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Power, positioning, and participation: Community-based watershed monitoring as a catalyst for learning and literacy toward socioecological transformation

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Power, positioning, and participation: Community-based watershed monitoring as a catalyst for learning and literacy toward socioecological transformation

By

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DISSERTATION

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ABSTRACT

This dissertation investigates learning and literacy as drivers of socioecological transformation, focusing specifically on the context of community-based watershed monitoring. Community-based monitoring is a form of citizen science, in which professional scientists and broader publics jointly engage in research or monitoring. Community-based monitoring is distinguished from other types of citizen science in that it is typically place-based and oriented toward local decision-making. The focal monitoring projects that this dissertation examines are situated within the specific context of dam removal and river restoration initiatives in Southern California and Western Montana, each of which carries the goal of increasing habitat connectivity to support threatened and endangered trout species, as well as overall watershed health. Addressing environmental problems - like the presence of obsolete dams - requires the collaboration of multiple groups wherein they collectively learn with and from each other to co-produce shared knowledge. This requires attention to issues of power, status, and rank, given the ways in which dominant science is typically privileged in environmental decision-making despite the robust forms of local knowledge found distributed within communities.

Leveraging sociocultural perspectives on learning and ethnographic methods, this dissertation takes up questions at the intersections of learning, literacy, power, science, and socioecological transformation. Chapter 1, the Introduction, synthesizes perspectives on these ideas from diverse fields such as education, science and technology studies, and political ecology. Chapter 2 empirically examines if and how power asymmetries mediate social learning trajectories as participants engage in deliberative dialogue in the Southern California case. The specific context is a project inspired by the principles of youth participatory action research in which educational researchers, students, educators, and land managers worked to co-design a community-based watershed monitoring initiative. Findings suggest that power asymmetries may

constrain opportunities for learning in-the-moment by mediating joint activity, while simultaneously creating the conditions for expansive learning to later occur. Chapters 3 and 4 empirically examine the construct of community science literacy, examining how local residents engage in field-based data collection to assess the health of a local creek and share data with land managers and scientists to inform adaptive management in the Western Montana case. In conceptualizing science literacy as a collective phenomenon rather than an individual trait, Chapter 3 examines how the work of monitoring is distributed across individuals and social structures. Findings demonstrate how individuals contribute their respective knowledge and practices to monitoring through processes of coordination work, and how these processes are mediated by individuals' opportunity to shift roles, the presence of brokers, and power relations. Chapter 4 builds on the findings from Chapter 3, taking up coordination work as an analytic lens to examine the role of material artifacts and the natural world in shaping processes of community science literacy. Findings from this chapter indicate that community science literacy, material artifacts, and the natural world are inextricably linked, suggesting community science literacy ought to be understood as a sociomaterial practice. Results from these three interrelated yet distinct chapters are synthesized in Chapter 5, the Conclusion.

In its entirety, this dissertation looks beyond the level of the individual to argue that community-based and place-based learning environments provide rich opportunities to activate the knowledge and practices found distributed within communities toward socioecological transformation. Doing so, however, requires disrupting hierarchies that privilege dominant scientific knowledge over other ways of knowing in both environmental management and in education. Honoring the local knowledge found in communities can support more equitable forms of learning that catalyze moves toward more healthy and just socioecological futures.

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ACKNOWLEDGMENTS

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Outside of my committee, I am appreciative of the many scholarly communities in which I am lucky to be a member. The UC Davis Center for Community and Citizen Science has consistently supported my work and is comprised of many members who have provided a robust community dedicated to understanding what possibilities can emerge from broadening public participation in science. I am also appreciative of support from the Graduate Group in Education and School of Education, as well as friends and colleagues in disciplines ranging from education, ecology, and geography at UC Davis and other institutions with whom I have been lucky to build community.

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DEDICATION

It is an honor to be able to dedicate this dissertation to my grandparents: Issa and Alice Jadallah, and Nadeem and Violet Mogannam. My grandparents were born and raised in Ramallah in the arid hills of Palestine, which at the time was a small agricultural village. We come from a long lineage of *fallaheen* whose livelihoods were organized around stewarding ancient olive groves in the terraced, rocky landscape surrounding Ramallah. Following the *Nakba* in 1948, all four of my grandparents migrated from Ramallah to the San Francisco Bay Area, where they still live today. It is from my grandparents, and all Palestinians, that I came to know the enduring relationships between people and place, and the power that comes from steadfast commitments to land.

POSITIONALITY

Broadly, positionality refers to the ways in which researchers' perspectives and stances are rooted in their particular social locations in relation to the specific context of their study. This concept draws largely from feminist research traditions that reject notions of research as an objective, neutral, and value-free practice (Collins, 1997; Haraway, 1988; Harding, 1991; Rose, 1997). Notably, researchers do not just collect data - we *produce* data. Researchers who practice reflexivity - a key tenet of qualitative research - consider who they are in relation to those studied as this influences the data being produced and how it is interpreted (Small and Calarco, 2022). In an effort to make this explicit, here I describe my own positionality.

This dissertation emerges from my own standpoint as a Palestinian researcher with strong commitments to land. I come from a long lineage of *fallaheen,* or peasant farmers, whose livelihood is dependent on reciprocal relations with land. Land is a central tenet in the Palestinian struggle for liberation, and *sumud,* or steadfastness, has long been a defining feature of Palestinians' collective identity stemming from our rootedness in land. Like the lands of what is now known as the United States, Palestine is also impacted by settler colonialism (Barakat, 2017; Khalidi, 2020) and *sumud* takes on new meaning in the face its contemporary manifestations - from ongoing home demolitions, attacks on olive orchards, and restrictions on movement as part of a broader project of dispossession.

I grew up engaging in land-based practices alongside my grandparents, who migrated from Palestine to the San Francisco Bay Area in the 1950s. My grandmothers are both excellent cooks, and would commonly prepare meals made with grape leaves and dandelions foraged from the backyard or neighborhood, as well as vegetables, fruits, and herbs tended by my grandfathers in the garden. Palestine and California share similar climates, and plants connected us across time and space. It is from these histories that I formed a love for the natural world, as well as a critical eye to the entanglements between power, people, and place.

I let these interests guide me down a meandering path, ultimately winding up in the Sacramento Valley to pursue a doctoral degree at the University of California, Davis. After working as a pollinator ecologist for many years, I was particularly interested in examining how the knowledge found distributed within communities - not just dominant scientific knowledge - could be recognized as an asset in supporting socioecological transformation. Working with the Center for Community and Citizen Science and with support from the Resources Legacy Fund's Open Rivers Fund, I have collaborated with community partners to co-design and study community-based watershed monitoring projects focused on dam removal and river restoration. Over the course of pursuing my graduate degree, I have worked closely to build relationships with these partners and support capacity-building for citizen science projects and programs in Southern California, Western Montana, and Western Washington. While doing this, I simultaneously layered in a program of research to examine if and how these projects support forms of learning and literacy relevant to watershed restoration, and more broadly, socioecological transformation. In addition to building relationships with partners, I have worked to build relationships with the creeks and rivers in each place - coming to know them as more than just field sites, but as assemblage of relations in which I am now an active participant and toward which I feel a sense of care and responsibility.

My positionality, drawn from this broader background, informs the stance I take in this dissertation and my overarching research agenda.

CHAPTER 1. INTRODUCTION

INTRODUCTION AND BACKGROUND

In this dissertation, I draw on perspectives from fields such as the learning sciences and science education research, science and technology studies, and political ecology to examine how community-based watershed monitoring initiatives produce collective forms of learning and literacy as they are relevant to socioecological transformation. Community-based watershed monitoring is a form of social activity in which scientists and broader publics jointly participate in the design and implementation of monitoring initiatives to assess and respond to the health of creeks, rivers, and their broader socioecological systems. Drawing on data from two study sites, one in Southern California and one in Western Montana, I ask how learning and literacy unfold as social, collective processes in which multiple sources of expertise are brought to bear on goals shared by multiple actors: making healthier river systems and watersheds. I take a dialectical approach in working to answer these questions, moving between social critiques of science, power, and environmental decision-making, and fine-grained analysis of ethnographic data to examine processes of collective learning at each study site.

Learning and literacy for environmental problem-solving

Environmental problems – such as the presence of obsolete dams – are fundamentally socioecological problems. That is, they are both social and ecological in nature, and not easily amenable to quick, technocratic fixes. Working towards solutions for these problems – such as dam removal – requires that diverse sets of actors learn with and from each other, and with and from the natural world, in order to imagine and enact the conditions for more healthy and just socioecological futures.

Because environmental problems will not be solved by individuals acting in isolation from one another, conceptualizing learning and literacy as collective processes is necessary in supporting socioecological transformation (Ardoin et al., 2023; Gibson et al., 2022). The complex nature of environmental problems requires that multiple perspectives be brought to bear in devising solutions through processes of collective learning, whereby individuals work collaboratively to layer their respective insights and co-construct new forms of knowledge. As a result, proposed solutions to environmental problems can come to better reflect the values, interests, and understandings of multiple groups, rather than solely reflecting dominant forms of knowledge (Berkes, 2009).

Collective learning and literacy do not mean that all individuals in a group or community are expected to learn the same thing; rather, it means that diverse individuals bring their varied repertoires of knowledge, skills, and practices together through processes of interaction and engagement. It is through these processes that the broader group can change, develop, and learn. This relates to Leont'ev's (1981) famous example of the 'primeval collective hunt,' wherein individuals' actions come together to form collective activity, allowing broader groups to achieve more than any individual would be able to otherwise through the division of labor oriented toward a shared goal. This stands in contrast to how learning is often conceptualized, where it is assumed to take the form of unidirectional knowledge transfer from expert to non-expert. Rather, in processes of collective learning, all individuals in a particular learning environment can contribute to the co-construction of shared knowledge.

Importantly, collective learning and literacy are not inherently a neutral process, particularly given how different actors (e.g., scientists, land managers, local communities) have been positioned in relation to one another in environmental science and decision-making. Given longstanding hierarchies in environmental management, where certain forms of Western science have been afforded greater epistemic authority over others, fostering equitable forms of collective learning requires active attention to, and disruption of, power hierarchies that marginalize certain knowledge systems.

Science, power, and environmental problem-solving in context

Tackling environmental problems at their root requires confronting the entrenched histories of power that pervade environmental management and create epistemic hierarchies. Most environmental problems – such as the impacts of dams on river systems and watersheds – can be attributed in large part to systems, structures, and institutions built on colonial logics of domination and extraction, in which humans are seen as separate from and superior to the rest of nature (Bang and Marin, 2015; Merchant, 1980; Liboiron, 2021). These logics further undergird the top-down, centralized, and coercive approaches that have long dominated environmental management efforts, resulting in harm for both ecosystems and human communities (Holling and Meffe, 1996; Liboiron, 2021). For example, ‘fortress conservation’ policies assume that Indigenous and other local peoples are sources of ecological degradation, and advocate for the delineation of protected areas free from people as a nature conservation strategy (Robbins and Doolittle, 2007). This is despite significant evidence that healthy landscapes rely on the stewardship of Indigenous peoples, and vice versa (e.g., Garnet et al. 2018; Hoffman et al., 2021; Waller and Reo, 2018). More broadly, these approaches to environmental management are implicated with the denigration of local and traditional ways of knowing, and specifically Indigenous ways of knowing (Liboiron, 2021; Simpson, 2014).

Dominant science plays a central, yet contested, role in environmental management. I often draw on Liboiron (2021) in using the specific term dominant science to refer to the particular forms of Western science that have become dominant to the point that "other ways of knowing, doing, and being are deemed illegitimate or are erased" (p. 21). Even within the banner of Western science, certain scientific approaches are afforded more epistemic authority than others. Historically, dominant science has been used as a tool with which to order and control nature, where land is converted into a resource from which to make property and extract capital (Merchant, 1980; Whitt, 2009). For rivers specifically, science is bound up in the law, regulation, engineering, and management surrounding their futures (Wölfle Hazard, 2022). As Liboiron (2021) writes, "dominant science can be used to fuel a militant universalism where a single knowledge becomes the touchstone for all other knowledge systems…" (p. 54).

Notably, however, dominant science does not possess any inherently superior epistemological status in relation to other ways of knowing; rather, it is through active social manipulation that scientific artifacts like theories, data, and instruments are legitimized (Latour, 1987). While these forms of scientific knowledge are obtained through investigations into the natural world, they are simultaneously produced by, and taken up into, sociopolitical regimes that order this knowledge in which sanctioned discourses and institutions grant them a higher status than other ways of knowing (Bazzul and Carter, 2017). In other words, dominant science gains its purported objective status and authority only because it is legitimized by a complex field of rules that recognizes them as such in relation to other knowledge systems (Latour, 1987). As a result, these forms of scientific knowledge command more authority in environmental decision-making than the knowledge and practices found distributed within local communities (Agrawal and Gibson, 1999).

Despite these problematic histories, the sciences still have much to offer to environmental management oriented toward socioecological repair. Adaptive co-management, for instance, relies on an iterative process of multiple partners working collaboratively to make management decisions based on scientific data, evaluating the results, and adjusting management decisions in response (Armitage et al., 2007). While adaptive co-management does not inherently disrupt power asymmetries between stakeholders, and is difficult to implement in practice for a variety of reasons (e.g., mismatch between science being conducted and decision-making realities), it represents an approach to environmental management that works against the "command and control" orientation that seeks to order and subdue nature (Aceves-Bueno et al., 2015; Holling and Meffe, 1996). Scientific approaches that honor and reflect the values of multiple groups, disrupt histories of power, and are integrated with action represent a promising path forward for solving socioecological problems.

Community-based monitoring

In the past several decades, scholars and practitioners have begun to look beyond dominant science and recognize the expertise found distributed within and across communities as essential for conceptualizing environmental problems and their solutions. As a result, there has been an increased emphasis on participatory, collaborative, and community-based approaches to environmental science and management as strategies for environmental problem-solving in large part because they promote learning across diverse sets of actors (Armitage et al., 2012; Berkes, 2009; Charles et al., 2020; Pinkerton, 1989).

Community-based monitoring offers a relevant example of a participatory approach to environmental science that brings broader publics into the work of science, sometimes (but not always) to the degree to which they fundamentally guide the nature of the work. Community-based monitoring is a form of citizen science or community science, where scientists and broader publics jointly engage collaborative inquiry to answer questions for the purpose of generating novel insights or informing decision-making (Danielsen et al., 2005; Shirk et al., 2012). These approaches to science span a range of methodological approaches and are rooted in multiple disciplinary traditions, with configurations of roles, practices, and infrastructures varying widely from project to project (Bonney et al. 2009; Miller-Rushing et al., 2012; Shirk et al., 2012). They have been demonstrated to result in benefits for the scientific enterprise, for individual participants, and for socioecological systems, across scales ranging from individuals to communities (Jordan et al. 2012; Shirk et al., 2012). For this reason, public participation in scientific research has increasingly garnered attention and research in fields ranging from environmental management (e.g., McKinley et al., 2017; Charles et al., 2020) to education (National Academies, 2018) as scholars and practitioners work toward supporting healthy socioecological systems.

Community-based monitoring provides an apt context for collective learning, as these sorts of projects provide a forum for interaction and engagement between scientists, land managers, and broader publics. By blurring the boundaries between scientists and the public, they provide an opportunity to examine if and how learning occurs as a collective process, wherein different forms of expertise are recognized and leveraged as assets in the co-creation of new shared knowledge.

THEORETICAL, METHODOLOGICAL, AND CONTEXTUAL THREADS

Building from ongoing and emergent conversations in the above bodies of literature, this dissertation consists of three empirical studies drawn from two distinct datasets. While each of these three studies is unique in its scope and aims, all three share several attributes in common. First, each chapter examines community-based monitoring in the context of dam removal and river restoration projects at sites in the Western United States. Second, sociocultural perspectives on learning and literacy provide the theoretical underpinnings for understanding how learning and literacy emerge through interaction and engagement across diverse sets of actors. Third, qualitative and ethnographic methods serve as the tools for examining these processes empirically, methods that were employed in the context of a broader set of relationships that came to be through taking an engaged approach to scholarship. These threads - detailed further in the following section of this chapter - run through the entirety of this dissertation, and serve as unifying links that tie the overall dissertation together.

Contextual focus: Dam removal and river restoration

Dams have been built along rivers for a variety of purposes such as flood control, water storage, and irrigation; however, they also impede socioecological processes necessary for healthy watersheds. In the context of the Western United States, histories of dam building - and dominant water resource development more broadly - are impossible to separate from the settler colonial project of dispossessing Indigenous peoples from their homelands, and transforming lands and waters into a resource from which profit could be extracted (for example, in building large-scale irrigation infrastructure to support intensive forms of agriculture) (Middleton Manning et al., 2018). Rivers have been treated as a resource to be ordered and controlled via feats of human engineering, rather than complex, dynamic, and living systems.

Today, many dams are obsolete having outlived their functional lifespan (Pejchar and Warner, 2001). No longer serving any purpose, their ecological costs outweigh any potential benefits as they remain standing and blocking the flow of rivers. To this end, dam removal has emerged as a strategy in broader watershed restoration efforts to restore unregulated flow regimes in rivers and streams, which can in turn restore critical processes that affect groundwater storage, sediment deposition, and habitat for riparian species through a series of complex biophysical feedback loops (Bednarek, 2001; Bellmore et al., 2019). While ecological response trajectories after dam removal are difficult to generalize, a growing number of empirical studies suggest that rivers can recover substantially from being dammed (Bellmore et al., 2019).

Theoretical perspectives: Sociocultural perspectives on learning and literacy

Sociocultural theories of learning and literacy have emerged largely from the work of Vygotsky, a Marxist psychologist perhaps most well-known for his commitment to understanding learning as a social activity - in contrast to dominant understandings at the time in which learning was conceptualized from individual cognitivist or behaviorist perspectives. Much of Vygotsky's early work on semiotic mediation and mental functioning serves as a foundation for more contemporary sociocultural learning theories (Vygotsky, 1978). According to Vygotsky, all learning occurs within a sociocultural context, involving "culturally informed tools and figures as part of a range of highly social activity systems, however alone the learner may be at particular moments" (Vygotsky, 1978 in Salomon and Perkins, 1998, p. 16). He goes on to argue that it is the use of signs (e.g., language) and tools (e.g., material artifacts) as part of mediated activity that replaces the simple, biological stimulus-response process and creates new forms of a culturally-based psychological process in which knowledge is internalized.

In contrast to the views of learning that conceptualize it as the unilateral acquisition of fact-based knowledge, sociocultural theories of learning build on these early ideas of Vygotsky and draw from additional fields such as anthropology, psychology, and cognitive science to emphasize the interactions between the individual and the social world as fundamental to the learning process. Taking individuals as the unproblematic unit of analysis fails to account for the larger cultural practices that co-evolve with learning (Gutiérrez and Rogoff, 2003). In other words, sociocultural perspectives understand learning not purely as cerebral or "in the mind;" but as a socially-situated process distributed across actors and mediated by material artifacts and social, cultural, political, and historical contexts. They broadly argue for the importance of local activity settings and examine learning through focusing on individuals' participation in particular activities, and how they draw on artifacts, tools, and other people to solve problems (Nasir and McKinney de Royston, 2013).

Methodology and methods: Community-engaged, qualitative research

The studies in this dissertation draw primarily on qualitative methods. Qualitative research assumes that reality is socially constructed, as opposed to positivist orientations that assume an objective reality that is observable, stable, and measurable (Merriam and Tisdell, 2016). I leverage multiple methods in the process of collecting qualitative data, specifically conducting participant observation and semi-structured interviews with scientists, conservation professionals, educators, young people, and volunteers, in addition to collecting relevant artifacts. This involved multiple extended visits to Western Montana, multiple short visits to Southern California, as well as extended virtual collaboration. From these data, I leverage interactional and cross-comparative analyses to generate findings for each chapter.

The broader methodological approach to this work has its foundations in critical and engaged scholarship. Increasingly, "researchers are using the language of methodology to name the assumptions embedded in their study about knowledge, reality, and the role of research in society, and retaining the language of methods to talk about specific methods of data collection or analysis" (Wilson, 2008 in Tuck and McKenzie, 2015, p. 79). Engaged scholarship can take many forms, from youth participatory action research - which inspired the study informing the second chapter of this dissertation - to research-practice partnerships (Coburn and Penuel, 2016)

- which inspired the study informing the third and fourth chapters. Central to my approach to engaged scholarship is building and sustaining relationships with individuals, organizations, and places at each study site. Before engaging in any data collection, I spent upwards of a year engaging in conversations with a range of stakeholders in both the Ventura River and Rattlesnake Creek watersheds in order to better understand their interests, strengths, needs, and goals. These relationships - grounded in principles of respect and reciprocity - are fundamental to ethical research praxis that disrupt dominant histories of extractive research. Community partners and I worked together in co-designing new projects, as well as tweaking existing ones, in accordance with these considerations. Over the course of my research with each project, I moved fluidly between the roles of researcher, educator, facilitator, problem-solver, advisor, evaluator, collaborator, boundary spanner, and friend.

STUDY SITES

Ventura River and Matilija Dam

The Ventura River flows approximately sixteen miles from its headwaters to its mouth (Figure 1.1). Fed by tributaries such as Matilija Creek in the Santa Ynez Mountains, it winds its way through rugged chaparral, oak woodlands, and citrus groves before forming a large estuary and then emptying into the Pacific Ocean. Like many rivers in Southern California, flows are highly seasonal and tend to peak during the rainy season in winter and spring, dropping to their lowest point in the late summer at which point they often disappear underground. Numerous species make their home in this watershed, including the federally endangered Southern California steelhead trout. The Ventura River flows through the ancestral lands of the Chumash people who have stewarded the lands and waters of the region since time immemorial.

Blocking the flow of Matilija Creek, directly above where it flows into the Ventura River, is the Matilija Dam. The Matilija Dam was built in 1948 by what was then the Ventura County Flood Control District to regulate flows in the Ventura River and provide water storage for the increasing population of settlers in the Ojai Valley. The concrete dam stands 168 feet tall, after being notched from its original height of 198 feet. Today, the reservoir has a storage capacity of near zero due to sedimentation, sediment that is largely prevented from reaching the Ventura River estuary and replenishing beaches of the Pacific Coast. Additionally, the dam blocks the upstream migration of the river's steelhead trout population from reaching its historic spawning grounds. In part because of these various conditions, preparation for the dam's removal is underway as stakeholders pursue feasibility studies, design plans, permitting, and for prerequisite downstream infrastructural projects. At this stage of planning for dam removal, there is not yet a robust long-term monitoring effort in place, and efforts developed by local communities could be included in such a regime in future years.

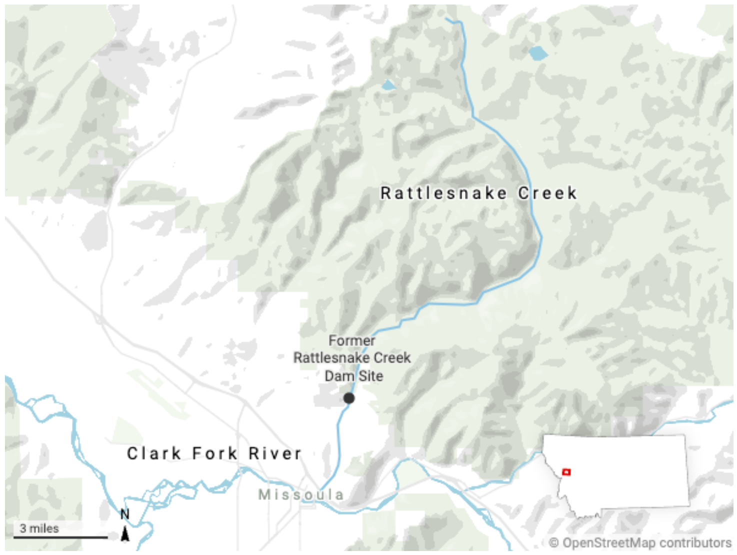
Figure 1.1 Map of Ventura River and Matilija Dam Study Site

Rattlesnake Creek and Rattlesnake Creek Dam

Rattlesnake Creek flows approximately twenty-six miles from its headwaters to its mouth (Figure 1.2). Originating in the Rattlesnake Mountains in Western Montana, the creek flows through conifer forest in a designated wilderness area, through a large urban park toward downtown Missoula, and ultimately into its confluence with the Clark Fork River. With its cold waters, Rattlesnake Creek provides important habitat for fish such as bull trout as well as other species like serviceberries, dippers, beavers, and bears. It typically flows year-round, with water levels peaking in early summer due to snowmelt and dropping to their lowest point in the fall. Rattlesnake Creek flows through the ancestral lands of the Salish and Kootenai peoples for whom it has been an important place since time immemorial.

The Rattlesnake Creek Dam was built in 1924 to provide water to the growing city of Missoula. Due to a Giardia outbreak in the 1980s, the city switched its water supply source to groundwater, rendering the dam obsolete. For nearly a century, Rattlesnake Creek Dam blocked the upstream migration of multiple fish species. After being acquired by the City of Missoula in 2017, it was removed in 2020 with leadership from Trout Unlimited as part of a larger restoration project on Rattlesnake Creek. With the dam's removal, over thirty miles of main stem and tributary habitat are now accessible to spawning fish. To assess the impacts of dam removal, Trout Unlimited developed a comprehensive monitoring effort involving multiple university, local, state, federal, and private partners, including Watershed Education Network, a nonprofit organization with an extended history designing and facilitating volunteer water quality monitoring programs. Watershed Education Network assumed the responsibility of working with volunteers to collect data on the biological, physical, and chemical indicators of creek health, with the data to be shared with Trout Unlimited and other land managers to inform adaptive management of the watershed.

Figure 1.2. Map of Rattlesnake Creek and Rattlesnake Creek Dam Study Site



EMPIRICAL WORK

Chapter 2: "Seeing power" between young people and conservation professionals in the design of a community-based watershed monitoring initiative

The first empirical study draws from work in the Ventura River watershed in Southern California. In this work, I partnered with students and educators from seven different local high schools to co-design a workshop series oriented toward developing community-based watershed monitoring projects related to the planned Matilija Dam removal. This work occurred during the height of the COVID-19 pandemic in 2020, and as a result, the workshop series were conducted virtually. Students and educators expressed interest in forging ahead with the collaborative project despite other constraints posed by the pandemic. While I directly supported youth through sustained engagement in developing a project rooted in their own interests - a departure from the typical citizen science initiative in which scientists determine parameters of study - I concurrently employed ethnographic observations and international analyses to examine how power figures into interactions between youth and conservation professionals. Conservation professionals came from several science and land management organizations working in the Ventura River watershed. Drawing on principles from cultural-historical activity to both design and examine the workshop series, I investigate how learning unfolds as a social process, where I map whose ideas are taken up and whose are not in relation to their social position.

Chapter 3: Towards socio-ecological transformation: Community science literacy through community-based watershed monitoring

The second empirical study draws from work in the Rattlesnake Creek watershed in Western Montana. While also taking place during the COVID-19 pandemic, this work primarily took place following the availability of vaccines, primarily outdoors, and during a time of decreased community transmission, and was thus possible to complete in-person. In this project, I partnered with Watershed Education Network - a nonprofit organization focused on citizen science - to document how community science literacy emerges in the context of two community-based watershed monitoring programs focused on monitoring Rattlesnake Creek's recovery following dam removal. Rather than conceiving of science literacy as an individual trait in which all citizen scientists are expected to achieve the same benchmark of science knowledge irrespective of their lived experiences, I conceive of science literacy as a community endeavor in which people from diverse walks of life contribute their respective expertise to environmental problem-solving through participation in shared practices. Through interviews with scientists, conservation professionals, project organizers, and volunteers, as well as ethnographic observations of monitoring activities, I empirically examine the different dimensions of community science literacy as well as identify factors that support its emergence.

Chapter 4: Community science literacy as a sociomaterial practice

The third and final empirical study draws from the same dataset as the second, produced through fieldwork with Watershed Education Network in Western Montana's Rattlesnake Creek watershed. In this study, I take up one of my findings from the earlier chapter - that community science literacy emerges through processes of coordination work - and apply this as an analytical lens. In closely examining robust episodes of coordination work between community-based watershed monitoring participants, I work to better understand the role that material artifacts and the natural world play in shaping processes of community science literacy. In doing so, I aim to empirically demonstrate the mutually constitutive relationships between the material world and human activity, challenging entrenched theoretical perspectives that treat place as a backdrop to - rather than a fundamental component of human activity.

ORGANIZATION OF THIS DISSERTATION

This dissertation consists of five chapters, including this introductory chapter. The bulk of the dissertation is composed of empirical chapters drawing on data from either the Ventura River or Rattlesnake Creek study sites using pseudonyms for individuals, organizations, and places. Each of these chapters - described in the above section - has its own theoretical and conceptual frameworks, description of methods, findings, and discussions. While interrelated, each is written with intent to stand alone separately from the rest of the dissertation. As a result, there is occasionally repetition throughout. The concluding chapter calls out key findings, and their implications for both theory and practice. Throughout the writing of this dissertation, to represent the collaborative research processes that made this work possible.

CHAPTER 2. "SEEING POWER" BETWEEN YOUNG PEOPLE AND CONSERVATION PROFESSIONALS IN THE DESIGN OF A COMMUNITY-BASED WATERSHED MONITORING INITIATIVE

INTRODUCTION

The complex socioecological challenges of the 21st century will require innovative solutions and collaborative efforts in which diverse sources of expertise are brought to bear on environmental problem-solving. Learning plays a fundamental role in these processes, and has long been established in research on environmental management as a key mechanism for achieving healthy and resilient socioecological systems - systems that have the ability to adapt and reorganize in the face of disturbance (Fernández-Giménez et al., 2019; Berkes, 2009; Jordan et al., 2016; Krasny and Roth, 2010). Particularly salient in the context of building socioecological resilience, and thus attracting the attention of scholars and practitioners in environmental management and conservation, is the idea of learning as a collective process in which diverse sets of actors interact and engage with each other co-construct shared knowledge with regards to a particular socioecological system (Ernst, 2019; Muro and Jeffrey, 2008; Reed et al., 2010; Suškevičs et al., 2019). By broadening the perspectives from which knowledge is generated, collective learning processes can foster conservation initiatives that are more attuned and reflexive to the ideas, values, and goals of diverse groups - an important principle for building resilience (Berkes, 2009; Eaton et al., 2021).

In contrast to top-down, expert-driven conservation initiatives, it is generally adaptive, collaborative, and participatory environments involving multi-stakeholder groups that support learning for socioecological resilience (Jordan et al., 2016; Reed et al., 2010). And yet, given that these environments by their very nature convene actors positioned with differing levels of status and authority, power relations play an important yet underexplored role in mediating learning processes (Ernst, 2019). Issues of power may be particularly pronounced in settings that cultivate interaction amongst groups of mixed professional status; in this case, young people and conservation professionals. Despite being critical members of their communities, young people are rarely afforded opportunities to meaningfully contribute to the design and planning of conservation initiatives in the places where they live. When they do participate, uneven power dynamics that privilege professionals' credentialed knowledge and social positions may constrain the contributions that young people can make.

To this end, the goal of this study is to investigate the relationships between power and learning as relevant to building socioecological resilience, and is guided by the following research question: How do power relations between young people and conservation professionals mediate collective learning trajectories in the context of this community-based watershed monitoring initiative? As such, we begin this study by reviewing relevant literature on learning through community-based monitoring, and considering how issues of power rooted in histories of conservation science may shape processes of learning, particularly with young people. After describing the case context, and the "backstage work" that was part of it, we then turn to our empirical analysis, where we leverage cultural-historical activity theory (Engeström, 1987) to focus on a workshop series involving young people, educators, and conservation professionals centered on a Southern California watershed. The workshop series sought to organize a community-based watershed monitoring effort in anticipation of planning for the removal of a large dam. Specifically, we examine a series of interactions among workshop participants, with the goal of revealing the ways that issues of power simultaneously constrains and creates opportunities for collective learning that can contribute to socioecological resilience.

Community-based monitoring as a context for learning

Environmental monitoring is a critical component of managing socioecological systems and conservation planning because it allows for adaptive decision-making in response to changing environmental conditions (Noss et al., 1997). Community-based monitoring - often falling under the umbrella terms of citizen science or community science - involves members of the public participating jointly in various monitoring activities alongside professional scientists, although the degree and quality of participation can vary dramatically (Danielsen et al., 2005; Shirk et al., 2012; National Academies, 2018). In contrast to conventional forms of environmental monitoring, community-based monitoring projects can result in a wide range of positive outcomes, ranging from science learning opportunities for individual participants to enhanced community capacity for stewardship (Jordan et al., 2012). In part because of these reasons, citizen science and community science projects broadly have caught the attention of scholars in the learning sciences studying how learning occurs across their diverse settings and participation structures (e.g. Harris et al., 2020 Hinojosa et al., 2021; Huang et al., 2018, Nguyen et al., 2021).

More recently, researchers have begun to demonstrate how community-based monitoring can lead to positive social and ecological outcomes through learning processes that extend beyond the individual acquisition of knowledge and skills (Conrad and Hilchey, 2011; Villaseñor et al., 2016). Jordan et al. (2016), for example, explicitly identify what they and others term *social learning* as a mechanism through which citizen science projects achieve these outcomes, in that it can help bring to bear multiple forms of expertise on environmental problem-solving in support of resilient socioecological systems (p. 489). Similarly, other scholars in environmental management and conservation have taken up research into the relationship between learning and resilience, where they focus largely on learning as a collective process (Berkes, 2009; Ernst, 2019; Gerlak et al., 2019). Through such learning, knowledge is collaboratively constructed through mutual engagement and interaction across diverse sets of actors (Muro and Jeffrey, 2008), akin to what Gutiérrez (2008) has described as *horizontal learning*, a process in which learning occurs within and across practices and communities, rather than *vertical learning*, a process of individuals moving from incompetence to competence.

Community-based monitoring as a power-laden site

While there is indeed potential for collective forms of learning to result from community-based monitoring - where scientists, conservation professionals, and communities learn with and from each other - interactions across these sets of actors are complicated by issues of power. Increasingly, learning scientists are taking up issues of power to understand how they shapes opportunities for, and processes of, learning (Esmonde and Booker, 2017; Politics of Learning Writing Collective, 2017; Philip and Gupta, 2020). Power relations have implications for who learns, what is learned, and how learning occurs (Esmonde and Booker, 2017). Here, we focus on power and epistemic hierarchies in the context of conservation broadly, and community-based monitoring specifically, to understand how it may shape trajectories of learning.

Understanding power in the context of conservation - and in community-based monitoring as a microcosm of such - necessitates taking a historical view. It is impossible to separate the United States conservation movement from processes of settler colonialism, in which Indigenous peoples are displaced from their lands, land is converted into property for settlers, and lands and waters become resources for extraction (Eichler and Baumeister, 2021; Hernandez, 2022; Simpson, 2004). Conservation science has been central to this process, where expert knowledge has been privileged over other ways of knowing as “the only legitimate source of knowledge upon which to base policy and institutional decision-making” (Hernandez, 2022; Kimura and Kinchy, 2016, p. 248). The authority of conservation science, however, is underwritten not only as a function of scientists’ specialized expertise, but also by the institutional arrangements that maintain this status, examples being symbols, rituals, and physical configurations (Burbules, 1986; Latour, 1987). Relatedly, a “command and control” orientation to conservation - organized around the domination of nature and in which local communities are excluded from decision-making involving the places in which they live - continues to shape the conservation field despite increasing recognition of the value of collaborative and community-based approaches (Berkes, 2021; Holling and Meffe, 1996).

Scholars of environmental management have begun to take up questions of power and learning given the fundamental role learning plays in collaborative environmental problem-solving processes. Ernst (2019), for instance, notes that the dominance of a few participants in participatory environments might limit equal participation in processes that aim to foster learning, while Suškevičs et al. (2019) explicitly find that power relations often hinder learning. Actors in positions of power can promote or restrict the availability of information because they may have access to ideas and information that others lack, which impacts collective learning trajectories in broader groups (Heikkila and Gerlak, 2013).

Community science and citizen science projects more specifically have been noted for their potential to level distinctions between experts and lay people (Kimura and Kinchy, 2016). Ballard et al. (2008), for example, note that the primacy of conventional science in community-based monitoring of forests risks “relegating” local ecological knowledge as a “potentially unnecessary add-on or extension to the more important conventional science” (p. 3). Even so, they found that many community-based monitoring still did support "power sharing" between scientists and local community members, despite the persistence of institutional constraints (e.g. working on federal lands meant that federal forest managers retained decision-making authority). However, this is not always the case, as more broadly across many citizen science projects, participants' role is often constrained to delivering data points rather than having the opportunity to fundamentally shape the nature of the scientific work (Cooper et al., 2021; Shirk et al., 2012).

In this study, we focus on how power relations and epistemic hierarchies between actors within community-based monitoring mediate trajectories of collective learning by examining who gets to shape the nature of the work. Drawing from the work of Bourdieu (1973), Foucault (1980), and Holland et al. (2001) we conceptualize power not just as a "possession" held by an individual or group; but rather, something that is diffuse, constructed relationally, and made visible through interactions in a given sociocultural context. Esmonde and Langer-Osuna (2013) build on the work of Holland and Leander (2004) to further elaborate on this understanding of power as a relational construct, articulating how power can be seen methodologically in interaction. They argue that power can be observed "in the ways in which people are positioned in relation to one another, in the ways in which they are given or denied access to particular physical and social spaces or kinds of actions, and in the ways in which issues of status and hierarchy are constructed and challenged" (Esmonde and Langer-Osuna, 2013, p. 290). These interactional perspectives help reveal how macro-level systems - systems informed by the power-laden history of conservation where experts are afforded authority over local communities - manifest at the micro-level in which learning occurs, and resultantly shape the structures and activities of community-based monitoring (Philip and Gupta, 2020).

Learning with young people in community-based monitoring

Intergenerational projects involving young people and adults working in concert can provide a rich context for collective learning (Vossoughi et al., 2021). However, they may also be a site where power dynamics are particularly salient. While conservation professionals and policymakers may indeed learn from young people's knowledge in conservation-related of projects (Hartley et al., 2021), adults are typically positioned hierarchically with more power and epistemic authority given the pervasive assumption that young people are less knowledgeable and experienced (Campbell et al., 2021). Despite often being positioned in a deficit perspective as lacking environmental knowledge - and thus ripe targets for educational interventions geared at motivating pro-environmental behavior change - young people can alternatively be seen as possessing unique funds of knowledge about the environment, rooted in their lived experience and community histories (Cruz et al., 2018). Funds of knowledge can be defined as the historically-accumulated knowledge and skills necessary for individual or household functioning and well-being (Moll et al., 1992). Leveraging these funds of knowledge for conservation, in which the goals, interests, values, knowledge, and skills of young people can be seen as assets in shaping environmental problem-solving efforts, can aid in bringing more diverse perspectives to bear on complex environmental challenges.

In an example of a funds-of-knowledge-informed approach, Calabrese Barton and Tan (2010), for instance, position middle-school youth as "community science experts" in researching urban heat island effects. In fact, when students have opportunities to leverage collective expertise distributed amongst themselves while engaging in scientific inquiry, in combination with other science knowledge and practices, greater opportunities arise for them to develop critical agency geared at social change (Schenkel and Calabrese Barton, 2020).

However, Schenkel and Calabrese Barton (2020) note that power hierarchies can impact students' opportunities to develop and be recognized for their expertise when they are working in groups toward a common aim.

These findings tie back to the idea of learning for socioecological resilience: if learning is in part a collective process in which different individuals contribute their perspectives to collaboratively construct knowledge, it cannot equitably emerge if power asymmetries preclude some perspectives from being taken up, or support some ideas at the expense of others. This may be especially true if groups consist of young people and adults, as such projects may risk reproducing divisions of power rather than expanding opportunities for youth to shape scientific endeavors (Stroupe and Carlone, 2021). In the following sections of this paper, we build upon and extend this literature to ask how power hierarchies amongst young people, teachers, and conservation professionals might mediate learning processes in the design of a community-based monitoring initiative.

THEORETICAL LENS: CULTURAL-HISTORICAL ACTIVITY THEORY

In order to understand how power asymmetries mediate learning processes in groups rather than individuals, we first needed to draw from theoretical perspectives that could help us simultaneously account for learning as a collective endeavor as well as power as a relational and diffuse construct (Jadallah and Ballard, 2021). To this end, we draw on sociocultural theories of learning to undertake our study design and analysis. In contrast to views of learning that conceptualize it as the unilateral acquisition of fact-based knowledge, sociocultural perspectives emphasize the interaction between the individual and the social world as fundamental to the learning process (Gutierréz and Rogoff, 2003; Nasir et al., 2021). In other words, these views understand learning not solely as cerebral, but as a socially-situated process mediated by tools, signs, and social, cultural, and historical contexts. Taking individuals as the sole unit of analysis fails to account for the larger cultural practices that co-evolve with learning; whereas focusing on relational processes allows us to understand context as a crucial component of learning processes (Gutierréz and Rogoff, 2003; Hecht and Crowley, 2020). In this view, learning can be understood as both participation in and as a dimension of a social practice in which a particular set of characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others (Lave and Wenger, 1991; Holland et al., 2001).

We specifically draw on insights from cultural-historical activity theory, or CHAT, which originates in the work of L. S. Vygotsky (1978) whose early studies on semiotic mediation and mental functioning are foundational to contemporary research on learning. Building on the work of Vygotsky, CHAT posits that knowledge is mediated through tools and artifacts, and uniquely focuses on object-oriented *activity,* activities being the ways in which people are actively engaged with the environment as embedded in social context (Engeström, 1987; Rogoff et al., 1995; Wertsch et al., 1995). Rather than focus on how individuals change, develop, and learn, CHAT takes learning to be a community-level process in which the design of new activities, and the knowledge and skills such design requires, merge together (Engeström and Sannino, 2010). As such, this orientation switches the focus from individual learners to the interactions of learners with their environment as part of a broader system directed at achieving specific goals (Bang 2015; Krasny and Roth 2010). An activity is object-oriented in that it has a particular goal, and involves complex and multi-faceted interactions amongst subject, object, motivation, action, goals, socio-historical context, and the consequences of the activity (defined below in Table 2.1) (Yamagata-Lynch, 2010). While a consideration of power is not explicitly built into the CHAT framework, it nonetheless offers space for it to be considered (Roth and Lee, 2007). For example, power may be seen in rules that constrain an activity, hierarchical divisions of labor, or the histories of artifacts (Esmonde, 2017).

Power asymmetries may result in tensions between different subjects in an activity system in respect to its other components. For example, the socio-historical context of an activity may position subjects differently with respect to said activity, as is the case in environmental management, with conservation professionals being positioned as having more authority than young people in determining appropriate management actions. These asymmetries may become visible as the different subjects negotiate the goals of the activity, surfacing potential tensions. This relates to Bakhtin's (1982) notion of multi-voicedness, where discourses interact - some with more authority than others - to generate meaning. Learning in this perspective is "an inherently multi-voiced process of debate, negotiation and orchestration" (Engeström and Sannino, 2010). Notably, CHAT acknowledges the potentially fruitful nature of these tensions: contradictions amongst the elements of an activity system can trigger expansive transformations, constituting learning at the collective level as the group envisions and enacts new possibilities for the activity (Engeström, 2001). These contradictions become the precipitates around which new practices must be established, which are negotiated and established outward from the site of interaction (Lee and Dubovi, (2020).

Taking CHAT as our theoretical basis, we regard the process of designing a community-based monitoring program as a type of consequential activity, in which the shifting nature of the activity is what constitutes learning. Given that both design and community-based monitoring involve learning about something which is not stable, nor understood ahead of time (a socioecological system, and in this case specifically, a watershed), CHAT helps to examine learning as an expansive and transformative process.

Table 2.1. Activity system components (Adapted from Yamagata-Lynch, 2010).

Activity System Component	**Definition**
Subject	Individuals or groups involved in the activity
Tool	Social artifacts that act as resources for the subjects in the activity
Rules	Formal or informal regulations that in varying degree can affect how the activity takes place
Community	Social group that the subject belongs to while engaged in an activity
Division of labor	How tasks are shared among the community
Object	Goal or motive of the activity, supporting a longer-term objective

Principles of CHAT inform our analysis, and additionally, align with our design of the planning workshops that we use as a research context (both of which are described below), as is common in interventionist, engaged methodologies (Gutiérrez et al., 2016). CHAT has been described as a praxis-oriented theory in that it can be used to cultivate a shared problem space (Akkerman and Bakker, 2011) "in which people can work together to envision and develop new forms of activity" (Severance et al., 2016, p. 534). Cole and Engeström (2005) highlight how CHAT can support researchers in partnering with community organizations to facilitate collaboration or problem-solving. In these collaborative efforts there is no ready-made solution that the researcher has devised; rather, the "contents and course of the intervention are subject to negotiation and the shape of the intervention is eventually up to the participants" (Engeström, 2011, p. 606). While we did not explicitly use CHAT in designing the workshop series presented in this study, we note similarities in our approach with how Engeström (2005, 2011) describes the affordances of CHAT in bridging research and practice.

METHODS

Describing the "backstage work"

The present study focuses on the initial phases of a community-based watershed monitoring project focused on dam removal beginning with a series of five, hour-long, virtual workshops that involved high school students, teachers, and conservation professionals. Because social interactions are the "crucible" through which individuals learn and co-construct knowledge (Angelillo et al., 2007), and because the participants represented disparate social positions with respect to environmental management and conservation, the workshops provide a unique and appropriate setting for investigating how power asymmetries mediate and structure learning processes relevant to building socioecological resilience.

The workshops were preceded by a series of scoping conversations in early 2020 between Chris and Ryan from the university research team and students and teachers from the Eco Campus Network (ECN), an extracurricular coalition of seven different high schools in the watershed. As part of a broader watershed restoration initiative, the researchers and the ECN agreed to participate in a project organized around determining monitoring priorities and developing a community-based monitoring framework for tracking and understanding environmental change in the watershed. Before describing the workshops themselves, where we focus our analysis, we first describe this "backstage work" - or what went on "behind-the-scenes" to form this partnership and workshop series - as this has a bearing on the workshop design and our analyses of specific interactions within the workshops to examine the relationship between power and learning (Goffman, 1959; Taylor and Hall, 2013).

The broader context of this project is an ongoing river and ecosystem restoration effort being planned by multiple local, state, and federal stakeholders in the Trout River Watershed on Chumash lands in Southern California, the linchpin of which is the planned removal of the Chaparral Dam. Built in the 1940s to provide water storage and flood control, the 160-foot concrete dam sits in a steep canyon where it blocks the flow of the Trout River's main tributary. Due to siltation, the current reservoir capacity behind the dam stands at zero acre feet of water - rendering the dam obsolete. As such, the dam poses a threat to public safety, blocks access to historic spawning and rearing habitat for anadromous trout (such as the endangered Southern California Steelhead), and impedes natural sediment transport regimes that improve sand replenishment at beaches along the Pacific Coast, amidst a myriad of other impacts. While many dam removals can be controversial, there is generally widespread support for removing the Chaparral Dam, which is expected to take at least another ten years due to a variety of factors such as funding needs.

In general, water projects in California, like dams, "share a common myopic attention to limited political economic values that perpetuate entrenched business interests and ongoing environmental and cultural injustice," resulting in ongoing Indigenous displacement and ecological catastrophe (Middleton Manning et al., 2018, p. 174). Dams have long been viewed as a hallmark of progress representing the "conquest of nature" (McCool, 2007); however, with the benefits of most dams being largely exaggerated and the costs frequently underestimated, dam removal is growing in prominence as a restoration strategy intended to bring about socioecological repair (Pejchar and Warner, 2001; Foley et al., 2017). Broader goals for dam removal typically include restoring connectivity and natural flow regimes to improving river health for fish and for people, as well as many other forms of riparian life.

Building capacity to remove the Chapparal Dam requires multiple layers of design, permitting, funding, construction, and monitoring, all of which may include varying forms of public involvement. Various stakeholders in the Trout River restoration effort expressed interest in developing citizen science programs, given their potential to foster public engagement and support for dam removal (Kelly et al. 2019; McKinley et al., 2017). At this stage in the dam removal effort, there is not a formal or robust long-term monitoring effort in place. To this end, a private funder issued a grant supporting the UC Davis Center for Community and Citizen Science in identifying local groups with interests in citizen science and community-based watershed monitoring, and then in supporting these groups in designing and implementing their own projects. In doing so, we were particularly interested in circumventing traditional models of citizen science that are scientist-driven - where members of the public are involved primarily in data collection - to instead support projects that were community-driven given the expansive outcomes they can support (Shirk et al., 2012). In late 2019 and early 2020, we approached a variety of community organizations - rather than first approaching scientists or science organizations - with interests in the Trout River watershed to gauge their interests, needs, and assets with regards to planning and carrying out a citizen science initiative.

Of the several groups with whom we connected, one was the Eco Campus Network (ECN), an extracurricular coalition of seven different high schools in the watershed whose membership consisted of students with interests in sustainability and stewardship. The Network consists of both public and private schools, with a primarily white student membership reflecting the broader demographics of the semi-rural city just a few miles away from the Chaparral Dam.

Ryan, having both attended and previously taught at one of these schools, contacted one of the teachers, Jaime, involved in the ECN with whom he had a prior relationship to discuss potential interest the ECN might have in developing a youth-led citizen science project. Ryan had an understanding, which was confirmed by Jaime, that the ECN was largely student-driven, wherein student representatives from each of the schools organized events and initiatives related to the environment, such as beach clean-ups, climate rallies, and clothing drives. Faculty representatives from each school played primarily a background role to provide administrative or logistical support for the ECN, which had its own student-created governance structure. After an additional conversation with Jaime and faculty representatives from other schools, Chris and Ryan attended a regular student meeting of the ECN in May 2020 to speak directly with students. During this meeting, we introduced ourselves, shared background on the dam removal, and in small groups, discussed students' relationships with the Trout River and what activities they enjoyed in the watershed, if any. Students then met separately after this initial meeting to decide whether or not they were interested in working with us to develop a citizen science project, at which point they contacted us to establish a partnership. In another meeting, we proposed this would begin with a workshop series in the next academic year, given uncertainties around the future of the COVID-19 pandemic.

In August 2020, we joined another ECN meeting to discuss plans for collaboration. At this point, it was clear that COVID-19 was here to stay. We were unsure if students would be interested in continuing with the project given that it would need to be moved to a virtual format rather than the trips to the river we had originally jointly envisioned. However, students indicated that they wanted to forge ahead with plans for a virtual workshop series, with the hope that there would be opportunities for in-person fieldwork in the near future.

The specific goal of the workshop series was determined through discussion between Chris and Ryan and the students. The aim would be to support ECN members in arriving at a focal topic for monitoring, where the topic emerged from their interests, while still contributing to the data needs of other stakeholders (e.g. land managers) in the watershed. We shaped this decision based on our own conceptualization of citizen science as being connected to broader social networks, and generative of data and other knowledge that can be actually used in the world. We hoped that the data students eventually collected would be consequential to stakeholders beyond them, not duplicate existing monitoring, and thus inform decision-making as part of the broader restoration initiative. However, we also knew that such criteria would need to be flexible as the process moved ahead. Thus, the design effort was initially organized so that the processes and outputs would be responsive to diverse stakeholders' watershed restoration goals while simultaneously being rooted in the interests and perspectives of young people.

Describing the workshop series

Workshops took place in late 2020 and were held virtually using Zoom as a collaborative digital platform. Workshops consisted of a primarily interactive activities, with each building on lessons and activities from the previous one, and were designed with input from ECN students and teachers as well as researchers at the University (Table 2.2). Participants who attended the final workshop series included two researchers (Chris and Ryan, both of whom served as conveners and facilitators), students and teachers from the ECN, and conservation professionals from three distinct regional non-profit and land management organizations. After confirming with students and teachers, Chris and Ryan invited conservation professionals who they had met via their previous scoping conversations, and who had expressed initial interest in citizen science. Attendance ranged from roughly 20 to 25 individuals (primarily students) at each workshop.

Chris and Ryan worked to position the students as leaders and designers of the space in accordance with the goal of dismantling hierarchical divides between students, researchers, and conservation professionals (Martin et al. 2017). We did this through several avenues. First, when inviting conservation professionals to speak, we shared that the goal of the workshops was to support students in identifying a topic for a citizen science project that would be simultaneously rooted in their interest, while also responsive to broader monitoring needs. We asked them to listen and share in response to student ideas versus lead with their own. Before the workshop series began, and between each workshop, we invited students to review and comment on our workshop plans, and to co-facilitate the space with us. At the beginning of each workshop, particularly those where we asked the group to make decisions, we reminded students that our role was solely to facilitate conversations and identify opportunities for decisions to be made that would advance the project, but that ultimately, specific decision-making directions would be in their control.

Table 2.2 Overview of workshop series with Eco Campus Network

Workshop Title	***Content Description***	***Date***
The Chaparral Dam: Past, Present, and Future	Overview of Chaparral Dam's history, its impacts on the watershed, and the status of current removal efforts.	October 13, 2020
Community and Citizen Science for Watershed Health	Introduction to various approaches for community-based monitoring in watersheds, including different project structures and example topics.	October 30, 2020
What's Our Stake in the Trout River Watershed?	Activities to identify our group's interests, values, and concerns as they relate to the watershed and the dam removal.	November 15, 2020

What Can We Do? Examining Project Approaches	Synthesis of different project structures and focal topics as they relate to the group's interests and the Chaparral Dam.	December 1, 2020
Project Determination and Taking Next Steps	Reflection and decision-making activities for students to identify next steps for enacting community-based monitoring.	December 15, 2020

The primary analytic focus of this study is on interactions that occurred in the third and fifth workshops, which we describe further in detailing our approach to data analysis below. Here we briefly describe the first two workshops, to provide important context for the learning environment. To do this, we draw on evidence from reflective memos written after each workshop by Chris and from workshop agendas and presentation slides. Our aim is to explicate "the power and limitations of our designs and pedagogy," to allow for more analytical precision and rigor in making claims about the events that occurred (Vossoughi and Shea, 2019).

In workshops one and two, Chris began by using presentation slides to walk the group through introductions, goals of the workshop series, and norms for participating. In addition to Chris, Ryan, and ECN members, different conservation professionals attended the first and second workshop. Peter, an engineer and well-known dam removal advocate in the region, attended the first which was focused broadly on the background to the Chaparral Dam removal. Marissa, a watershed scientist at a local nonprofit organization committed to environmental advocacy, attended the second which was focused broadly on citizen and community science as an approach to watershed monitoring. After introductory material, participants were asked to engage in reflective activities using the Zoom chat and Mural board, a digital whiteboard tool. Example prompts for all participants, not just young people, included:

- What activities and experiences do you enjoy in the Trout River watershed?
- What social and/or environmental issues do you care about in our community?
- Why do citizen and community science in our watershed?

Participants then either shared more about their discussion using the Zoom breakout room feature, or in whole group discussion. Peter and Marissa were asked to participate in the discussion and respond to the ideas they were hearing from ECN members before sharing more about their work and what they saw as potential priorities for community-based monitoring.

These first two workshops, as well as the later three, were organized to be specifically different from how standard conservation outreach activities are often designed, where a guest expert is invited to give a lecture sharing their content knowledge, and students might respond with questions for the expert to answer. This was a guiding design principle, aligned with CHAT, in which we sought to avoid privileging the expertise of conservation professionals over that of the students. The workshops ended with whole group discussion, in which we asked the conservation professionals to respond to student ideas and closing thoughts. Activities within the workshop were necessarily constrained by time, with teachers and students having collaboratively agreed on keeping sessions to a maximum of one hour in duration.

In addition to serving as a learning environment, the workshops also serve as a data source for this study. While similarities exist between this project and design-based research, we note that this work was not originally conceptualized as a design study - whereby researchers craft interventions with the goal of using them as settings to study learning (Sandoval and Bell, 2004). Rather, our initial and primary goal was to support young people in gaining new authority and exercising discretion as they moved toward defining the project’s goals and taking action for environmental stewardship. In seeing an opportunity for research, we layered our inquiry on top of the workshops; rather than designing the workshops with the explicit goal of testing or building theory.

Data collection

We focus our empirical work on the workshop series described above. Multiple data sources were collected in relation to each workshop. Approximately six hours of video and audio data from workshops were captured using built-in recording features of the virtual Zoom platform, for which all participants provided informed consent. Audio data were then transcribed verbatim, inclusive of fillers like "um" or "like." While we used punctuation to distinguish significant speech features like long pauses or laughs, we focused primarily on the accuracy of content and sequence of turns rather than intonation or other discourse properties (Barron, 2003). While transcribing the recordings, we simultaneously noted observations of on-screen activity captured by the video recording that corresponded with the audio data. Examples of on-screen activity included gesture and facial expressions, the appearance of other pets and family members within participants' windows, and the use of tools such as icons for raised hands and applause, polls, and screensharing.

Transcribed audio data, text shared via the Zoom chat feature, and observations of on-screen activity were integrated into a single table on a datasheet. This was organized temporally, in which a new row was created for each conversational turn in the audio data. If a speaker was interrupted, we considered the turn complete. Additional columns were created in which we input corresponding text from the Zoom chat, as well as observations of on-screen activity, that aligned with each conversational turn. These transcription and data organizing conventions allowed us to consider these data sources in tandem so as to uncover their "embedded meaning" given the ways in which interactional phenomena rely on both verbal and nonverbal components (Barron, 2003; Derry et al., 2010; Green, 1983). Additional data comes from artifacts created in relation to the virtual workshops. These include reflective memos, presentation slides, workshop agendas, and virtual whiteboards collaboratively developed using Mural.

Data analysis

The process of data collection and analysis was recursive and dynamic as is standard in qualitative research (Merriam and Tisdell, 2016). Early analysis took place during the writing of reflective memos immediately after each workshop, where we noted thoughts, feelings, and reflections as they related to specific moments and events during the workshop series and the broader purpose of the research. Debriefing conversations after each workshop with Ryan, a co-designer and co-facilitator of the workshop series, as well as Jaime, one of the main organizing teachers, served as another space for reflection and form of early analysis. In this space, our shared insights into the events of what took place both informed key moments for later analysis and guided the design of the following workshops, so as to best support youth leadership in determining the project direction (Martin et al., 2017).

More formal analysis, informed by the principles of interaction analysis (Jordan and Henderson, 1995) took place using Dedoose, a computer-assisted qualitative data analysis software program, in which coding of the data corpus took place in multiple rounds. A first pass involved identifying moments of *interaction* between students, teachers, researchers, and conservation professionals. These interactional events, involving actors from different social groups, serve as the unit of analysis given our conceptualizations of interactions as an important site where learning occurs (Nasir et al., 2021; Webb, 1982), power as a relational construct (Burbules, 1986; Foucault, 1980), and learning as a sociocultural process in which knowledge is collaboratively constructed (Akkerman and Bakker, 2011).

For the present analysis, we considered interactions to include both verbal and nonverbal components, consist of two or more conversational turns about a single topic and involving at least two participants. Shifts in conversational topic marked a new interaction and helped bound the unit of analysis, which were identified as when a speaker introduced a new idea or line of conversation in opening a conversational turn. Interactions occurred either in spoken discourse, in the Zoom chat, or distributed across both modes of communication (i.e. if someone initiated an interaction via the chat feature which somebody else then responded to aloud). Rather than attempt to maximize objectivity, as is common in more positivist orientations to research (Merriam and Tisdell, 2016), we intentionally did not exclude interactions in which researchers were involved, given our status as facilitators interacting with the participants (Cole and Engeström, 2005).

In a second pass of coding, we decided to then further identify interactions that specifically involved young people and conservation professionals that could be categorized as *proposal negotiations*, or sets of collaborative exchanges in which participants decided what to do or think (Engle et al., 2014). While other types of interactions in the workshops occurred, we focus here on proposal negotiations because they provide a site in which the social construction of power can be more readily observed when simultaneously accounting for the interactants' status and authority (Langer-Osuna, 2016). According to Engle et al. (2014), proposal negotiation units consist of two phases: a proposal bid in which somebody offers an idea, question, or thought, followed by the proposal then being taken up, altered, ignored, or rejected by other participants. These potential responses to proposal bids reflect those offered by Barron (2003), who offers the additional response option of them being further discussed. We then coded conversational moves using these distinct components of proposal negotiation units.

Given that observations occurred in a virtual environment, proposal negotiations and other relevant data were often distributed across multiple data sources within the bounded time of one workshop (for example, in spoken discourse, text from the Zoom chat window, and in student-created artifacts) as well as across multiple workshops (for example, if an idea was resurfaced in a later workshop). To make sense of the connective threads between them, we then chose to integrate these coded data sources into broader *analytic narratives* (Angelillo et al., 2007; Engle et al., 2014), or a set of episodes made up of proposal negotiations units and organized around temporal turning points focused on the same topic. In the next phase of analysis, we categorized data around the proposal negotiation units using the CHAT framework in order to attend to the broader context of the interactions that were occurring. That is, we further coded the analytic narratives to better understand the subjects, community, object, tools, division of labor, and rules.

Ultimately, with respect to the watershed monitoring content and goals of the workshops, members of the ECN and some local stakeholders held a shared concern about invasive plants in the watershed, specifically that of Tamarisk (*Tamarix* spp.), and decided on this as a focus for a community-based monitoring project after the culmination of the workshop series. Because this became their mutually agreed-upon focal topic, we focus our analysis in this paper on tracing this particular idea's emergence and evolution, analyzing the many moments and episodes of proposal negotiation throughout the process in which it was discussed. The decision to focus on this particular analytic narrative about Tamarisk was made out of concern not for broader representativeness of interactions (Miles et al., 2013), but primarily in an attempt to answer the conceptual questions about how power asymmetries mediated learning processes between these different actors.

In our findings, we report the analytic narrative in two phases: Phase 1, which provides context for the idea's emergence, and Phase 2, which highlights the focal interactions occurring primarily in the third and fifth workshop between the two UC Davis researchers, a local land manager, several students, and one teacher focused on proposal negotiations around monitoring Tamarisk. The third and fifth workshops are where discussions around Tamarisk largely occurred, hence why we focus our analytical attention here. After sharing the analytic narrative, we make visible our analysis of these interactions drawing on Engle et al.'s's framework (2014) as well perspectives from CHAT to illustrate how we can "see" power relations play out in interactions by attending to the sociocultural context of the learning environment as well as the negotiated positionality of different actors.

FINDINGS

Phase 1: Determining a project topic

Stemming from the activities described in the Case Context, where the group engaged in discussions around the Chaparral Dam removal and different structures for community and citizen science in the early workshops, the main focus of the third workshop, where the present analytic narrative begins (as this is where Tamarisk was first raised as a point of discussion), was for members of the ECN to identify their individual environmental priorities related to dam removal and arrive at a collective priority for the group to investigate through a community-based monitoring effort. Various environmental topics that different individuals identified as of interest in the first and second workshop were presented at the beginning of the third workshop in an 'Idea Bank' in the Mural platform. After reviewing the Idea Bank, each workshop participant then had a chance to share their individual environmental priority for individual monitoring, and the reasoning for their priority, aloud. For instance, one student, Cody, chose recreation and human use as an environmental priority because the river is up the street from his house, and he likes to "go and play there with his family." Another student, Katherine, noted a special interest in sediment given her experiences surfing in the Pacific Ocean near the Trout River estuary, and seeing firsthand how the Dam has resulted in beach erosion by impeding sediment flow through the watershed. Other examples included wildlife habitat, water quality, and pollution. During this discussion, Ryan took notes in the virtual Mural whiteboard space attempting to capture all participants' top environmental priorities, further organizing them by theme from the Idea Bank.

In addition to members of the ECN, this workshop was attended by Tyler, a self-described "conservation bureaucrat" who is a well-connected and knowledgeable conservation professional with decades of professional experience in the environmental field. He directs a local conservation organization that owns and manages much of the land around the Trout River below the Dam and that was described by one student, Adriana, as "having a big say in the local community." Tyler was the last participant to share his environmental priority, initially foregrounding the issue of sediment management as being most central to the dam removal:

> Uh yeah. It's interesting listening to this discussion, maybe this is a segue to a broader discussion… The sediment is such a central theme and it's such a concern for the County and for the partners like the Water District, that you know, it's gonna get monitored and engineered to the nines. I mean it is really such a central focus on the protection of life and property in the river bottom neighborhood… I think the sediment is, again, just too central. Whereas my impression is that interplay between water quality, public use, and habitat, that's where as [our organization], who you know very likely will be the land stewards of all the land where the dam currently is, um some point in the future, you know, what can we plan for, what are we monitoring today, and deepening our understanding of how we're gonna manage that in the future?

While sharing that sediment is an environmental priority for watershed managers and other partners in the dam removal, Tyler goes on to note that it will be the focus of significant professional monitoring and he sees an unfulfilled need in monitoring other topics like public use of the watershed, a monitoring priority also identified by Marissa, the watershed scientist in the second workshop. Later, Tyler further elaborates on the notion of monitoring public use and recreation in the watershed, noting "[he] would love to see some public surveys, some attitude surveys," as a central priority as it can inform recreation planning:

> I'm almost singularly focused on this question of recreation and recreation planning because, um, it's just come up a lot lately. Um, it will help inform this setting of the vision that will help the community kinda get re-inspired about the dam removal.

Stemming from this activity, each participant identified a different environmental topic that was their individual priority for monitoring. At Chris's direction, the group then proceeded to whole group discussion in order to try and determine a collective priority from this list.

Phase 2: Focal interactions about Tamarisk

While continuing to share about ongoing environmental issues in the watershed as part of the whole-group discussion, Tyler mentioned a concern about Tamarisk, a non-native tree species taking root in the reservoir above the dam.

> By the way, just a note from the field, I don't know if any of you guys have seen this uh, explosion of Tamarisk up in the lakebed. Since the County dewatered the lakebed above the dam, uh there's been this huge explosion of invasive Tamarisk in those hills up there. And people are freaking out, because we don't really have a Tamarisk problem in the watershed, but we will very soon if that stuff all goes to seed.

The mention of Tamarisk, despite it initially being a tangential comment offered by Tyler, marks a turning point in the analytic narrative as several students and teachers express further “situational interest” (Azevedo, 2018) in this concern that was not shown for other topics brought up by Tyler such as sediment and human use. One teacher, Denise, later referred to this moment as “the spark that got us going.” Naomi, a student, asks aloud, “What’s Tamarisk?” then pauses before repeating her question, “What is Tamarisk?” to which Tyler responds,

> Oh, I’m sorry. Tamarisk is, uh, a non-native tree that is like, like Giant Reed or *Arundo,* a very high water user and will just create a monoculture in the riparian areas of these rivers in the desert southwest and Southwestern California.

A series of early interactions immediately proceeds in which several students and one of the teachers inquire about the addressing the Tamarisk concern via both monitoring and removal given its time-sensitive nature and their overall goal of consequentially “helping the watershed,” a goal articulated by Chris in the introductory framing of the workshops as well as by several of the students independently when asked their reasons for participating in the project. These early interactions in the third workshop additionally involve Tyler and Chris, in which negotiations around whether or not the ECN could address the Tamarisk issue initially appear to preclude the group from selecting it as their focal topic. However, after a shift in the goal of the activity and who was present, the topic resurfaced in the fifth workshop when the Tamarisk problem was mentioned again and determined to be an issue on which the ECN wanted to take action. In the following sections, we undertake an in-depth analysis of these particular interactions to reveal the role power played in mediating and structuring collective learning processes.

Power asymmetries constrain learning in-the-moment

After Tyler first introduced the Tamarisk concern in the third workshop, a proposal negotiation immediately occurs in the Zoom chat. Esther, a student, privately messages Chris with a proposal bid, asking, "Is it possible to remove the tameris" [sic] as Naomi simultaneously writes a parallel proposal bid to the entire group, "is it something we could do?" They were able to do this, in part, because the rules of the activity had allowed for all participants to access the conversational floor by initiating turns when desired (Engle et al. 2014). Chris responds with a message that could be categorized as a *proposal discussion*, or a response that acknowledges their bid but does not accept them or reject them outright. He says, "Naomi and Esther - is that something you could research for us and report back? If Tamarix removal is something that volunteers could do?" As written in a reflective memo immediately after the workshop, Chris notes this was because he "wanted to position students as being able to find the answer instead of relying on Tyler to tell them that they could or couldn't."

Meanwhile, as the broader conversation about Tamarisk continues aloud, Chris ties Tyler's point about Tamarisk being a high water user back to the other environmental topics raised by other participants, saying,

> So, Tyler, what you're saying and what I think has now come up from a bunch of folks is the interconnectedness of all these issues. Like, even in talking about Tamarisk you talked about how it uses a lot of water and how that relates to things like flow, which is something Natalia mentioned being concerned about,

Tyler nods in response to Chris's summary of this point, and then Chris then asks if people have questions for Tyler, or if they have thoughts they'd like to share with him. Natalia, a teacher, unmutes herself and offers a proposal bid that marks the start of another proposal negotiation:

> The one thing that I will say is that, you know, it just came up in this conversation and it seems like something that is very tangible and perhaps um time sensitive is, is the removal of the Tamarisk that just came up. And yeah, I don't know what I saw in the chat, that um, that maybe is something for us to research as participants. And I just wonder in doing that, what, what would you know, what are the questions we would need to answer to be able to answer that question? Of whether that's something that volunteers could do?

By building on Esther and Naomi's earlier comments and further asking if Tamarisk removal is something that they could research or "do," given its tangible and time sensitive nature, Natalia amplifies the students' proposal bid for environmental action. Chris then jumps into the conversation and asks Tyler to respond, saying, "Mhm, Tyler, do you have any immediate thoughts on that? Like, volunteers being involved in invasive species removal?" Tyler responds and says,

> Um, I don't know how secure those sediments are if we go out, I mean it's all young enough you could probably mow it. You know it's going to flower right now, and if it does, if it sets seed in the rain, it's just gonna get all the way down the watershed and uh, so, I mean, the right people know, people like Paula at the County Watershed Agency. I just haven't seen any email traffic today on you know, somebody saying, 'Hey, let's deploy four weekends of volunteer effort to get out there.' I love your spirit of saying, 'Hey, here's an immediate issue, let's go deal with it.' I'm not sure what the answer is yet, and uh, I wish I had a better answer. I mean, we're just finding out about it.

In response to Esther, Naomi, and Natalia offering proposal bids to address the Tamarisk concern, Tyler responds with what could be categorized as a proposal rejection. In saying that the ECN's research and removal efforts are not needed because "the right people know," with the right people being other conservation professionals involved in dam removal like Paula at the County Watershed Agency, he effectively constrains an opportunity for participation for students and teachers despite some members of the group showing an emerging interest. Naomi later responds to Tyler, saying, "Yeah, it just seems like something important and if we can do something about it that would be really cool." While Tyler indicates his openness to the idea, responding "I love your spirit," he does not offer a path forward for further participation.

This above series of proposal negotiations helps illustrate how power plays out in learning processes by attending to moment-to-moment interactions between individuals. Because learning is conceptualized as the shifting nature of the broader activity, power asymmetries between Tyler, Chris, Natalia, Naomi, and Esther mediated learning in that they prevented the activity from shifting toward a focus on Tamarisk despite an interest in this from those with less authority than Tyler. Tyler was positioned as an authority on the call, and enacted power by constraining access of students and teachers to the action of Tamarisk removal despite having been the one to raise it as a concern. It is also broadly reflective of the larger history of conservation in which community participation has been limited, or has only been allowed once appropriate actions have been determined by "the right people," as Tyler says, meaning those conventionally trained in conservation science and affiliated with official institutions.

Of additional consequence in these interactions is the role of Chris, the researcher, in facilitating the proposal negotiations around Tamarisk between Esther, Naomi, Natalia, and Tyler. Facilitation has the potential to both entrench and disrupt power asymmetries, and is a powerful role in and of itself in that facilitators make decisions about if, when, and how to enforce particular rules or norms. When Tyler initially brings up the point of Tamarisk being a novel issue in the watershed, Esther and Naomi pose questions about whether or not removing it was something they could do, questions that were aligned with the objective of the workshop series which was to identify priority topics for environmental monitoring. Chris then asks if it was something they could research using the Zoom chat feature. However, when Natalia brings this same point up aloud, asking if Tamarisk research and removal were something that volunteers could do, Chris waits a few seconds before specifically directing the question to Tyler, a move in which Tyler is then further positioned as an authority on the call. While authority may to some degree be a characteristic of individuals, it is also affected by local negotiations about "who should be considered to be a more or less credible source of information vis-à-vis the particular topics being discussed," (Engle et al., 2014, p. 253). By directing Natalia's question to Tyler, Chris structured access to the conversational floor, or the "evolving, socially negotiated space in which one or more particular people is allowed to present contributions" (Clark and Schaefer, 1989, in Engle et al. 2014), in a way that limited others' opportunities to potentially respond and further entrench Tyler's authority in the space. This is in addition to Tyler already being positioned with a high degree of authority, given his role as a special guest in the workshop.

Bringing in a cultural-historical lens helps make further visible the role of the sociocultural context in the interactions described above, and helps interpret how changes within the context create contradictions that introduce tensions to activities. Contradictions between elements of an activity system play a central role as a source of development and learning, and trigger expansive transformations in which participants collectively envision new possibilities for the activity (Engeström, 2001). In this view, while the above contradiction between the subjects' respective visions and the broader object of the activity may have constrained the direction in which the activity could evolve in relation to student interest and thus mediated social learning, the contradiction can also be seen as a catalyst of learning for the group which we describe further below (Lee and Roth, 2007).

In the above interactions, the *subjects* are Tyler, Chris, Natalia, Naomi, and Esther, with the *community* including the Trout River watershed and the conservation community broadly. The *object* in this activity was to identify a priority environmental topic for student-led monitoring that is responsive to the values of both young people and conservation professionals (as stated multiple times throughout the workshop series), with an emphasis on aligning with stakeholders' goals. The primary *tools* mediating this activity were the Zoom platform, which created the format for the deliberative dialogue, and the Mural platform (Image 1), in which participants' ideas were captured and categorized on a shared screen. The *division of labor* can be seen in how the individuals were specifically positioned within the activity, with Chris being the facilitator, Tyler being centralized as a special guest, and students and teachers being encouraged, not just to ask questions of Tyler, but to share ideas with him as well. *Rules* were explicitly shared at the beginning of the workshop verbally by Chris and via a slideshow presentation, examples including "Active discussion, reflection, and sharing is encouraged. You can unmute yourself to speak and/or use the chat box in Zoom throughout the workshop" and "Recognizing that everyone brings relevant expertise and knowledge."

Bringing a CHAT perspective into the analysis of the above interactions reveals how the broader context of the activity shaped the nature of the learning that occurs. These interactions do not exist in isolation from the subjects involved, community, object, tool, division of labor, and rules. For instance, while Chris structuring access to the conversational floor in a way that positioned Tyler as an authority, his degree of authority was additionally socially-negotiated by the division of labor of the activity system, in which he was positioned as a special guest (Engle et al., 2014). And yet, other elements of the activity system may have helped disrupt power. For example, the rule of "Active discussion, reflection, and sharing is encouraged. You can unmute yourself to speak and/or use the chat box in Zoom throughout the workshop" is in part what allowed for Naomi, Esther, and Natalia to openly ask questions and share perspectives both aloud and using the Zoom chat feature in contrast to an alternative scenario if the rule were that "participants must remain muted until called upon by the facilitator." Furthermore, a CHAT perspective reveals how the stated object of the activity was in tension with the subjects competing interests: what was the group to do with the topic of monitoring and removing Tamarisk given responsive to young people's interests but not aligned with what Tyler saw as valuable?

Power asymmetries introduce tensions that trigger expansive learning

Of importance in this analytic narrative is that ultimately, members of the ECN indeed chose Tamarisk monitoring and removal as a focal topic after the culmination of the workshop series despite Tyler's initial proposal rejection. In the fourth workshop, with Tyler no longer present, one student, Noah, asked Chris and Ryan, "Where in your, based on what you know, do you think our help would be most valuable?" to which Chris responded,

> There are probably going to be conservation professionals or scientists or land managers in the watershed who will tell you that, 'these are the things that will be helpful to know.' And you all can totally pick that up and monitor it and be contributing in a unique way. But what I think is really interesting is to monitor the things that are most rooted in your values and priorities, whether or not those are perfectly aligned with the professionals' priorities, because I think by starting that monitoring and getting that process going there could be this community groundswell, this more grassroots effort where that thing that's your priority becomes a priority for other people. Like, maybe they didn't see it as a priority to begin with, but because you did as students and young people who have a really important voice in this watershed they're like, 'Oh yeah I didn't originally see that as a data need, but now that I come think of it, they're doing such cool work. Like, that is really important to know about.' I would say considering how this work can be useful to others and fit into the broader landscape of monitoring is important, but also just for it to

> be most grounded in your values and your own priorities is one of the most important things.

Chris's response can be seen as a renegotiation of the *object* guiding the activity, which he had the authority to do as a designer and facilitator of the workshop series. Whereas the earlier focus had primarily been identifying a monitoring project that aligned with the priorities of conservation professionals like Tyler, Chris now reframes the object as identifying a monitoring priority primarily rooted in the ECN's values. This emerged in response to previous contradictions between the subjects and the object of the activity.

Later on, in the fifth workshop, as the group continues to discuss potential monitoring project topics that they would be interested in and that might simultaneously be responsive to other stakeholders' needs, Natalia responds to a point from Chris about combining biodiversity and pollution monitoring. In doing so, she used her status as an educator with status in the space to amplify students' earlier situational interest in Tamarisk despite Tyler having rejected the proposal bid. This plays a key role in influencing the learning trajectory of the group. She re-voices her proposal bid from the third workshop,

> The same could be done with, you know, removal of invasive plants like the Tamarisk, as you're monitoring, you know whatever flora and fauna are there, or measuring the water, whatever, you could also be pulling up whatever you find around you that's not supposed to be there.

Chris then responds by accepting the proposal bid, while several additional students nodded their heads, saying,

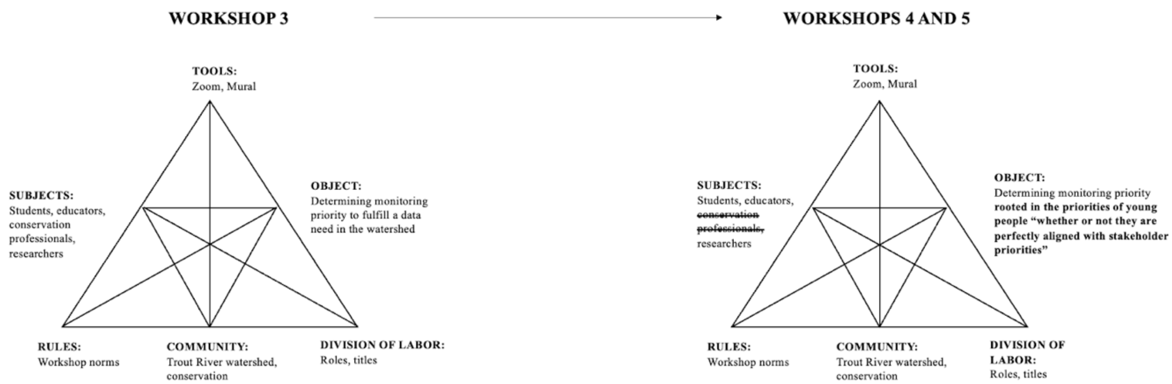
> Totally, yeah, and within the invasive plants it's interesting to think about the links between monitoring and those actions. Like, the monitoring can tell where those actions are most needed because it tells you where there's the most invasive plants, that would be interesting to know.

This proposal acceptance was affirmed by Ryan who nods while saying "mhm." Natalia responds again, saying

> There's something really satisfying about the idea of both learning about the watershed while we're there. Um, it feels like a form of taking from the watershed and at the same time giving back through our care for it. Um, so yeah as you guys talk about that approach that seems really appealing to kinda roll a couple of things in service to the watershed. And a learning and gathering of information from the watershed.

While she says this, Naomi vigorously nods her head. During these interactions in the fourth and fifth workshops, various elements of the activity system had shifted from the third workshop (Figure 2.1). The *subjects* of this subsequent interaction include Natalia, Naomi, Chris, and Ryan with the *community* being the ECN as neither Tyler nor additional conservation professionals attended this workshop as it was primarily designed to be an internal decision-making space for ECN students and teachers. The *division of labor* remained the same, with Chris and Ryan being facilitators, Natalia being a participating teacher and Naomi being a student. The *tools* and *rules* remained consistent as well, however, the *object* may have shifted with Chris's reframing of the goals of the workshops as to identifying a monitoring topic more rooted in the ECN's values, with attention to the larger monitoring context, but less so being directly constrained to topics for which conservation professionals have identified a need. This reframing of the object, in combination with Tyler's lack of attendance, may have been what created the opportunity for Natalia to re-voice the proposal bid about invasive plant removal. What Tyler defined as valuable as a conservation professional (recreation monitoring) contradicted what Natalia and some students found as valuable and interesting (Tamarisk monitoring).

Figure 2.1. Shifts in activity system over course of workshop series



Various members of the ECN continued to bring up invasive plant monitoring in discussion when Tyler was not present, and this may have been what catalyzed a shift in the activity toward this topic more aligned with their interests. For instance, after Natalia's re-voicing of the proposal bid which was accepted by Chris and Ryan, another student, Nicole, unmuted herself and builds on Natalia's point to initiate another related proposal bid,

> There's something that I also wanted to say about the project. I was wondering a way to possible combine a couple of those like [audio freezes for five seconds] I really think the invasive Tamarisk removal and other invasive plants is a really good way we can directly make a change and also um combining elements of water and soil monitoring around where those plants are [audio freezes for two seconds] and where there aren't invasive plants present. Seeing if the water content and the soil changes.

Chris responds by saying,

> Mhm, yeah, I love how you're thinking about ecosystem connections. That's so great. I could imagine if maybe there's a big Tamarisk removal effort, that's great, but what if it also disturbs the soil and causes more sediment to go into the water downstream and increases turbidity or something? That's a great scientific question we could totally monitor.

Here, Chris accepts while slightly altering the proposal bid, refining Nicole's ideas into a more targeted question to be taken up through a monitoring effort.

The above sequence of interactions illustrates how changes in the components of the activity context may have been what allowed for the group to take up invasive plant monitoring as their focal topic for community-based monitoring, despite earlier interactions in which power relations between Tyler and members of the ECN initially hampered the development of this idea. In taking a cultural-historical perspective, evidence of learning here is evidenced by the activity becoming more oriented toward the goals and suggestions of young people in response to earlier contradictions between the subjects and object of the activity.

DISCUSSION

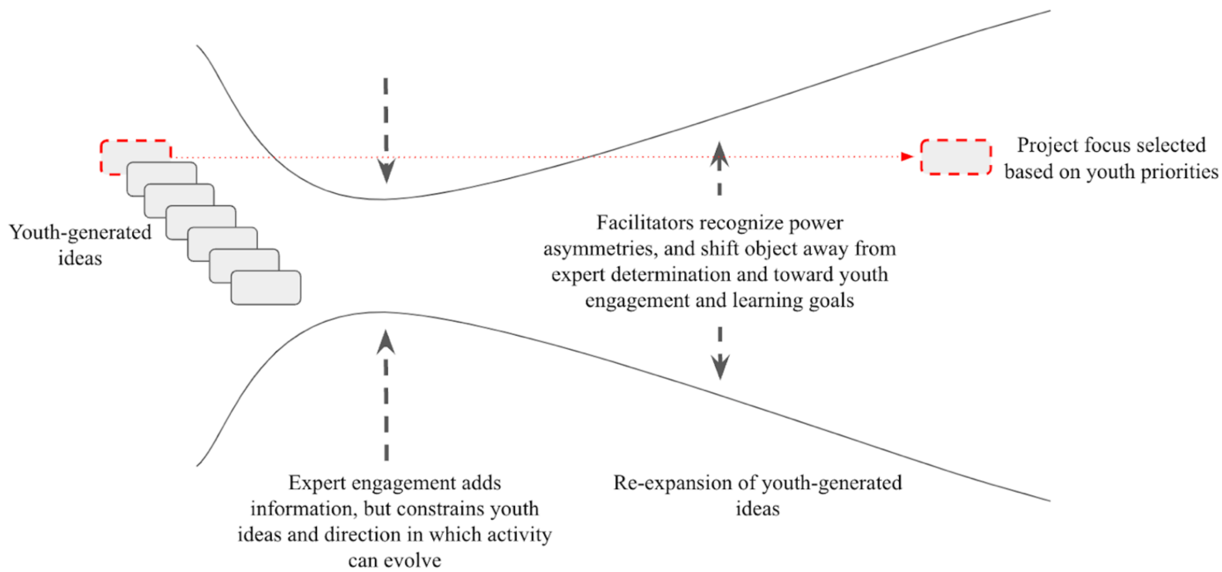
This work begins to respond to a series of critical questions raised by Stroupe and Carlone (2021) who investigate field science as a pathway for expanding science teaching and learning. They ask, "who decides what is 'local' or 'relevant' in field science? What role can youth play in such decisions?... How can those with power ensure that every student in a learning setting has opportunities to shape the practices of the community rather than perpetuate unjust epistemic hierarchies?" (p. 27). Focusing on citizen science, and similarly discussing issues of participation and epistemic justice, Herzog and Lepenies (2022) conceptualize projects as potential "deliberative systems" in which "citizens do not only deliver data points, but also participate in discussions about the goals and implications of research" (p. 499). In the present study, we attempted to design a community-based watershed monitoring initiative that countered dominant, scientist-driven approaches to citizen science, thereby creating a "deliberative system" where young people could determine priorities for monitoring in accordance with their own values and interests. However, our analysis makes visible how power relations between young people, educators, conservation professionals, and researchers still mediate opportunities for learning and participation. Our findings offer insights into how power relations may shape the learning processes that are necessary as diverse sets of actors seek to collaboratively address environmental problems.

In the focal interactions we analyzed, power mediated social learning in mundane yet significant ways. The land manager's preliminary rejection of students' proposal limited their further participation in the conversation despite an emergent situational interest. Power in this instance came from the land manager's pre-existing status as someone "with a big say in the community" in addition to being socially-negotiated in the moment via facilitation choices and his role as a special guest. His degree of authority may have been less pronounced in activity systems where all subjects were, say, other conservation professionals, further indicating how power and authority are often socially-negotiated and context-dependent (Engle et al., 2014). Even though he may not have intended to limit participation, this enactment of power played a role in precluding young people's perspectives being taken up in terms of determining a relevant project. This was despite a goal of the workshop being to determine project topics rooted in student interests, and a common goal of community-based monitoring broadly being to carve space for broader participation in conservation (Danielsen et al., 2005; McKinley et al., 2017). And yet, later in the workshop series as the context of the activity changed due to a reframing of the object of the activity and a shift in who was present, members of the ECN re-voiced their proposal bid to engage in the monitoring of Tamarisk which was ultimately taken up. Here, evidence of learning comes from how the group navigated the conversation and the directions in which they planned to take the practice of monitoring.

While there have been widespread calls field to consider power relations in research on learning as it has been conceived in the environmental management field, few studies explicitly address it as central in their research design (Ernst, 2019; Suškevičs et al., 2018). The learning sciences, on the other hand, have begun engage deeply with questions of power and positioning (Esmonde and Booker, 2017; Hennessy Elliott, 2020; Philip and Gupta, 2020). While CHAT - a theory widely used in the learning sciences - allowed us to investigate the relationships between the workshop context and the learning that took place at the micro-level, it did not account for hierarchies between young people and conservation professionals. To accomplish this, we needed to bring in additional critical perspectives that explain the power hierarchies latent in the history of conservation science that bar participation from those without credentialed forms of expertise (Kimura and Kinchy, 2016). Further integration of critical theories with sociocultural theories will continue to reveal how various systems of oppression manifest in processes of learning, and allow for better mapping of how interactions are mediated by power (Esmonde and Booker, 2017).

Despite these constraints, CHAT still helped reveal how power asymmetries between actors both constrain learning in-the-moment while also creating contradictions for learning to unfold in generative directions aligned with youth interests over the course of the workshop series (Figure 2.3). Whereas other studies in environmental management point out that power *hinders* learning (Suškevičs et al., 2019), perspectives from CHAT reveal that tensions created by power relations can simultaneously *trigger* learning processes. Furthermore, this theory leads us toward expanding our unit of analysis beyond the individual learner, instead focusing on the broader activity system and social relations as sites for learning (Bang, 2015; Esmonde, 2017; Hecht and Crowley, 2020). This allows us to trace the negotiation and establishment of new monitoring practices, which in and of itself constitutes learning, vis-à-vis power relations.

Figure 2.2 Tensions introduced by power asymmetries mediate social learning processes by shaping the nature of the activity



This methodological approach further demonstrates how power can be "seen" in interaction through the careful tracing of conversational moves between actors in a real-world setting. Other scholars have identified the challenges of this work. As Esmonde (2017) points out, an enduring challenge in sociocultural analyses is to identify the relationship between macro-level systems of power and micro-level interactions. This is echoed by Philip and Gupta (2020), who note that "fine-grained analyses of learning have demonstrated rich and varied trajectories of sensemaking, participation, and becoming, but have struggled to adequately capture historical, social, political, and economic processes of power" (p. 196). Whereas critical social theories often operate at the macro-level of social structures, methodologies for the study of learning - such as interaction analysis and microgenetic analysis - often operate at the micro-level. Here, we attempt to bring the two together, through careful analysis of interaction in the form of proposal negotiation units infused with a view of power contextualized in the particular learning environment we studied. Additional work is necessary to further reconcile this mismatch in scale in the form of new theoretical and methodological tools, tools that Philip and Gupta (2020) point to as emerging from a nascent body of literature in the learning sciences examining the co-construction of power and learning.

In terms of practice, our findings point to the importance of facilitation choices and pedagogical moves in influencing learning processes. Previous studies have recognized the important role of facilitation in supporting learning across actors (Ernst, 2019). Our findings suggest that facilitators can play an important role in disrupting power asymmetries by *acknowledging and managing* them, rather than ignoring or avoiding their influence. As a facilitator, Chris structured access to the conversational floor in a way that initially reified Tyler's authority; however, then used his position to renegotiate the object of the activity as to foreground young people's interests. We also note the generative possibilities that can emerge when learners are brought into discussions around power in science, where they are afforded the opportunity to critically reflect on the value of epistemic heterogeneity and the problems that arise when issues of epistemic justice go unaddressed (Bang, 2015).

Additionally, we call specific attention to the pedagogical moves by Natalia, who persistently used social position as a teacher with authority in the space to elevate and affirm students' interest in monitoring Tamarisk as a valuable idea. In doing so, she validates and amplifies their ideas, which is what in part allowed for the group to select Tamarisk as a focal monitoring topic despite initial constraints from Tyler. Higgs et al. (2020) refer to "amplifying" as "practices that seek to turn up the volume of voices often sidelined or silenced in education" (p. 585). By amplifying and re-voicing proposal bids from students such as Naomi and Esther, she increases the status of their ideas and elevates them from individuals with less status in the workshop series than Tyler, the conservation professional, to leaders guiding the group's actions. Facilitators and others positioned in similar roles can learn to notice when more powerful voices dominate interactions in fleeting moments of talk, and then engage in moves that position marginalized individuals as knowledgeable in response (Patterson Williams et al., 2020, 2021; Wager, 2014). Specifically, facilitators can amplify young people's contributions by "assigning competence" to, and thus increasing the status of, their ideas in student-community collaborations to position them as worthy of engagement (Cohen and Lotan, 2014). This can ultimately influence if and how young people's ideas are taken up, and how the group engages with them.

We can offer additional practical implications for the design of workshops and other programs so as to uplift youth leadership in collaborative learning environments involving conservation professionals. Many of these implications emerge in relation to the "back stage work," which is largely what structures opportunities for less hierarchical engagement and for the ideas of young people to be taken up in spaces where outside "experts" are present. For instance, clearly articulating the object or goals of the activity as foregrounding young people's interests - and setting up a division of labor that allows for such - can in part allow for decision-making less constrained by community partners' priorities. Co-creating rules that aim to foster equitable engagement may be what allows those traditionally positioned with less authority to voice proposal bids. Additionally, while bringing young people together with scientists and conservation professionals can be an important catalyst, creating spaces where conservation professionals and those with more authority are *not* present may be what allows individuals to re-voice and further discuss proposal bids that might otherwise be rejected. In these moments in our data, researchers and educators became more oriented to student interests and priorities rather than being caught up in the normative authority structure and either deferring to or affirming the authority of conservation professionals. This is not to say that conservation professionals should not be involved, as they can lend valuable expertise to co-designing monitoring initiatives. Rather, it is to say that having both spaces - where conservation professionals are present, and where they are not - may be productive in supporting projects that aim to center youth agency with respect to conservation. These and other design choices can elevate the ideas and contributions of young people in student-community collaborations.

There remain further issues of power to be seen in the long-term that are beyond the scope of this particular analysis. For instance, how will conservation professionals - who ultimately retain authority within current land management systems to act on whatever youth might find - respond to projects that are conceived and led by young people? Will youth-led projects be taken seriously, or will they be discounted? What contextual factors and circumstances might mediate outcomes in this regard? Evidence from cases focused on environmental justice suggest that community concerns and community-generated data might be delegitimized or dismissed if they challenge dominant state or corporate actors (Kimura and Kinchy, 2016; Ottinger, 2010). Questions of this nature merit further investigation to determine the degree to which young people's ideas, values, and perspectives can come to inform - and transform - current structures for conservation decision-making. In citizen science more broadly, this has implications for what it means to truly flatten hierarchies where members of the public do not just contribute data to scientist-led projects, but fundamentally shape the nature of the scientific work to ensure its responsiveness to multiple perspectives.

While our analytic approach illustrates how power and its impacts can be "seen" methodologically, we cannot with confidence offer conclusions about the role of power in highly varied contexts of other participatory conservation endeavors involving youth and adults. Further analyses might attend to other forms of proposal negotiation, in which proposal bids by young people are accepted by conservation professionals, proposal bids by conservation professionals are rejected by young people, or alternative forms of interaction. Intentionally seeking out counterexamples and discrepant cases (Erickson, 1986) offers "important resources for theorizing from the vantage point of both successes and challenges in the work" (Vossoughi and Shea, 2019, p. 331). Additionally, we note that power operates along other lines that merit further investigation: specifically racial, gendered, classed, political, linguistic, and more in which individuals' social positions partly shape their perspective and influence. As demonstrated in research from fields such as political ecology (Robbins, 2012), these factors are highly salient across cases of environmental conflict and collaboration given the social, political, and cultural roots of environmental problems. For instance, how might a similar analysis play out in collaborative settings involving federal scientists and Indigenous peoples, given the specific and targeted ways in which Indigenous sovereignty has been undermined as a function of conservation, despite how Indigenous ways of knowing can guide more justice-oriented - and effective - approaches to conservation (Diver, 2016; Hernandez, 2022; Reo et al., 2017; Simpson, 2016)? Future studies might explicitly consider how these additional factors, as well as their many intersections, figure into learning processes in order to support more equitable conservation decision-making.

CONCLUSION

Participatory approaches within conservation such as community-based monitoring are increasingly recognized by researchers and land managers as imperative for contributing to the resilience of complex socioecological systems in large part because they foster learning. This study leverages sociocultural theories of learning and micro-ethnographic methods to construct an analytic narrative that helps us "see" how power relations may mediate the nature of the interactions that occur in this specific case of community-based watershed monitoring. Of course, power relations will vary across settings depending on actors involved, the histories of particular socioecological systems, and other contextual elements of multi-stakeholder conservation projects. Understanding how to notice and attend to power asymmetries - as both a research method and pedagogical practice - can help disrupt epistemic hierarchies that privilege the knowledge of "experts" over those traditionally considered "non-experts" within community-based monitoring and other community-based conservation initiatives. Ultimately, doing so can better leverage the diverse perspectives found distributed within communities to catalyze more equitable learning, a practice that will allow for the collective reimagination of how we solve environmental problems to support resilient socioecological systems.

CHAPTER 3. COMMUNITY-BASED MONITORING AND COMMUNITY SCIENCE LITERACY: TOWARDS SOCIOECOLOGICAL TRANSFORMATION

INTRODUCTION AND BACKGROUND

Solving complex environmental problems - an increasingly urgent endeavor - necessitates that individuals with different sets of knowledge, practices, and perspectives come together to learn and co-produce shared knowledge. Informal learning environments, particularly those that are place-based and community-based, are well-positioned to catalyze forms of learning and literacy that foster more healthy and resilient socioecological systems. While learning and literacy can be observed in individuals, and have been primarily conceptualized as individual endeavors in science education research, they can also occur at the group or community-level as diverse sets of actors interact and engage with one another through participation in shared practices.

As such, this study focuses on the construct of *community science literacy* as a conceptual lens for understanding the relationships between science learning environments and systems-level socioecological transformation. We draw the term community science literacy from Roth and Lee's (2004) definition of science literacy as a collective, social practice in which the focus is on "the level of participation, division of labor, and knowledgeability rather than on decontextualized or procedural knowledge" demonstrated by individuals (p. 264). From this definition, we understand science literacy as emerging when scientists, science-related professionals, and people from other walks of life actively engage with each other over contentious and personally-relevant issues, with implications for environmental problem-solving (Roth, 2003). While community science literacy as a construct has garnered conceptual attention and attracted the interest of researchers and practitioners, there are few empirical studies that describe its nature or trace its emergence (National Academies, 2016). The purpose of this study is to document how community science literacy takes shape, and discuss its relevance for socioecological transformation – by which we draw on Freire (1970) to mean people making change toward the repair of social and ecological relations, which are inextricably linked from one another (Ostrom, 2009) To accomplish this, we analyze evidence from a case study of a community-based watershed monitoring initiative in the United States Mountain West focused on a river restoration and dam removal project. In this context, we ask if and how different sets of science-related knowledge, skills, and practices were brought into coordination in service of building a healthier watershed. The following research questions guide this article:

- What are the dimensions of community science literacy?
- What factors mediate the emergence of community science literacy?

Community-based monitoring and learning for socioecological transformation

This study focuses on community-based watershed monitoring as a context in which to examine and better understand different dimensions of community science literacy. In environmental management fields, monitoring is recognized as a critical process in adaptive approaches to environmental decision-making in which relevant stakeholders collect and analyze data to assess trends relevant to management objectives (Holling, 1978; Lindenmayer and Liken, 2010; Nichols and Williams, 2006). For example, government agencies might monitor aquatic temperature in rivers and streams to determine when to take fisheries management actions such as instituting fishing restrictions, or they might monitor for the presence of invasive species to determine when interventions may be necessary. Ecological monitoring is often considered distinct from science in that it involves assessing trends for the purpose of site-specific decision-making rather than creating generalizable knowledge; however, despite differences in purpose, both monitoring and science rely on similar practices of inquiry.

Typically, land managers and scientists lead and carry out monitoring efforts with little to no public participation. However, participatory and community-based approaches to monitoring have increasingly been touted as a strategy to overcome insufficient data collection in monitoring schemes, promote greater stakeholder engagement, and support the integration of multiple knowledge systems in decision-making (Aceves-Bueno et al., 2015; Ballard et al. 2008). Through participatory approaches to monitoring, such as collaborative and community-based monitoring, scientists, land managers, broader publics, and other stakeholders jointly participate in monitoring efforts. These projects come with opportunities for interaction and engagement over shared issues, particularly at the local level (Jansujwicz et al., 2013). Typically, local residents participate in monitoring as volunteers. Project structures may vary widely, with different individuals being differentially involved in various science practices that occur across the lifespan of the monitoring initiative, largely dependent on their role as scientist, land manager, or volunteer (Shirk et al., 2012).

Community-based monitoring is generally considered under the umbrella of citizen science or community science, for which appropriate terminology remains an evolving conversation (Cooper et al., 2021; Eitzel et al., 2017) and for which there has been significant interest in these projects' potential to catalyze learning (Bonney et al., 2009). Research on these forms of learning can be categorized into two distinct but related categories. In the first body of literature, educational researchers discuss and measure the learning outcomes that might emerge for individual volunteers who participate in community-based monitoring. Often within the specific realm of science or environmental education, studies of this nature attend to matters such as change in science content knowledge or inquiry skills, as well as a range of other individual learning outcomes (Phillips et al. 2018). In the second body of literature, researchers in fields such as natural resource sociology and environmental governance discuss and measure what has come to be termed "social learning," focusing not just on individual volunteers' takeaways but on how learning occurs across stakeholder groups (Jadallah and Ballard, 2021; Reed et al. 2010). Studies of social learning do attend to individual learning outcomes but tend to focus more strongly on knowledge co-creation processes that occur as people from different walks of life interact and engage with each other. Across both bodies of literature, there is a driving focus on how said forms of learning can foster socioecological transformation.

Community science literacy

Echoing discussions of social learning, but rooted in science education research, is the concept of community science literacy. Two significant reports released by the National Academies of Sciences, Engineering, and Medicine amplified this concept. In 2016, a report focused on science literacy that explicitly calls out how communities "accomplish various goals, by virtue of their collective literacy, that cannot be easily attributed to the actions of any particular individual" (NASEM, 2016, p. 73), and further name community-based monitoring as a context in which this form of literacy may be observed. One of their key conclusions is that communities can meaningfully contribute to science knowledge through taking action with local scientists – although what is meant by "contribute" is left vague. In a later report on citizen science, community-level learning is similarly noted as a possible outcome (NASEM, 2018). Both reports highlight that community science literacy does not require that all individuals meet some standard, arbitrary benchmark of science knowledge; rather; it comes to fruition when the knowledge collectively held by many individuals comes together through networks of trust, behavior, relationships, power, and mechanisms of sharing (National Academies, 2016; 2018). This aligns with other literature on learning in informal environments that highlights the distributed nature of problem-solving, in which problem-solving is "embedded in a social network that collectively performs necessary tasks and cognitive work" (Nasir and Hand, 2008, p. 144).

As community science literacy is the focal construct we investigate in this study, here we synthesize relevant literature to discuss the concept's theoretical underpinnings. Understanding science literacy as a community endeavor represent a marked departure from longstanding debates about the normative nature of science literacy (DeBoer, 2000; Laugksch, 2000; Roberts and Bybee, 2014). Despite highly pertinent differences (for example, as to whether science literacy should be organized around *knowledge within science* or *knowledge about science-related situations*, e.g., Roberts, 2007), these debates remain unified by their focus on the individual learner. The idea behind community science literacy, instead, emerges from the work of a small but growing number of researchers in science education who have called for expanding beyond traditional notions of science literacy as an individual trait. Over two decades ago, Roth and Lee (2002) were among the earliest to argue that science literacy - rather than being an individual phenomenon - emerges *collectively* between scientists, science-related professionals, and people from other walks of life as they engage with each other over contentious and personally-relevant issues. They further write that science literacy "characterizes interactions irreducible to characteristics of individuals" (Roth and Lee, 2002, p. 42). There may be other way to infer meaning from the term community science literacy. These might include literacy specific to the context of community science, scientists building literacy about how to communicate and collaborate with communities, or many individuals within a community developing science literacy. However, we draw on the literature presented above to understand it as a social practice emerging from interactions between individuals with disparate knowledge, skills, and practices toward a common aim.

Framing science literacy as a community endeavor stands in contrast to traditional, top-down modes of science learning where science is disconnected from community. In conventional science education, normative descriptions of discipline-specific subject matter in schools can restrict the intellectual and expressive opportunities for learners, particularly learners from marginalized backgrounds (Bang et al., 2013). Taking a more expansive view allows us to think of science learning in relation to everyday life in which learning - for both youth and adults - is driven by interest (Azevedo, 2013), occurs in place (Bell et al., 2013), and is geared toward meaningful (both personally and for one's community) use (Feinstein, 2011). Epistemological diversity is embraced rather than flattened into a set of facts divorced from the lifeworlds of learners (Bang et al., 2013). These more progressive visions of science education are rooted in critical perspectives that reject science as axiologically neutral and value free (Bang et al., 2016; Morales Doyle, 2018), and in this vein, science education becomes in service of developing community capacity for change (Ballard et al. 2017; Calabrese Barton, 2012; Sjostrom and Eilks, 2018) rather than moving all individuals toward some universal level of science literacy.

A number of related theoretical perspectives lend useful insights in bolstering this new conceptualization of science literacy as collective praxis, many of them sociocultural in nature and rooted in the writings of L.S. Vygotsky (1978) whose foundational work has shaped understandings of learning as a social activity. Lave and Wenger (1991), for instance, draw on Vygotsky to highlight how people learn through legitimate peripheral participation in communities of practice. Communities of practice are social units in which members share understandings concerning what they are doing and what it means in their lives. These social units are constituted and reconstituted by their members; thus, the activities of individuals have implications for how the broader group and its core set of knowledge evolve over time. Hutchins (1995) similarly draws on Vygotsky in his discussions of distributed cognition, where he describes how networks of people, artifacts, and tools collectively learn. Through complex webs of relations and interactions between people, artifacts, and tools, distributed cognitive systems are able to learn and achieve more than individuals alone (Salomon, 1997). These perspectives are useful in that the unit of analysis extends beyond the individual learner; it includes the community of practice or distributed cognitive system. According to Barron (2003), a core implication of this view is that to understand the nature of collaborative work and learning, we need to articulate how social goals and the norms of an activity interact with learning processes that lead to the co-construction of knowledge.

Common across sociocultural theories is the understanding that learning across groups often happens at boundaries, at the edges of practice where new ideas and skills are introduced and tested (Lave and Wenger, 1991). Boundaries serve as ambiguous, yet productive sites for learning in which different people engage in collaborative learning processes (Akkerman and Bakker, 2011). Learning environments that convene diverse groups in which they learn at the boundaries of different practices and communities. This has the potential to promote robust, expansive forms of learning (Hardie Hale et al. 2022; Roth and Lee, 2007), and spanning disciplinary, organizational, and cultural boundaries is necessary in supporting the co-production of knowledge to address sustainability challenges (Goodrich et al., 2020). Whereas most research on learning and literacy has focused on individual outcomes and processes related conceptual change and developing expertise, taking a sociocultural view helps make visible how meaning is created at the community-level as individuals interact with each other and their sociocultural contexts.

Critical perspectives on community science literacy

It is possible to argue that conceiving of science literacy as a community endeavor is inherently critical, as such an understanding compels us to consider literacy in social context rather than take narrow and individualized views of learners. However, further critical interrogation is necessary to ensure that interactions between scientists, science-related professionals, and broader publics produce equitable forms of learning and literacy. "Community" in and of itself is a beleaguered term that has been critiqued for its assumption of shared understanding and for glossing over differences in power and participation (Tuck and McKenzie, 2015). Questions of power are central to consider in discussions of community science literacy in order to design equitable learning environments that take seriously the contributions of people from diverse walks of life. To this end, we pay particular attention to issues of power and participation in our investigation into community science literacy by layering in critical perspectives on the history of science and environmental management.

We focus specifically on power as it relates to epistemology in community-based monitoring, which we understand as being conferred partly through one's pre-existing level of status and authority while simultaneously being negotiated through moment-to-moment interaction (Holland et al., 2001). While community-based monitoring initiatives may theoretically carry the goals of broadening participation in science, integrating diverse ways of knowing, and blurring boundaries between scientists and the public, there are important considerations with regards to epistemic hierarchies for these goals to be realized. Jasanoff

(1990) writes that when an area of intellectual activity is “tagged with the label ‘science,’ people who are not scientists are *de facto* barred from having any say about its substance” (p. 14), preserving it as an elite arena. Community-based monitoring projects might blur these boundaries, but can also reproduce inequities that further entrench the power of dominant scientific paradigms - often at the expense of other forms of knowledge - if not designed to center multiple ways of knowing.

How has dominant science become “dominant”? Conventional forms of scientific knowledge are typically considered as superior to other ways of knowing about the natural world. However, scientific knowledge does not possess an inherent epistemologically elite status. Scientific knowledge is produced through investigations into phenomena and is then taken up into sociopolitical regimes through which it is *positioned* as higher rank through sanctioned discourses and institutions (Bazzul and Carter, 2017). In other words, it is through active social manipulation that scientific artifacts like theories, data, and instruments are legitimized and afforded higher status (Latour, 1987).

In the specific context of environmental science and management in the United States, these issues of power, status, and rank have much to do with entanglements between science and the state. Conventional science has historically been appropriated by the state as a tool for ordering nature and transforming it into a natural resource for human extraction (Scott, 1998). This is heightened in the context of settler colonialism in which land is an asset for state-building at the expense of Indigenous peoples, where Indigenous ways of knowing have been specifically subject to targeted denigration and erasure (Simpson, 2004). Even when the goal of environmental management is conservation and not necessarily extraction, scientific knowledge has typically been equated with more effective environmental management because it theoretically affords humans greater control over ecological processes (Scott, 1998; Robbins, 2012). However, such “command-and-control” orientations to environmental management are ineffective given ecosystems’ inherent dynamism (Holling and Meffe, 1996), and they often operate without regard for implications with respect to local communities.

Stemming from these understandings is the recognition that more scientific data alone will not inherently result in more effective environmental management. Rather, there is a need for approaches in which researchers and relevant stakeholders - particularly those most affected by environmental decision-making - jointly define what constitutes “better” environmental management and co-produce knowledge through adaptive co-management (Armitage et al., 2007; Charles et al. 2020). Integrating multiple ways of knowing requires respect, thoughtful collaboration, and careful attention to power. This relies on sustained interaction, mutual trust, and long-term relationship-building rooted in the context of specific places and histories (Ballard et al., 2008; Fernández-Giménez et al., 2008; Hardie Hale et al., 2022). This is particularly true with regard to Indigenous ways of knowing, which have been subject to targeted attacks in the context of environmental management (and for which “integration” has been critiqued as a process), but are increasingly recognized as critical for healthy socioecological systems (Nadasdy, 1999; Reo et al., 2017). It is from this recognition that community-based monitoring has garnered attention for potentially disrupting hierarchies and power asymmetries.

Better understanding community science literacy – with a particular eye towards dynamics around knowledge and power – represents an important area for research. In the following sections of this paper, we report on a case study of a community-based monitoring initiative focused on dam removal and river restoration in which we sought to examine the shape and structure of community science literacy and identify design features relevant to its emergence.

METHODS

Case context

This study draws from a larger research project examining how participatory approaches to ecological monitoring produce forms of learning and literacy that foster socioecological resilience. More specifically, the purpose of this broader research is to understand if and how community knowledge and practices are leveraged in service of environmental problem-solving via community-based monitoring, and to identify practices that promote this.

We focus here on the specific case of a collaborative, community-based watershed monitoring effort in the Mountain West led by an education nonprofit whose mission is oriented around watershed stewardship. The monitoring program was developed in partnership with a national conservation science and management organization, as well as various other local, state, and federal agencies involved in a creek restoration effort. The conservation organization spearheaded the overall collaborative monitoring program, with the education organization taking responsibility for the community-based, citizen science components.

The impetus for this monitoring initiative was the removal of Caddisfly Creek Dam, a structure that had provided drinking water for downstream users but eventually rendered obsolete after the local community switched to groundwater as its primary water source. In addition to no longer serving any functional purpose, the dam also continued to inhibit the upstream migration of threatened and endangered fish species on Caddisfly Creek, such as the iconic bull trout, to their historic spawning grounds. Dam removal has increasingly been recognized as a successful strategy for creek and river restoration (Bellmore et al., 2019; Pejchar and Warner, 2001) With the ultimate removal of the dam in 2020 came the potential for change to watershed that local stakeholders aimed to assess through monitoring. The dam removal effort more broadly (not just the monitoring aspect) was led by the conservation organization, in collaboration with government partners such as the nearby City Parks and Recreation Department, Federal Wilderness Land Management Authority, and National Forest.

The community-based components of the dam removal monitoring effort consisted of two programs: Stream Team and Backcountry Stream Corps (Table 3.1). Both programs are interrelated yet distinct. Stream Team is a long-term volunteer program where local residents meet with project organizers weekly to collect data on biological, physical, and chemical parameters that provide indicators for understanding the form and function of the creek. Stream Team consists of multiple levels, the primary of which featured relatively simple data collection protocols at highly-accessible sites along the creek and involving no sustained commitment, with more intensive levels involving more complex protocols and a specialized volunteer base able to dedicate greater time and effort to monitoring. Backcountry Stream Corps, on the other hand, is a two-week intensive monitoring effort where roughly six high school students conduct large woody debris surveys and beaver dam inventories to map riparian habitat in the upper reaches of the watershed. In addition to collecting data at monitoring sites, which are accessible only via mountain biking, participants engage in other activities such as nature journaling and hearing from guest speakers.

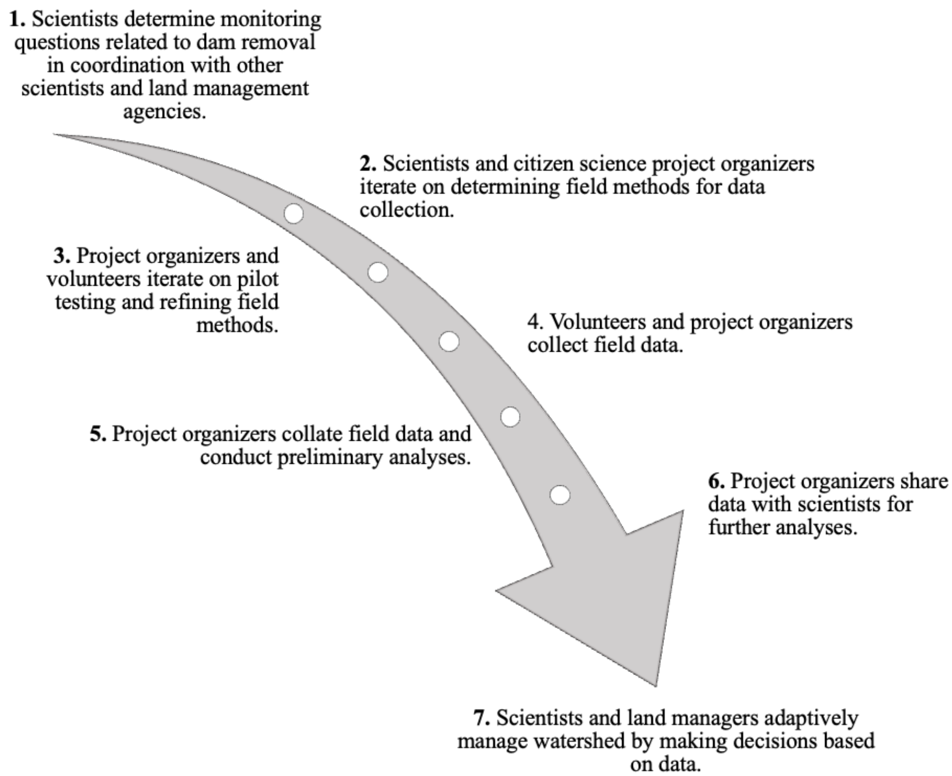
Table 3.1. Focal community-based monitoring program characteristics

Program	**Scientific Parameters Monitored**	**Volunteer Age Range**	**Participants**	**Sites Monitored**	**Monitoring schedule**
Stream Team	Biological	Adults	Between three and six volunteers on any	Urban park accessible via	Weekly, summer through fall

	E.g. Vegetation assessments Physical *E.g. Channel cross-section profiles* Chemical *E.g. Dissolved oxygen*		given day, two to three project organizers	automobile and public transit	
Backcountry Stream Corps	Large woody debris surveys Headwater beaver dam inventory	High school	Six students, two to three project organizers	Designated wilderness, accessible via mountain biking	Two-week intensive, summer

We use the term "participants" to describe all the individuals who were involved in community-based monitoring. Our sample is bounded to these individuals, regardless of their respective role. We use pseudonyms throughout this article when referring to participants in order to protect individuals' identities in accordance with protocols for ethical research with human subjects and guidance from the UC Davis Institutional Review Board. Project organizers are the primary coordinators responsible for designing, organizing, and facilitating community-based watershed monitoring in ways that attend to both collaborating scientists and conservation professionals' goals as well as volunteers' needs and strengths. Collaborating scientists and conservation professionals primarily lent technical expertise toward monitoring, with a vested interest in the data being collected. Volunteers are local residents who elect to participate in either Stream Team or Backcountry Stream Corps for a variety of motivations. While the students in Backcountry Stream Corps received a small stipend for their contributions, we still refer to them as volunteers for the sake of simplicity. Together, these sets of individuals collectively contributed to the community-based monitoring effort (Figure 3.1). While diverse in their social positions and roles with respect to the project, the majority of participants were white with some being Asian and/or mixed race. This reflects the the broader racial demographics of the city and region in which this study took place.

Figure 3.1. Overview of Caddisfly Creek community-based monitoring process



As researchers, we approached this project with a desire to support local organizations in building capacity for community-based monitoring in addition to studying the learning processes that it fostered. Beyond collecting and analyzing ethnographic data using the methods detailed below, we worked closely with our on-the-ground partners to provide insights on program design as well as general technical assistance, and produce practitioner resources (Meyer et al., 2020). This process involved coming to mutual understanding via ongoing conversations before, during, and after periods of more formal data collection. Thus, forming sustained relationships with both the people and organizations interested in Caddisfly Creek - as well as the creek itself - was a central tenet of this work that came to result in blurred lines between research and practice.

Data collection

Data collection took place primarily over the course of two months in the summer of 2021, with additional data collected in the summer of 2022. We draw on qualitative, ethnographic methods with a case study design for collecting and analyzing data to answer our research questions (Yin, 2017). Qualitative research often carries the goal of uncovering meanings of participants to describe phenomena for which there is a lack of existing theory or when existing theory is inadequate (Merriam and Tisdell, 2015). This approach relies on inductive processes and rich description, and is iterative and recursive in nature with the goal of building understanding from local participants' perspectives. Specific methods for data collection included:

Interviews. We conducted twenty-five semi-structured ethnographic interviews with project participants, each lasting between forty-five minutes and one hour in length. Participants included project organizers, collaborating scientists, conservation professionals, and volunteers who were involved in each community-based monitoring program. We used both purposive and snowball sampling, beginning with project organizers and asking who else we should talk to at the end of each interview. We ultimately interviewed nearly all active participants in the project at the time of the data collection, minus the few who were unavailable or declined to participate. Example questions included:

- How would you describe your specific role within this project?
- Can you recall a specific moment or event that you feel really illustrates that role?
- What expertise were you able to bring to this project?

The majority of interviews were conducted at or nearby monitoring sites along Caddisfly Creek with the goal of eliciting 'emplaced' data (Tuck and McKenzie, 2015). Interviews were audio-recorded and transcribed verbatim, with the primary focus of transcription being the content of what people said rather than speech features such as intonation or prosody. After each interview, we wrote reflective memos to begin the process of distilling key themes, patterns, and notable moments.

Participant observations. We wrote ethnographic fieldnotes (Emerson et al., 2011) during participant observations of field-based monitoring activities over the course of six weeks. Fieldnotes focused primarily on episodes of field-based data collection, although we also observed meetings between project organizers, scientists, and conservation professionals, as well as new volunteer training. Given the sociocultural perspectives guiding our conceptualization of community science literacy, we focused our attention while writing fieldnotes primarily on interactions between participants, as well as participants and their contexts. Sociocultural theories of learning and literacy highlight social interaction as a key site in which learning occurs (Nasir et al., 2021). We additionally took audio-recordings of select monitoring activities during which writing fieldnotes proved difficult, for instance, while wading through deep water. Fieldnotes and audio recordings were integrated into narrative recountings of the days' encounters, with the goal of turning quick jottings into extended text that included concrete details of the scenes, actions taken by participants, and both direct and paraphrased quotes. Similar to when we conducted interviews, we also wrote reflective memos while writing fieldnotes.

Focus group. We facilitated and audio-recorded one hour-long focus group with six youth participants from Backcountry Stream Corps, as well as four educators and project organizers, on the last day of the two-week program under a stand of pine trees along Caddisfly Creek. The focus group served as both a pedagogical tool to support youth meaning making and reflection around their experiences, as well as a data source to understand how science literacy emerged collectively within their activities. Like interviews, this focus group was audio-recorded and transcribed verbatim, focusing on the content of what people said.

Artifacts. We created copies of several dozen artifacts related to the broader monitoring project. These included planning documents, monitoring protocols, datasheets, meeting notes, reports, brochures, and public recruitment materials that the conservation and education organizations had developed and disseminated either internally or for the broader public.

Data analysis

We began our analysis by reading and re-reading fieldnotes, interview and focus group transcripts, artifacts, and reflective memos. Using the cross-comparative method (Glaser and Strauss, 1967), we engaged in an iterative process of both deductively and inductively coding our data, and then reviewing and organizing our codes by grouping, dividing, and further structuring them into different thematic categories. In building out themes from the data, we looked for confirming and disconfirming evidence of emergent patterns in our codes relevant to community science literacy. While doing this, we wrote analytic memos to aid in the process of refining categories that were relevant to our research questions and guiding theoretical perspectives that helped to represent community science literacy. Below are some specific analytical procedures that informed our analysis.

We took a first pass of deductive coding the data corpus to identify the science practices in which people were engaged across the course of the community-based monitoring project to understand if, when, and how people were engaging in science given that this is foundational to community science literacy. We developed codes by drawing on the practices from the National Research Council's Framework for K-12 Science Education (2015). These practices come from those employed by scientists as they investigate phenomena and build models and theories about the world. These include *asking questions*, *developing and using models*, *planning and carrying out investigations*, *analyzing and interpreting data*, *constructing explanations*, *engaging in argument from evidence*, and *obtaining*, *evaluating, and communicating information* (National Research Council Framework, 2015). Given the preponderance of episodes in which people were planning and carrying out investigations - largely due to the fact that our observations focused primarily on groups conducting fieldwork - we further separated this practice into two categories of sub-practices, *determining methods* and *collecting data*, based on our data and to better represent nuance and complexity. Notably, our goal in this analytical pass was to categorize the myriad of activities and tasks that make up an environmental monitoring effort rather than trying to discern individuals' science reasoning practices. Thus, we used these practices to categorize various aspects of the monitoring project, rather than individuals' engagement in these practices. If, for instance, our fieldnotes depicted a team of volunteers engaging in fieldwork to collect data in the creek, and one of them happened to pose a science-related question, we coded the episode as *collecting data* rather than *asking questions*. This helped us maintain our focus on the practices on the broader project and community involved, rather than those of individuals.

Next, given the theoretical perspectives that inform our conceptualization of community science literacy, we inductively coded our data by beginning with a process of open coding. In doing so, we paid particular attention to interactions between individuals, as well as individuals and their contexts, given our theoretical framework. Specifically, we draw on the notion of *data catchments* as defined by Lee and Dubovi (2020) to aid in this effort. Lee and Dubovi (2020) use the term to describe families' work with data with regards to the health of their children with Type I diabetes, toward the eventual goal of managing a children's health. We use it to describe streams of ecological data moving in various directions toward the eventual goal of managing a healthy watershed. This is made particularly salient by the watershed-based context of this study as Lee and Dubovi (2020) borrow the term from geological catchments, "where water from various natural resources moves through and temporarily resides in various landforms and structures as it moves toward its eventual destination" (p. 13). Using the concept of a data catchment, we focused our analytical attention on how information and data flowed across actors and artifacts through interactions, both within and across different science practices, to understand the broader division of labor comprising this project.

We engaged in additional open coding to capture emergent phenomena relevant to our theoretical framework and research questions. For example, we identified when people made *suggestions*, and later examined if and how those suggestions were taken up in the project. This helped us understand issues related to power, as power can be seen in how people are positioned in relation to one another and who is afforded the opportunity to construct and challenge different ideas with regards to particular spaces or actions (Esmonde and Langer-Osuna, 2013, p. 290). For another example, we noticed a preponderance of episodes in which people divided the work of a particular task and assumed different roles while doing so, and so we assigned these episodes with the code *division of labor* (which we note is also a place where power can be observed, e.g., Esmonde, 2017). We present a subset of codes in Table 3.2 to illustrate further select definitions and examples.

Table 3.2. Select codes and empirical evidence from data corpus

Code	**Definition**	**Examples**

Local knowledge	Individuals share or demonstrate situated understandings of place-based phenomena derived from their lived experiences.	While collecting data, a volunteer remarks aloud to a project organizer, "If you go a little bit further up the creek, there's a beaver dam near the bridge."
Suggestion	Individuals make suggestions or offer feedback relevant to the work of monitoring.	A project organizer tells a collaborating scientist they need to rethink the locations of monitoring sites to that they will be more physically accessible for volunteers.
Tension	Moments in which individuals experienced disagreement, frustration, or conflict, ranging in significance from major to minor.	Science advisor and project organizer disagree about methodological decisions and struggle to reach consensus.

Our next step of analysis involved developing axial codes, in which we used the cross-comparative method (Glaser and Strauss, 1967) to engage an iterative process of reviewing and organizing our codes by grouping, dividing, and further structuring them into different thematic categories (Miles et al., 2013). While doing this, we wrote analytic memos to aid in the process of refining categories that were relevant to our research questions and guiding theoretical perspectives that helped to represent community science literacy. For instance, in looking across excerpts tagged with the code *division of labor,* as well as other open codes such as *roles,* we noticed that the division of labor was relatively fluid as people moved across roles. This led us to identify *shifting roles* as a key theme relevant to community science literacy. Importantly, we also intentionally sought out counterexamples and discrepant cases to capture nuance and complexity in our data – such as in examining instances where the division of labor was *not* fluid (Erickson, 1986).

Having coded data corpus, our next step of analysis involved cross-referencing our axial codes and emergent themes to identify how they were distributed within and across different science practices. This allowed us to construct a social representation of the practice of community science literacy across the data catchment of community-based watershed monitoring. In doing so, we paid particular attention to which individuals were involved in which practices, how this related to their formal role within the project, and the degree to which they were afforded opportunities to shape and produce data and information. Specifically, we looked at episodes of coordination work to identify what factors were present in shaping processes of coordination. This allowed us to observe how issues of status and rank figured into community science literacy.

We summarize the entirety of our analytical process in Table 3.3, drawing on Harry et al. (2005). In the following sections, we paint an empirical picture of community science literacy drawing on evidence from our data corpus.

Table 3.3. Overview of analytic procedures employed across data sources

Analytic Procedure	**Description**
1. Deductive coding	Characterize the *science practices* (National Research Council Framework, 2015) that capture the activities in which people were engaged as part of their participation in community-based watershed monitoring.
2. Open coding (1st pass)	Guided by the concept of *data catchments* (Lee and Dubovi, 2020), but not relying on deductive codes, characterize interactions between individuals, as well as individuals and their contexts, within and across science practices.
3. Open coding (2nd pass)	Identify emergent phenomena related to individuals' participation in science practices.
4. Axial coding	Group the discrete codes according to conceptual categories (themes) that reflect commonalities across the codes.
5. Interrelate the explanations	Cross-reference themes to identify relationships between them and the construct of interest – community science literacy – to map its structure and mediating influences.

FINDINGS

Characterizing community science literacy

In pursuit of our goal of operationalizing and characterizing community science literacy, we found that participants - regardless of their formal status - brought diverse repertoires of knowledge and skills to community-based monitoring through their participation in various science practices. We found that this allowed groups to collectively achieve more than individuals could on their own. This occurred through processes of coordination work, which we observed occurring both in-the-moment as well as distributed across time and space.

Individuals bring diverse repertoires of knowledge and skills to community-based monitoring

The social practice of community science literacy relies on the knowledge and skills distributed throughout a community. Throughout the course of this community-based monitoring initiative, we observed that many participants demonstrated local knowledge related to the watershed stemming from expertise developed over time and in place. This local knowledge seemed to develop largely in relation to their personal hobbies and interests that involved spending time outdoors, reflective of this mountain town's dominant outdoor recreation culture. For instance, one adult Stream Team volunteer, Charlie, pointed to a dark boulder in the main channel of Caddisfly Creek during a research interview. Charlie fly fishes regularly in his spare time, and says, "I can guess right now there's a pretty big cutthroat right there behind that boulder," referring to the cutthroat trout - a fish species whose spawning was previously blocked by the Caddisfly Creek Dam. When asked how he knows that, he responded,

> "In river or creek waters there's what's called seams, it's where you have the current of the water pulled against the slackwater. You can even see there's two little seams on the right side of that stick out rock. And what they'll [the trout] do is hold next to those seams, there's a couple reasons. Usually the pools are deeper

> and there's colder water and there's that eddy where they don't have to push against the current there, and they're right next to a feeding trough."

This example demonstrates Charlie's astute observation and reasoning practices, practices that are entangled in nuanced local knowledge of stream ecology gleaned from and embedded within Charlie's history of fly fishing. One project organizer remarked, "a lot of our volunteers and our staff live in the Caddisfly. They come here all the time. It matters a lot to them. They know what the site is supposed to look like in different seasons, for example, how deep the water is supposed to be at different times of year." This comment illustrates the extent to which volunteers - all of whom are local residents who live in the watershed - hold knowledge, skills, and practices relevant to the work of monitoring (given that a goal of monitoring was better understanding the watershed). In fact, across interviews, various participants - from project organizers, to scientists, to volunteers - repeatedly acknowledged the necessity of multiple people's contributions for this project to succeed.

Individuals not only demonstrated intimate knowledge of the watershed's inhabitants and rhythms; they also brought these unique scientific repertoires directly into science practices to shape the community-based monitoring initiative. In another example, one high school student named Logan who participated in Backcountry Stream Corps had spent extensive time hunting elk in the same watershed given its proximity to the neighborhood where they lived and their family's hunting background. During an interview, Logan described themself as a leader in the project, saying, "I just had a lot of time there in the Caddisfly. I had walked around some of the exact spots where we were and have sort of a mental map of the Caddisfly in my head." They went on to articulate how they contributed their intimate knowledge of Caddisfly Creek's morphology to better support the group in mapping large woody debris. Logan shared that on the first day of monitoring, the project organizers expressed concern that navigating the many beaver dam complexes and braided stream channel would pose too many challenges for the group. Drawing on their familiarity with the place, Logan reassured the project organizers that the main channel becomes more easily identifiable at a particular point upstream, and at the project organizers' request, proceeded to lead the group in that direction. Not only did Logan illustrate valuable knowledge of the place, like Charlie did above; here, they actively contributed this knowledge to furthering the goals of the project. In a similar example, during one observation of two project organizers and two volunteers conducting vegetation assessments, the lead project organizer comments how skilled both volunteers are with plant identification, and how they would not be able to do monitoring at this level of detail without them. She later speculated in an interview that one of these volunteers might not continue with the project due to his old age, "I'm freaking out, because what happens if he's not around? Shawn and I can't go out there and ID every single plant." In this case, this volunteer's knowledge was not just helpful for the project - it was essential.

Examples of individuals contributing their knowledge and skills to community-based monitoring also extended beyond what might immediately be conceived of as science-related. For instance, one volunteer, Emma, described some interest in fieldwork and collecting data, with the caveat that she was "in no way as into it as everyone else." She recounted approaching one of the project organizers and asking about other ways to be involved in the work, to which they presented her a list of other opportunities. She continued, "They mentioned communications, and I was intrigued by that because I do some photography. So I actually started taking pictures for the project and created a calendar and postcards." In obtaining and communicating information, Emma took photos over the course of an entire year, and intentionally organized them in a way to document changing seasons. She later said, "I hope the photos inspire people to connect with the Caddisfly, because it's a really special place." Photography, while perhaps not considered a science practice by some, allowed Emma to communicate information and contribute to the project's ultimate goal of supporting a healthy watershed. Project organizers recounted other instances where individuals contributed in more artistic ways, for instance, by creating jewelry from caddisfly casings sold at fundraising events. In describing these sorts of contributions, one project organizer said, "We definitely want to encourage it. Everyone's skills have a place here." Creating space for diverse modes of participation allowed for the inclusion of a broader set of individuals in science-related practices, to which they could leverage their knowledge and skills toward building a healthier watershed.

Community science literacy emerges through processes of coordination work

In examining our coded instances of types of interactions between individuals and engaging in science practices, we found that *coordination work* was the key site in which community science literacy emerges; that is, community science literacy can be conceptualized as intertwined with processes of coordination work. This emerged from our original conceptualization of community science literacy from Roth (2003) that focuses on episodes of engagement between scientists, science-related professionals, and broader publics. We borrow the term coordination work from Lee and Dubovi (2020), and further define it as episodes during which two or more actors collaboratively worked to complete tasks, make decisions, or solve problems that moved the work of monitoring forward. These episodes occurred both in-the-moment, as well as over time and space. They happened both within science practices as well as across them. It is through coordination work that data are produced and move through the broader community-based watershed monitoring network. While individuals may hold diverse repertoires of science knowledge and practices rooted in their own life histories, our data demonstrate that those knowledge and practices come to figure into community science literacy only when they are brought into coordination with each other. We specifically identified coordination work occurring at three levels: group, program, and organization (Table 3.4). We found that it was in these episodes of coordination work when different knowledge systems, perspectives, and goals were brought into conversation with each other, negotiated, and where there was opportunity for diverse ideas to be taken up - actualizing the collective praxis of science literacy.

Table 3.4. Levels of coordination work

Level	Definition	Examples
Group	Individuals work collaboratively in-the-moment to complete tasks, making decisions, or solving problems relevant to advancing the work of monitoring in the short term.	Volunteers and project organizers work together to identify unknown plant species and record their presence on a datasheet.
		Volunteers measure and record stream channel morphology.
Program	Individuals work collaboratively to complete tasks, make decisions, or solve problems relevant to the broader program's structure.	Project organizers solicit feedback from volunteers on pilot monitoring protocols and adjust based on volunteers' responses.
		Project organizers, volunteers, and collaborating scientists determine location of monitoring sites based on different considerations, from ecological relevance to physical accessibility.
Organization	Individuals work collaboratively to determine organizational roles and responsibilities with regards to the broader division of labor.	Collaborating scientists, project organizers, and other stakeholders identify which organizations will assume which forms of monitoring.
		Project organizers send macroinvertebrate samples to laboratory for taxonomic identification; laboratory returns summary data to both project organizers and collaborating scientists.

At the *group-level*, we saw coordination work occur in-the-moment as individuals worked collaboratively in real time, in the same physical space, while engaging in shared practices to make progress toward meeting monitoring goals. We most commonly observed this form of activity as small teams of volunteers and project organizers engaged in fieldwork to collect data. For instance, groups of young people and project organizers in Backcountry Stream Corps engaged in coordination work as they assumed different roles while walking stretches of the creek to map trout habitat. Forming teams of three or four, one person would record data on the datasheet while the others assessed and measured pools and large woody debris. In another example during Stream Team, adult volunteers and project organizers engaged in coordination work as they identified and recorded different plant species along a transect, debating identifications or discussing strategies in doing so. Multiple individuals would gather around a patch of plants in order to document the presence of particular species, leveraging their prior knowledge and coming to consensus as they did so. During episodes of group-level coordination work, individuals contributed their respective knowledge and skills to further the social practice of monitoring actions.

At the *program-level*, coordination work occurred primarily as project organizers, and other select individuals, worked collaboratively to make program-relevant decisions in which they could meet their goals. For instance, while determining methods for assessing vegetation, project organizers and a scientific advisor went through an iterative process to determine what methods would help answer their particular question as to how dam removal impacted riparian plant communities at and below the dam site. Drawing on different references and resources, as well as the input of their colleagues, these individuals went back and forth on deciding the approach they would use for establishing transects and determining what data would be necessary. These decisions were then formalized as part of the broader project monitoring plan. Occasionally, program-level coordination work involved volunteers - particularly those who had demonstrated commitment and interest to the program. For instance, program organizers invited volunteers to pilot data collection protocols in the field and provide feedback as part of the broader process of determining methods. Project organizers then took up and updated protocols with these volunteers' feedback in mind. Coordination work at the program-level came to influence the broader of the project beyond fleeting moments, which determined opportunities for individual participation and the ways in which they could engage in various science practices.

At the *organization-level*, coordination work occurred as organizational actors negotiated broader roles and responsibilities within the scope of the community-based monitoring initiative. Like program-level coordination work, this occurred across time and space. For example, the conservation and education organizations engaged in coordination as they worked to reach agreement on what forms collaborative monitoring would take and what roles each organization would assume. This happened with respect to particular scientific parameters, as the education organization would lead the oversight of some, but not others, as well as with respect to particular practices. For instance, in seeking to understand the impacts of dam removal and whether it was meeting its intended ecological goals, scientists and conservation professionals from the conservation organization developed an initial list of monitoring questions and parameters, at which point they approached the education organization. They did this because of the education organization's decades-long history working with volunteers to collect data on biological, physical, and chemical indicators of riparian health. From this list, they jointly identified the parameters for which the education organization would lead monitoring efforts based on respective capacities and interests. Then, they also identified the degree to which each organization would have oversight over specific science practices. For instance, it was determined that the education organization would lead the process of determining methods and collecting data, as well as early analysis and interpretation of the data, but that ultimately the conservation organization would undertake more formal analyses of the data as a basis for making decisions about the watershed. These examples of coordination work occurred over a series of in-person meetings, emails, and phone calls over several months, and were iterative in nature. Organizational coordination work was less about individuals' contributions; and instead involved organizations identifying their roles in the collaboration based on their respective goals, capacities, and assets, which informs the ultimate shape and structure of community science literacy.

Factors shaping community science literacy

We found that several factors of community-based monitoring were consequential in shaping the emergence of community science literacy. These factors mediated how individuals brought their respective knowledge and practices into coordination with each other as they collaboratively completed tasks, made decisions, or solved problems. Here, we highlight three primary factors that shaped these processes: opportunities for individuals to shift between roles, the presence of brokers, and uneven power relations. These factors – identified early in both reflective and analytic memos – were emergent from the data and present across episodes of coordination work.

Shifting roles

As individuals participated in community-based monitoring, they frequently moved between different roles. This includes formal roles, such as when individuals transitioned from volunteer to collaborating scientist, as well as informal roles when individuals moved between and within different science practices while keeping the same formal title. Many times, individuals occupied multiple roles simultaneously. As people shifted roles and moved fluidly across boundaries, they accumulated science-related knowledge and skills that they could then leverage toward other areas of community-based monitoring.

From our interviews, we learned that multiple individuals transitioned between formal roles in the project. For instance, three of the participants occupied a formal scientific role at the time of the interviews, working in a local laboratory performing professional taxonomic identification to identify macroinvertebrate samples they received from across the United States. The education organization contracted with this lab to identify macroinvertebrate samples collected by Stream Team volunteers in Caddisfly Creek. Before taking these positions, all three of these individuals had previously volunteered with Stream Team for extended periods of time where they engaged primarily in field-based macroinvertebrate sample collection. One individual, Max, had volunteered with the education organization for nearly ten years before becoming a professional lab technician. Max continues to volunteer in the Stream Team program on weekends while working as a taxonomist in the lab. Additionally, Max regularly leads macroinvertebrate sample collection trainings for new Stream Team volunteers. Max described how their experiences in both settings - in the field and in the lab - has allowed them to deepen their familiarity with macroinvertebrates and contribute said expertise to the broader project. In another example of people moving between formal roles, a retired biologist named Andy initially began volunteering with Stream Team as a volunteer to collect data. Drawing on his previous professional experience, Andy approached project organizers to suggest changes to Stream Team's methodological approach for measuring dissolved oxygen to ensure greater replicability - a suggestion that was taken up. Andy eventually became one of several scientific advisors for the project to assist with refining additional methods as well as analyzing and interpreting data, while also continuing to collect data as a volunteer. In these multiple roles, Andy drew on his prior knowledge both as a volunteer as well as a retired biologist to contribute to the project. We can infer from the above cases that individuals had the opportunity to deepen and leverage their expertise toward the overall goals of the monitoring effort by moving across boundaries and shifting formal roles.

In addition to the finding that individuals moved between or held multiple formally designated roles, often across science practices, we also observed how individuals moved across roles informally *within* particular science practices. This typically occurred as groups divided the labor of particular tasks. This division of labor allowed groups to achieve more collectively, and also seemed to facilitate greater flow of information across actors to help build community science literacy. During the focus group with high school students who participated in Backcountry Stream Corps, several shared about how they worked together as a team to accomplish their goals:

> Riley: We never really fell into certain roles. We'd always switch around. I think that no one would fill out the data sheet every single time - we'd switch it up once in a while.
> Leigh: I think it helped benefit us because everyone was getting a chance to do the jobs.
> Jesse: It kind of happened naturally though. I can't think of a point where it all switched, but I think it just got more comfortable.
> Leigh: We were all able to learn at a similar pace because at the beginning we didn't know much about data collection.

While taking fieldnotes, we observed what the Backcountry Stream Corps members described above. Individuals would form teams of three or four people to collect data on the abundance and distribution of large woody debris and beaver dams, wading upstream along the streambank and noting the presence and size of wood, log jams, and different pool types.

Using a clipboard, one person would record information on a datasheet while the others used stadia rods - measuring sticks made of PVC pipe - to take measurements and shout out information for the other person to record. Individuals would rotate between these different roles, taking turns. They developed shorthand communication - calling out, for example, “Okay, large with a rootwad, um, it’s a downstream plunge pool, and okay let’s get the depth…” drawing on the structure of the datasheet. When asked later in an interview about this process of rotating between roles, Riley elaborated further, saying, “It was helpful, because we would, like, know what the other person was talking about. Like if someone yelled ‘lateral scour’ and I had the datasheet I’d automatically know what they were talking about because I had just done it myself. And so it just made us work like a well-oiled machine.” As evidenced by the above examples, individuals’ opportunity to shift between different roles within different science practices - in this case, the practice of collecting data - increased the group’s collective capacity to forward the work of monitoring.

We also call attention to the fact that while many participants moved between roles in this project, not all did. Some chose to focus on particular science practices because they were more aligned with their interests. In an interview, one volunteer, Lee, described their role as a “data collector. I guess that’s the main thing. I’m helping to collect data. The more I do it, the more I want to keep doing it,” later saying, “I don’t want to be the statistician, I hate that stuff… I always thought that collecting data is the most fun part. I don’t want to sit in an office. I want to be outside.” Another volunteer, Mel, similarly indicated a preference for fieldwork, describing other science practices as “all this math… it’s not really my cup of tea.” Others stayed in the same role but because of various constraints. One volunteer, Aria, holds a master’s degree in geology and but has struggled to find employment in her field, and is currently working in retail. She said, "I would love to help answer questions like, 'does this method work?' Or I'm really good at making figures and I could do data analysis with Excel. I have experience with all of that, and I think maybe if I wasn't working so much at [the store], I would be totally happy to volunteer my time for that kind of stuff, but I'm just a little too drained right now when I get off work." These discrepant cases offer important counterexamples and help demonstrate complexity: while opportunities to shift between roles may play an important role in building community science literacy, doing so is not always aligned with individuals' interests or capacities.

Brokers and boundary spanners

Opportunities to shift between roles relates to the notion of boundary spanning, or when people work across disciplinary and organizational boundaries. Notably, we found that there was limited interaction between scientists and volunteers at either group, program, or organizational levels of coordination work. Rather, we saw select participants and organizations - primarily project organizers - serve as brokers who, through processes of coordination work, were key actors mediating the flow of data and information across the boundaries between individuals, organizations, and science practices.

Through our interviews, collaborating scientists and volunteers alike consistently and repeatedly identified project organizers as instrumental for ensuring the success of the project. Much of this commentary was focused on one organizer, Dani. As the lead organizer, Dani both facilitated experiences for volunteers (e.g., leading field-based data collection sessions) while also working closely with collaborating scientists (e.g., developing methods for collecting data). She engaged in coordination work to span boundaries most prominently at the program-level, where she herself described her primary role in the project as balancing multiple goals and “bridging the gap between [the education organization], Andy, and [the conservation organization]. And figuring out how they all work together because we’re all so different, in what our needs are, and what we can do and what we can’t do.” One volunteer who had been involved in monitoring with the Stream Team for multiple years - even before its focus on dam removal - described how Dani “breathed new life into it and sort of took it to a whole new level, which is really cool.” Upon being asked who they went to with questions, ideas, or suggestions, all volunteers we interviewed first named Dani. The lead collaborating scientist at the conservation organization, reflecting on what made the project successful, described Dani as “an ace in the hole, if you will as far as finding someone who could walk that line, who’s excited about the education and getting people out in the stream, but also someone who can elevate that to the next level and collect the data we need.” This was to the point that Andy explicitly wondered “what would happen if Dani went away tomorrow,” calling the situation fragile. By serving as a broker, Dani connected the work of volunteers with the work of scientists, bridging and facilitating the flow of information and data between each group and bringing the larger project into coordination.

In addition to seeing individuals such as Dani serve as brokers and boundary spanners, we also found that the education organization served as a sort of “boundary organization” (Guston, 2001). Within this particular monitoring initiative, the education organization’s central role came to be negotiating and balancing their relationships with volunteers as well as their relationships with collaborating scientists to facilitate the flow of information. Through organization-level coordination work, the education organization served as the central actor mediating interactions across different groups, for instance, in iterative processes of identifying data collection methods that involved input from scientists and from volunteers. Furthermore, the education organization employed the additional strategy of drawing on expertise that was external to the dam removal monitoring project of focus. By leveraging their relationships with local university researchers, for instance, the education organization gained access to example data collection protocols and sampling approaches that they could modify to suit their capacities and data needs for Stream Team. One project organizer described the education organization as a "hub" that served as a central actor connecting local residents, conservation professionals, and scientists with an emphasis on Caddisfly Creek. This helps illustrate that the broker role was filled by more than just individuals - it was also filled by organizations.

Brokers and boundary organizations served as key nodes in the broader community-based watershed monitoring initiative, serving as conduits to facilitate the flow of information, data, and knowledge within and across groups of actors. As such, even if individuals in the broader network did not engage with one another directly in the same physical space, they were connected to one another through the work of brokers. These individuals and organizations played a key role in supporting coordination work beyond the level of individuals, so that community science literacy could build at the collective level.

Power relations

Taking heed of Roth and Lee's (2004) call to focus on the levels of participation in conceiving of science literacy as a collective practice, we documented the degree to which different participants were afforded and constrained in opportunities to participate in varying science practices, while noting if and how this related to their respective project roles. Power can be seen in who has access to particular spaces and actions (Esmonde and Langer-Osuna, 2013); hence, critically examining how participation structures are set up makes visible how power shapes opportunities for individuals to contribute to the project of community science literacy.

Generally, we found that participants' formal roles determined their access to particular science practices in the broader community-based monitoring initiative beyond that of data collection. Ultimately, scientists retained ultimate decision-making authority as to the constellation of tasks and activities. This was related to the division of labor of the broader project. Take the science practice of asking questions, one that is particularly important in that it sets up the other practices that follow. While we observed many participants - specifically volunteers - asking their own questions related to observations from being in the field, these questions were not taken up in the project beyond fleeting interactions, typically with other volunteers or project organizers with whom they shared the questions in-the-moment. On the other hand, questions posed by scientists and conservation professionals set priorities for the monitoring, and pursuantly, structured the subsequent activities in which others would be involved. Monitoring was guided by a set of project-level questions and associated indicators developed by scientists and conservation professionals at the conservation organization through coordination work at the organization-level. This consisted of two primary strategies. In the first, scientists worked to document existing monitoring efforts on Caddisfly Creek so as to identify questions answerable by those data. For example, according to project documents, the monitoring question, "Did dam removal increase fish passage?" would be answerable based on long-term data collected by the State Fish and Wildlife Department who had been conducting annual electrofishing surveys to evaluate changes in abundance and/or species of composition of different fish related to the timing of dam removal. We learned in interviews with scientists that another strategy for developing questions included consultation with agencies such as Federal Wilderness Land Management Authority, National Forest, and the City Parks and Recreation Department, all groups with various levels of formal land management decision-making authority in the watershed. Project organizers and volunteers, on the other hand, did not have the opportunity to contribute to determining project-level questions.

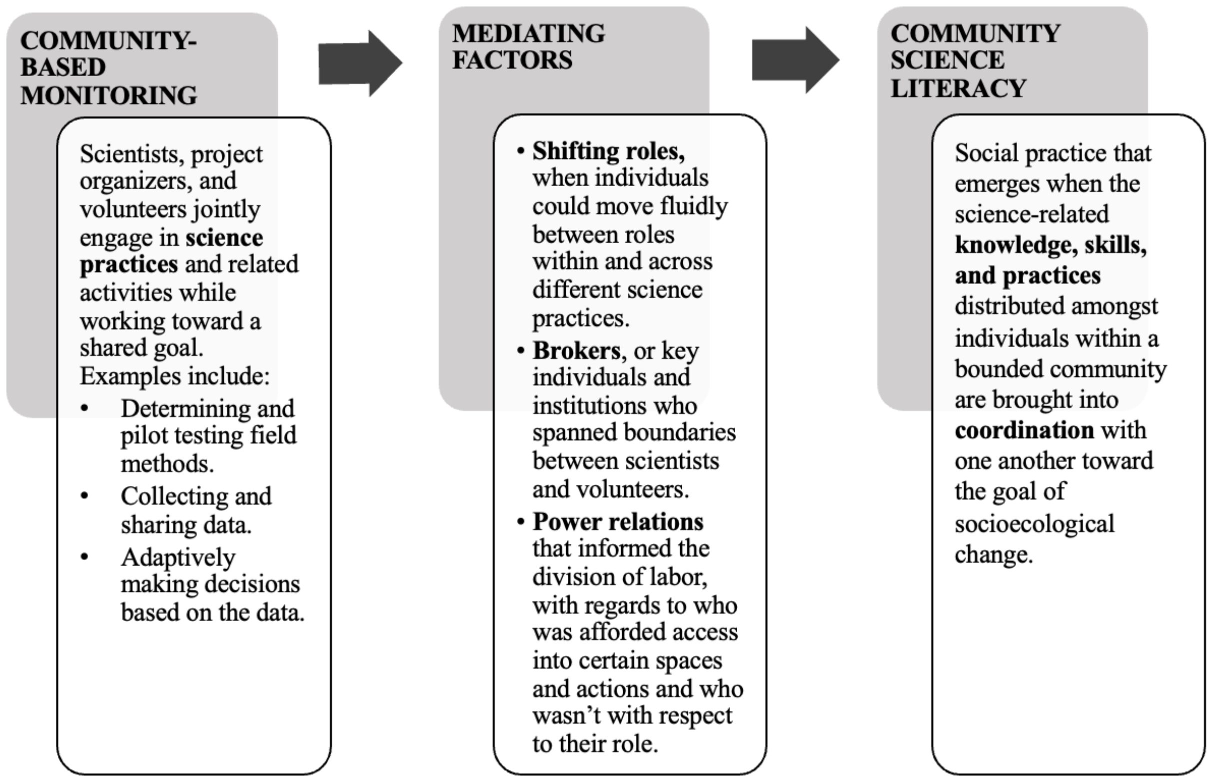
Despite this, we also observed how project organizers made concerted efforts to flatten hierarchies and broaden participation in science practices, which influenced the structure of community science literacy. Project organizers like Dani repeatedly asked volunteers for feedback and input. During interviews, volunteers frequently recalled this with a sense of appreciation that their opinions were valued and even taken up - at least within the scope of structures pre-determined by collaborating scientists. For example, while monitoring topics were set in advance, project organizers offered volunteers the chance to pilot data collection protocols and suggest changes. One volunteer, Rocky, said, "that's why I like [the education organization] so much. I feel like Dani treats me as an equal." Volunteers who demonstrated particular or persistent interest in different aspects of monitoring - such as analyzing and interpreting data - were invited to participate in those practices more fully. One volunteer, Bee, for instance, recounted in an interview that she worked to create a map that integrated data collected by Stream Team with other local climatic data from another local organization focused on climate resilience. As a recent college graduate struggling to find work in the environmental field, she was invited to step into this activity after being encouraged to do so upon expressing her interest in data visualization to project organizers, saying "I think just because I have very specific data analysis skills and because I knew that's what I'd be most useful for." Project organizers repeatedly and enthusiastically articulated their reliance on volunteers and the expertise they brought.

In this sense, the project organizers played a critical role in navigating issues of power in their role as brokers and boundary spanners. In brokering between scientists and the volunteers they worked with – particularly at the group and program-level – they upheld boundaries in some instances, while making boundaries more permeable in others. At the organizational-level, preexisting arrangements between collaborating institutions structured

DISCUSSION

As a concept, community science literacy helps move beyond the individual in considering processes of learning, and in doing so, provides a conceptual bridge for understanding how science education and learning can build capacity for socioecological transformation. In early calls for reconceptualizing science literacy, Roth (2003) describes the choreography of a public meeting focused on drinking water contamination, going on to later write about a creek restoration effort in which students "actively participated in the social life of their community by contributing to the available database on the health of one local stream" (Roth and Lee, 2004, p. 286). Both initiatives involve activities that are common practices in community-based monitoring, which provides a forum for interaction between scientists, science-related professionals, and local residents of a place – although the degree and quality of said interactions can vary (Danielsen et al., 2005; National Academies, 2018; Shirk et al., 2012). In this study, we describe key dimensions of community science literacy to bring further detail to its definition, as well as identify design features of community-based monitoring initiatives that mediate its emergence (Figure 3.2). These findings are simultaneously theory-driven and data-driven, emerging from previous conceptual research into community science literacy, and nuanced through thick empirical description rooted in the present case.

Figure 3.2. Conceptual model for how community-based monitoring results in community science literacy



In this particular case, all individuals involved in community-based monitoring brought diverse science-related knowledge and practices rooted in their own interests and experiences to inform various science practices in the project. In fact, the work of scientists, in this case and in field science more broadly, would not be possible without the contributions of local experts (Stroupe and Carlone, 2021; Vetter, 2016). We observed how volunteers demonstrated local knowledge and practices (Ballard et al., 2008) to the project, having developed them from time spent outdoors - much of it in the very watershed being monitored. This familiarity with the specific location reflects the notion that community science literacy is a function of community life (Roth and Lee, 2004). It additionally reflects the primacy of place in shaping processes of learning and literacy, where knowledge and knowledge construction emerge in relation to specific settings and contexts (Bell et al., 2013; Lanouette, 2022; Pugh et al., 2019). We see these findings as helping interrogate dominant assumptions about expertise in science and environmental decision-making. Often, dominant models of science-related communication or engagement rely on a logic model that assumes unidirectional knowledge transfer from expert scientists to non-expert publics (Kearns, 2021; Stilgoe et al., 2014). While scientists indeed hold specialized forms of expertise, deficit views of local communities fail to account for the rich and layered funds of knowledge they hold (Moll et al. 1992). Beyond funds of knowledge, community members bring varied and complex identities (e.g. fly fisher, hunter) that they are integrating with the work of monitoring – identities not always associated with the work of ecological restoration, but identities from which new insights can be garnered, and identities that can expand through participation in monitoring. Designing forms of joint activity that involve both scientists and broader publics can take this into account and honor and uplift community knowledge and identities in environmental problem-solving, as solving complex challenges requires adaptively drawing on diverse sources of expertise.

Not only did individuals demonstrate local knowledge in this case; said knowledge was leveraged toward advancing watershed monitoring through processes of coordination work. This is critical to the project of community science literacy: not only is it reflective of the knowledge and practices collectively held in a community; it centers on the social practice through which said knowledge and skills are brought into coordination with each other (Roth and Calabrese Barton, 2004; Roth and Lee, 2004). At its core, learning results from engaging in coordinated cultural activity (Nasir et al., 2021). We found that coordination work - occurring at three different scales - is a key site in which community science literacy is produced. Homing in on coordination work helps operationalize the concept of community science literacy, providing a lens for understanding and seeing how it manifests in real-world learning environments. Harkening back to Lee and Dubovi's (2020) notion of a 'data catchment,' we observed how coordination work in this case is what facilitated the work of science via the production of ecological data, as well as the flow of data and information across actors and artifacts. Data is what largely connected scientists, conservation professionals, project organizers, and volunteers, even if they didn't interact or engage with each other in shared physical space.

Rather than there being rigid boundaries and roles, we saw how individuals often flowed between multiple roles while participating in community-based monitoring both formally and informally. This type of boundary-crossing is an ambiguous, yet productive site for learning (Akkerman and Bakker, 2011), and is often a characteristic of community-based monitoring and citizen science projects broadly. Drawing on Sadler et al. (2010), Ballard et al. (2017) note that participating in real, complex scientific efforts offers "a wide variety of entry points to pursue different interests and roles that authentic science requires" (p. 73). Here, we observed that individuals not only pursue different interests and roles; they also move between them. This seemed to bolster the capacity of the broader group to make headway on the work of watershed monitoring as individuals accumulated knowledge and skills in one area that they could then put to work in another.

Brokers also played a key role in supporting the emergence of community science literacy. While there was significant interaction and engagement across participants in this initiative, it was not evenly distributed. When collaborating scientists and volunteers came together, for instance, it was typically in happenstance moments or as they navigated holding multiple roles. For the most part, interactions between scientists and volunteers were mediated by project organizers who served as 'boundary spanners,' people who work across disciplines and engage in functions such as connecting producers and users of knowledge (Goodrich et al., 2020). These individuals were critical in facilitating the flow of information across actors, balancing multiple roles and objectives, and generally advancing the work of monitoring. Other studies from wide-ranging bodies of literature - from educational research, to science and technology studies, to biodiversity conservation - have similarly demonstrated the important role knowledge brokers play in supporting learning (Akkerman and Bakker, 2011; Dilling and Lemos, 2011; Hardie Hale et al., 2022). These individuals typically hold several key attributes, being skilled at communication, possessing social capital, and demonstrating cross-cultural competencies (Goodrich et al., 2020; Jesiek et al. 2018).

We found that power relations, as seen in the division of labor of the community-based monitoring initiative, ultimately mediated the structure of community science literacy. While boundaries were fluid and crossed by some individuals as they shifted between roles, scientists and conservation professionals retained ultimate authority in the design of this initiative, and dominant scientific ways of knowing were thus at the forefront of the project. This is common in citizen science projects, where the role of broader publics is limited primarily to data collection and the expertise of scientists structures opportunities for learning (Jadallah et al., Chapter 2; Shirk et al., 2012). Many have called for citizen science projects to address issues of power, and pivot to align themselves more fully with their participant goals, motivations, and values (Pandya, 2012; National Academies, 2018; Cooper et al. 2021). While different participants were able to bring different knowledge and practices into this broader structure - largely as a result of brokers' efforts to carve out space for further volunteer participation - we see there being missed opportunities when it comes to broadening the perspectives from which knowledge is co-generated (Stroupe and Carlone, 2021). Volunteers remain broadly limited in their ability to shape the structure of this project. Those who did come to deepen their involvement and take on more specialized or senior roles often had strong interests in science, as well as formal scientific training. Max, for instance, began as a volunteer but was able to offer suggestions to shift the practice of how the project took dissolved oxygen measurements - a suggestion that was ultimately taken up. This may have been at least in part because he was a retired biologist, giving his ideas more sway. Even as hierarchies were flattened in some ways, dominant scientific ways of knowing continued to structure possibilities for the direction of this effort, as is often the case in science learning environments (Bang et al., 2012). This represents a missed opportunity for multiple ways of knowing beyond that of dominant science to be considered environmental problem-solving.

This study carries several limitations, which also point to opportunities for future research. For one, we focus our understanding of "community" as bounded to participants in this particular community-based watershed monitoring initiative. While we account for diversity in participants' social position, rather than taking a flat or static notion of community where we assume shared understandings (Tuck and McKenzie, 2015), our analysis does not include community members beyond those who participated in this community-based monitoring initiative. Because of this, we miss asking about broader science-related knowledge and practices that could be relevant to this watershed. Relatedly, the majority of participants in this project had strong interest, or previous experience, in science practices or conservation work - even if not holding the formal title of scientist or conservation professionals. This reflects common trends in citizen science projects (Lowry and Stepenuck, 2021; Pandya, 2012), and is in part because these individuals may be more likely to elect to participate in something like Stream Team or Backcountry Stream Corps, as well as because of the watershed's location near a city with a strong outdoor recreation culture and an abundance of science and conservation-focused institutions. These include but are not limited to a public research university, land management agencies, and several nonprofit organizations. Thus, it could be argued that this context is one where community science literacy might inherently be more likely to develop and more readily observed.

We suggest future research might take up questions around community science literacy in more diverse contexts - urban settings, community-classroom collaborations, projects with more racially-heterogeneous groups, sites with more contentious relationships to science, etc. - to lend further nuance to our findings, particularly those around power. Calabrese Barton and Tan (2010) and Vakil et al. (2022) for instance, both examine how young people enact critical agency in the context of out-of-school science and technology programs where young people investigated phenomena of relevance (urban heat island effects and surveillance and policing technologies, respectively) and produced documentaries. What is the relationship between these forms of disciplinary agency and community science literacy, and what potential might there be for community science literacy to emerge from these contexts? In the realm of socioecological transformation, specifically, future research might attend to sites marked by environmental conflict and controversy rather than cooperation as was the case in this study. Here, analyses that similarly attend to questions of power and history could further elucidate the sociopolitical, and not just sociocultural, dimensions of community science literacy.

In terms of practical implications, emergent findings from our data point to several potential design features for community-based and place-based learning environments that can catalyze the emergence of community science literacy for socioecological transformation. First, is for designers to create opportunities for people to move fluidly across different roles and science practices in ways aligned with their respective interests and capacities. Second, is to identify brokers and equip them with the training, tools, and supports to span across and bridge between boundaries. Third, is to attend to, notice, and disrupt the myriad of ways in which power might shape participation structures and forms of interaction. Designing learning environments with these principles in mind, and with community science literacy as an end goal, can harness the knowledge and skills found distributed within a community, bring them into coordination with each other, and produce forms of social activity that transform social and ecological relations.

Ultimately, we see great possibility in conceptualizing science literacy as a community endeavor in thinking about how science education can support moves toward healthier and more livable environments. Environmental problems are complex, and solving them requires more than just dominant scientific knowledge – it requires the knowledge, skills, and practices of multiple groups, wherein these groups learn with and from one another (Berkes, 2004, 2009; Krasny and Roth, 2010; Wals, 2007). Science learning environments can better contribute to environmental problem-solving should they be designed to embrace heterogeneity and support these processes, particularly in ways that attend to and disrupt dominant hierarchies of power (Bang et al., 2012).

CONCLUSION

In this study, we document how community-based watershed monitoring represents a rich context for the emergence of community science literacy. We found that community science literacy consists of two distinct yet interrelated components: the knowledge and practices collectively held by a community, as well as the process through which said knowledge and practices are brought into coordination with each other toward a common end. In this case, the common end was co-producing new forms of knowledge about the creek to support a thriving watershed. The network of actors involved in this initiative functioned and developed as a result of the knowledge and practices brought by many individuals. We found that this process was mediated by opportunities for individuals to move across roles, the presence of brokers, and power hierarchies rooted in issues of status and rank. We suggest that using the concept of community science literacy can aid in the design of learning environments where the goal is less about moving individuals toward attaining a predetermined benchmark of science knowledge, and more about catalyzing the knowledge and practices already distributed within communities toward the goal of building more healthy, resilient socioecological systems.

CHAPTER 4. COMMUNITY SCIENCE LITERACY AS A SOCIOMATERIAL PRACTICE

INTRODUCTION AND BACKGROUND

Science education can play an important role in environmental problem-solving, an area of research that has attracted increased scholarly attention (Ballard et al., 2017; Campbell et al., 2021; Morales-Doyle and Frausto, 2021; Wals et al., 2014). Solving complex environmental problems requires that diverse sets of actors work collaboratively to take collective action (Ardoin et al., 2023; Muro and Jeffrey, 2008; Wals, 2007); however, much of science education research tends to focus on individual learners rather than the processes through which groups and communities work collectively. To this end, this study focuses on the concept of *community science literacy*. In working to conceptualize science literacy as a community endeavor, we draw on empirical evidence from a case study of a multi-pronged community-based watershed monitoring effort where scientists, conservation professionals, and broader publics worked together to document the recovery of a local creek following dam removal.

Community science literacy

Science literacy is often considered a normative goal of science education in the United States, and yet, amid several decades of ongoing debate, the meaning of the term has evolved and shifted over time with there remaining limited consensus through the present day (DeBoer, 2000; Laugksch, 2000; Roberts and Bybee, 2014). In reviewing this debate, Roberts (2007) uses the language of Vision I and Vision II to name two distinct perspectives on science literacy that have emerged, the first focusing on *knowledge within science*, and the second focusing on *knowledge about science-related situations* (p. 730). Both of these perspectives, while different significantly in their implications for science teaching and learning, conceptualize science literacy as a property characterizing individuals.

An alternative perspective can be seen in conceptualizations of science literacy as an emergent collective phenomenon rather than an individual trait, henceforth referred to as *community science literacy*. Here, we draw on Tuck and McKenzie's (2015) reading of Donna Deyhle (2009) who describes community not as a uniform group of people, but as place, focusing our understanding of community science literacy as a place-based phenomenon. Importantly, community science literacy is more than the sum of the knowledge held by individuals in a community; rather, it comes together through established networks of trust, behavior, relationships, and power as people from diverse walks of life interact over contentious and/or relevant issues (National Academies 2018; Roth, 2003). In other words, community science literacy can be understood as consisting of two dimensions: the knowledge, skills, and practice distributed within a community, as well as the processes of interaction and engagement in which such knowledge, skills, and practices are brought into coordination with one another toward a shared goal (Chapter 3).

Understanding community science literacy as a social practice builds on the proposition that not every single individual needs to possess the same generalized body of science knowledge and skills by a certain age as a standardized outcome of science education (Falk et al. 2007). Research on the actual use of science in everyday life has instead revealed that individuals' possess their own unique science repertoires that are applied directly to personally-relevant problem-solving (Feinstein 2011). It is through diversity in science knowledge and skills held by individuals that "communities can achieve levels of sophistication in science literacy that transcend the knowledge and skills of any individual in the community" (National Academies, 2016, pp. viii). In other words, the community itself becomes more literate as a whole because of the diversity of evolving experiences and understandings that can be brought to bear on science-related problems. This occurs when individuals have the opportunity to contribute said knowledge and skills back to the community through engagement in shared practices and collective, consequential activities as part of everyday life.

Why conceptualize science literacy as a community endeavor?

Conceptualizing science literacy as a community endeavor can provide benefits to individual learners. While many conventional science learning environments "[coax] individuals into certain performances," for instance, rote following procedures in a science lab experiment to achieve an expected result, community science literacy as a design goal can support learning environments with "a variety of participatory modes, more consistent with a democratic approach in which people make decisions about their own lives and interests" (Roth and Calabrese Barton 2004). Indeed, framing science literacy as a community endeavor stands in contrast to traditional, top-down modes of science learning where science is disconnected from community life. In conventional science education, normative and rigid descriptions of discipline-specific subject matter in schools can restrict the intellectual and expressive opportunities for learners, particularly learners from marginalized backgrounds (Bang et al. 2013). Standardized curricula and testing in formal science education, guided by individual definitions of what science literacy should entail, flatten science learning into "vocabulary acquisition, the development of procedural skills, the use of labs that have known outcomes, and the reproduction of textbook explanations" (Stroupe and Carlone, 2021). Recognizing and building from the science-related knowledge, practices, and other assets that individuals carry can support sustained participation in science, in which there is meaningful value for learners as it is connected to their interests and their communities.

Beyond benefitting individual learners, community science literacy provides a conceptual lens for understanding how science education can play a role in enhancing community capacity for solving science-related – and specifically environmental – problems. Fundamentally relational, community science literacy is enacted when scientists, science-related professionals, and broader publics mutually engage and interact with each other to co-produce knowledge (Roth and Calabrese Barton, 2004). As these actors mutually engage with each other in the shared practice of science, they may build trust, mutual understanding, and social capital through learning that strengthens the broader social network's adaptive capacity to address shared problems or goals (Fernández-Giménez et al., 2008). In fact, there is a robust body of literature in environmental sociology and governance examining how learning processes increase a system's adaptive capacity (Suškevičs et al., 2018). Jordan et al. (2016) suggest that learning feedbacks provide an appropriate mechanism for studying how projects that "foster and engage in partnerships with scientists, managers, and the public who gather, analyze, and share scientifically valid, or authentic, data" support community capacity and ultimately change and transformation (p. 488). Given that complex environmental problems require the collaboration of individuals with different sets of expertise (Jadallah and Ballard, 2021), fostering community science literacy can build capacity for environmental problem-solving.

Sociocultural perspectives on learning, literacy, and materiality

Understanding science literacy as a community endeavor aligns with other literature on learning in informal environments that highlights the distributed nature of problem-solving, in which problem-solving is not done by lone individuals but rather "embedded in a social network that collectively performs necessary tasks and cognitive work" (Nasir and Hand, 2008, p. 144). Theories of distributed cognition, for example, assert that learning and literacy occur not just "in the mind," but rather, are spread out amongst multiple individuals, tools, and structures, and dependent on material and cultural artifacts (Hutchins 1993, 1995). Distributed cognition emerges from the Vygotskian-tradition of sociocultural scholarship that recognizes learning as a fundamentally social endeavor between individuals and their historically-constructed social worlds (Vygotsky, 1978). Sociocultural perspectives on learning and cognition emphasize the fundamental role of mediational means within broader social, cultural, political, and historical contexts as constitutive components of learning and literacy (Sawyer, 2005; Nasir et al., 2020). Sociocultural theories of learning point us to meaningfully consider the role of the material world in processes of learning, "[blurring] the sharp boundaries that cognitive theories of learning have placed between individuals and their environments" (Esmonde, 2017, p. 9).

Material infrastructure forms a critical dimension of the sociocultural context of science learning environments. For instance, amateur astronomists depend on an extensive and varied array of material artifacts to engage in their hobbyist practice - artifacts that enable their sustained and interest-driven participation (Azevedo, 2012). Middle school students' learning of computational concepts as part of computer science education is driven by the weaving and manipulating of fabrics and other craft materials in a public school's design studio (Keune, 2022). As Tang (2022) puts it, "materiality in this sense is not simply about the use of objects in science investigations, but a reexamination of how materials, in coordination with our speech and gesture, work to create joint meaning" (p. 971). Scholars in science and technology studies have described how the work of science, material artifacts, agency, and interaction mutually constitute each other (Barad, 2007; Latour, 2005), with scientific inquiry being fundamentally rooted in the material world (Tang, 2022).

While considering the role of the material world has offered valuable affordances for the study and design of learning environments and learning processes, sociocultural theories also come with their limitations. As Bang (2017) has pointed out, sociocultural theories attend primarily to interactions between humans and focus minimally on interactions in and with nature, reifying colonial premises like human exceptionalism in which the natural world is seen as a backdrop to, rather constitutive component of, human activity. These ideas are rooted in Cartesian logics that separate the body and the mind, a Eurocentric idea pervasive in dominant knowledge systems (Tuck and McKenzie, 2015). Other perspectives - such as those rooted in Indigenous epistemologies - further recognize the inseparability of mind, body, and land in which humans do not occupy a privileged position as the only agentic actors in the world (Bang and Marin, 2015). Recent research has highlighted the importance of physical interaction between humans and more-than-human nature as contributing to learning and identity development (Hecht and Nelson, 2021), and as well as how embodied movement can foster connections to more-than-human nature (Stapleton and Lynch, 2021).

Community-based monitoring as a context for community science literacy

Taking the above perspectives into account, we focus our study on a case study of a community-based watershed monitoring project. Community-based monitoring, conceptualized as a distributed cognitive system, does the work of "propagating and acting upon information using various forms of media for representation across space, time, and actors" to some common end (Hutchins, 1995, in Lee and Dubovi, 2020), the end in this case being watershed restoration and stewardship. Community-based environmental monitoring projects may serve as learning environments that foster community science literacy because they can be designed to support the engagement of multiple actors and multiple ways of knowing in science-related practices (Ballard et al. 2008). In some of their early accounts describing community science literacy, Roth and Lee (2004) examine a creek restoration effort in which students “actively participated in the social life of their community by contributing to the available database on the health of one local stream” (p. 286). Because students contributed data, this effort might today be characterized as community-based monitoring, or more broadly, as a form of citizen science or community science.

Citizen science and community science - while different in their specific forms and traditions - can be broadly defined as authentic scientific research in which people who are not professional scientists participate in some or all stages of scientific research or monitoring projects, usually alongside professional scientists (Bonney et al. 2009; Cooper et al. 2021). Community-based monitoring is another form of public participation in scientific research, often distinguished from other types of citizen science or community science by being place-based and primarily informing local decision-making as opposed to informing scientific discovery (although monitoring can and does inform novel scientific discovery). These types of projects span a variety of methodological approaches and are theorized to have a wide range of positive social and ecological outcomes related to learning and stewardship at multiple scales (Jordan et al., 2012). In fact, these projects have been proposed as a particularly meaningful context for science learning because they can be designed to provide learners with opportunity to engage in complex socioecological systems and in authentic problem-solving in ways that are reflexive to their own interests, values, and priorities (Ballard et al. 2017; Mueller et al. 2011; Roth and Calabrese Barton, 2004). A National Academies report on *Learning through Citizen Science*

(2018) specifically suggests that citizen science may foster community science literacy, noting that the "learner" may be broader than individuals given the nature of citizen science projects and activities (p. 64).

Community-based monitoring has been shown to help build the resilience of socioecological systems in part because it allows for multiple perspectives to be brought to bear on environmental problem-solving (Ballard et al., 2008; Conrad and Hilchey, 2011; Fernández-Gimenez et al., 2008). Many environmental problems do not lend themselves to being solved by dominant forms of science alone given their complexity, as well as the challenges in briding science and decision-making. Berkes (2004) argues that this necessitates a new kind of environmental science – like community-based monitoring in which researchers, stakeholders, and communities interact to define important questions, objectives of study, and relevant evidence. This entails ensuring that problem-solving processes uplift forms of expertise beyond that of dominant science - for example, local and traditional knowledge - as essential for devising more thorough, effective, and equitable environmental solutions. Community science literacy helps provide a conceptual lens for further understanding the processes through which community-based monitoring can build resilience and foster socioecological transformation.

Research Question

Drawing on the above perspectives, the purpose of this study is to further examine how the sociocultural context of learning environments – and specifically community-based monitoring – mediates processes of community science literacy within the broader context of socioecological transformation. We focus specifically on the material and natural dimensions of learning environments. Despite increased attention on these constructs, and desires for science learning environments to catalyze environmental change, there has been little empirical research investigating their relationships. As a result, we ask the following research question: *How do material artifacts and the natural world - as core features of community-based watershed monitoring - mediate processes of community science literacy?*

To answer this research question, we focus on a case of a multi-pronged community-based watershed monitoring initiative that arose in response to a dam removal effort in the Mountain West. Specifically, we sought to examine how different actors work together through the shared practice of monitoring as part of the practice of community science literacy, and how both material artifacts and the natural world figure into this work. This is part of a larger study in which we investigate processes of community science literacy, seeking to describe if, when, and how it emerges from community-based watershed monitoring, and what factors shape its emergence (Chapter 3). In the following section, we describe the context for the specific community-based watershed monitoring projects in which we collected this data, then describe our specific methods for data collection and analysis.

METHODS

Case Context

This study focuses on community-based monitoring within the context of a broader collaborative monitoring program related to the removal of the Caddisfly Creek Dam in 2020. Caddisfly Creek is a coldwater mountain stream on the ancestral lands of the Salish and Kootenai peoples flowing from its headwaters in designated wilderness areas, through an urban park, and ultimately to its confluence with a larger river downstream for which it is a tributary. Goals for removing the dam - which was rendered obsolete after the local municipality switched its water source to groundwater - include restoring upstream spawning historic habitat for threatened trout species, improving public safety, and increasing recreational opportunities for the local community. Monitoring is an important component of all conservation initiatives but especially for dam removal given the high levels of uncertainty with these projects and the need to adaptively integrate research, decision-making, and action through adaptive management (Holling, 1978; Groves, 2019).

Both community-based monitoring programs (Table 4.1) are coordinated by a small informal education organization in the watershed. The nonprofit initially became involved in monitoring the impacts of dam removal after being approached to initiate a partnership by a larger conservation organization that spearheaded the dam removal and manages ongoing restoration efforts in the watershed. The first project, Stream Team, involves a varying number of adult volunteers of all ages who collect data on biological, physical, and chemical indicators of creek health in small teams with project organizers on a weekly basis after attending an in-person training event. Trainings are hosted several times a year, and volunteering requires no long-term commitment. The second program, Backcountry Stream Corps, involves high school students who count and map the distribution of large woody debris and riparian pools with project organizers in the creek's headwaters during a two-week intensive effort. Monitoring sites are accessed via mountain biking. Data from both programs are collated by the education organization's staff, who then share it with the conservation organization and other stakeholders to use it in decision-making regarding the health of the watershed.

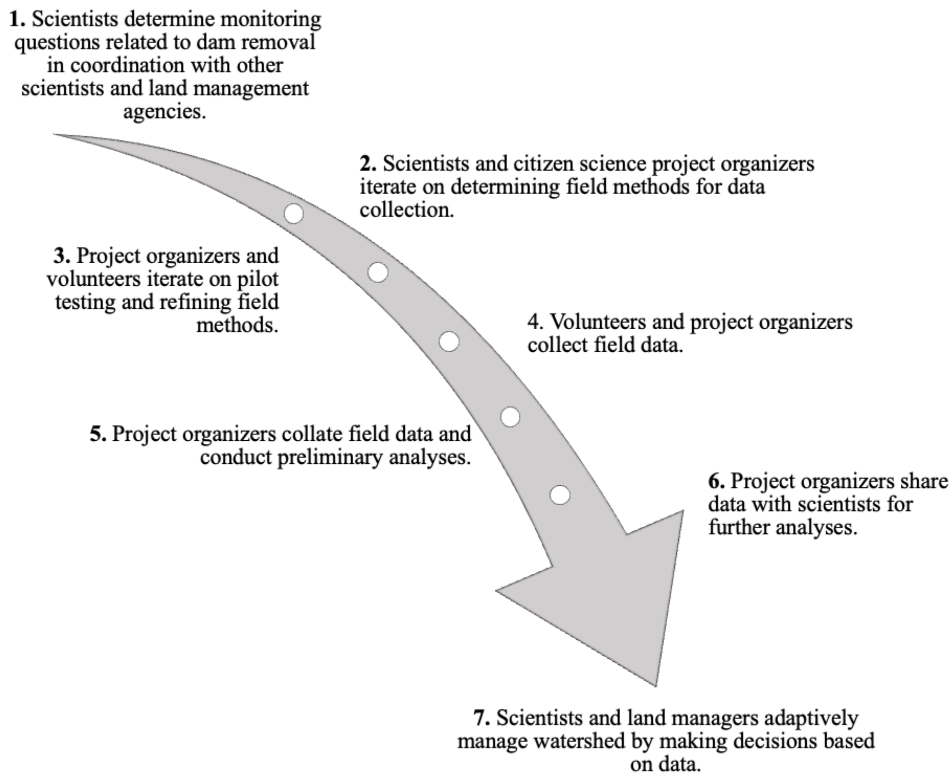
Table 4.1. Community-based monitoring program characteristics

Program	**Scientific Parameters Monitored**	**Volunteer Age Range**	**Sites Monitored**	**Monitoring schedule**

Stream Team	Biological *E.g. Vegetation assessments* Physical *E.g. Channel cross-section profiles* Chemical *E.g. Dissolved oxygen*	Adults	Urban park accessible via automobile and public transit	Weekly, summer through fall
Backcountry Stream Corps	Large woody debris surveys Headwater beaver dam inventory	High school	Designated wilderness, accessible via mountain biking	Two-week intensive, summer

We use the term "participants" to describe all the individuals who were involved in community-based monitoring. Our sample is bounded to these individuals, regardless of their respective role. We use pseudonyms throughout this article when referring to participants in order to protect individuals' identities in accordance with protocols for ethical research with human subjects and guidance from the UC Davis Institutional Review Board. Project organizers are the primary coordinators responsible for designing, organizing, and facilitating community-based watershed monitoring in ways that attend to both collaborating scientists and conservation professionals' goals as well as volunteers' needs and strengths. Collaborating scientists and conservation professionals primarily lent technical expertise toward monitoring, with a vested interest in the data being collected. Volunteers are local residents who elect to participate in either Stream Team or Backcountry Stream Corps for a variety of motivations. While the students in Backcountry Stream Corps received a small stipend for their contributions, we still refer to them as volunteers for the sake of simplicity. Together, these sets of individuals collectively contributed to the community-based monitoring effort (Figure 4.1). While diverse in their social positions and roles with respect to the project, the majority of participants were white - reflecting the broader racial demographics of the city and region in which this study took place.

Figure 4.1. Overview of Caddisfly Creek community-based monitoring process



Data Collection

Data collection - using qualitative methods - took place primarily over the course of two months in the summer of 2021, with additional data collected in the summer of 2022. We use pseudonyms throughout this article to identify individual participants to ensure confidentiality in accordance with protocols for ethical human subjects research and guidance from the UC Davis Institutional Review Board.

Interviews. We audio-recorded twenty-five semi-structured, ethnographic interviews (Weiss 1995), each approximately an hour in length, with volunteers, project organizers, and collaborating scientists in both Stream Team and Backcountry Stream Corps. Participants were primarily white, reflecting the broader demographics of the region. Interviews were primarily conducted *in-situ*, at or near monitoring sites along Caddisfly Creek with the goal of eliciting "emplaced" data (Tuck and McKenzie, 2015). Questions attended primarily to individuals' roles, contributions, relationships, and experiences within the context of their participation in the community-based monitoring projects. Example questions included:

- What does a typical day look like for you when you are participating in this project?
- How would you describe your specific role in this project?
- How has your work in that role changed over time, if at all?
- Who else is part of this project, and what has it been like to work with them?

Immediately after each interview, we wrote reflective memos to capture emergent thoughts, feelings, and ideas in order to begin identifying salient connections to our research question, and to both identify similarities and differences across situations or across people in an effort to document heterogeneity (Small and Calarco, 2022).

Focus group. We facilitated and audio-recorded a one hour-long focus group with six youth participants from Backcountry Stream Corps, as well as four project organizers, on the last day of the two-week program under a stand of pine trees along Caddisfly Creek. The focus group served as both a pedagogical tool to support participant meaning-making and reflection around their experiences, as well as a data source for the present study.

Participant Observations. We wrote ethnographic fieldnotes (Emerson et al., 2011) during participant observations of monitoring activities - primarily while both youth and adult volunteers were collecting data alongside project organizers - occurring as part of both Stream Team and Backcountry Stream Corps. While writing fieldnotes, we paid particular attention to participant interactions with each other and with their contexts. We also included rough landscape sketches and sensory details in an attempt to foreground the embodied dimensions of learning and the relevance of the biophysical setting (Hecht and Jadallah, In press). We additionally took audio-recordings of select monitoring activities during which writing fieldnotes proved difficult, for instance, while wading through deep water. Fieldnotes and audio recordings were integrated into narrative recounting of the days' encounters, with the goal of turning quick jottings into extended text that included concrete details of the scenes, actions taken by participants, and both direct and paraphrased quotes. Similar to when we conducted interviews, we also wrote reflective memos while writing fieldnotes.

Documents and Artifacts. We collected internal organizational documents about the origin and organization of the collaborative monitoring project, data collection protocols, datasheets, and other artifacts produced by core organizations such as websites, articles, brochures, etc. This allowed us to better understand the history of the project, how it was framed to volunteers, and the ways in which it was portrayed to external audiences (Merriam and Tisdell, 2016).

Data analysis

Given our understanding of community science literacy as a social practice informed by sociocultural perspectives of learning and literacy, we conducted a first pass of open coding interview transcripts, focus group transcripts, ethnographic fieldnotes, and project documents to classify episodes of interaction between individuals, and interactions between individuals and their contexts, as they engaged in science-related practices. Employing multiple methods and looking across multiple data sources helped us increase internal validity (Merriam and Tisdell, 2015). Example codes included *decision-making, negotiations,* and *training* as being used to characterize the types of interactions in which people were engaged. We also classified episodes of interaction between individuals, human-made objects, and the natural world, with example codes including *tool use, swimming,* and *plant identification*, in an effort to expand our focus beyond human-human interactions. We present a subset of codes in Table 4.2 to illustrate select definitions and examples.

Table 4.2. Select codes and empirical examples from data corpus

Code	**Definition**	**Examples**
Decision-making	Processes in which individuals selected a course of action amidst multiple potential options.	During fieldwork, project organizers and volunteers needed to determine which route to take through forested areas to get to particular sampling sites.
Training	Individuals either providing or receiving guidance from one another, either formally or informally, related to project activities.	Project organizers, seasoned volunteers, and others with project-relevant knowledge explained and demonstrated procedures and skills to novice volunteers.
Plant identification	Processes in which participants document and describe particular plants' species or genus.	Individuals conducting vegetation surveys worked to identify individual plants using Latin and/or common names.

Using the cross-comparative method (Glaser and Strauss, 1967), we engaged in an iterative process of reviewing and organizing our codes by grouping, dividing, and further structuring them into different thematic categories. After grouping multiple codes together, we identified episodes of *coordination work* - drawing the term from Lee and Dubovi's (2020) discussion of family engagement with health-related data - as a prominent category of interaction amongst individuals occurring across both programs and across multiple stages of the scientific process. Coordination work is a key dimension of community science literacy (Chapter 3). For the purpose of this analysis, we define coordination work as episodes when multiple actors work together to make decisions, complete tasks, and achieve goals. Coordination work can occur in-the-moment, or can be distributed across space and time, at group, program, and organizational levels, and it is through coordination work that we understand community science literacy as a social practice to be enacted (Chapter 3).

After identifying episodes of coordination work, we conducted a second pass of coding examining these episodes. This analytical pass was guided by theories of distributed cognition - that recognize the central role of material artifacts and biophysical context in learning (Hutchins, 1995; Bang, 2017). The goal of this analytical pass was to identify if and how these factors mediated episodes of coordination work, and resultantly, community science literacy. We considered material artifacts as primarily those created by humans - such as waders, insect collection nets, notebooks, and datasheets. As part of our efforts to interrogate and deconstruct the artificial binary between nature and culture, we considered the natural world to consist of both ecological and built environments, such as trees, macroinvertebrates, rocks, roads, and trails. By identifying codes that co-occurred with episodes of coordination work, and distilling themes from reflective and analytic memos written throughout the data collection and analysis process, we identified the specific ways in which various factors mediated coordination work, and thus, community science literacy given coordination work is how we understand community science literacy as a social practice to be enacted (Chapter 3). We intentionally sought out and report on discrepant cases to understand how these factors both facilitate and hinder coordination work, in order to generate our findings on how the material context of the learning environments we studied played a role in community science literacy.

FINDINGS

In examining our data, we found that embodied interactions with material artifacts and the natural world were prominent across episodes of coordination work as individuals engaged in science-related practices with each other. Specifically, we found that material artifacts aided in the completion of scientific tasks and navigating scientific uncertainty, while also being embroiled in issues of power, status, and rank. We also found that the natural world aided in the completion of scientific tasks and shaped processes of decision-making around ecological monitoring. The following episode of coordination work, condensed from our ethnographic fieldnotes, provides a rich example of coordination work in action, and helps illustrate these findings:

> **Vignette taken from ethnographic fieldnotes on June 24, 2021**
>
> Two project organizers - Dani and Taylor - along with two volunteers - Andy and Charlie - set out to one of their annual monitoring sites to conduct a vegetation assessment, the data from which they will use and share with collaborating scientists to track changes in plant community structure over time as part of a broader watershed restoration effort. A short walk from the main trail and the creek itself, tall pine trees towered overhead as we pushed aside brush to follow a small deer trail to the site. Following protocols developed in coordination with collaborating scientists, they needed to set up a transect with the exact same endpoints as last year's transect in order to reduce annual variability in their data collection. To find these endpoints from last year's survey they had left large metal nails - about a foot long - near the base of two trees about forty yards apart to mark them. Additionally, Taylor brought a hand-drawn map she made of the site last year, marked with the main trail, the deer trail, and the location of specific, visually-distinguishable trees, in order to further narrow where they would have to search to find the nails endpoints. Taylor and Dani huddle together, looking up and down periodically, and pointing back and forth between the paper and the trees to move toward where they suspect the endpoints are. Once they narrow down the area to a few trees, Andy turns on his metal detector and begins to scan the ground until he finds the nails.

From this vignette, we see that locating the endpoints of the transect - a task necessary to advance the scientific work of vegetation assessments - required coordination not just between Dani, Taylor, Andy, and Charlie; it simultaneously necessitated coordination with physical and representational tools (e.g. the nails, metal detector, and map) and the natural context of the place itself (e.g. the trees). In drawing on these artifacts and the natural world, the group was able to extend its cognitive capacity (Hutchins, 1995), allowing them to address the short-term goal of conducting vegetation assessments in service of the long-term goals of understanding the impacts of the dam removal on the health of the watershed and adaptively managing the watershed for sustainability. Below, we detail the specific ways in which these factors served to mediate community science literacy by drawing on examples from our data corpus selected for their representativeness of findings.

Community science literacy is mediated by material artifacts

Material artifacts aid in the completion of scientific tasks

At a foundational level, artifacts played a central role in moving the work of ecological monitoring forward as individuals necessarily coordinated with each other and with the tools of science. Throughout field-based data collection, decisions and tasks were made possible entirely because of artifacts. For instance, we documented in our fieldnotes how volunteer participants used GPS units to map the location of log jams - masses of large woody debris gathered in the creekbed that help create fish habitat - that they recorded on paper datasheets to later be shared with project scientists and land managers. In another example from our fieldnotes, we documented how project organizers informally crafted quadrats - square structures often used in ecological sampling - from white plastic pipe and twine that they used with volunteers in order to assess vegetation. Given the high cost of quadrats from formal scientific outfitters, they built these quadrats using materials from a local hardware store. Both of these tasks, mapping the location of log jams and assessing vegetation - would have been impossible had not individuals coordinated with material artifacts in creative and complex ways.

We also documented how individuals relied less on artifacts over time as they engaged in field-based data collection. In addition to mapping log jams while sampling for large woody debris, volunteer participants also classified stray logs by size and recorded this information as they waded through the creek. To do so, they used stadia rods - meter-long poles that functioned as a measuring stick - that they held up alongside the diameter of logs in the creekbed to determine whether they were small, medium, or large using the predetermined protocol. Toward the front end of the program, volunteer participants relied heavily on the stadia rods to classify log size. Toward the latter end, volunteer participants would make judgment calls as to log size without using the stadia rods, calling out size classifications to other volunteers who confirmed or questioned their decision and recorded it on a datasheet. These tools helped people attune to the features of the natural setting and read the landscape more closely to the point where they no longer used them.

Additionally, we recorded how participants drew on material artifacts during episodes of coordination work across other stages of the scientific process beyond field-based data collection, for instance, while creating protocols and datasheets, compiling data into an online database, and analyzing data using specialized software. These episodes primarily included project organizers, collaborating scientists, and more seasoned volunteers who had assumed specialized roles in the program - as opposed to novice volunteers - as it was only these people who participated in these spaces and actions.

Material artifacts aid in navigating scientific uncertainty

Beyond being necessary to advance the work of monitoring broadly, artifacts played a notable role in helping individuals engage to complete tasks and make decisions in the face of uncertainty. Uncertainty - latent in the work of science - is particularly prevalent in ecological monitoring given the many intricacies and challenges of making precise observations in the field. Locating the endpoints of transects for vegetation assessments, as described in the earlier vignette, provides an example. However, uncertainty can also be a productive space for scientific reasoning and argumentation as people draw on tools and evidence in order to engage in science practices (Kirch, 2010; Pickering, 1995).

Taxonomic identification of different species in the field is an example of a scientific practice rife with uncertainty. This can be very difficult for novice and seasoned individuals alike given the diverse characteristics of different plant and animal species; and yet, tracking changes in biodiversity over time can often require these data. We observed this in action through our observations and documented several instances in fieldnotes. In one example, two individuals - Taylor and Charlie - worked together to identify plants within a quadrat. Taylor, the project organizer, holding the datasheet on a clipboard, read the different line items aloud. Charlie, the volunteer, brought a personal copy of a native plant guide, which he consulted at various times to confirm his identification of particular plants. When unsure about how to classify a plant, both of them called over Andy, the other volunteer also serving as a science advisor to the project, who was well-versed in plant identification given his former career as an ecologist. This also exemplifies how this community-based monitoring initiative adaptively drew on diverse sources of expertise beyond just those of paid project staff.

Notable, however, is that when it came to navigating uncertainty in fieldwork, material artifacts were not treated as sacrosanct, and participants sometimes actually questioned the accuracy of the tools - particularly more seasoned participants. During another observation, Dani and Andy were using a plant identification app on Dani's phone to identify a particular plant. The lead author asked if they always use the app to help, and Andy said, "well, it's dangerous because it doesn't always work." The app identifies the plant as in the *Arnica* genus. Andy squats by the plant, touching its leaves, and says, "no, it's definitely not that," to which Dani agrees saying, "that can't be right." They mark the plant as unknown on their datasheet, and take a picture that Andy says they will try to "key out" at lunch to identify - in other words, using a dichotomous key from a different plant identification guidebook he carried with him. Here, both individuals used an identification app to aid their decision-making; however, ultimately relied on their familiarity with local flora, as well as the book, rather than deferring to the identification generated by artificial intelligence.

Outside of fieldwork, individuals similarly drew on artifacts to navigate uncertainty as they engaged in other scientific practices. Datasheets, for instance, were a primary project artifact as they were used by volunteers to record and share observations. During the process of designing datasheets as part of determining protocols for data collection, project organizers and project scientists included sections for participants to record relevant metadata - data about the data. Recording metadata - such as the date or time or weather conditions when data are collected - is a key practice for reducing uncertainty in science as metadata can be used to statistically model bias to increase the validity of project data (Newman et al., 2017; Kosmala et al. 2016). The datasheets as artifacts were thus created in a way to support later navigation of the uncertainty that comes in analyzing ecological data.

Material artifacts are embroiled in issues of power, status, and rank

As individuals negotiated issues of status and rank, we documented multiple instances in which artifacts played a role in mediating these interactions across multiple timescales. Notably, artifacts do not exist as isolated from history. They carry with them a "residue of the activity of prior generations" (Cole, 1996, p. 10). In other words, artifacts are shaped by cultural history just as much as they shape cultural history (Esmonde, 2017) and cannot be isolated from the contested meanings ascribed to them.

Developing monitoring protocols provides an example of how power and artifacts are intertwined on *shorter-term* timescales. Through interviews, we learned how the projects' data collection protocols were jointly developed via coordination work between scientists leading the creek restoration effort and project organizers at the education nonprofit. Scientists initially determined the research questions and ecological indicators to be monitored, and invited the education nonprofit to participate given the nonprofit's history monitoring the same creek. This entailed both the development of new protocols for the nonprofit (e.g. large woody debris surveys), and the refinement of existing protocols (e.g. macroinvertebrate counts). Staff from the education nonprofit led this process with consultation from partner scientists. This coordination work was distributed over time and space, occurring iteratively over conversations that took place through both in-person meetings and emails. Education staff solicited volunteers for feedback on the protocols, and their feedback was often written down and taken into consideration by project organizers. By the time the protocols and associated datasheets were seen by volunteers, however, they already had a history shaped by conversations in which scientist partners set the parameters. Most volunteers did not have access to these spaces and actions, reflecting how power informs who is afforded the opportunity to shape dominant scientific practices.

In an example of how power and artifacts are intertwined on *longer-term*, structural time scales, we learned how the gendered history of scientific artifacts often served to preclude participation in the work of ecological monitoring. One volunteer, Cassie, described "the wader issue" as a gendered barrier to participating in field science practice because she did not have something that she could comfortably wear in the stream due to her body size. For a while, she was able to wear the children's waders until her hips got bigger and she could not put them on anymore. Science and the outdoors have historically been male-dominated spaces, and this history manifests in how science tools and equipment like waders are designed to fit to normative bodies - those of able-bodied men.

Community science literacy is mediated by the natural world

The natural world played an active and important role as people worked together to make decisions or complete tasks with regards to monitoring. Bell et al. (2013) write that, "in contrast to being merely a backdrop against which interesting social activity occurs, place is simultaneously structured by and structures human activity." Indeed, this can be seen in many episodes of coordination work, in which the natural world was inextricably linked with the social practice of community science literacy.

The natural world aided in the completion of scientific tasks

Features of the natural landscape supported individuals in orienting to the place in which they were conducting ecological monitoring. Take the vignette presented at the beginning of our findings. In addition to using a hand-drawn map to locate the endpoints of the transect, Dani and Taylor, the project organizers, coordinated their attention and observation with the trees to determine where they placed nails last year. The trees, in this instance, played an important role in completing this task. Dani, in a later interview, describes herself as being "really good with being out there and recognizing where we're at in the stream, and going back to places, and knowing where we're at geographically." She continues to describe a different instance when she and another participant disagreed about the location of a monitoring site as they were trying to locate it. She says, “when we got to the site, he wanted to turn around because it looks similar to another site, but I knew I was right. I’ve spent enough time in the outdoors and I’m observant of that Ponderosa there, and there’s a juniper there.” In moments like this one and in the earlier vignette, Dani was walking and reading the land (Marin and Bang, 2018), drawing on her local knowledge of the place and leveraging it toward the work of watershed monitoring.

Other participants, including volunteers, similarly oriented their attention with biophysical features of the setting as part of monitoring processes. Cooper, a high school student in Backcountry Stream Corps who regularly hunts and fishes in the area, said, “I’m in the Caddisfly all the time. I know all the little secrets, like nobody knows that there’s bighorn sheep in Beaver Creek, except for me and a couple of friends.” As a result, he described himself as more comfortable in the area, and leader in helping the group collect data. Repeated, long-term engagement in the place helped him calibrate his attention to the contours of the landscape, knowledge that he then used toward advancing the work of science. Notably, not all volunteers shared repeated histories of engagement in the place, and yet, through their interest in the natural world, were able to develop similar repertoires to coordinate with the natural world. Leah, for instance, who struggled with the physicality of the work during the first few days of the program, reflected on how her understanding of the stream changed over the course of the program, saying, “I think it just made me more observant. Like when I go out now, I’m looking harder and noticing better things better than I used to.” When asked what contributed to that understanding, she said, “I think walking through the stream… Sometimes I was like, wow, not many people get to do this and connect to it and even feel the push of the stream, like how strong it would be.” Through engaging in the program, Leah developed a more intimate relationship with the natural world that allowed her to more fully engage in scientific practices such as observation that she contributed to the group while collecting data on large woody debris.

Additionally, many scientific tasks and practices relied on embodied activity - like Leah describes above in feeling the push of the stream. Identifying plants, as another example, required the individuals to collaboratively make sense of the plants' diverse physiological traits using a broad sensory repertoire, particularly sight, smell, and touch. For instance, as Charlie and Dani were working together to jointly identify plants, crouching over a small quadrat, they were cocking their heads to look at them from different angles, touching and reorienting the leaves, and occasionally smelling the plants. One variety of *Osmorhiza*, for example, smells like licorice when bruised, which they used to distinguish it from another visually-similar plant. Charlie, an amateur naturalist, taught this to Dani and Taylor. For other plants, they touch their stems to see if they are sticky or have spines. This embodied engagement with the natural world was essential to advance the work of science, and was frequently drawn upon as a resource as individuals collaboratively worked to complete tasks.

The natural world shaped decision-making around ecological monitoring

Outside of fieldwork itself, design decisions around community-based monitoring protocols were necessarily shaped by the contours of the landscape. For example, decisions as to monitoring site locations were made in coordination with natural features of the watershed. Taylor explains, "we don't like to have our volunteers bushwhacking through stuff, getting in dangerous spots, so [our sites] are all by trails or an easy access point. Relatedly, project fieldwork is scheduled with the seasons in mind, taking place primarily during the late summer and autumn when stream conditions are more favorable to wading due to both temperature and flow. Rather than devise a sampling plan divorced from the ecological context of the place, project organizers took features of the setting into account - in essence, coordinating with the natural world - to make decisions as to when and where sampling could occur. These decisions were made largely out of concern for the safety of volunteers; project organizers repeatedly articulated finding themselves in the position of balancing what practices would garner high-quality scientific data and what would broaden and sustain volunteer engagement.

In a related example, project organizers and scientists decided to skip over beaver dam complexes when conducting large woody debris surveys. Beavers engineer the floodplain's topography, creating riparian habitats (dam complexes) whose structural diversity made large woody debris surveys impractical given capacity constraints. Upon arriving at a beaver dam complex while wading upstream, participants would mark its downstream and upstream boundaries with GPS units to map its location, and not proceed with collecting large woody debris data until passing through. This example, in addition to those above, demonstrates how features of the natural world - from vegetation, to creek flow and temperature, to beavers - shaped scientists' and project organizers' decision-making practice of community-based watershed monitoring.

DISCUSSION

Learning at its core is about engaging in cultural activity, in which it is embodied and coordinated through social interaction (Nasir et al., 2021). Relatedly, community science literacy is produced as individuals from different walks of life interact and engage with each other through science or science-related practices. By looking at evidence from across our data corpus, we documented and identified the ways in which different features of community-based watershed monitoring support interaction and engagement across diverse sets of actors, and resultantly, supports community science literacy. Specifically, we examined how physical, non-human features of the setting - both material artifacts and the natural world - figured into the processes in which community science literacy is achieved. Rather than make universal claims about the role of the material and the natural world in processes of community science literacy across settings, our goal is to provide rich description with lessons and implications that may be transferable to other cases in which scientists, science-related professionals, and broader publics coordinate with each other through the work of science.

On materiality in community science literacy

Our findings as to the role of material artifact help expand on previous definitions of community science literacy as a *social* practice (Roth and Lee, 2002) to further conceptualize it as a *sociomaterial* practice. While many recognize the importance of things like non-human actors (Roth and Lee, 2002) and “reports, spatial arrangements, and historical context” (Roth, 2003, p. 17) for community science literacy, our findings aid in demonstrating empirically how these elements of the sociocultural context come to mediate coordination work, and resultantly, community science literacy (given that we understand coordination work as the site where community science literacy emerges). Other scholars have similarly drawn attention to the role of materiality in science learning environments, for example, in considering processes of argumentation (Tang, 2022) or how extensive and varied material infrastructure sustained interest-drive participation in science-related hobbies (Azevedo, 2018). This demonstrates the need to consider the biophysical elements of the places where learning occurs as essential (rather than extraneous) to science learning and literacy (Bell et al., 2013). Building community science literacy similarly relies on these factors: it is fundamentally a material process just as it is a social one.

We found that individuals collaboratively drew upon material artifacts to complete tasks that would advance the work of ecological monitoring while engaging in shared practices. This reflects established understandings in science and technology studies that show how the work of science is reliant upon the stylized use of specific materials (Barad, 2007; Latour, 2005). We specifically documented instances in which project organizers and volunteers engaged in moments of improvisation to craft tools necessary for completing tasks like data collection and analysis is ubiquitous amongst field scientists - despite not often being thought of as part of the practice of science (Wölfle Hazard, 2022). These artifacts often served to extend the cognition of individuals as they engaged in problem-solving (Hutchins, 1995). However, as novices developed an intimacy with both the project, the biophysical setting, and the material artifacts themselves, they came to rely less on artifacts and more on their own intuition in completing scientific tasks such as classifying objects by size or identifying plants. Shifts in the use of artifacts for problem-solving can be considered learning (Nasir and Cooks, 2009).

More specifically, we found that material artifacts played a special role as individuals worked to mitigate uncertainty. Navigating uncertainty is an essential component of science broadly (Star, 1985) and science education (Manz and Suárez, 2018). Reducing ecological uncertainty is often a central goal in the adaptive management of socioecological systems (Fernández-Giménez et al., 2019; Rist et al., 2013); however, as Sarewitz (2004) argues, scientific uncertainty in environmental controversies is less about a lack of scientific understanding and more about a lack of coherence among competing scientific understandings. Our findings demonstrate how individuals design project-relevant artifacts (e.g. datasheets) and draw upon external artifacts (e.g. field guides) to reduce uncertainty. However, we also found that individuals with higher levels of experience do not draw solely on artifacts to navigate uncertainty; they often give equal or greater weight to their own place-based knowledge rather than deferring to artifacts as unassailable arbiters of truth. While artifacts play an important role in helping people move the work of science forward; supporting individuals with different levels of expertise is similarly necessary in processes of community science literacy.

This is made particularly salient in acknowledging how power, status, and rank show up in relation to material artifacts. Our findings help illustrate how "artifacts carry history with them, and how the creation and dissemination of artifacts is linked to social relations of power" (Esmonde, 2017, p. 17). Furthermore, the potential of material artifacts exists in relation to people's experiences with them, experiences that are shaped by different knowledge systems' varying sociopolitically-consequential orientations to materiality (Tzou et al., 2019). What one person may interpret from engagement with a material artifact may differ from what another person may interpret given differing social positions and ways of knowing. Additionally, access to specialized artifacts is not always evenly distributed and often governed by those with authority in a particular context (Nasir and Cooks, 2009). In considering these factors, we seek to foreground the necessity of considering material artifacts not as neutral features of learning environments, but as imbued with political, epistemic, and social power (Latour, 1995; Bell et al., 2013).

On the natural world in mediating community science literacy

In addition to describing how material artifacts figure into processes of community science literacy, we further expound on the role of the natural world in mediating its emergence. Dominant forms of science and science education often seek out placelessness as a defining feature (Calabrese Barton, 2012) and privilege laboratory science over forms of local inquiry situated in the field within communities (Stroupe and Carlone, 2021). Through our findings, we demonstrate the instrumental role that the natural world plays in community science literacy by documenting how individuals work not just with each other, but with features of the biophysical setting to engage in shared science practices.

Specifically, we identified how coordinating with the natural world aided in the completion of scientific tasks while individuals were working in the field. Collaborative processes in which individuals engaged in shared scientific practices - such as observing phenomena and recording data - did not happen in abstraction from the setting; rather, they happened in relation to the biophysical features of Caddisfly Creek, where trees, water, rocks, and more played an active role. Drawing on Indigenous epistemologies, Marin and Bang (2018) describe how "knowing and learning is accomplished through corporeal interactions where land provides the grounding for the emergence of action and knowledge building" (p. 92). They further describe learning to read land as a relational activity, in which people use "discursive, kinesthetic, and behavioral resources to establish a mutually shared orientation to phenomena and entities of interest and support observational inquiry," a process "structured by interactions with other people and more-than-human life, including land itself" (p. 92).

In addition to in-the-moment coordination with the natural world to complete scientific tasks in the field, we also document how people - specifically project organizers and collaborating scientists - necessarily made decisions about project design in ways that accounted for the centrality of the biophysical setting. The natural world affords or constrains opportunities for action as these individuals make decisions as to the temporal or spatial extent of monitoring activities, as said activities necessarily involve coordination with weather, geography, beavers, and other elements of the setting. These elements thus shaped science practices, indicating the impossibility of separating social practice - and in this case, community science literacy - from place, as each plays a vital role in co-constituting the other. Field scientists have long embraced the places where science occurs, and have developed unique practices to engage in place-based work (Stroupe and Carlone, 2021). According to Vetter (2016), the environmental and physical features of a place are explicitly part of the knowledge produced as field scientists negotiate practices within the limits that the natural setting permits.

In discussing the role of the natural world in science learning and literacy, we call particular attention to the consideration of how understandings of what constitutes "nature" and the "natural world" are culturally-situated and structured by historicized relations of power (Bang, 2015; Ginn and Demeritt, 2009). In the context of the United States specifically, settler colonialism governs land relations, and in fact, coloniality is expressed in and through the land itself (Middleton, 2015). Whereas the dominant logics that undergird settler colonialism and much of Western science situate humans as separate from, and hierarchically ordered above, the "rest" of nature, other ways of knowing - particularly those rooted in many Indigenous epistemologies - see humans as part of nature (Bang and Marin, 2015; Kawagley, 2006; Wildcat, 2009). These knowledge systems "confound the Western animacy hierarchy" that attributes "greater and lesser aliveness" to some humans over more-than-human actors (Tallbear, 2017, p. 180), actors to whom many Indigenous standpoints would understand as acting with agency and intentionality (Bang and Marin, 2015). Building from these perspectives, we aim to push against sharp divides between nature and culture, humans and more-than-human beings, and people and place, and we suggest further research rooted in Indigenous epistemological frameworks could interrogate how the natural world agentively figures into, mediates, and structures community science literacy.

Further Implications

In addition to the theoretical contributions we develop in conceptualizing community science literacy as a sociomaterial practice, this study carries implications for the design of science learning environments that support community science literacy.

Community science literacy emerges not just through discourse; it simultaneously emerged through embodied engagement with material artifacts and in the natural world. Hence, we must not take for granted the role of material objects nor lands and waters in teaching and learning activities, particularly given the histories and meanings imbued in them. This leads us to recommend designing learning environments to support intentional interactions not just between humans, but between humans, material artifacts, and place as interconnected elements of learning processes, similarly to recommendations by others examining processes such as naturalist identity development (Hecht and Nelson, 2021). Here, we suggest that doing so can also support outcomes beyond the level of the individual learner.

We also suggest that these findings are relevant to other emergent conversations on community-level or collective environmental literacy, made 'environmental' because of a focus on natural systems of coupled human-natural systems (Ardoin et al., 2022, 2023; Gibson et al., 2022). While our study focuses on the coupled-human natural system of an ongoing watershed restoration project, we focus on community science literacy because of the science-related nature of community-based monitoring. However, this study further illustrates how community-based monitoring and other citizen and community science projects can create synergies between science and environmental education (Wals et al., 2016). Common in all these frameworks is a focus on how groups of individuals collectively learn with and from each other as fundamental to broader processes of making socioecological change.

CONCLUSION

This study elucidates how community science literacy emerges in, with, and from both the material and natural worlds. Our findings provide greater empirical texture to this construct of growing interest for science educators and science education researchers, and can inform the design of science learning environments that seek to harness the collective knowledge and skills across diverse sets of actors. In the context of complex-social ecological systems like watersheds, environmental problem-solving and action requires that individuals from diverse walks of life work together to bring their respective knowledges and practices into coordination to address shared social and ecological goals. Community-based watershed monitoring provides a forum for these processes, processes rooted in the physical watershed context. As groups engage in coordination work through community-based watershed monitoring and resultantly build community science literacy, they draw on both material artifacts and the natural worlds to complete scientific tasks and make decisions, increasing their capacity to advance the work of environmental stewardship.

CHAPTER 5. CONCLUSIONS

Working towards solutions for complex environmental problems requires that diverse sets collectively learn from each other to co-produce new knowledge greater than the sum of its parts (Armitage et al., 2011; Berkes, 2009). To this end, the objective of this dissertation has been to examine if and how community-based watershed monitoring projects - a type of citizen science - serve as learning environments that foster collective forms of learning and literacy, with critical attention to the mediating roles of power and history. These projects provide a forum for scientists, land managers, and broader publics to participate in shared practices oriented toward river restoration and stewardship. While many studies have examined the individual learning outcomes that can emerge from these sorts of initiatives – usually focusing on how volunteers learn dominant science – understanding how these sorts of projects foster learning and literacy at the community-level represents a new horizon for research, and a promising strategy for environmental problem-solving (Table 5.1) (Ardoin et al., 2022; Jordan et al., 2012; National Academies, 2018).

Table 5.1 Individual and collective processes in research on learning through citizen science as conceptualized in existing research

	Individual Learning	Collective Learning
Process of Learning	Volunteer participation in designated activities, and sometimes hearing from scientists.	Participation in shared practices with varying degrees to the division of labor, dialogue, and co-construction of inquiry and monitoring design.
Content of Learning	Content, process, and nature of science knowledge; skills of science inquiry; interest, self-efficacy, and motivation; behavior and stewardship	Community knowledge and practices, contextual understandings, value in the local ecosystem; science knowledge, measurement and monitoring practices, value in broader systems.

Who Learns?	Volunteers	Volunteers, land managers, and scientists

In reality, the dichotomy in Table 5.1 does not fully represent the dynamism of learning. Learning occurs at both individual and collective levels, and cannot fully be separated into discrete categories. These trends, however, broadly reflect much research that has examined learning in citizen science (National Academies, 2018). An overemphasis on individual learning – perhaps in part because of the dominance of cognitive and behaviorist theories that treat learning as an individual phenomenon – has characterized much research on learning in citizen science, leaving much to be learned about the promise and potential of collective learning in making socioecological change (National Academies, 2018)

SUMMARY OF FINDINGS

In Chapter 2, I leverage micro-analysis of conversational moves in a co-design space to reveal how power asymmetries constrain social learning processes in-the-moment, while simultaneously creating the conditions for expansive learning to later occur. This co-design space involved young people, facilitators, educators, and land managers coming together to determine a focal topic for a youth-led, community-based watershed monitoring project that would inform broader restoration goals in the context of a planned dam removal. This stands in contrast to dominant forms of citizen science, where scientists are those who typically determine the aims and parameters for monitoring. While many studies have attended to how power can negatively impact the conditions under which social learning evolves (Ernst, 2019; Suškevičs et al., 2019), taking a cultural-historical approach in this study revealed how power can simultaneously introduce tensions that trigger the collective reorganization of activities.

Facilitators and educators play an important role in this process and can productively manage power relations to foster social learning.

In Chapter 3, I bring multiple sources of ethnographic data to bear in order to further develop the concept of community science literacy with data from an extant community-based monitoring initiative. While there has been significant theoretical attention examining how science literacy may emerge as collective praxis rather than an individual trait (Roth, 2003; Roth and Calabrese Barton, 2004; National Academies, 2016), few studies empirically examine if and how this plays out in real-world learning environments. I found that community science literacy consists of both the diverse knowledge, skills, and practices distributed within a community, as well as the process in which those knowledge, skills, and practices are brought into coordination with one another. I additionally found several key factors that mediate processes of coordination work, and thus the emergence of community science literacy: opportunities for individuals to shift roles, the presence of brokers, and issues of power, status, and rank. Ultimately, I suggest that community-based watershed monitoring is a rich context in which community science literacy can emerge, and in which the diverse knowledge, skills, and practices existing within a community can be put to work toward socioecological transformation.

In Chapter 4, I build on these findings to apply the concept of 'coordination work' as an analytic lens to examine community science literacy as a sociomaterial practice. To accomplish this, I draw on sociocultural theories of learning that reject binary logics artificially separating human activity from its biophysical setting (e.g. Bang, 2017; Hutchins, 1995). In examining how material artifacts and the natural world figure into processes of coordination work, and thus community science literacy, I found that they are inextricably linked, and in fact, mutually constitutive of one another. This suggests the fundamental role that place plays in community science literacy, and suggests that it is a more-than-human process in which humans are not the only consequential actors. This resonates with Indigenous perspectives on relationality that recognize the fundamental interconnectedness between humans, lands, and waters, whose collective relations constitute reality (Wilson, 2008).

CONTRIBUTIONS

Spanning both conservation social science and educational research, this dissertation contributes to ongoing and emergent conversations on how to best catalyze socioecological transformation through learning and literacy. I draw theoretical and methodological tools from multiple disciplines to conceptualize and measure processes of learning and literacy beyond the level of the individual. These include conceptual frameworks like social learning, drawn from the field of environmental management (Reed et al., 2010; Ernst, 2019; Jadallah and Ballard, 2021), and community science literacy, drawn from the field of science education (Roth, 2003; Roth and Lee, 2004), as well as methodological tools like interaction analysis, drawn from the learning sciences (Jordan and Henderson, 1995; Philip and Gupta, 2020), and ethnographic observation, drawn from sociocultural anthropology (Emerson et al., 2011; Glaser and Strauss, 1967). In leveraging these tools to conduct theoretically-driven, empirical analyses of two cases of community-based watershed monitoring, I reveal how scientists, land managers, educators, young people, and volunteers – working together to monitor the health of their local rivers and creeks as part of broader restoration initiatives – co-construct shared knowledge that undergirds social and ecological resilience. More specifically, I aim to push against the societal privileging of dominant science, which has been pervasive in both environmental science (Liboiron, 2021) and science and environmental education (Bang et al., 2012), to the point that it has become considered the only legitimate sources of knowledge upon which to base policy and practice (Kimura and Kinchy, 2016).

What is the role of science in environmental change-making? It is impossible to separate the history of dominant science as intertwined with empire and colonialism, and as a result, land degradation and environmental harm (Liboiron, 2021; McKittrick, 2020). Even forms of dominant science that purportedly seek to bolster sustainability (e.g. agriscience research that seeks to develop novel seed varieties to be patented by biotechnology companies) often reinscribe unjust power relations (e.g. by constraining the choices of smallholder farmers) and ultimately fail to transform socioecological relations. However, science can and does play an important role in informing environmental management; hence the need for forms of place-based science that are accountable to local communities and relevant stakeholders (e.g. community-based watershed monitoring). By activating the local knowledge, skills, and practices already distributed within communities, these emergent forms of science are well-positioned to contribute to catalyze more equitable forms of collective learning and literacy should they be designed to disrupt epistemic hierarchies and redistribute power. Finding ways to center diverse ways of knowing in learning environments, as opposed to solely integrating them into dominant knowledge paradigms, will be critical in catalyzing more just and sustainable futures (Medin and Bang, 2014; Nadasdy, 1999; Rosebery, 2010; Wölfle Hazard, 2022).

Limitations

This dissertation focuses primarily on power as it relates to issues of epistemic authority, largely at the level of interactions between scientists, land managers, and local watershed residents who volunteer in community-based monitoring projects. While questions of epistemic authority are particularly relevant to processes of learning and literacy, this is only one domain in which power operates. Additionally, the contexts in which each of the two studies took place were both dam removal projects for which there was generally widespread agreement that the dams were obsolete and removal was the best option, as opposed to dam removal cases marked by conflict and controversy. In cases of conflict or controversy, science might take on different meaning with issues of epistemic authority taking on new layers and becoming more complex (Fox et al., 2016; Kimura and Kinchy, 2016). While power is omnipresent and has influence even in relatively mundane situations (Foucault, 1980), understanding how power shows up to mediate learning and literacy in more contentious situations is an important area for future research. On a related note, the dam removals in each case were in places with majority-white populations. The demographics of the focal community-based monitoring projects reflect this, as do the samples in each of the studies composing this dissertation. Future research ought to more explicitly attend to how power operates along the intersections of racial, gendered, classed, linguistic, and related lines, as these factors are highly relevant across cases of environmental conflict and collaboration given the social and political roots of environmental problems (Robbins, 2012).

IMPLICATIONS FOR PROJECT DESIGNERS AND ORGANIZERS

Synthesizing findings from the chapters of this dissertation have led me to identify several design features of community-based watershed monitoring initiatives that mediate the processes through which diverse knowledge, skills, and practices are brought into coordination with each other, including opportunities for individuals to shift roles, the presence of brokers, power dynamics, material artifacts, and the natural world. Broad takeaways include:

- Communities hold diverse repertoires of knowledge, skills, and practices that are distributed across individuals, tools, and structures - knowledge, skills, and practices that can be activated toward socioecological transformation.

- Fostering interaction and engagement across diverse sets of actors - from scientists, to land managers, to broader publics - via community-based, place-based initiatives in which they work toward shared goals can produce forms of collective learning and literacy. This can then become the basis for environmental decision-making that is more responsive to multiple perspectives and values.

- During deliberative processes, project organizers, facilitators, and others positioned in similar brokering roles play an important role in reinforcing or disrupting power asymmetries between actors, and in how projects are structured, at group, project, and organizational levels. This takes on particular salience in science-related settings given the historic privileging of scientific knowledge over other ways of knowing in conservation and restoration practice.

Notably, I suggest that these takeaways are transferable across a wide range of contexts and settings. That is, they have relevance for researchers and practitioners working in environmental management and conservation - such as in designing an adaptive co-management initiative - to those working in education - such as in designing an informal environmental education program. Across both fields, processes of collective learning and literacy can lead to expansive change and transformation, where outcomes extend beyond those for individuals to include those for socioecological systems.

FINAL THOUGHTS

My hope is that this work contributes to moving us away from conventional paradigms of environmental management, as well as conventional paradigms of science and environmental education, that privilege dominant scientific knowledge at the expense of more diverse ways of knowing. Instead, I hope to engender new approaches to both conservation and education that are rooted in community and in place, embrace a multiplicity of viewpoints, and disrupt power asymmetries to take seriously the knowledge, skills, and practices of broader publics in making socioecological change. Doing so represents one of the most promising paths forward for fostering forms of learning and literacy that bring about just and thriving worlds.

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APPENDIX I. Interview Protocols for Rattlesnake Creek Study

Before beginning the official protocols, the interviewer will establish rapport by asking about the participant's day. For example: How is your day going so far? *The interviewer will ask permission to audio-record and remind the participant that they can stop at any time or skip any question that they do not want to answer.*

Thank you so much for agreeing to be interviewed as part of this study. The reason we're doing this is to talk about your experiences with citizen science (*replace with specific project name in questions below, e.g. Stream Team*) to better understand the role it has played in this watershed. I want to hear your perspective and thoughts. I am going to audio-record the interview and will be taking some notes. As a reminder, when I type this up, I'll be replacing your name with a pseudonym. You do not have to share anything you do not want to, and we can skip any questions you'd like. You are also able to stop the interview if you need to. Do I have your permission to continue with the recorded interview? *Obtain and document verbal consent.* Before we start, do you have any questions?

Generalized Interview Protocol for Volunteers

Great, so I want to start by asking some broad questions about you and the citizen science project.

1. So first of all, can you tell me a little bit about yourself and your connection to this place?
2. In your own words, can you describe what this citizen science project is all about? What would you say are its goals?
3. How did you initially learn about this citizen science project, and what made you decide you wanted to participate in it? What was it that appealed to you?
4. Did those things end up being true? Was the project how you thought it would be?

Thanks for answering those questions. Now I want to ask a few questions about your specific role as a volunteer with this citizen science project.

5. How would you describe your role within this project?
    a. What does this role typically look like for you on a day-to-day basis when you're doing project work? What do you do in your role?
    b. How long have you been involved in the project?
    c. Has your work in that role changed over time, and if so, how?
    d. Can you recall a specific moment or event when you were doing citizen science activities that you feel really illustrates that role?
    e. How would you change your involvement if you could?
6. What other roles do you see as being important in this citizen science project?
7. Who are the main other people who are part of this project? Have you worked with them, and if so, what has that been like?
8. What systems or tools do you use for communicating in this project?

9. How does decision-making work in this project? What role do you play in decision-making?
10. I'm wondering if you've noticed or been part of any tensions related to this project - if so, can you describe them? Can you give a specific example?
11. Do you think you've learned anything as part of this project, and if so, can you describe that learning?
12. Can you describe if and how you have been able to take any of what you've learned to other areas of your life outside of the citizen science project?
    a. Do you talk about it with family or friends? If so, what do you talk about?
13. What missed opportunities have there been for learning in the project?
14. What other things would you like to see go on in this project?
15. What steps would you take to make those things come to fruition?

Thank you so much. We have gotten through most of our questions, and I really appreciate your thoughtful responses. I have two last quick questions, what is your gender, however you describe it? And what is your race or ethnicity, however you describe it? Thank you. Is there anything else you think I should know about your experience for my project? Do you have any additional questions for me?

Probing Questions:
1. Can you tell me more about that?
2. Can you describe a specific example to me?

Generalized Interview Protocol for Conservation Professionals and Scientists

Great, so I want to start by asking some broad questions about you and the citizen science project.

1. So first of all, can you tell me a bit about yourself and history working in the environmental field?
2. Tell me about your current organization, and your role within the organization.
3. In your own words, can you describe what this citizen science project is all about?
4. How did you initially learn about this citizen science project, and how did you come to participate in it? What was it that appealed to you?

Thanks for answering those questions. Now I want to ask a few questions about your specific role as a volunteer with this citizen science project.

5. How would you describe your individual role within this project?
    a. What does this role typically look like for you on a day-to-day basis? What do you do in your role?
    b. How long have you been involved in the project?
    c. Has your work in that role changed over time, and if so, how?
    d. Can you recall a specific moment or event when you were doing activities related to the project that you feel really illustrates that role?
    e. How would you change your involvement if you could?
6. How would you describe your organization's broader role in the citizen science project?
7. Who are the main other people you have worked with as part of this project? Have you worked with them, and if so, what has that been like?
    a. To what extent are you interacting with the volunteers, and what are those interactions like?
8. Generally, what do you think of community members being involved in monitoring?
9. What systems or tools do you use for communicating in this project?
10. How does decision-making work in this project? What role do you play in decision-making?
11. I'm wondering if you've noticed or been part of any tensions related to this project - if so, can you describe them? Can you give a specific example?
12. How would you change your involvement in the project if you could?
13. Do you think you've learned anything as part of this project, and if so, can you describe that learning?
14. Can you describe if and how you have been able to take any of what you've learned to other areas of your life or your work outside of the citizen science project?
15. What missed opportunities have there been for learning in the project?
16. What other things would you like to see go on in this project?
17. What steps would you take to make them come to fruition?

Thank you so much. We have gotten through most of our questions, and I really appreciate your thoughtful responses. I have two last quick questions, what is your gender, however you describe it? And what is your race or ethnicity, however you describe it? Thank you. Is there anything else you think I should know about your experience for my project? Do you have any additional questions for me?

Probing Questions:

3. Can you tell me more about that?
4. Can you describe a specific example to me?

APPENDIX II. MEMO PROTOCOL

Guiding Questions for Reflective Memo Writing after Data Collection

1. Did that (observation or interview) go as expected? Why or why not?
2. What was the most surprising thing that you saw or heard? Why was it surprising?
3. What was the least surprising that occurred or that you heard? Why was it unsurprising?
4. What did you hear or see that excited you? Why was it exciting?
5. What moments seem relevant to the research questions about power and positionality?
6. What connections can you make to theory or the literature?