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Adaptive Epistemologies: Conceptualizing Adaptation to Climate Change in Environmental Science

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Abstract

This article explores how scientists adapt to a changing climate. To do this, we bring examples from a case study of salmon habitat restorationists in the Columbia River Basin into conversation with concepts from previous work on change and stability in knowledge infrastructures and scientific practice. In order to adapt, ecological restorationists are increasingly relying on predictive modeling tools, as well as initiating broader changes in the interdisciplinary nature of the field of ecological restoration itself. We explore how the field of ecological restoration is shifting its conceptual gaze from restoring to past, historic baselines to anticipating a no-analog future and consider what this means in terms of understanding the adaptive capacity of knowledge infrastructures and epistemic communities more

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broadly. We argue that identifying how scientists themselves conceptualize drivers of change and respond to these changes is an important step in understanding what adaptive capacity in science might entail. We offer these examples as a provocation for thinking about "adaptive epistemologies" and how adaptation by scientists themselves can facilitate or hinder particular environmental or sociotechnical futures.

Keywords
adaptation, environmental science, ecological restoration, knowledge infrastructures, ecology, climate change

Introduction

For many people in the Pacific Northwest, 2015 was a wake-up call. The winter of 2014–2015 saw record-low snowfall. The high temperatures, drought, and low stream flows of the following spring and summer brought devastation to the environment, especially to salmon. For ecological restorationists, 2015 was a benchmark for how bad things would become in the future, and for many, it represented an oracle of sorts. Globally, 2015 was the warmest year on record, immediately following the previous warmest year in 2014 (Blunden and Arndt 2015). As salmon made their way up the main stem of the Columbia River in early summer, record-high water temperatures exceeded survivable levels and mass die-offs ensued (NOAA Fisheries 2015). The Northwest Power and Conservation Council (NW Council) estimates that around 250,000 sockeye died in the Columbia River and its tributaries as a result of the warm water: well over half of some runs (NW Council 2015). One ecological restorationist recounted,

> 2015 kind of gave us a little bit of a reality check: Oh, wow! . . . It was a really tough summer . . . . It was 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)

According to climate models, the future of the Pacific Northwest will, indeed, look like 2015. Winters are predicted to be warmer and wetter, while summers will be hotter and dryer. This means that there will be less snowpack, decreased stream flows, and increased water temperatures—all of which are detrimental to salmonid survival (Nolin, Sproles, and Brown

2012). These changes will accelerate in the Columbia River Basin over the next few decades (Roberts et al. 2015). Meanwhile, conservation scientists and practitioners are working to recover salmon populations by restoring habitat throughout the basin. They are trying to understand and adjust to these changes, which add a new layer of complexity and uncertainty to their already difficult task. To do this, they are actively adapting their work to meet the challenges of climate change in different ways such as planting alternative tree or shrub species that might tolerate future conditions. But adaptations also extend to more fundamental changes including rethinking restoration ecology itself in order to better anticipate the future. As one practitioner put it: "Everything has changed . . . I, personally, believe that going back is not a realistic goal" (R34).

Traditionally, ecological restoration practices and policies assumed a stable climate and an ecological model based on a potential equilibrium (West et al. 2009), usually seeking to return ecosystems to a historic state of some form. Yet, the uncertainty introduced by climate change challenges the restorationists working to measure and identify ecological thresholds and create management goals (Suding and Leger 2012; Hobbs, Higgs, and Hall 2013). What were at one time common scientific and management tools are no longer reasonable metrics for success because historic conditions no longer exist (Seastedt, Hobbs, and Suding 2008). Restorationists are therefore rethinking what is possible (Light, Thompson, and Higgs 2013; Hobbs, Higgs, and Hall 2013), and anticipating the future is becoming an increasing preoccupation. This conceptual shift has brought new "paradigms" (Choi 2007), research objects, and theoretical concepts to the field. These include "hybrid ecosystems," which reorient restoration science toward a future ecological state (Choi 2004; Hobbs, Higgs, and Harris 2009), or "novel ecosystems" which contain species combinations that have never previously occurred (Hobbs et al. 2006). The effects of climate change have also led some key voices in the field to claim that traditional restoration goals are now "unachievable" (Zedler, Doherty, and Miller 2012; Hobbs, Higgs, and Hall 2013). This may indeed be the case for some Columbia River salmonids, as water temperatures and flows shift, making it difficult for them to survive in parts of their historic range (Mantua, Tohver, and Hamlet 2010).

While theoretical advances within the field have been crucial in coming to terms with the fact that there will likely be a "no-analog" future environment that has never previously existed (Williams and Jackson 2007), exactly how changing ecological conditions are negotiated by environmental scientists and managers is not well understood. 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 may not be enough time to establish a rigorous scientific method. As van Diggelen, Grootjans, and Harris (2001) lamented in reference to ecological restoration almost two decades 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).

Ecological restoration of salmon habitat in the Columbia River Basin therefore offers the opportunity to study an epistemic community at a critical time of uncertainty and change. There is no doubt that science is always changing. 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, as policy to support scientific work coproduces particular futures and sociotechnical imaginaries (Jasanoff 2004). While there has been much written about philosophical questions related to the value of nature in ecological restoration (e.g., Higgs 2003; Light and Higgs 1996; Allison 2012), case studies that engage with ecological restoration from a critical perspective have been scarce despite a few notable exceptions. These include work on the role of expertise and natural resource management (Bocking 2004), restoration as a public experiment (Gross 2010), neoliberal political economies of river restoration science (Lave 2012), and recent multispecies research on beavers and restoration (Woelfle-Erskine 2017). The case of ecological restoration in this instance offers an opportunity to explore how an epistemic community adapts to change—in this case climate change.

The goal of this article is to bring attention to dynamics of change and adaptation in epistemic communities. We argue that identifying how scientists conceptualize different drivers of change and respond to these changes is an important step in understanding what adaptive capacity in science might entail, not only in the context of ecological restoration but in other scientific fields that are also coping with adaptation to environmental, social, and ontological change. In what follows, we bring the results from a large-scale ethnographically informed study of salmon habitat restorationists in the Columbia River Basin to explore these dynamics. First, we outline some of the ways that change has been conceptualized in scientific practice and the knowledge infrastructures that support this practice. Following this, we give a brief background of salmon habitat restoration in the Columbia River Basin, then outline examples of changes both in scientific practice, including increasing reliance on modeling to anticipate the future, as well as broader changes in the interdisciplinary nature of the field of ecological restoration itself. Finally, we conclude by discussing how the field of ecological restoration is shifting its conceptual gaze from restoring to past, historic baselines to anticipating a no-analog future and discuss the implications of thinking through "adaptive epistemologies" as a lens, as well as the potential for designing knowledge infrastructures that consider the adaptive capacity of epistemic communities more broadly.

Conceptualizing Adaptation in Science

Change in the Columbia River Basin is not a new phenomenon. Environmental and social changes have been drastic and ongoing since European settlement, as well as the millennia before, as Indigenous peoples also shaped and reshaped the landscape. Science in the basin, too, has always been changing, with scientists constantly adapting their practices to different drivers of change. In this article, we consider the different ways that restorationists are adapting their own practices to deal with change, and how the field as a whole is shifting. For this, we turn to theoretical concepts and previous work on stability and flexibility in knowledge infrastructures as well as literature on change in scientific practices and epistemic cultures.

One way to tease apart different aspects of change in science is to follow Ribes and Polk (2014) in considering three different "sensitizing concepts" (Glaser 1978) or what they call "facets of change." In their case, Ribes and Polk (2014) are investigating flexibility in research infrastructure, yet their typology of change as encompassing technoscientific, sociotechnical, or institutional facets is useful for thinking about adaptation in epistemic communities more broadly. In their schema, technoscientific change includes ontological changes in the object of research, as well as changes in practices such as methods, instruments, and the experts involved in these practices (Ribes and Polk 2014). This category draws on Latour's (1987) term "technoscience," which recognizes both the individual and collective interactions between the work of scientists and their objects of research. Empirical work on technoscientific change in knowledge infrastructures, for instance, has shown how changes in scientific practices are related to changes in the infrastructures that support those practices (Knorr Cetina 1999; Star 1999). The sociotechnical facet of change includes social organization within the epistemic community such as coordination, data sharing, and tools that facilitate collaboration like standards or databases (Ribes and Polk 2014). Changes in the institutional facet include shifts in funding, policy, or regulation, as well as institutions and governance structures (Ribes and Polk 2014). While institutional change and institutional responses such as shifts in environmental regulation and increasing recognition of tribal treaty rights play a vitally important role in the environmental science carried out in the basin, due to limited space, we review this topic elsewhere (Hirsch and Long 2018).

It is important to remember that these facets of change are "interlinked" and not only blur into one another but also influence each other in complex ways, yet the typology is nonetheless helpful for our purposes in thinking about different kinds of change in a scientific field. The creation and maintenance of research infrastructures, for instance, requires ongoing work across these facets (Star and Griesemer 1989; Karasti, Baker, and Millerand 2010). Knowledge infrastructures support the work that scientists do and influence the way that science is applied (Bowker and Star 2000). As such, they can be designed and maintained in ways that facilitate or hinder adaptation (Ribes and Polk 2014). As has been described elsewhere, however, infrastructures are also "paradoxical" in the ways that they both support and stifle adaptation and change (Star and Ruhleder 1994). 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 (Bowker and Star 2000), meaning that knowledge infrastructures need to be both rigid and flexible: universal yet able to change (Edwards et al. 2013). Adaptation is therefore required if knowledge infrastructure is to remain sustainable, useful, and relevant to the scientists that might use it in the future (Ribes and Finholt 2009). This tension becomes especially clear in places like the Columbia River Basin, which includes many large-scale infrastructures where sociotechnical systems have a spatially and temporally broad reach.

In one sense, ecological restorationists in the Columbia River Basin are adapting to basic, ontological changes as their object of research—the river environment—is altered by climate change, but the adaptations that follow this ontological change also include epistemic changes in scientific practices. The practices of scientists themselves are constantly remaking the social fabric, or culture, of science. Therefore, science can also be understood as both performative and temporally emergent through practice (Pickering 1995). Examining scientific practice highlights the role of individuals and their actions in either remaking or extending—in other words, *changing*—a particular scientific culture. Pickering (1995) describes this process of cultural extension in science in what he terms the "mangle of practice," whereby the goals of scientific work are constantly "accommodated," revised, or "tuned" as scientists encounter "resistances" in their work. Resistances could be things that don't quite fit into a computational model, technologies that fail, or difficulties encountered when collecting data in the field. According to Pickering, the dialectic process of "resistance" and "accommodation" is what drives practices to change and thereby scientific culture to shift. As scientists cope with the uncertainty of a shifting climate, they also shift their epistemological practices: they find ways to deal with "resistances" to their efforts by adjusting to or "accommodating" them. Therefore, practice is one place where we can observe the adaptation of scientific work.

In addition to the practices of individual scientists, scientific communities are more broadly constituted through an epistemic culture. Epistemic cultures include the ways and norms of working and achieving expert status within a particular scientific field, and like all cultures, they change (Knorr Cetina 1999). Looking more closely at the virtues behind these changing epistemic cultures and practices, we find specific "forms of the scientific self," as epistemologies hold to particular virtues, or "ethos" that are both "ways of being" and "ways of knowing" (Daston and Galison 2007). Like epistemic cultures, these virtues are historically situated and change through time. Epistemic virtues and norms like truth, objectivity, replicability, or creativity become important for scientists to engender at distinct historical moments. While they are only one aspect of a much broader epistemic culture, they play an important role in epistemic work, shaping the field and the way that science is conducted. For example, in their history of objectivity, Daston and Galison (2007) find that epistemic virtues such as "trained judgment," or expert interpretation, evolve through time and upholding them can deem a scientist "virtuous" during a particular point in history.

Literature on adaptive environmental science and management also often focuses on change, arguing for the importance of knowledge to support adaptation in socioecological systems. The details of this dynamic, however, are unclear. What kinds of knowledge would be adaptive? 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? Words such as resilience, flexibility, sustainability, and adaptability have also been applied in the context of knowledge infrastructures (Ribes and Polk 2014). Yet much more work needs to be done in order to parse out these dynamics of change as well as conceptualize what *adaptive capacity* within epistemic communities, such as ecological restoration, might mean. In social systems, adaptive capacity signifies the existence of institutions and networks that are capable of learning and possess flexibility so that they are resilient in the face of change (Folke, Colding, and Berkes 2002). Whether and how an epistemic community changes, then, should be related to its adaptive capacity, yet more studies on adaptation in science need to be done in order to conceptualize this relationship.

This study combines the interpretive qualitative methods of situational analysis (Clarke 2005), archival and policy analysis, and ethnography, including interviews and participant observation of the epistemic community of ecological restorationists working on salmon habitat in the Columbia River Basin. In our field work, we paid attention to practices and strategies that individuals employed to deal with climate change and spoke people who were conducting restoration research and monitoring activities. The Columbia River Basin encompasses a large region, so in order to deal with this, we sampled a cross section of restorationists from different sectors across the basin as well as going in depth in certain locations to gain a more detailed perspective of the issues. As themes emerged, they were integrated into future in-depth interviews, in order to "test" them out with participants. We interviewed a total of forty-two individuals in one to one and a half hour semi-structured and open-ended interviews that we transcribed and coded.

In addition, we conducted participatory observation at several major regional conferences and associated workshops and participated in both webinars that were held regularly among practitioners in the region. We also analyzed policy documents from organizations in the basin such as the Northwest Power and Conservation Council. We were generously invited to join restorationists in the field and were shown around many of their restoration sites. We participated in site visits with managers and researchers where restoration experiments were taking place and methods were being showcased and debated. These visits allowed us to contextualize the issues that participants discussed in interviews, further triangulating emerging topics and concepts.

The Case of Ecological Restoration in the Columbia River Basin

The Columbia River Basin was 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 for the purpose of economic development (White 1995). 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 2018), but they have also devastated habitat for aquatic species. In response, ecologists have been working to understand how hydropower development impacts anadromous fish populations, and through this work, they have found that, in addition to habitat loss, the 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). Reminiscing about a long career of implementing and monitoring habitat restoration projects, one restoration ecologist said: "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."

Thirteen salmonid species are now listed under the Endangered Species Act (ESA) as either endangered or threatened. Habitat loss due to hydroelectric infrastructure, agriculture, forestry, and municipal development have all been considered major factors in declining populations of salmonids in the basin, yet habitat protection was not a priority until the late twentieth century. Despite this delay, habitat restoration now plays a critical role in programs that work to mitigate the impacts of dams and increase salmon survival, particularly in rearing and spawning phases of their life cycles (Stanford, Frissell, and Coutant 2006). The large scope and scale of ecological restoration in the Columbia River Basin is driven by mandates from both the ESA and tribal treaty rights. The region receives substantial funding compared to restoration efforts in many other river systems: at least US$300 million per year is spent on habitat restoration in the basin (Katz et al. 2007; Bernhardt et al. 2005; Rieman et al. 2015). Yet, for those tasked with restoring salmon habitat in the Columbia River Basin, the scope and scale of this "wicked" problem can be overwhelming. The task is only made more complex by climate change.

The scientific and natural resource institutions and organizations that were put in place to support the development of the river still influence the material possibilities in the basin today as technological fixes like hatchery science and fish passage technologies became the preferred methods for tackling salmon decline (Taylor 1999). Despite the mandates and the money, the restoration of salmon and their habitat in the basin remains 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 hydroindustrial complex while at the same time maintaining anadromous fish populations. Restoring salmon and their habitat to the Columbia River Basin—"fixing" all of the problems caused by an industrial hydrosystem—is a kind of megaexperiment on a massive scale. At the same time, restorationists are having to deal with changes in the climate that are already being experienced, and the devastating impacts to fish populations—such as those during the record-breaking year of 2015—are compounding this challenge. As the restoration effort has evolved over the past decades, the epistemic community of restoration specialists has had to adapt to these new challenges, discovering as they go what it means to manage such a complex and large-scale task through a time of unprecedented environmental change. In the following section, we describe some of the ways that ecological restorationists in the Columbia River Basin are dealing with climate change as it acts as an exogenous force, altering both the individual practices of restorationists and the field itself.

Shifting Practices

As the effects of climate change become increasingly felt in the Columbia River Basin, ecological restorationists are finding their object of research itself to be changing. As water temperatures rise and snowfall turns to rain, the elemental makeup of the environment itself is shifting. So too are the goals of restorationists: although restoration of salmon habitat remains the overarching goal, the interventions they believe necessary to meet this goal are different. For example, identifying and restoring cooling groundwater or creating shade in riparian areas has become an increasing preoccupation (Beechie et al. 2013). This ontological shift represents one of the main drivers of change for the restoration community as shifting objects of research require an altered response. This response includes technoscientific changes in the methods, instruments, and practices that are being used to understand and restore the environment. One example of these technoscientific changes can be seen in the way models are increasingly relied on to understand future environmental conditions.

Models as Tools, Modeling as Practice

Methods that incorporate computational and predictive models as scientific tools are becoming increasingly important in terms of anticipating potential futures for the river environment. In many scientific fields, including ecology, computer modeling has come to "complement or even replace" both laboratory and field experiments (Edwards 2010, xix). Models in ecological science are used to organize data, synthesize information, and predict the future (Oreskes 2003). Data within the Columbia River Basin are fast becoming model-dependent, either being "fed" into models or being derived from them, and a modeling infrastructure that is facilitated by multiple agencies and organizations has emerged in the basin. These models are often used for decision-making, and they are becoming increasingly complex as they are used to account for new parameters of environmental and social data. Models facilitate monitoring, planning, and prioritization of restoration sites, but modeling work also includes the development of fisheries' life cycle and population models as well as hydrologic models related to dam operations or stream flow. By using models, restorationists are able to anticipate and "try out" different futures including restoration treatments that employ techniques to mitigate climate change effects. As one restorationist described: "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." In other words, regardless of *what* is being measured, the *way* it is being measured, and the way the data are being handled and modeled, is changing.

Temperature models like NorWeST StreamTemp, which combine temperature and stream data from multiple spatial and temporal scales, are increasingly being used to anticipate future environmental conditions. Restorationists have found that modeling efforts such as these, which predict stream temperature changes up to one hundred years into the future, are particularly useful for locating areas where restoration could be most beneficial to fish populations in a climate-changed future. Yet, for short-term and small-scale restoration work at the project-site scale, temperature models can also help restorationists anticipate potential climate impacts at the local scale: restorationists are using them to determine where small pockets of groundwater infiltrate. Identifying these cold-water refuges using remote sensing and stream temperature logging devices has become a big concern for restorationists, and modeling techniques, combined with new instrumentation technologies, are helping them home in on future conditions in specific locations, allowing them to prioritize restoration areas that will make the biggest difference in terms of mitigating the effects of climate change.

Ecological restorationists are using models to look to future states and set future goals. This shift to looking to the future for guidance in restoration planning and design is one way that the field is adapting: 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)

Restorationists acknowledge the increasingly uncertain conditions that climate change is bringing to their work as well as a lack of ready-made protocols to deal with them. Therefore, the field of restoration is adapting, and changes in the technoscientific practices, methods, and tools that they are using are already being seen. As one restorationist pointed out: "As conditions in the river change . . . 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).

Becoming Interdisciplinary

Although these practices describe adaptations in scientific practices in the basin, the field of ecological restoration is also changing in response to climate change at the level of the epistemic community itself. Across the Columbia River Basin, the disciplinary divides within ecological restoration are breaking down, as practitioners create new collaborative tools, encourage data-sharing, and work to facilitate integration of concepts that have often been at odds. This reorganization of the social divisions in restoration can be seen in the increasing interdisciplinary meetings and working groups that are being formed throughout the epistemic community.

For example, process-based and engineering-based restorationists have been in tension throughout the evolution of the field, and many people still firmly situate themselves in one "camp" or another. The goal of process-based restoration is to restore the processes of ecological succession or at least to speed them up so that they could return to a state that has been lost due to a disturbance (Bradshaw 1987). In other words: reset and let nature take over. In river and stream restoration, this can be done using the stream itself, by removing barriers and allowing its waters to infiltrate and reconnect to a floodplain, for example. On the other hand, engineering-based restoration takes a more hands-on, interventionist approach in which restorationists might build large in-stream structures or pumping systems to create desired environmental conditions, engineered infrastructure that often needs ongoing maintenance. One reason for this divide is that some restorationists view the legacy of engineering "solutions" as a major contributor to the problems that got rivers into trouble in the first place. Engineers and early restorationists constrained and straightened river channels, often destroying salmon habitat in the process (White 1995; Taylor 1999). 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.

Some restorationists think that restoring ecological processes takes too long. 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. Yet, after witnessing the devastating salmon die-offs of 2015, many people are willing to implement innovative measures—engineering *or* process based—to prevent this kind of ecological disaster from happening again. In practice, then, many restorationists find themselves pulling from both toolboxes—process-based restoration and more technologically based engineering solutions to try to "hedge" the uncertainty that climate change introduces. The collective goal is increasingly to bring fish back by creating habitat *by any means* necessary. Therefore, a disciplinary divide is breaking down as tactics that were once seen as incompatible come together in restoration projects.

One example of this disciplinary breakdown is found in the "beaver dam analog" (BDA)—an engineered dam structure that mimics a beaver dam, often intended to entice a beaver to take it up as its own (Castro et al. 2015). Beaver restorationists have measured positive fish response to the restored wetlands and complex pool systems that beavers create (Pollock et al. 2014). Through the work of beavers, ecosystem processes are set in motion, unpredictability is embraced, and emergence is thereby encouraged. Woelfle-Erskine (2017) labels beavers "stochastic transgressors against Manifest Destiny engineering projects" (p. 5), highlighting their transformative abilities as they become collaborators with restorationists in transforming rivers. 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, and so on. A lot of models also assume a steady state or balance in an ecosystem. Yet biogenic dams, such as the ones that beavers construct, are meant to upset this balance. Although difficult to model and monitor, restorationists believe that BDAs are highly functional in restoring natural processes to a river system.

The two philosophies of restoration, process based and engineering based, come together and find some common ground through BDAs. While BDAs lack much resemblance to the structurally based restoration designs that have been most common until recently, many engineering firms are adopting them into their designs. This demonstrates how highly embedded epistemic cultures can shift, as unfamiliar concepts and methods can be tolerated in order to see what happens—to foster emergence by allowing multiple cultures to coexist. One restorationist and educator described the process this way:

> 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)

Although 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 and disciplines. Daston and Galison's (2007) study of objectivity demonstrates that a plurality of virtues and differing "visions of knowledge" are foundational to science, while others have argued that scientific work is actually conducted through heterogeneous, patchy cultures and practices that are not uniform conceptually but instead "mutually" adjust to each other (Hacking 1992).

Scientists themselves are also advocating for changes in how scientific work is organized in the basin:

> You tend to have these groups that are built around certain science-policy outcomes and they become wedded together. In the late 90s that's what it was all about. There were major debates. We have improved and moved a long way past that. Now those camps are still set up, but there is more of an effort at collaboratively looking at these results. (R23)

This type of collaborative work is part of an evolving restoration community in the Columbia River Basin. More and more, people are embracing experimentation, improvisation, and interdisciplinarity so that novel strategies to adapt to climate change can emerge. As ecological restoration matures as a field, many of the lines that were "drawn in the sand" are gaining less traction as the new common foe of climate change enters the picture.

Conclusions: Locating Adaptation in Science

In advocating for adaptation in socioecological systems, 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 socioecological systems highlights the importance of increasing "predictability of system dynamics" so that decision makers can better estimate potential outcomes. Yet increasing knowledge will only occur if it can still be produced. Scientific practice and the knowledge infrastructures, institutions, and organizations that support this work will also need to adapt to change. We therefore want to bring attention to the dynamics of adaptation to environmental change within scientific work and the infrastructures that support it. In order to do that, we identified some responses to climate change in the field of ecological restoration and explained some of the ways in which the epistemic community itself is also adapting to environmental change. These are only some examples of the ways that scientists, not only in the Columbia River Basin but throughout the world, are adapting their work to changing environmental conditions and the challenges they introduce. We are certain that there are many other strategies that individual scientists and epistemic communities are using as they cope with change. Nevertheless, we offer this focus on "adaptive epistemologies" as a starting point to begin thinking about how scientists deal with environmental change or sociotechnical transitions and how adaptive capacity may even be fostered. One way to start this inquiry is to conceptualize what adaptive knowledge infrastructures might entail.

Salmon habitat restoration in the Columbia River Basin is supported by a large-scale knowledge infrastructure, which includes norms such as standards and routines, as well as physical spaces and materials such as cyber-infrastructures that support restoration work. As people come to understand the complexities involved in managing the environment through a changing climate, increasing attention needs to be given to these knowledge infrastructures and their role in enabling or constraining adaptive capacity. Their design has consequences for the science that results (Edwards et al. 2013). The knowledge infrastructures in place today will shape future scientific capabilities and programs dedicated to salmon recovery in the Columbia River Basin by supporting specific kinds of scientific practices.

One of the ways that restorationists may be able to cope with environmental uncertainty and change is by orienting these infrastructures to what Karasti, Baker, and Millerand (2010) refer to as "infrastructure time" or looking to future needs and orienting infrastructures to the goal of sustainability and adaptation. In terms of designing a sustainable monitoring infrastructure, this requires considering the future and organizing for it at the institutional level. This design work, which intentionally considers how the infrastructure that is established today will enable particular futures, has been called the “long now” of infrastructure design (Ribes and Finholt 2009). By looking to these long-term temporal 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 for ecological restorationists and other environmental managers as it considers long-term sustainability and the need for adaptive capacity in knowledge infrastructures themselves. Some other examples of orientation to “the long now” could include anticipating categories of data or metrics that might be needed to understand future conditions, such as stream cover that provides shade and cools water, or employing sensing techniques and representations that include groundwater infiltration. Some of these techniques are beginning to be used by restorationists in the Columbia River Basin. Both abstract and physical infrastructures that will support the science necessary for managing a climate-changed future river need to be considered in order to create an adaptive knowledge infrastructure.

In an effort to restore ecosystems to historical states, ecological restorationists have often oriented their work toward the past. However, in light of the present and coming impacts of climate change, this will no longer be possible. This constitutes an important epistemic and conceptual shift for a field like ecological restoration, which has been guided by the past for so long. If a field such as this one can change a fundamental ontology and tenet of its scientific perspective, this surely points to the ability for other fields to adapt to environmental change in a relatively short time period as well. Whether in an ecological or social sense, being “resilient” means that a system, or in this case a knowledge infrastructure, is able to adjust without losing its fundamental function (Folke, Colding, and Berkes 2002). This is the task that ecological restorationists in the Columbia River Basin are dealing with as climate change impacts their practices and their epistemic community. The adaptations outlined above describe some of the ways that individuals are doing this work. Exploring how scientists are adapting their practices in other fields, through ethnographic, historical, and performative studies of science, should be a next step in better understanding adaptation in scientific work itself.

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, scientific goals are revised. By becoming aware of the dynamic nature of knowledge production and scientific practice, we open a new space for intentionality and adaptation within science itself. This is a step away from the promises of modernity—technoscientific 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 as it unfolds and anticipates the future through individual practices.

In many instances in the Columbia River Basin, there is little time to wait for answers about what to do or how to monitor or measure the effects of restoration: inaction is unacceptable. Therefore, restorationists are forced make decisions based on whatever information, experience, or intuition appears useful at the moment. If ecological restoration is to be successful in a climate-change-altered future, not only will restorationists themselves have to continue to adapt but so will the knowledge infrastructures, institutions, and organizations that support them.

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