stuff that 50 years

> from now people will say, ‘yeah you made the right choices about what to monitor, and you made those choices so you could actually monitor them for 50 years?’…If our society had the will to spend a billion dollars monitoring all of the Columbia Basin for all of those qualities for the next five decades, sign me up. I’d be willing to pay my taxes to support that, but it’s not going to happen. (R33)

How does one know what to monitor? Indeed, how does anyone know what will be a useful baseline to have in fifty years? Are the same things that matter to society now going to matter in the future? What if it is all too little too late, and monitoring is a waste of resources? And after all that: who is going to pay for it? The restorationist quoted above is not the only one who is concerned. This kind of adaptive thinking about what kinds of data should be collected now in order to be useful in the future is not just an anxious worry of a frugal scientist. These questions need to be considered seriously in order to create an adaptive ecological restoration science that is enduring, useful, and cost-effective into the future.

In Pickering’s (1995) conceptual model of change in scientific practice, scientists encounter “resistances” and work out “accommodations” to overcome them. These challenges are ever-present, but with climate change, they are growing. While some of them are due to environmental or social change, others are more fundamental to the nature of any large-scale environmental management effort, such as restoring salmon to the Columbia River Basin. These large temporal and spatial scales can present resistances and impede scientific work, and in monitoring, they are rife.

For example, the complexity of overlapping cycles of fish migration, ocean cycles, and global climate make monitoring a multi-layered and multi-level endeavor. Further, these cycles are often at odds with the cycles and timescales of politics, funding, or even careers. Restorationists are keenly aware of this mismatch. Reminiscing about a long career of implementing and monitoring projects one restorationist said:

> Even if you have a perfect method of monitoring all of those things, the interaction of them is complicated. You might be doing great habitat work, which theoretically will produce all sorts of benefits and abundance, but the adults are going back out into a terrible ocean in an eight- or ten-year cycle, which you have to wait through to see the benefit. And humans have a really hard time being

> patient. You might only get two or three of those cycles in your whole scientific career. How do you make the managers wait through that to see if it really paid off or not? It is hard. (R24)

Restorationists have had to adapt to these complexities in scale in both simple and innovative ways, and they have had to do so quickly, accepting uncertainty as a given.

Short-term changes can be difficult if not impossible to detect when the life-cycle of a salmon is from five to eight years, and much of their lifetime is spent in the ocean, thousands of miles away from a restoration project site. This means that there are a multitude of factors affecting their survival, not just the quality of habitat in the rivers. Because of this complexity and scale, restorationists struggle with effectiveness monitoring. After completing a major restoration project in the headwaters, one restoration manger pointed out that the project,

> could make all the difference in freshwater survival but…if we have so many Caspian terns and double-crested cormorants and so many harbor seals and a “blob” out in the ocean, who cares if you have a five-fold increase in your population if your population is nothing. (R31)

It is very difficult to tell if a habitat action has had a positive effect on a population if that population has been negatively impacted downstream by dams, warm water, predation, fisheries, or even further afield: ocean conditions.

The ocean is often referred to by restorationists as a “black box.” Research on the ocean phase of the salmon life-cycle has been scarce compared to that in freshwater. This is partly due to the fact that restoration and mitigation actions occur in the rivers. But this research focus is also a legacy of the research institutions and organizations that were created in the early 1900s. A focus on hatchery research and counting fish in the rivers has been the status quo for decades (Taylor, 1999). Counting “fish in and fish out” of the river system, has been one of the only continuously collected data since Holmes’ time. Slowly, this is beginning to shift as the ocean becomes recognized as a major factor in salmon abundance—partly due to the effects of the “blob” phenomenon described in Chapter Three. Ocean life-cycles are now seen as a critical factor in recovery, and new metrics for restoration success that take these larger spatial and temporal scales into account are emerging as the practices of ecological restoration shift to meet the challenges of climate change. According to one restorationist, "you are never really going to have an understanding of what you did right and what you did wrong." (R7) The long-term project of restoration lends itself to long-term monitoring, but the resources are often misaligned with this need.

While a lot of money has been spent on monitoring, given the scale and complexity of the problem of fish recovery, and the need to understand whether or not the millions of dollars being spent on habitat restoration is working, people still question whether monitoring is an appropriate use of funding. Most restorationists discuss the importance of collecting monitoring data and establishing baselines. They also advocate for rigorous scientific work to back up their contention that the habitat restoration they are doing is actually "moving the dial" in the right direction. Despite this, most restorationists agree that establishing a comprehensive monitoring program presents major challenges: "It has been challenging to fund, and it has been challenging to coordinate, and it has been challenging to outreach the results." (R21)

Although, on the surface, it may seem like a lot of money is going into monitoring, and "research monitoring and evaluation" accounted for 30 percent of BPA's recovery budget in 2016, only 16 percent of that portion, or $13.3 million USD went toward habitat monitoring (NW Council, 2017). The majority of the monitoring money goes toward hatchery effectiveness evaluation (NW Council, 2017). In a technologically updated version of Holmes' marking projects described in Chapter Two, the most common monitoring action consists of PIT tag arrays, which count fish that pass on their way upstream or down. Yet most PIT tags are in the flesh of hatchery fish, not wild fish. Of course, even then, they are only able to provide abundance estimates that can be used in models, not absolute population numbers. Detecting numbers of fish is crucial to figuring out if recovery targets have been met, but counting fish does not necessarily demonstrate the effectiveness of habitat restoration itself, especially when the difference between achieving or failing to reach a recovery goal can be a few dozen fish.

Even if a lot of money and effort is being spent on monitoring, people are anxious that it might not be going toward the right things or that it is simply not enough. For instance, although BPA mitigation funding is funneled towards monitoring through the ISEMP, CHaMP, and IMW projects, there are many other local projects that only see minimal monitoring, usually only to meet BPA's required five-year period. This means that even large restoration projects often get implemented with almost no effectiveness monitoring to follow. For some restorationists, losing this chance to collect data and understand ecological systems is a grave loss to science. As one restoration contractor lamented:

> Nobody is paying for monitoring and nobody is paying to publish the lessons…We are doing some of the biggest flood plain projects in the Western United States, yet I can't point you to a good case study about them because nobody wants to spend the money to write it up. You have probably never even heard of the [recent, large] restoration that we have done. It's been a 14-year project. They spent millions. Millions and millions of dollars have been spent and it's revitalizing critical blueback salmon habitat. And it is working! It is really enlivening a 2-mile floodplain. Holy-moly! It's incredible! I could go on all night about the projects we have done that are really changing the local ecology and changing how floodplain function is benefiting salmon and I can't give you a single case study. To write up one of those case studies is thousands and thousands of dollars…can we spend 1% for science? Can we spend 2%? (R5)

Finally, while restorationists want to know if their work is making a difference, there is also anxiety about what the answer will be. For example, one restorationist worried:

> The IMW gives us the opportunity to put all of our money in one place and say: 'Okay, what if we *did* have enough money to provide restoration treatments to all of the areas that we think are suitable for restoration? Is that enough?' And I think a lot of people are really afraid of that answer. Because what if it isn't? What if we take all these areas on [public] land where we have a supportive landowner and a mandate to protect and we do all of that and it's not enough? That's a really ugly spot to be in. Right now, with the money that we are putting into [it] we should be able to restore the Columbia in about 200 years, and that assumes no further degradation. So, if I go in front of [the funding agent] and say, 'We are

> doing great work and all you have to do is keep funding us for the next 200 years, and we are totally going to get to our recovery goal!' What then?" (R31)

If monitoring is, in fact, so critical, why isn't it occurring in an efficient, effective, and comprehensive way? There are several answers that restorationists give. One answer is that monitoring work is simply getting in the way: people want to get on with the business of improving habitat, and they don't want to waste time and money on looking back at what they have already done. In the words of one restorationist:

> It has always been a challenge. You know, if you are improving habitat, how much of your time do you spend improving habitat and how much of your time do you spend measuring the effects of improving habitat? (R24)

Some people compare it to doing accounting: it's a pain, but if someone finds a mistake, it can save a lot of expense. As one person said,

> I think a lot of people perceive it as a waste of money because they discount the value of it over time. They aren't gaining anything from it now, but 5 years from now it might be really critical. (R30)

Looking to the future, understanding and establishing baselines now is necessary, but it is often undervalued and underdone. In addition, the things that restorationists choose to monitor now not only affect decision-making today, but will also create the baseline that will be needed to understand changes in a future basin. This future basin will potentially have a drastically altered climate and ecological condition, as well as monitoring technology that could be very different from what exists today. Considering information needs for a decision-making context requires understanding what objectives are desirable, and over what temporal and spatial scale. This means that scientists must acclimate their work to the future, in a process of adjustment that allows them to continue their work in the face of all of the uncertainty described. Instead of ignoring or putting of making decisions about what actions are effective and what to monitor, restorationists are grounding their epistemic work in a pragmatic process that allows them to move forward with the restoration project in the face of uncertainty. The strategy of "acclimation" describes this creative work.

Acclimation

Scientists in the basin are not just lazy or lacking in rigor. They are facing real structural and epistemic challenges—or resistances—to their practices. So, how do restorationists continue to practice their scientific work and to monitor in the face of such uncertainty and change? I argue that they do so by using an adaptive strategy that I am calling "acclimation," in which they must adjust in a relatively short time period. This requires developing knowledge infrastructures that take the future, or "the long-now," into account, as well as changing their practices to incorporate more "trained judgment." This allows present epistemic needs to be met, while adjusting to a changing environment.

"Acclimation," in an ecological sense, is a process of adjustment to a new environment that occurs over a relatively short period of time to an individual. Examples include aquatic species adjusting to a new PH, or an animal shedding its fur in the spring. This is in contrast to adaptation, which occurs over a generational time-scale. Because I am discussing how individual restorationists are changing their practices in a short time-scale and making decisions immediately in the face of uncertainty, acclimation provides an appropriate metaphor and term for the framework of adaptive epistemologies. The strategy of acclimation is about choice and action. It shows how people act in the face of uncertainty. "Trained judgment" offers a way to explain how scientists choose, and philosophical pragmatism offers a way to discuss how scientists cope with uncertainty by accepting it.

Philosophical pragmatism is practical for the purposes of this work because it is rooted in acknowledging uncertainty and recognizing the "contingent and unruly" nature of the world (Bromley, 2008). Therefore, as a philosophical theory, it explains reasons for human action (Bromley, 2008), and it is helpful in understanding how people deal with change in their scientific work. Pragmatism is rooted in an abductive form of reasoning, first articulated by Peirce (1887) as inference to the best explanation (Bromley, 2008). According to Peirce (1887), a belief is a rule for acting, and so possible actions "exist in the *imagination* of the decision-maker" (Bromely, 2008, p. 6). For pragmatists, “a belief is that which we are prepared to act” (Bromley, 2008, p. 10), because “our beliefs guide our desires and shape our actions” (Peirce, 1877).

Bromley (2006) builds on these ideas in his work on “volitional pragmatism,” which is a “theory of choice” that posits that we work towards what seems possible. Because the world is “stochastic” and “nature is complex and indeterminate,” the futures we strive toward change as we work toward them (Bromley, 2008, p. 4). Adaptive management is similar in that it works through a pragmatic process: imagined possibilities for action are revisited as new information becomes available. Pragmatist theory aligns with adaptive management both in the way that it looks to the future and provides a framework for taking action in the face of uncertainty (Langston, 2003), and volitional pragmatism also aligns well with adaptive management because it describes similar forms of reasoning and motives for action. Yet, “acclimation” as an adaptive strategy is more than adaptive management: it is a way of doing epistemic work that embraces change and uncertainty in the immediate. In many cases in the Columbia River Basin, there is no time to wait for answers about what to do, or what to monitor: inaction is unacceptable. Therefore, restorationists are forced to acclimate, and to choose. Pragmatism offers a way forward for restoration practice.

Acclimation as a strategy for dealing with climate change also extends to data collection, and therefore to scientific practice itself. While long-term, rigorous monitoring programs are clearly important in the broader scope of species recovery, more immediate information is also required. Restorationists need to know whether or not their riparian planting or floodplain reconnection project is making a difference in lowering stream temperatures because salmon survival may immediately depend on it. They also need to know if their engineered log-jams and channels are withstanding flooding events and behaving the way they expected. To answer these questions, many restorationists have decided to simply use their own expert interpretation, or what Daston and Galison (2007) call “trained judgment.” Trained judgment involves an “expert” making decisions about what they are seeing. In the case of restoration monitoring, this often involves simply taking a walk around a restoration site and drawing conclusions about its success. In this way, trained judgment describes another way of choosing in the face of uncertainty: an immediate process of adjustment, or acclimation. The example of how restorationists are dealing with monitoring provides a good example of acclimation as a strategy, and illustrates how pragmatic approaches to scientific practice, as well as trained judgment are being used to make choices in scientific practice and the design of knowledge infrastructures.

Rethinking Monitoring for the Future

While restoration and monitoring programs have been fragmented across the basin, making coordination difficult, a basin-wide monitoring coordination effort is being created. This is an attempt to meet the needs of all restoration programs and orient them toward the future. The development of the Pacific Northwest Aquatic Monitoring Program (PNAMP) provides an excellent example from which to illustrate how the strategy of acclimation is employed when dealing with future uncertainty.

PNAMP was created in 2004 to fill a need for coordination among federal, state, tribal, and private organizations involved in aquatic monitoring programs throughout the Pacific Northwest. Their main goal is to work as facilitators to help monitoring efforts coordinate efficiently and effectively in providing information to inform decision making. They aim to accomplish this by facilitating the exchange of scientifically-based monitoring data collected by voluntary partners throughout the region. PNAMP has several ongoing projects in which they are working to standardize and coordinate aquatic habitat monitoring throughout the Columbia River Basin. One of these is the Integrated Status and Trend Monitoring (ISTM) Project. The ISTM is a strategic program that aims to demonstrate how coordination and standardization of habitat data can help address questions that bridge scales from local to region-wide (Puls et al., 2014). Another PNAMP program, the Coordinated Assessments project, is standardizing data on anadromous fish, so that it can be shared throughout the Columbia River Basin. Through on-going working groups that span multiple agencies, PNAMP partners have been developing a list of "Regional Habitat Indicators" that can be used across the basin. PNAMP facilitates data standardization through web-based tools, standardized data collection protocols, and knowledge exchange. The PNAMP working group is specifically tackling this standardization project in anticipation of climate change, and is developing a list of standardized measures in order to establish ecological baselines *now*, which will still be useful in a climate-changed *future* environment. Changes in monitoring practices and types of data have come with changes in technology and policy, as well as the climate. Deciding what to measure *now* requires thinking to the future and designing knowledge infrastructures that take the "long-now" into account.

Changing Data Collection Methods

Changes in science often occur when new innovations or technologies become available, and this is no different in the Columbia River Basin, where the ways in which ecological data are collected and recorded have shifted relatively quickly over the past two decades. Digital technologies have replaced analogue field methods, and increasingly sophisticated remote-sensing capabilities have become more accessible. Emerging technologies are facilitating changes in monitoring on small and large scales. New monitoring instruments and technologies include inexpensive temperature logging devices and drones, as well as the development of more sophisticated and detailed computer models to process this data, often using satellite uplink systems for instantaneous data collection.

Yet even if the ways data collection practices are changing, many of the things being measured are the same. As one restorationist said, "I think that there's a big shift in how we collect data and process and handle it. But as far as *what* we are collecting, it still feels like it is largely the same." (R22) Regardless of what is being measured, the way it is being measured, and the way the data is being handled and modeled, is changing. These new monitoring practices are helping restorationists adapt to the need to understand environmental variables at different temporal and spatial scales and in greater detail. These new practices are becoming integral to the monitoring effort to understand whether or not restoration is working, what actions to take, and what kinds of metrics might be available or useful in the future. This is a key part of PNAMPs work and it is an example of acting in the face of uncertainty through a volitional pragmatism in which they are creating metrics for monitoring that accept uncertainty, yet also act.

Standardization and Classification

PNAMP is attempting to create a knowledge infrastructure that, while oriented to the future, is still useful today. In order for a knowledge infrastructure to function, it relies on standardization and classification (Star and Bowker, 2010). Setting standards is a part of scientific practice that takes a lot of time and energy, although it is often overlooked. According to Star and Bowker (2010), infrastructure is actually made up of layers of standards. In their words: "it is standards all the way down" (Star and Bowker, 2010, p. 6). While standardization and classification have political implications because "seeing" something and counting it can be matters of power and control (Scott, 1998), they also have practical implications for the everyday work that scientists do. This study is concerned with what knowledge infrastructures do, and how they can enable or constrain adaptation.

Bowker and Star (1999) differentiate between standards and classifications, although they are closely related. They argue that classification systems are a central feature of social life (Bowker and Star, 1999, p. 13). Classification is a complete system with consistent segmentation, in which everything has a place, whereas standards are sets of "agreed-upon rules" that "span more than one community of practice" and "persist over time" (Bowker and Star, 1999, p. 13-14). This allows standards to work across spatial and temporal distances. Standards are often enforced and even created by legal bodies or to satisfy legal requirements, and they also possess their own "inertia," because they are difficult to change (Bowker and Star, 1999).

The work that PNAMP has done to create the Regional Habitat Indicators provides a good example of the "practical politics of classifying and standardizing" (Bowker and Star, 1999, p. 44). In other words, this is the often messy and heavily negotiated design work that goes into creating a knowledge infrastructure. One working group member described the process this way:

> We thought that the coordinated assessment project would move a lot faster… But it turns out that it is a lot more time-intensive and complicated to get the indicators that we want…every year is different, which means that all the data compilers have to go out and work with a biologist and say 'well what is your analysis saying this time?' There is a lot of documentation and work that goes in to getting that data. (R24)

In developing the Regional Habitat Indicators, the partners involved in PNAMP worked through a process of negotiation in which trade-offs between different standards were clarified. After a longprocess of negotiation, the working group decided upon a set of indicators that could demonstrate changes in flow, macro invertebrates, stream temperature, and water quality. Questions concerning what could be measured and how it could be measured efficiently often arose. These practical difficulties were especially clear when discussing the newest indicator: macroinvertebrates. Part of the reason for looking to a new indicator such as macroinvertebrates is to get away from the old data paradigm of simply counting fish. As one participant said: “We are trying to gently say: ‘well you can count other things.’ Because there are a lot of things that affect salmon, because there are seven years before they come back!” (R22).

While water quality, temperature, and flow have been measured with regularity in most parts of the basin for decades, macroinvertebrates have not. Therefore, the kinds of data that are needed to understand this indicator are not even available, and an infrastructure that supports this data collection is not yet in place. Despite this, the group acknowledged the importance of the indicator and the potential for it to be useful in the future. Setting aside the practicalities of collecting the data, the working group decided to keep the indicator on the list just in case it could be useful someday, and collecting the data may become more practical in the future. People in the working group came to agreement on what indicators to use by thinking creatively about future epistemic needs and making a decision to adjust their current work accordingly.

Through the work of the Regional Habitat Indicator Project, it became clear to the participants that creating a comprehensive data collection system that was completely standardized was going to be an impossibility. Through the negotiation process, participants realized that complete standardization may also not be entirely desirable, because, as Bowker and Star (1999) point out, residual categories, or those that don’t quite “fit” into the classification system provide an important way to “dilute” uncertainty.” Restorationists also see this as an important hedge against climate change. In the words of one participant: “don’t put all your eggs in one basket. Measure multiple things” (R37). The residual category of “macroinvertebrates” might not entirely fit into the system of standards at this time, but keeping instead of discarding the category builds in the potential to adapt to future knowledge needs, another example of pragmatism in action.

Once a standardization system like the Regional Habitat Indicators is in place, this kind of work is often overlooked (Bowker and Star, 1999), but it is an important part of the epistemic work that ecological restorationists undertake in the basin. As one participant said:

> It's the tough part. It's really contentious and it's really hard to do. You end up coming up with a lot of surrogates and for practical reasons there is an ideal indicator that is actually possible given your budget constraints. So, there is a real art to it. When it is done well it is incredibly powerful and galvanizing, and you can get a diverse set of people around a table to accomplish something much greater than any one organization can do. (R25)

This exemplifies how the work of classification can extend across social worlds, creating cooperation between entities (Star and Griesemer, 1989). It is therefore an important site for considering the facilitation of adaptive knowledge infrastructures. Standardization work must correlate across large stretches of time as well as space. Fish lives, BiOps, careers, and climate change must all be considered. As new information about what works and what doesn't in restoration becomes available, new metrics for monitoring may need to be developed. Quantifying diversity of habitat, "Stage 0" streams, or macroinvertebrates is difficult, yet these indicators may be some of the most important in terms of climate change. By thinking pragmatically and creatively to imagine future epistemic needs, restorationists are "acclimating" the knowledge infrastructure to the changing climate. In terms of designing a sustainable infrastructure, this requires considering future concerns, or what has been called the "long now" of infrastructure design (Ribes and Finholt, 2009). By looking to these long-term temporal and large spatial scales, infrastructure developers can intentionally incorporate management goals and desirable futures for the Columbia River Basin, into infrastructure development. In this way, designing for "the long now" in infrastructures becomes a potential adaptive strategy, as it considers long-term sustainability and the need for adaptive capacity (Ribes and Finholt, 2009).

Trained Judgment

While some restorationists would rather (or are required to) monitor to prove and quantify their impacts, trained judgment is becoming more common. In order to deal with these gaps in information, some restorationists have worked quickly to come up with their own monitoring programs. One restorationist recalled the process:

> We cobbled together some funds to jury-rig together a monitoring plan…we had spawning survey crews going through and we just kind of by hook or by crook got this monitoring together. We were spending a lot of money and we were putting a lot of work in on the ground and we really didn't know what was going on. (R 16)

These kinds of "quick and dirty" monitoring programs are commonplace and illustrate a local-scale adaptation in scientific practice that embraces trained judgment.

One person who worked on monitoring for decades found that going back to "the old science" and "just going on a good old-fashioned walk" around a restoration site was a useful practice (R11). These scientists described their field walk as monitoring practice. Walking throughout the site, they could observe where structures withstood high water or where groundwater was infiltrating the floodplain. According to them,

> Those [observations] are extremely helpful…I don't need to be a statistician. All I need to say is, 'This project is designed like this, and was intended to do this. And, this is what it looks like once it was finished, five years later or seven years later'...what I need to know is how did this design element in this hydrologic, geomorphic situation affect the fish habitats. That is what I'm after. (R8)

Due to financial and time constraints, these kinds of on-the-ground observations may be the only monitoring activity that some restoration sites receive. But, in the absence of a formal field study, many consider those judgments to be sound enough to warrant decision-making. Practices like these, which incorporate the trained judgment of individual scientists is helping to verify larger-scale assumptions and inferences. These inferences are then useful to the diverse ecological circumstances throughout the basin, all of which are anticipating the localized effects of climate change in different ways, and develop new baselines that will remain useful into the future. Trained judgment such as this is a strategy for making epistemic choices in the face of uncertainty, and helps restorationists acclimate to climate change, something which is currently being experienced. While this kind of scientific practice may not be ideal, it is a way forward, and it can be seen in the monitoring strategies restorationists are now using.

Conclusion

The intensity of co-production between science and policy leads some restorationists to refer to restoration science in the Columbia River Basin as an "ESA-centric science." Some fisheries biologists view this categorization and standardization of populations as a problem that is at odds with diversity, a quality that is becoming recognized as critical to adaptive capacity. The ESA often seems to facilitate a science that counts fish. This is partly because the biological recovery goals are set for each population and species within the BiOps. This quantification, however, has not been easy, and categorizing fish in terms of run-specific populations has not been straightforward. For instance, drawing a distinction between Spring and Fall Chinook can be problematic, especially when those life histories and run-timings are shifting with climate change. One restorationist, troubled by the way that salmonids are categorized pointed out:

> We love to categorize them. We love to throw calendar dates on them. All that is just detrimental to respecting diversity. There are numerous populations and they don't fit into the norms and we just ignore that. (R28)

Fisheries biologists recognize this diversity as being a critical feature contributing to a viable population that can adapt to climate change because it gives a species capacity to deal with environmental changes. Yet, the ESA as an institution requires metrics and measures according to BiOps, which could stifle this adaptation. As one policy-maker pointed out: "We get all wrapped around the axel on the ESA, but it can also be very detrimental." (R14).

From the standpoint of restoration science, the ESA and the legal requirements for recovery entail a certain kind of applied scientific lens, which can come to dominate, especially through the BiOps. One restorationist worried that:

> It forces us to look at the world through a certain lens and if the biological opinion says over the next ten years you have to deliver X number of SBUs [survival benefit units] and that is what we are judged against. That forecloses the opportunity to maybe do other things that would be yielding different benefits that may be harder to quantify or that occur over a longer time frame (R14).

Some restorationists fear that, by limiting their focus to certain metrics, other opportunities for restoration could be missed.

While fish numbers can be counted and estimated fairly well, making a judgment about whether or not *habitat* is improving has not yet been possible given the data that is available. This means that recovery is understood through the data at hand. While we could conclude that the ESA and other regulatory frameworks are *dictating* the knowledge that is needed in the Columbia River Basin, co-production provides a more dynamic perspective, whereby science can also drive policy. In employing different metrics, such as macroinvertebrates, restoration scientists in the Columbia River Basin push back at the metrics mandated by the ESA, finding new ways to measure recovery success that might be more appropriate than simply "counting fish."

Despite these adaptations, restorationists are also cautious about these kinds of measures, and acknowledge that the rigidity of the ESA is also what makes it a strong environmental law:

> The ESA says we have to count the salmon and that is a problem. But, there are surrogates for that, and I think that invertebrates are probably the easiest thing to count. But, there is a lot of skepticism around that among salmon managers. The law says that you have to count the salmon and nobody wants to say, 'let's open the ESA' right now. (R22)

This tension between flexibility and rigidity in law goes deep into the science of restoration itself, and is always under the surface.

Covering restoration sites with temperature loggers and groundwater monitors is one way to prove that restoration is positively affecting stream temperature. Setting up nearby control watersheds or upstream reaches where there hasn't been any restoration is another way, but this work is time consuming, expensive, and might not provide answers fast enough to adapt to climate change effects. While rigorous experimentation is still the most respected form of creating new knowledge in the restoration community, shorter-term observations are increasingly important. Recalling the history of temperature monitoring, one restorationist said,

> Fifteen or twenty years ago it was a lot of guesswork. In the last decade, we have reduced a lot of the guessing into knowing. What we do is a relatively new

> industry. There is a lot of learning going on. Some of the stuff we are going to do we know is effective. We won't know *how* effective because every individual site varies but we know that if we store more water in the ground, that we are going to have a positive impact on stream temperatures and flows. (R19)

Opinions like this one are common: if restorationists can *prove* that what they are doing is working, that is, of course, better. But if not, they still *believe* the actions they are taking are making positive difference in adapting to climate change. As one restorationist pointed out,

> If we can't get the baseline, maybe we should be looking at the trend…I'm a proponent of learn by doing. Sometimes just starting to do something allows you to learn something which allows you to do it better (R33).

Ostrom (2009) highlights the importance of measurability of environmental variables in SESs. In an adaptive SES, finding ecological markers that can be measured accurately and reliably enables mangers to adapt to changes, whereas unpredictable or invisible conditions hinder the learning that is necessary to adjust management decisions (Ostrom, 2009). Yet restorationists not only acknowledge the need to act with imperfect information, they also recognize that this is the only way they can move forward in their work. These practices now permeate restoration work, as a strategy of acclimation that is being embraced with the onset of climate change. As one restorationist pointed out: "empirical information is preferred, but sometimes we need to connect the dots between what we did and how the fish respond" (R37). In the end, being able to say something about trends and patterns over the long-term is the best that many hope for.

Restoration monitoring has always been complex and contentious. Yet, while climate change is occurring, monitoring in the basin is moving forward. In a sense, restorationists are being forced to acclimate. This is a process of adjustment—an acclimation of epistemic work in which choices are made about how to move forward using trained judgment and a pragmatic approach to scientific work. Acclimation shows how restorationists can act in the face of uncertainty, adapting their practices and the knowledge infrastructures that support them. Along with emergence, these tools are helping the epistemic community deal with and adapt to change. The next strategy:

anticipation, will describe how restorationists relate to the future through their present modeling work.

Chapter 7: Anticipation

Introduction

In many scientific fields, especially ecology, computer modeling has come to “complement or even replace” both laboratory and field experiments (Edwards, 2013, p. xix). Models in ecological science are used to organize data, synthesize information, and predict the future (Oreskes, 2003). Data within the Columbia River Basin is fast becoming model- dependent, either being “fed” into models, or being derived from them, and a modeling infrastructure has emerged in the basin. These models are often used for decision-making, although they are increasing in complexity as they account for increasing numbers of environmental and social parameters. This can often be at odds with their ability to accurately predict into the future (Oreskes, 2003). Modeling for climate change in the basin is done through global climate models, as well as down-scaled and localized models that focus on one or two variables such as stream temperature or sea-level rise. These models facilitate monitoring, planning, and prioritization of restoration sites. In addition, modeling efforts in the basin also include fisheries life-cycle and population models and hydrologic models related to dam operations or streamflow.

In addition to experimental methods and trained judgment, most restorationists rely on models to fill in the gaps where monitoring doesn’t occur. In the past, predictive decision-making tools such as models were based on historical observations and baselines, yet now decisions need to be made in a changing system with shifting baselines. Monitoring must be ongoing so that data can be collected and then used to update models themselves, ensuring that they are adaptive and useful for planning or prioritization. Yet, while the large-scale impacts of climate change on biota are relatively well understood, the responses of communities and individuals at finer spatial and temporal scales are not as easy to model (Conroy et al., 2011). The impact of increased variability in climate and interactions among different dynamics such as changes in snowpack are just beginning to be understood. Adaptive learning through modeling is one strategy that people use to overcome this gap in knowledge.

Anticipation is an affective state of “thinking and living toward the future,” and it can permeate scientific practice and become an epistemic virtue (Adams et al., 2009). Yet, anticipation is also a strategy for epistemic adaptation in which restorationists are orienting their work toward the future, and aligning scientific practices and knowledge infrastructures toward those possible futures. In an effort to restore to historical ecosystem states, ecological restorationists have often oriented their work toward the past. However, with the present and coming impacts of climate change, this will no longer be possible. The emerging virtue of anticipation, as well as other forms of “anticipation work” (Steinhardt and Jackson, 2015) are therefore key strategies that ecological restorationists are using to adapt. The strategy of anticipation can be seen in the way that the scientific practice of ecological restoration has shifted from mainly fieldwork-based toward modeling-centered work, changing the locus of knowledge production. While field-collected data still informs modeling, as new models are developed, they are taking the place of field-produced knowledge, and restorationists are coming to rely less and less on field science alone. Instead of gathering data about current and past conditions and using them to draw a baseline and determine restoration goals, the future is now simulated through predictive modeling, and sites are restored in light of an anticipated future.

Modeling practices tie together past and future, local and global. Most importantly for understanding how restorationists deal with climate change, modeling practices link scientific practices to future goals (Pickering, 1995, p. 56). Modeling helps restorationists envision future outcomes by creating metaphors, taming epistemic indeterminacy, and dealing with unruly complexity. This anticipation of the future represents a shift in restoration-thinking: instead of looking to the past for baselines to restore *to,* restorationists are orienting their work to the future through a new, anticipatory epistemic culture.

Modeling and Uncertainty

Modeling is a way of dealing with uncertainty in science. Yet, within modeling itself, different types of uncertainties already exist. Many of the monitoring issues outlined in the previous chapter are related to the need to establish a baseline from which to measure changes in the environment. Yet establishing a good baseline in a highly altered system like the Columbia River Basin is a major challenge. Further, dealing with a baseline that is constantly shifting as the climate changes makes this a highly complex task. Useful baselines are just beginning to emerge from the past two decades of restoration monitoring work, but these baselines can also be destroyed by an unexpected event such as a fire, drought, or high flows. In the words of one restorationist: “when you are on this roller coaster you are like, ‘Whoa! Slow down!’ It's very difficult. It's very difficult to try to get some scientific answers in such volatile systems” (R18).

While most of these uncertainties can be accounted for within models themselves, some are fundamental to socio-ecological systems. One reason why modeling contributes to adaptive scientific practice is that it is a way of accounting for uncertainty. Conroy et al. (2011) classified uncertainty in environmental modeling into four types. *Environmental variation* includes changes in variables such as climate. In the Columbia River Basin, these changes are now mostly assumed. The uncertainties caused by environmental variation are complexities that modelers are dealing with through incorporating downscaled climate modeling and other modeling tactics.

Yet because of the large and diverse spatial scale through which salmon migrate throughout their life-cycle, the second type of uncertainty: *partial observability,* is still a major issue in the models that restorationists use. Partial observability, or the need to estimate what is unseen, is what establishes a need to estimate through modeling in the first place. For example, many restorationists refer to the ocean as a “black box,” where little is known about what salmon do, where they go, or their survivability rates in different ocean conditions. Early models simply made a best guess at survival rates models and were run using that number. Yet, as more data become available and the life-cycle models are refined, survivability is becoming calculable, and uncertainty more quantified.

A third type of uncertainty, *partial controllability,* is also being exacerbated by climate change, and is making modeling even more critical to understanding the system. Partial controllability is the inability to apply management actions precisely across sites. Designing experimental controls in a highly stochastic system such as a river is practically impossible. Drawing inference between watersheds thus becomes difficult without the use of models.

Finally, *structural uncertainty* describes the uncertainty inherent in models themselves. While the first three kinds of uncertainty can be dealt with through statistical distribution, the last one—structural uncertainty—cannot be dealt with statistically. It will always be present, and needs to be clearly stated in order for a model to be useful for decision-making (Conroy et al, 2011). Models help restorationists deal with uncertainty, but they also help them anticipate the future in particular ways by tackling difficulties associated with long time-scales, unruly complexity and epistemic indeterminacy.

Anticipation

I am defining the strategy of anticipation as a re-orientation toward the future by use of scientific practices and knowledge infrastructures to facilitate the exploration of possible futures. As articulated by Adams et al. (2009), anticipatory scientific regimes occur when "sciences of *the actual* are displaced by *speculative forecast*." Ecological restorationists in the Columbia River Basin carry out "anticipation work" (Steinhardt and Jackson, 2015) through their scientific practices by modeling using spatial and temporal scales that take "the long now" into consideration (Ribes and Finholt, 2009). According to Steinhardt and Jackson (2015), "anticipation work" involves "practices that cultivate and channel expectations of the future, design pathways into those imaginations, and maintain those visions in the face of a dynamic world." These include practices that are able to connect individuals and cultures through this future "vision" as well as travel across scales (Steinhardt and Jackson, 2015). These practices help sensitize the field of restoration ecology to the future, and to emergent ideas that still enable scientifically-based decision-making. This is a kind of "dual futurity" (Weber, 1946) in which humans are oriented toward the future and allow this future to guide their present actions. This constitutes an epistemic and conceptual shift for a field like ecological restoration, which has been guided by the past for so long.

Following Steinhardt and Jackson (2015), "improvisation and adaptation are an integral part of anticipation work." Anticipation becomes a way of orienting oneself and one's work, but this must be supported by culture—through what Adams et al. (2009) call "regimes of anticipation," or cultures that "authorize speculative modes of engagement." The scientific practice of modeling in ecological restoration is increasing in importance as climate change is necessitating the development of new, future-oriented baselines and goals. According to Pickering (1995):

> The goals of scientific practice are imaginatively transformed versions of the present. The future states of scientific culture at which practice aims are constructed from existing culture in a process of *modeling* (metaphor, analogy) (p. 19).

While Pickering (1995) is referring to a broader notion of modeling than I am here, through predictive modeling, anticipation becomes an important scientific practice and a strategy for dealing with uncertainty.

Models as an Anticipatory Strategy

To overcome the increasing uncertainty that climate change introduces, modelers in the Columbia River Basin are developing more sophisticated and scalable models. Two modeling efforts in particular, life-cycle modeling and stream temperature modeling, represent adaptive, anticipatory strategies. By co-producing models with policy-makers and choosing metrics to minimize and contain uncertainty, Van Hemert (2013) found that hydrographic modelers "tame" the epistemic indeterminacy climate change introduces. Restorationists in the Columbia River Basin are, similarly, using models to "tame" indeterminacy. For example, one restorationist described a floodplain restoration project in this way:

> In spite of what the Independent Scientific Review Panel [of the NWCouncil] would like us to do, we can't monitor every single action. We just do not have enough people. That is really expensive and very time-consuming. So, if we follow some models that have already been done and have been demonstrated to be effective, we are going to be pretty confident. (R19)

Another restorationist described the relationship between field-collected data and estimation in modeling in this way:

> We've always gone to get data when we need it. And it can take a long time. You can be collecting data for 20 years and just getting things more and more detailed,

> or sometimes it's just updating stuff. But a lot of people either don't have the time, or maybe they don't...get funding to go out and do data collection. Some people do, and they are really good at it, but not everyone. I think it's just our scientific approach, I think the thing that I get nervous about is if you start to estimate things that I've never measured before...But if I know that it's important, it's not hard to go get the data for that. (R1).

Many restorationists described a similar tactic of drawing inference through a combination of experimentation, trained judgment, and modeling, in a pragmatic move which, while not eliminating uncertainty, contains and "tames" it so that decisions can still be made. Models are an important tool for this anticipatory work. Without modeling, anticipating different futures would be far more opaque. Modeling and monitoring are important scientific practices that allows restorationists to deal with "unruly complexity."

Tacking Between Past, Present, and Future

Conceptual tacking back-and-forth between temporal or spatial scales can occur between specific and abstract, local and global, and past, present and future (Adams et al., 2009). This movement between scales is captured in the way that scientific modeling is used to predict, and deal with, the complex nature of ecology and change (Taylor, 2005). Through using models, restorationists are able to and anticipate and "try out" different futures, including what restoration treatments to employ. They then monitor these actions in order to further inference. This facilitates pragmatic decision making and the strategy of "acclimation" discussed in the previous chapter.

Predictive modeling as a scientific practice requires tacking back-and-forth between larger, regional scales and longer time-spans, and local scales and shorter time-spans. Scale is important, but being able to think about multiple scales is critical. As one restorationist put it: "if we really are in this for recovery of fish, let's look at it at the right spatial and temporal scale, and let's try our actions at that right temporal and spatial scale." (R2). Dealing with uncertainty is not only about creating finer-detailed models to highlight local complexities at the site or river-reach scale. Instead, restorationists often rely on models to help understand longer-term diversity and larger-scale stochastic elements of the system. Hierarchical relationships can be built into models by including interactions across system scales. Multiple tools can also meet the needs of different users and different scales so that restorationists can adapt their practices to meet uncertainty at a scale that is meaningful for their work. As climate change becomes more apparent, anticipating futures through modeling practices that use multiple scales is helping to deal with the complexity it introduces.

While this adaptive process of negotiation and tacking is key to adaptive management and decision-making more generally, anticipation extends throughout epistemic work and includes changing practices that surface in everyday actions. One restorationists explained:

> We are trying to get a set of indicators that we can check back with and check up on and adapt in our planning based on how we see the trends moving through time. I don't do the policy side of things so I haven't seen how it happens. We repeat our work a lot...we did this really fast, quick and dirty back of back-of-the-envelope version a couple years ago and then a couple years later they go 'okay now we have the tools to do this a little more dynamically so let's build a model and then validate it with fieldwork' so I guess that's kind of just what we do. (R3)

In this way, restorationists anticipate the future while working in the present, accounting for and "taming" epistemic indeterminacy, while at the same time taking action and continuing forward with their work. This action is possible because of the anticipatory practices of modeling, which can identify possible futures and what it may take to adapt to them.

The "Long Now" of Infrastructure

As discussed in the previous chapter, knowledge infrastructures can be standardized and scaled to orient scientific work toward the "long-term" (Karatsi et al., 2010). In this way, scientific work becomes allied with particular infrastructures that anticipate future spatial extents. Setting standards is a kind of "anticipation work" because it establishes what data will be comparable "across space and time" (Steinhardt and Jackson, 2015). In creating standards that orient toward the future, and anticipating social and environmental change, more resilient systems may be built (Steinhardt and Jackson, 2015). This kind of "anticipation work" orients infrastructures to the "long term" (Edwards, 2003). Many of the knowledge infrastructures that support ecological research and restoration in the Columbia River Basin are still evolving, and as described in the previous chapter, are still in the development or early implementation phases.

Looking to the future when designing a system requires collaboration between organizations and must be coordinated across projects and disciplines (Ribes and Finholt, 2009). In terms of designing a sustainable infrastructure, this may require considering the “long now” of infrastructure design, as infrastructures are built to meet a particular goal, or vision of what the future should look like (Ribes and Finholt, 2009). Some restorationists are already orienting towards this “long now” of infrastructure. As one restoration consultant stated:

> We need to stop thinking about systems as a one-time capital expense, like: ‘I am going to go invest in this big database and it is going to take a few years and then be done with it.’ We've cautioned and tried to get people to think more long-term. You really need to think about how you're going to have software that adapts and changes to your program, otherwise it becomes irrelevant or disused and just slowly dies a slow death. So, we try to do whatever we can to try to caution people and get people to think about that. (R25)

Investing in databases that will support modeling into the future is therefore one anticipatory strategy, but there are many ways that anticipation permeates the work that restorationists do. The following examples of recently developed models will serve to demonstrate this strategy.

Life-cycle Models

Life-cycle models in the Columbia River basin have become increasingly sophisticated, and now incorporate previously unknown parameters such as “stochasticity, density dependence, and climate variability and change” (Zabel et al., 2015). While not new to fisheries ecology, life-cycle models are becoming increasingly important in helping prioritize restoration efforts (Zabel et al., 2015). The development of a robust model that covers all life-stages of anadromous fish and overlays this with climate change scenarios is a novel development that is still in progress.

In order to satisfy the courts that NOAA had thoroughly considered climate effects and hatchery influences in its modeling, incorporating climate change into life-cycle models in the Columbia River Basin became an important focus after the failure of the 2008 BiOp. These models will make it possible to understand the effects of climate change on discreet populations. Because salmon often stray and run-timing varies and overlaps, it has been challenging for scientists to classify salmon into these discrete populations. However, once populations are classified as separate, life-cycle models can be used to "follow" salmon as they migrate throughout the river. One modeler described the standardization process for grouping populations as a time-consuming, yet necessary part of their work:

> A lot of data management work is actually fairly tedious agreement on very specific protocols to figure out exactly what to call things and where the specific boundaries are. But all that definitional work just allows you to roll the information up into units that you know are agreed to by everyone. (R24)

Here again, this data standardization is key to creating the knowledge infrastructure that will support adaptation.

Once climate change models are layered on top of population models, a temporal resolution as small as a day can highlight the particular thermal niche that a fish is traveling through as it makes its way up the river. These types of models will eventually be able to show how temperature affects a population as it moves through a river system and identify potential problems like the warm waters that caused the massive die-off in 2015. Further, models like these can be used to predict when cold water runoff will interact with particular kinds of habitats and where fish will need them most when migrating. For many restorationists, the "holy grail" of life-cycle modeling will be linking habitat monitoring and prioritization with life-cycle models. By extending the time-scale and including climate change scenarios into life-cycle models, areas for restoration can be prioritized, while at the same time anticipating different futures for different populations of fish.

NorWeST StreamTemp

NorWeST StreamTemp is a project facilitated by the US Forest Service that gathered together stream temperature data that were recorded by over 100 resource agencies across the Western US. These data were then compiled into spatial statistical network models using air temperature and discharge rates from thirty-six historical and future climate scenarios. The result is an interactive temperature map that shows current and expected temperatures for all streams in the Western US.

Creating the database was not an easy task. Although the data existed, they came from hundreds of sources throughout the basin and were often not interoperable. While scientists like Harlan Holmes collected data on fish numbers and sometimes stream temperatures, much like restorationists in the Columbia River Basin do today, the data that were collected in the early twentieth century must first be contextualized to current standards and locations. Similarly, stream temperature data from the past several decades have been collected, but in order for it to become useable, the data had to be cleaned of errors. Transitioning the data to the database required a team of full-time staff to “clean” it.

In terms of utility to restorationists, the maps derived from these models have become invaluable in determining where restoration may have the highest impact, especially for cold-water species of bull trout, where temperatures dictate their survival and spawning patterns. There have been some concerns that the ability to prioritize and locate streams that may be too hot to support salmonids in the future could lead to “giving up” on restoring some areas, but the models are not intended to be at a scale that would be precise enough for this kind of decision-making. Instead, they are meant to help with identifying trends and more general areas to focus restoration efforts. Restorationists across the basin are excited about the potential of the models in planning:

> It’s really taking off. I think the reason that that hasn't hadn't been a big piece before is just that we didn't have the data that are in the models. So that's part of the story, right? We have now a lot of remote sensing and modeling techniques that just weren't there. We had no way. I remember when we started out on this case study in 2003 or so and everyone said, ‘it would be great if we had temperature models, how do we do that?’ ‘Oh, that's too hard, forget it.’ But it's such a fundamental biological driver. It has to be there. And it's tied into climate change, obviously. So yes, now the challenge is how to manage all the data and interpret it correctly (R3).

Temperature models like NorWeST StreamTemp, which bring together temperature and stream data from multiple spatial and temporal scales are becoming critical to anticipating the future. Modeling efforts such as these, which predict stream temperature changes one hundred years into the future, are particularly useful for thinking about longer-term climate change. Yet for short-term and small-scale restoration work at the site scale, these models can also help anticipate potential impacts. This ability, to tack between local- and large-scale and short- and long-term fills the gap in knowledge between decadal time-scales and more fine-scale spatial patterns, and can help ensure the survival of a species from season to season as well as over the long-term. These dynamics are becoming particularly important when considering climate change, and determining where maintaining or restoring cool stream temperatures, often found in small pockets where ground water infiltrates, is key to this anticipatory work. Identifying these cold-water refuges using remote sensing and stream temperature loggers is a big concern for restorationists, and modeling techniques such as these can help focus future restoration efforts on sites that will make the biggest difference in terms of mitigating the effects of climate change.

Conclusion: Anticipating Futures Through Models

Models like these make it possible to look to future states and set future goals. This shift to anticipate the future is necessary in order to be adaptive, and models are one strategy for anticipating and exploring these futures. One restoration ecologist described this process:

> They'll run this model using basically professional opinions for conditions in each reach. They'll estimate how good they think it was historically how good they think it is now, and they also might say, 'what if we did some restoration? If we restore the riparian zone or if we remove these culverts, will that change things?' So, they use it in a smart way to figure out where the restoration opportunities are...They use data where they can, but people don't measure things on every reach, and they don't measure every month on every reach (R1).

Models create metaphors and analogies from which new practices can emerge. They make space for "what if?" questions. Pickering's (1995) description of models as "the link between existing culture and the future states that are the goals of scientific practice" is helpful here (p. 56). But he is careful not to be deterministic: "the link is not a causal or mechanical one: the choice of any particular model opens up an indefinite space of modeling vectors, of different goals” (p. 56). In this way, modeling as a scientific practice helps to bring about particular goals, socio-technical imaginaries, or future-natures in the Columbia River Basin by anticipating the future, but not determining it. Nevertheless, the choices that go into creating and using models, as well as the data that go into them, shape the way the river is restored into the future because they enable particular environmental and scientific imaginaries.

Anticipation is also a normative force, orienting scientific work towards particular goals, some of which are defined by legal institutions such as the ESA. These institutions determine what scientific interventions are most appropriate and authorize particular kinds of research. Modeling helps set restoration goals by facilitating the prioritization of sites and targets. In this way, anticipation facilitates co-production of science and society. Through anticipatory norms and future imaginaries, knowledge infrastructures forge trajectories for scientific work. Anticipation “articulates” between the goals of institutions and scientific practices because anticipation predicts what is possible and creates openings for technoscientific interventions (Adams et al., 2009).

Anticipation also has a moral quality to it. It embodies a moral injunction (Adams et al., 2009) to look to the future and address the coming issue of climate change. This moral injunction to anticipate what will come is becoming an important facet of the culture of ecological restoration, and breaks with a cultural tradition of looking to the past and trying to minimize risk and uncertainty. As scientists orient themselves to a climate-changed future, anticipation is increasingly becoming an epistemic virtue, and it embodies a scientific culture whereby restoration science embraces the future, as well as the uncertainty it brings.

The long time-scale necessary to restore salmon to the Columbia River Basin presents an incredibly complex challenge to the epistemic community of restorationists that are working toward this goal, and their practices will have to change to meet new challenges and incorporate new technologies. Restorationists acknowledge the intensification of increasingly uncertain conditions, as well as a lack of ready-made protocols to deal with them. Therefore, restoration practice is adapting, and strategies that anticipate the future are already being employed. As one restorationist pointed out: “As conditions in the river change because of sedimentation or lack of sedimentation, the methods that we can use are going to be different, and where we have to go to collect data is different...you have to adapt." (R30).

It is possible that the time-scales that restoration projects encompass are far too short. A very long-term restoration plan may look fifty years into the future, but most plans only look to the next funding cycle, with project start and end dates a few years apart. Except in a few of the region's long-term monitoring, IMW sites, data will only be collected for a few years. This may prove to be one of the biggest "blind-spots" in creating an adaptive restoration ecology. Time-frames may need to be extended beyond what individuals usually conceive.

As a counterpoint to the short time-scale of a restoration "project," the restoration plans of many Columbia River tribes represent the longest—and some ecologists would say—the most realistic time-scales in the basin. One tribe's restoration plan, for instance looks 300 years into the future, and a restorationist working on the plan pointed out:

> An old growth forest takes 300 years to grow. This is something that I've struggled with personally. You go back to a restoration site that is 10 years old, and its exciting, but it's also really depressing to see those trees that you planted. You are never going to see them old. My daughter might see them, but it's going to be a long time. [The plan] is a useful planning tool to say okay, these great problems are not going to be addressed in our lifetimes, but someone has to start doing it (R31).

These kinds of anticipatory practices represent a strategy for adaptation that increasingly runs throughout the restoration community in the Columbia River Basin, and enable restorationists to work intentionally toward alternative futures, or adapt to one that is arriving.

Anticipation as a strategy describes another way that restorationists are dealing with unruly complexity and uncertainty. By tacking between scales in models and orienting knowledge infrastructures to the "long now," they are able to contain uncertainty in a way that enables restoration to continue. This is different than minimizing or ignoring risk and uncertainty. Instead, anticipation facilitates pragmatic decision-making through modeling and metaphor. For ecological restoration, which has been traditionally based on looking to the past and using field-based methods, this shift to look to the future using modeling is a big change for the epistemic community, but it highlights how adaptive epistemologies can be.

Chapter 8: Conclusions

Thinking About Adaptation and Change

The role of science in adaptation and change in SESs has been under-conceptualized. While gathering data and increasing knowledge will undoubtedly help facilitate decision-making, adaptation within epistemic communities themselves also requires attention. In the previous chapters, I have brought concepts from different disciplines together in order to explore adaptation to environmental change in science. In doing so, I have defined three strategies for adaptation that can be seen in scientific practice, knowledge infrastructures, institutions and organizations—emergence, acclimation, and anticipation. I have also shown that it is important to consider how collective goals for environmental management (whether manifested through policy or not) relate to knowledge production through co-production. But finally, I hope I have demonstrated that interdisciplinarity provides a productive opportunity for exploring complex problems.

The field of restoration was born out of the idea that environmental repair was about looking to the past. But over time, the discipline has transformed to look forward, and even to anticipate the future. This has been a crucial adaptation, but it has not come easily. The examples in the previous chapters demonstrate how restorationists struggle with the uncertainty, shifting goals and expectations, and physical disruptions that climate change introduces to their field. In naming the different strategies that restorationists use to deal with environmental change, I wanted to make them visible. By being visible, they can be intentionally fostered by both restorationists and policy-makers. While ecological restoration in the Columbia River Basin serves as an example of an adapting epistemology, these strategies may extend to other fields that are dealing with environmental or social change in different ways.

Across the field and throughout the basin, restorationists are using strategies to foster the emergence of alternative practices, pragmatically acclimate these practices, and anticipate possible futures. The terms used to describe the strategies were chosen because they bridge disciplines and can be applied to multiple scales of epistemic work. These strategies highlight the ways that knowledge production, and scientists themselves, play in adaptive change. Restorationists struggle with climate change and uncertainty. Yet instead of remaining passive to these changes, which are being immediately felt, the epistemic community of restorationists is actively adapting. I argue that this is part of an evolving collective empiricism, which embraces experimentation, improvisation, and interdisciplinarity, so that novel strategies can emerge.

Change in Science

In order to sustainably manage SESs we need adaptive knowledge institutions and organizations that are supported by adaptive knowledge infrastructures. The scientific institutions and organizations within the Columbia River Basin may facilitate or hinder the production of knowledge, which will, in turn, affect possibilities for adaptation to climate change that relies on this knowledge through co-production. As people come to understand the complexities involved in managing SESs, increasing attention needs to be given to these institutions, organizations, and knowledge infrastructures and their role in enabling or constraining adaptive capacity.

According to SES theory, adaptive institutions are flexible enough to deal with multiple and shifting objectives (Pahl-Wostl, 2009). Yet institutions, as well as infrastructures, also contain their own kind of "inertia" that can be difficult to shift. Some restorationists in the basin worry that the institutional and organizational structure is too rigid to deal with the novelty of climate change. However, a historical perspective helps to see how much these infrastructures, organizations, and institutions have actually changed. Some of the restorationists that have been involved in the development of the field over the past two to three decades—from the time of ESA listing—have this arc of change in view. In the words of one restorationist whose career spanned this long term:

> If I knew fifteen years ago what I know now, we would have made a lot more progress. But I think that can be said of everybody that I work with. I didn't realize—and I don't think that any of us realized—fifteen years ago that we were basically redesigning an industry, and there was so much to learn. No, it's not *re*designing it *is* designing. We didn't have an industry! And if we had a chance to do it over we would do it a lot faster and we would do it a lot differently (R19).

This quote illustrates how the task of salmon recovery is about much more than getting salmon back into the streams. It is also the task of developing the institutions and the infrastructure to support this recovery—and there was no road-map for the early restorationists to follow when they embarked on this effort. As I have shown, these institutions are supported by knowledge infrastructures that can take emergence, acclimation, and anticipation as strategies to cope with climate change.

These strategies can be seen in the scientific practices, the epistemic cultures, and the virtues that the community holds. While these epistemic qualities can and do change, when talking about normative interventions in science in an effort to facilitate adaptive capacity, policy and management can play a role in creating adaptive organizations and knowledge infrastructures. By orienting them toward the future and fostering emergence, restorationists are more likely to have the support that they will need to adapt. Yet, what restorationists choose to measure and standardize now will also impact how nature is valued, and how the future itself is anticipated. At one point in history, riparian areas themselves were a “residual category.” They went unseen, uncared for, and were even destroyed (Langston, 2003; Fiege, 1999). Restoration ecology is, in some ways, the story of these riparian areas becoming visible. What else needs to become visible in order to adapt to a climate-changed future? Further, what about voices that have been silenced in the institutions and organizations that exist today? Tribes and treaty rights are one example of an emerging and important shift that highlights silenced voices. We need to ask how institutions and organizations could be co-produced in a more just way in which these voices are taken into consideration. Science’s role in creating these more just sociotechnical and environmental imaginaries should not be ignored.

Collective Goals/Futures

Restorationists in the Columbia River Basin are already experiencing climate change. They have been living through it for the last fifty years (Mote et al., 2013). The snowless winter, record droughts, and high temperatures of 2015 were a window into one potential future. These potential futures need to be anticipated, and actions to adapt to them (or better yet, mitigate them) need to be purposefully considered. Instead of looking to science to “inform” policy independently, science also needs to share responsibility in making value judgments (Dietz and Stern, 1998). This can be done through fostering an anticipatory practice in which we “think” and “live” toward the future (Adams et al., 2009). Adams et al. (2009) refer to this as a “politics of temporality,” in which we not only have a moral responsibility to “secure the best possible futures,” but we recognize that technoscientific futures “ratchet up” hopefulness and give possibility. Science, has always played a role in “reconfiguring ‘the possible’” (Adams et al., 2009). This is not the same as embracing a technological modernity to “solve” environmental and societal problems. Instead, it is a recognition that there are places within science where different goals and intentions can facilitate different sociotechnical imaginaries. The example of co-production of monitoring standards and the ESA within the Columbia River Basin illustrates this, whereby some qualities of the ecosystem become important, and more visible, while others, that are more complex, are more likely to remain invisible.

While future imaginaries for ecological restoration within a changed climate are still emerging, some new goals have been discussed. One of these may be simply ecological complexity itself (R11), or another priority may be finding what will “move the dial” toward species recovery, and only focusing on that (R9). Another may be to shift priorities of some of the institutions in the basin, such as the Columbia River Treaty, which could consider ecosystem function as a goal, in addition to hydropower and flood control (Cosens, 2012). In order to do this, the emergent quality of research requires that new categories, processes, or representations be incorporated as they arise (Ribes and Polk, 2015). The examples in the previous chapters highlight how interests and goals within science can and do change, and a pragmatic adaptive management (Langston, 2003) would take future imaginaries into account, specifically considering what future “we” want for the river.

It is important to remember that once knowledge infrastructures, institutions and organizations are created, they can also change. This is one of the findings of this research. Goals can be “tuned,” as scientific practice unfolds (Pickering, 1995). As resistances such as climate change or societal shifts such as tribal treaty rights gain power, goals must be revised. By becoming aware of the dynamic nature of knowledge production, we open a new space for intentionality, and adaptation, within science itself. This is the important insight that science studies brings to the table: by looking at scientific practices, knowledge infrastructures, institutions and organizations, I have shown how science changes in all of these different sites. Carefully examining these sites of change is one way to see how epistemologies adapt. This highlights the power of an interdisciplinary perspective in foregrounding what can often remain invisible.

A Place Called "Transdisciplinarity"

At first glance, this dissertation may already seem to contain conflicting—maybe even irreconcilable—parts. This work is framed using critical theoretical perspectives that may seem at odds with the productive and normative efforts of one of the main audiences for the results of this work—natural resource managers and policy makers. In these pages, pragmatic approaches to management meet the often radically deconstructing potential of science studies. The theories, perspectives, and ideas presented here are not often brought together in polite conversation, and doing so renders theoretical and practical tensions that, in all likelihood, cannot be resolved. This is not a mistake, but it is the purpose and the point: to sit in the uncomfortable borderlands of this in-between, "transdisciplinary," or even "undisciplinary" (Haider et al., 2017) place in order to see what emerges here. While this engagement of what may seem like conflicting ideas is not an accident, as so much in life, this project came about not entirely by plan. This project was conceptualized after taking a leap into a world that has always been troubling to me—the world of trying to "manage" nature. My aim is not to sweep these tensions under the rug, but rather to openly engage them.

The problematic relationship and perceived divide between utility and control of the environment vs. preservation or conservation of nature has been an ongoing tension throughout my own life, and this personal history has extended into my academic work. In large part, my research has been about facing these tensions head-on. Before delving into academia, I spent my time engaged in radical and utopian environmental and political movements that included building intentional, sustainable, communities and spaces. Like many others, my environmentalism was something that emerged organically as an extension of my fascination with and love of nature and the outdoors. As a young person, I didn't connect it to any particular ideology; it just seemed "right." Yet my nascent, and unnamed, environmentalism was always overshadowed by a practical conundrum—my livelihood was dependent on my family's logging business. I spent my childhood in the mill-yard behind our house, playing on descriptively-named logging equipment, like "chippers" and "fellers" and "skidders." After school finished for the day, I would often take jarring rides in the old log trucks with my father to the clear-cuts and mills. I knew, at an early age, where our livelihood came from, and I also saw the pride that my family took in the work they did—they saw themselves as woodsmen and hunters, making a living from the earth. While those ugly clear-cut scars and the birds made homeless (that we ended up caring for) when their forest was removed disturbed me, I learned to live in this in-between world. I didn't reconcile or surrender my values, but held onto them in this intermediate place. This feeling is similar to doing transdisciplinary work: it's uncomfortable, and there is no "right" answer (although there may be a more "just" or "equitable" one).

It took me a long time to get to the point where I could work in this in-between place and engage different worldviews in my academic work. My academic path led me to critical theory and radical geography. However much I enjoyed it, I decided not to stay there. Maybe it was the unsettling contradictions of my nature-exploiting/nature-loving upbringing, or a more egotistical need to take on an impossible challenge. But whatever it was, I decided to join an applied natural resources management and policy program. Now I work directly within the vast empire of ideas that has caused so many problems in the natural world. Here, my goal is to bring the theoretical concepts from critical social sciences into conversation with natural resources management in order to see what emerges. The fields of natural resource management and constructivism rarely come together, and ethnographic methods are often shunned in a field that venerates statistics. But here I want to bring them together in this in-between place of interdisciplinary, transdisciplinary, or even undisciplinary work.

Interdisciplinary work is defined as research that integrates concepts and tools from two or more disciplines (Cronin, 2008). Transdisciplinary research takes interdisciplinary work outside of the academy to collaborate or co-produce knowledge with non-scholars (Walter et al., 2007). While this work is undoubtedly interdisciplinary because it brings together concepts from history of science, philosophy of science, social studies of science, and sustainability science, it can also be seen as somewhat transdisciplinary because it incorporates the perspectives of restorationists through the use of ethnographic methods and grounded theory. Scholars in interdisciplinary fields such as cultural studies (Johnson et al., 2004), and more recently sustainability science have argued that "problem-based, integrative, interactive, emergent, reflexive" forms of science more accurately reflect the process through which scholarship orients itself to complexity (Haider et al., 2017; Robinson, 2008). This is similar to the emergent quality of this work as it engages with the complex issues of environmental management and climate change. I hope that the concepts—some from vastly different worlds—that were brought together in this work have been unsettling, because that was my aim. I also hope that, by bringing them together, I have introduced a way to think differently about environmental science and environmental change that can foster some new ideas about how to confront the large-scale and complex problems that we are faced with.

Interdisciplinarity and Collective Empiricism

While this is not a comprehensive study of virtues and ethics, there were some trends that emerged from the interviews that point to shifts in epistemic virtues toward more collective empiricism. Daston and Galison (2007) define "collective empiricism" as "the collaboration of investigators distributed over time and space in the study of natural phenomena too vast and various to be encompassed by a solitary thinker" (p. 27). I argue that a kind of collective empiricism has arisen in the Columbia River Basin, where the spatial extent and magnitude of the problem are far too large for individuals to overcome.

Collective ways of working contrast with competitive modes (Gibbons et al., 1994). Large-scale scientific endeavors, especially, can lead to more collective ways of working because they rely on cooperation to succeed (Knorr-Cetina, 1999). They are also increasingly important in fields with high levels of uncertainty (Nowotny et al., 2001). These types of collective ways of working can be found in the restoration enterprise of the Columbia River Basin, as scientists and practitioners work toward the common goal of salmon habitat restoration. The mechanisms for implementing these collective modes include such practices as modeling for prioritization and creating knowledge infrastructures for data-sharing. To be sure, this does not to erase the many conflicts and often-cited economic competition between actors within the Columbia River Basin. There are many. This is just to acknowledge a trend that many participants spoke about in interviews, applauded at conferences, and write into their organization's vision-statements.

Through a culture of anticipation, "the future arrives as already formed in the present, as if the emergency has already happened" (Adams et al., 2009). The "emergency" here is climate change, and people in the restoration community are adapting their cultures to anticipate it. I would like to extend the notion of collective empiricism outward, across disciplines and ways of knowing. Throughout this work, I have developed the inter- or trans-disciplinary conceptual framework of adaptive epistemologies, as a way to foster the emergence of new ideas to confront, and adapt to, environmental change. By bringing together unfamiliar concepts and methods and tolerating them, I hope the transdisciplinary engagement within this dissertation can inspire more, potentially risky, yet fruitful, engagements between disparate disciplines and fields.

A Final Word

In this "transdisciplinary place," I will give the final word to a restorationist, whose sentiment was echoed across the Columbia River Basin, from field sites to conferences, to city office towers to engineering firms:

> I think people often think that we are just going to go away and that this is a short-term little shot of government largesse. But my mantra is that restoration is the future. The West has been discovered. Everything has been discovered. Now we have to re-think that, with our climate and all of our infrastructure. It is all going to be re-built. It all has to be made sustainable and compatible with the natural environment. So, I think that, for young people starting out in their career, there is a really huge and bright future in trying to recover landscapes and watersheds and rivers and estuaries and the ocean. We have a lot of work to do. And none of it is impossible. We can fix everything. People really do know what is going on, I think. And I think that is an important thing, when we are looking at climate change and adaptation to climate change—that right now things may feel really

> negative, and mentally it is huge. I think there is a little bit of pushback, but we have no choice (R17).

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Appendix A: IRB Approval

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: Jerrold Long

Cc:

Shana Hirsch

From: Jennifer Walker, IRB Coordinator

Approval June 23, 2016 Date:

Title: Science and environmental management in a changing climate--salmon habitat restoration in the Columbia River Basin.

Project: 16-043 Certified: Certified as exempt under category 2,4 at 45 CFR 46.101(b)(2,4).

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the research project “Science and environmental management in a changing climate-- salmon habitat restoration in the Columbia River Basin” has been certified as exempt under the category and reference number listed above.

This certification is valid only for the study protocol as it was submitted. Studies certified as Exempt are not subject to continuing review and this certification does not expire. However, if changes are made to the study protocol, you must submit the changes through VERAS for review before implementing the changes. Amendments may include but are not limited to, changes in study population, study personnel, study instruments, consent documents, recruitment materials, sites of research, etc. If you have any additional questions, please contact me through the VERAS messaging system by clicking the ‘Reply’ button.

As Principal Investigator, you are responsible for ensuring compliance with all applicable FERPA regulations, University of Idaho policies, state and federal regulations. 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. The Principal Investigator is responsible for ensuring that all study personnel have completed the online human subjects training requirement.

You are required to timely notify the IRB if any unanticipated or adverse events occur during the study, if you experience and increased risk to the participants, or if you have participants withdraw or register complaints about the study.

University *of* Idaho
Office of Research Assurances Institutional Review Board
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Phone: 208-885-6162
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To: Jerrold Long Cc: Shana Hirsch From: Jennifer Walker

IRB Coordinator Date: November 03, 2016

Title: Dissertation Grant--Adaptive Epistemologies: Scientific practice and environmental restoration in a changing climate

IRB #: 16-043 Submission Type: Protocol Amendment Request Form Review Type: Exempt

Protocol Approval Date: 06/23/2016 Protocol Expiration Date: None

The Institutional Review Board has reviewed and **approved** the amendment to your above referenced Protocol.

This amendment is approved for the following modifications:

- Change title from *"Science and environmental management in a changing climate--salmon habitat restoration in the Columbia River Basin" to "Dissertation Grant--Adaptive Epistemologies: Scientific practice and environmental restoration in a changing climate"*

Should there be significant changes in the protocol anticipated for this project, you are required to submit another protocol amendment request for review by the committee. Any unanticipated/adverse events or problems resulting from this investigation must be reported immediately to the University's Institutional Review Board.

Appendix B: Description of Methods and Data

Following grounded theory (Charmaz, 2005) and situational analysis (Clarke, 2005; Clarke et al., 2015), this work was carried out through an iterative process. Interview questions changed as themes emerged through coding exercises. Grounded theory is a systematic method for analyzing large amounts of qualitative data. It aims to answer the question: "What is happening here?" (Glaser, 1978). It begins with identifying a case or incident, and develops abstract conceptual categories that explain relationships within the data (Charmaz, 1996). Theoretical development and the research process are iterative. Meanings, and reasons for action of the participants are made explicit through the systematic analysis of the data (Charmaz, 1996).

What follows is a brief outline of the iterative interview, data collection, and coding process. In addition to this work, ongoing archival and policy analysis was carried out, along with attendance at regional conferences and workshops, and visits to restoration field sites, which all included grounded-theory memoing exercises in which the researcher reflects on emerging themes and areas of interest that are emerging from the data.

Stage One:

- Initial participants for in-depth interviews were identified using situational mapping, which is an analytic exercise meant to answer the questions: "Who and what are in this situation? Who and what matters in this situation? What elements 'make a difference' in this situation?" (Clarke, 2005, p. 87).
- From this initial group, eight individuals were selected for 1-1.5 hour semi-structured and open-ended interviews (sample interview questions below).
-These interviews were transcribed.
-The transcriptions were then coded using MAXQDA software, looking specifically for "sensitizing concepts," which aim to categorize the data and generate initial concepts using the participants own words (Bowen, 2006). (sample codes below).
-Initial themes and areas of interest were identified using sensitizing concepts and questions and interview sample revised.

Stage Two:

-A second group of eight individuals were identified in relation to the areas of interest identified from the first stage.

-1-1.5 hour semi-structured interviews were conducted (sample interview questions below).

-Interviews were transcribed.

-The transcriptions were coded using MAXQDA software using a more complex coding schema aimed at interrogating the emerging themes to develop categories that link the participants words to emerging conceptual themes (Charmaz, 2005). (sample codes below).

Stage Three:

-This stage repeated stage two, but was aimed at identifying key individuals that would be able to speak to the emerging themes.

-A total of nineteen individuals were interviewed in this stage and they were asked questions that would help triangulate the emerging themes.

-All interviews from this stage were transcribed and coded using MAXQDA.

-Codes were analyzed and the three emergent themes were identified.

-Follow-up questions were asked of some participants to clarify, validate, and triangulate relations to the themes that emerged.

Table 1: Interviews

Number	Category	Type	Date
	Stage One Interviews		
1	Fisheries Ecologist	Interview	1-Mar
2	Fisheries Scientist/Manager	Interview	1-Mar
3	Fisheries Biologist	interview	7-Mar
4	Natural Resource Scientist/Manager	interview	8-Mar
5	Engineer/Consulting Firm Executive	interview	9-Mar
6	Fisheries Scientist	interview	13-Mar
7	Fisheries Scientist/Marine Ecologist	interview	27-Mar
8	Hydrologist/Restoration Manager	interview	29-Mar
	Stage Two Interviews		
9	Restoration Manager/Decision-maker	interview	11-Apr
10	Fisheries Biologist/Restoration manager	interview	11-Apr
11	Restoration Scientist/Manager	interview	11-Apr
12	Restoration Manager	interview	11-Apr
12	Restoration Manager	interview	12-Apr
13	Restoration Manager/Decision-maker	interview	12-Apr
14	Restoration Manager/Decision-maker	interview	13-Apr
15	Restoration Consultant/Engineer	interview	13-Apr
	Stage Three Interviews		
16	Restoration Manager	interview	23-May
17	Restoration Manager	interview	24-May
18	Biologist/Restoration Manager	interview	25-May
19	Restoration Manager	interview	5-Jun
20	Fisheries Biologist	interview	6-Jun
21	Restoration Manager	interview	7-Jun
22	Fisheries Biologist	interview	9-Jun
22	Fisheries Biologist	interview	9-Jun
23	Policy Analyst	interview	12-Jun
24	Restoration Manager	interview	11-Jun
25	Engineer/Consulting Firm Executive	interview	12-Jun
26	Restoration Manager	interview	12-Jun
27	Restoration Manager/Decision-maker	interview	13-Jun
28	Restoration Manager	interview	13-Jun
29	River Transportation Industry	interview	13-Jun
30	Modeler	interview	14-Jun
31	Restoration Ecologist/Manager	interview	25-Jul

32	Restoration Manager	interview	26-Jul
33	Modeler	interview	26-Jul
	Miscellaneous and Follow-up		
34	Restoration Manager	walking interview	16-Aug
35	Ecologist	talk	25-Apr
36	Modeler	interview	26-Jul
37	Restoration Manager/Ecologist	workshop	5-Feb
38	Restoration Manager	walking interview	21-Aug
39	Restoration Manager	walking interview	24-May
40	Modeler	interview	26-Jul
41	Restoration Manager	walking interview	17-Aug
42	Restoration Manager	walking interview	24-Feb

Round 1 Sample Questions (in bold):

Present/Future:

What is the relationship between science and the practice of ecological restoration in the basin?

-What role do you see yourself in? Scientist? Manager? Practitioner?
-Can you talk a little about your background as a scientist/manager?
-What discipline or disciplines do you feel a connection to?
-How did you get into this field (restoration)?

What are the struggles that managers and decision-makers are facing and how are they dealing with them in their research and practice as they confront climate change?

-What organizations or groups do you interact with in your work?
-How do you see your work fitting into salmon habitat restoration in the larger basin?
-What do you think are the most important goals for salmon restoration in the basin?
-What are some of the greatest opportunities?
-What are some of the greatest challenges?
-Do you think that habitat restoration is successful? Why or why not?
-How often do you think about climate change impacting your work?
-Do you see climate change as affecting your work? How?
-Can you describe some specific examples, situations, or scenarios where climate change has been an issue?
-Do you remember if or when you began to think about it in your work?
-Do you remember when you first began to notice the phrase "climate change" and/or when it began to be discussed in your field?
-Do you see any challenges ahead in terms of climate change impacts? In your work? In your interactions with others? In your field?

What tools are they using to cope with indeterminacy and uncertainty?

-What are some of the scientific concepts, models or tools that you use on a regular basis?
-Has this changed in relation to climate change?
-How do you deal with uncertainty?
-How do you deal with making decisions with uncertainty?
-How do you view adaptive management?
-Has climate change influenced the ways that you make decisions?
-Has climate change influenced what you study or how?

Is the science of ecological restoration adapting?

-Do you think that your work (or your field) has changed over the past decade(s)? If so, how would you describe these changes?
-Have any tools, data, or models been transformative for your work? Can you think of any that might be?
-Can you describe how you see future challenges or opportunities in your field?
-In what ways do you see yourself or your field as adapting to climate change?
-Do you foresee any potential constraints or collaborations with others in the basin?

<u>Historic:</u>

-Thinking back to the development of your field....

How did efforts to restore salmon in the Columbia River Basin come to focus on restoration of habitat for salmon?

-What kinds of changes have you seen in the field of restoration over your career?

What were the first habitat restoration projects?

-How did you first become involved with habitat restoration?
-Do you remember what some of the early restorations looked like?
-Where did they take place and who was involved?

How did the science of ecological restoration evolve?

-Do you remember when ecological restoration first emerged?

What are the major institutions that have been developed to facilitate salmon science in the region, and how did they come to be?

-Who or what institutions were involved?

<u>Final:</u>

-Where do you think habitat restoration in the basin should go from here?
-What policies or institutions could strengthen it?
-Is there anyone that you think it would be important for me to talk to about salmon habitat restoration in the basin?
-Is there anything else that you would like to say? OR anything that you think is important to consider, or that I have not mentioned?

Round 2 Sample Interview Questions:

-How did you first become involved with habitat restoration?

-Thinking back to the development of your field, what kinds of changes have you seen in the field of restoration over your career?

-Have any tools, data, or models been transformative for your work or created a paradigm shift in the field?

-Do you remember when you first began to notice the phrase “climate change” and/or when it began to be discussed in your field?

-Has climate change influenced what you study or how?

-Can you describe some specific examples, situations, or scenarios where climate change has been an issue?

-What are some of the scientific concepts, models or tools that you use on a regular basis to deal with climate change?

-Do you know of any restoration projects that have been particularly innovative in dealing with climate change?

-What kinds of data do you think are going to be critical to adapting restoration to climate change?

-In what ways do you see yourself or your field as adapting to climate change?

-How do you view adaptive management?

-Do you foresee any potential constraints or collaborations with others in the basin?

-What do you think are the biggest opportunities or challenges goals for salmon restoration in the basin?

-Where do you think habitat restoration in the basin should go from here?

-What policies or institutions could strengthen it?

-Is there an overall message that you would like others to hear about where restoration should go, or what you need to do your job in the face of climate change?

Round 1 Sample Codes:

Climate change
Epistemic community/culture
Epistemic virtues
Institutions
Collaboration
Unexpected
Scientific method
Structural/Engineering fix
Creating guidelines
Anxiety—need to address
Uncertainty
Cost
Spatial Concern
Developing Scientific Agenda
Time concern
Future Orientation
Adaptation
Larger Goal
New tools/methods
Gatekeeping
Law
Contradiction/tension
Conflict
Need
Science important
Development of science/organizations

Sample Round 2 Codes:

Residual categories
Adaptive Epistemology
Multiple approaches
Transparency
Efficiency
Complexity
Nature working/doing
Measuring
Judgment
Algorithms and rules
Baselines
Monitoring
Statistics
Experimental ideas
Scale
Diluting uncertainty
Climate change not being addressed
Risk
Spatial
Territory
Early restoration
Resilience
Adaptive management
Adaptive governance
Infrastructure
Scaling up
Design
Databases
Categorization
Creating structure
Flexibility
Emergence
Synthesis/standardization
Repurposing
Networks
Drones/Lidar
Ecosystem processes/function
Beavers
Refugia
Models
Ethics/justice
Planning/prioritization
Bureaucracy