THESIS

# MEASURING SOCIAL-ECOLOGICAL RESILIENCE IN FIRE PRONE SYSTEMS OF NORTHERN COLORADO

Submitted by

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ABSTRACT

MEASURING SOCIAL-ECOLOGICAL RESILIENCE IN FIRE PRONE SYSTEMS OF NORTHERN COLORADO

This thesis fills a gap in temporally and spatially applied knowledge on the perceptions people hold about social-ecological system (SES) resilience. Using a SES framework, we developed a contextualized set of resilience indicators and through stakeholder interviews and surveys we used these indicators to characterize subjective measures of SES resilience in two fire-prone watersheds of northern Colorado. Through stakeholder perceptions, we assessed current and wildfire-driven changes to resilience as well as recommended pre- and post-wildfire management actions and priorities for future systems resilience. Except for watershed processes variability, large scale wildfires did not significantly influence perceived resilience of most ecological indicators. Wildfire events, however, had strong negative influence on perceived resilience of ecosystem service indicators but were perceived to catalyze benefits in social dimensions of resilience. In terms of management actions and future resilience, stakeholders underscored a need for increased pace, scale, and connectivity of fuel treatments with particular interest in prescribed fire. While current stakeholder connectivity was high, continued prioritization of partnerships remains a focus for future resilience. Our findings can be used to improve wildfire management actions for both ecosystems and communities and our resilience indicators can be applied to comparable watershed systems to measure subjective perceptions of SES resilience.

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## Chapter One: Introduction

Wildfire management is increasingly a complex problem, requiring managers and practitioners to grapple with longer fire seasons, increasing fire severity, and a growing human population in the wildland urban interface (Abatzoglou & Williams, 2016). This challenge is particularly heightened in the western U.S. While this region has historically seen fire on the landscape and has a variety of ecosystem-specific fire regimes, the frequency and severity of large-scale fires is increasing (Baker, 2014; Keane et al., 2008; Keeley & Syphard, 2021). Historically, frequent low severity fires on western U.S. landscapes were common. After European settlement and the subsequent policies of fire suppression, western landscapes experienced an extended period of limited fire (Keeley & Syphard, 2021). Consequentially, fuel loads grew denser with higher connectivity and are a cause of present-day large frequent fires (Keeley & Syphard, 2021). In addition to historical fire suppression serving as a driver of present-day large-scale high severity fires, climatic impacts are contributing to increasing temperatures that are creating the changes we are seeing on western landscapes today. Human-caused climate change is a primary factor, driving more severe and intense fires (Abatzoglou & Williams, 2016; Parks et al., 2018; van Mantgem et al., 2013). With climate change, shifting disturbance trends are occurring across many landscapes. Ecologically, severity and frequency of fires are increasing, and there are more days with extreme fire weather (van Mantgem et al., 2013). Additionally, there are longer and more frequent droughts, leading to greater fuel aridity and a higher likelihood of wildfire spread (Abatzoglou & Williams, 2016).

Wildfire can change the hydrology and water quality of watersheds (Writer et al., 2014) thus impacting ecosystem services derived from the watershed (Kinoshita et al., 2016). This is particularly true with services related to water provisioning and sediment regulation (Kinoshita et al., 2016). This is a result of the ecological changes that occur post fire- primarily increased sedimentation in post fire runoff (Robinne et al., 2020). Wildfires in the Rockies have been linked to cascading disturbance effects from increased sediment runoff (Wohl et al., 2022). Such cascading ecological disturbances from sediment runoff and changes in water quality impact aquatic wildlife habitats (Bladon et al., 2014). In the western U.S. this problem is of particular concern because forested landscapes serve as the primary water catchment system for human population's water supply (Reneau et al., 2007; Robinne et al., 2020). Many of these catchments across the west are in a state of highly dense vegetation, prone to stand replacing wildfire with severe water quality impacts (Badik et al., 2022). Increased fire severity threatens the quality and quantity of water supplies for both urban and agricultural users (Reneau et al., 2007; Robinne et al., 2020). In addition, these losses can be costly economically with property damage, rehabilitation costs, loss of recreation revenues, and loss of endangered species habitat (Jones et al., 2022).

Wildfire-prone ecosystems in the western U.S. are a classic example of a social-ecological system (SES) due to the interconnectedness of the ecosystems and the people—both in terms of the governance systems that manage fire and the communities affected by fire. SES refer to systems in which the human elements and natural elements of a system interact (Liu et al., 2007). Systems can be viewed as three types of variables including those of the natural world, human-driven systems, and the reciprocal interactions between the two. Similarly, wildfire prone systems can be viewed as linked social and ecological elements and processes whose interplay results in weakened system health (Fischer et al., 2016). A number of SES approaches have been developed and applied to understand wildfire risk management (Vigna et al., 2021). Resilience is a key part of SES frameworks as it allows researchers to analyze shifts in multiple variables of a system given a disturbance, and refers to the maintained and adaptive capabilities of the ecological, social, and social-ecological interactive variables of a system to return to a pre-disturbance state, structure, and function (Liu et al., 2007). The concept of resilience offers a framework for looking at interactions between SES components given the inherent complexity of these systems (Sterk et al., 2017). There are a number of resilience principles that provide useful multivariable (social and ecological) indicators to analyze the resilience of SES systems. Example resilience principles include: maintain diversity and redundancy, manage connectivity, foster slow variables and feedbacks, create an understanding of SES as complex adaptive systems, encourage learning and experimentation, broaden participation, and promote polycentric governance systems (Biggs et al., 2012; Sterk et al., 2017).

Several studies on wildfire resilience have focused on ecological resilience. One school of thought suggests that ecological resilience is tied to the ability of a forest to return to a pre-disturbance state (Johnstone et al., 2016). Others have interpreted this definition of ecological resilience more broadly and focus on the system's ability to return to a pre-disturbance state in terms of the ecosystem's capability to rebound to its previous set of structures and processes (Waltz et al., 2014). Measuring resilient communities takes many different forms, but have included assessing inequities, such as equal access to evacuation and post disturbance relief, understanding community involvement in natural resource management, and measuring partnerships and organizational links across natural resource governing bodies (Norris et al., 2008). Specific recommendations for enhancing community resilience to wildfire include, but are not limited to, incorporating communities into decision-making processes surrounding forest management and removing inequalities of resource access (Norris et al., 2008). One critique of this literature on measuring resilience is that present approaches to resilience do not capture the full complexity of coupled systems (Chuang et al., 2018) with few studies of fire-prone landscapes of the western U.S. considering SES resilience in a holistic lens (Spies et al., 2014). Furthermore, useful research needs to apply concepts of adaptive resilience and transformative resilience on top of traditional views surrounding return of state and function (McWethy et al., 2019). Adaptive and transformative resilience frame response to disturbance as more than just recovery alone, but additionally stress the need for changing or shifting systems in ways that reflect current climatic realities (McWethy et al., 2019).

One conceptualization for measuring resilience is that there are value-free and value-explicit measures of resilience (Higuera et al., 2019). Value-free, which can be considered objective measures, capture resilience in observable ways that are free of human perceptions or values. These measurements are typically used to understand ecological resilience, or forest resilience. These types of measurement are useful because they allow managers to quantify specific elements of a system, such as tree regeneration, and then manage around the current trends of that variable accordingly. An alternative way to measure resilience includes using subjective, or value-explicit, measures that come from stakeholders (Higuera et al., 2019). These types of metrics are important to include because stakeholder values can be diverese and measuring them allows us to understand how stakeholders are prioritzing particular elements of the given system. Incorporating subjective measures, through measures of people's perceptions, has been suggested by conservation social scientists to increase the effectiveness and viability of practitioner's objectives (Bennett et al., 2017). Thus, to effectively manage wildfire, there is a need to fully understand SES resilience from both value-free and value-explicit dimensions.

There is also a need for resilience research that focuses on specific spatial and temporal scales, to capture relative resilience (Allen et al., 2018). While it is common in ecological research on resilience to focus on a specific fire or landscape, much of the SES research currently available is largely theoretical, with no application to a specific spatial or temporal boundary (Waltz et al., 2014). However, it is necessary to characterize SES resilience in specific places and at specific times to be useful to managers and decision making. This type of characterization can allow measures of resilience to be translated into specific management actions and transform systems toward desired states. Another area in SES resilience with gaps, is how different types of management actions influence the resilience of a system (Biesbroek et al., 2017).

In this thesis, we help fill these research gaps by (1) developing a set of value-explicit (subjective) SES resilience indicators specific to wildfire-prone watersheds in the western U.S.; and (2) applying these indicators of SES resilience to characterize the resilience of a specific spatial and temporal context--the Poudre River and Big Thompson River Watersheds in Colorado. The overall goal of this thesis is to characterize SES resilience for these watersheds and to assess whether current management actions and governance approaches are obtaining the desired characteristics of SES resilience preferred by stakeholders. The specific research questions this thesis answers are: (1) What are stakeholders' past and current perceptions of SES resilience in the Poudre and Big Thompson Watersheds? (2) How did recent 2020-wildfire events impact perceived SES resilience?; (3) How has SES resilience been influenced by specific pre- and post-wildfire management actions that are occurring in these watersheds?; and (4) What future actions are perceived as important to improve SES resilience in these systems (i.e., future resilience)? Within our study, we are defining pre-wildfire mitigation as administering prescribed burning, creating defensible space and thinning forests (by hand and mechanical). Actions we included within our definition of post-wildfire mitigation actions included mulching post-fire landscapes, reforesting post-fire landscapes, and stream restoration and stabilization projects post-fire.

Value-explicit measures of SES resilience have been quantified by a handful of studies through surveys (Allen et al., 2018; Salomon et al., 2019), but not for wildfire specifically. This research builds on these existing studies to develop indicators of SES resilience that can be used in the context of wildfire, adding to the literature that holistically measures SES resilience using value-explicit measures. This study helps characterize the resilience of two Colorado watersheds over time. Insights across time aim to determine the way indicators of SES resilience are influenced by wildfire events. This research also provides insights into how specific wildfire management actions influence SES resilience. The measured set of indicators are useful to managers who aim to optimize SES resilience by providing them information to characterize current SES resilience in their watersheds and to understand the relative resilience of their watersheds. Additionally, the set of indicators and responses informs where future management actions are needed in order to move toward desired states of resilience. In sum, this research, and similar studies that characterize both value-free and value-explicit indicators of resilience, can offer managers and policy makers a strong signal for understanding current resilience and prioritizing future action (Higuera et al., 2019).

The rest of this thesis proceeds as follows, in Chapter two I overview relevant background including the theoretical frameworks and existing research this thesis builds on. In chapter three I describe the methodology with focus on data collection and analysis for both qualitative and quantitative components of the research. Chapter four outlines the results of the work and is broken down into qualitative and quantitative findings. In Chapter five I discuss the connections between qualitative and quantitative findings, provide potential rationales for findings, and connect results to existing literature. This section ends with a conclusion of the thesis. Throughout the majority of the work, I refer to the research team as "we" indicating that decisions on the priorities and directions of the research were formed with my advisor and with feedback from other experts in the field. The use of "I" emerges as within the methodology section when I describe data analysis. This change to the use of a singular pronoun indicates that I only performed data analysis tasks.

## Chapter Two: Background

*SES Resilience*

SESs, also called coupled human and natural systems, refer to systems in which the human elements and natural elements interact (Liu et al., 2007). Systems can be viewed as having three main types of variables including those of the natural world, the human-driven system, and the reciprocal interactions between the two (Liu et al., 2007). These systems are complex and dynamic, changing with time. Thus, to study or manage them effectively demands interdisciplinary science (Ostrom, 2007). Characteristics of these complex systems include heterogeneity, legacy effects, surprises, thresholds, feedback loops, and resilience (Liu et al., 2007). Understanding these characteristics of a system is crucial to analyzing the system in its full complexity (Liu et al., 2007). To understand a systems complexity involves acknowledging the relationships between system structure and behaviors and their subsequent results (Meadows, 2008). Furthermore, systems must be viewed not only as the sum of elements included, but also for the interconnectedness between elements as well as their function or purpose (Meadows, 2008).

Several multi-variable SES frameworks have been developed to capture the complexity of these systems. Frameworks facilitate researchers of diverse disciplines and perspectives to come together around a unifying diagnostic tool (McGinnis & Ostrom, 2014). Research in this field utilizes qualitative and quantitative methods to study the interactions between variables that alter the environmental outcomes for the system as a whole (Ostrom, 2009). SES frameworks have evolved over time to accommodate the increasing developments in the field of environmental governance (McGinnis & Ostrom, 2014). A common framework used by social scientists is the SES Framework (SESF) that allows for comparisons of multiple variables and the relative impact each individual variable has on the system of interest (Binder et al., 2013; Ostrom, 2007, 2009). The SESF can be used to examine variables pertaining to “the resource system, the resource units generated by that system, the users of that system, and the governance system” (Ostrom, 2007, p. 15181).

Due to the increasing pressures of climate change, SES resilience has become a topic of increasing concern to academics and natural resource managers. SES resilience considers the ecological variables of a system, the social variables, and the complex linkages between the two (Greiner et al., 2020a). Resilience in this context is defined as “the capability to retain similar structures and functioning after disturbances for continuous development” (Liu et al., 2007, p. 1515). A more compelling definition may be “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, and feedback” (Walker et al., 2004, p. 1). This definition allows researchers and managers to define function, structure, and feedback in indicators targeting ecological or social elements of a coupled system. Using a definition that includes function, structure, and feedback can be translated into multiple disciplines and can yield more comprehensive management plans.

It is important to consider governance and management implications within the discussion of resilience because of the large potential impact human management can have on a system's resilience (Liu et al., 2007). Furthermore, it is worth noting that resilience varies drastically between SESs given their respective governance and management regimes, but also social and community inequalities, and/or the frequency and severity of disturbances that the system experiences (Liu et al., 2007). Increased resilience is often a function of improved human systems of economies and communities, and involves elements of development and sustainability (Folke, 2016).

*Measuring SES Resilience*

Increased interest in managing for resilience has led to the development of different indicators, or metrics, to characterize resilience (Quinlan et al., 2016). In general, there has not been the development of a standardized set of indicators to measure resilience given the dynamic nature of SES systems and different focal interests (Quinlan et al., 2016). However, one recent standardized tool for measuring resilience was developed by the Stockholm Resilience Centre's Wayfinder program and provides an online platform for resilience assessment and planning in SESs (Stockholm Resilience Center, 2018). Measuring current resilience of complex and nuanced systems allows for shared learning and improved future management though collective deliberation (Stockholm Resilience Center, 2018).

When measuring resilience, it is important to clarify the resilience as it relates to whom and under what motivation (González-Quintero & Avila-Foucat, 2019). For example, if the resilience measurement is for policy makers then indicators should target elements of a SES that can be molded through policy (González-Quintero & Avila-Foucat, 2019). There are many works that measure SES resilience in non-fire disturbance case studies. Climate change and the consequential changes to disturbance regimes have been a large area of focus in the literature, as have studies on the changing resilience of coastal regions (González-Quintero & Avila-Foucat, 2019). Measuring a wider set of indicators often allows for a more comprehensive understanding of system dynamics and thus benefits resilience research and management recommendations at a higher level (Quinlan et al., 2016).

One way to categorize the different ways of measuring resilience is between using value-free or value-explicit indicators. Value-free indicators (objective) rely on empirical information while value-explicit (subjective) include stakeholder's subjective perceptions of resilience as shown in Table 1. For example, subjective indicators are derived from stakeholder perceptions through social science methods including surveys and interviews, or a mix of these methods. Objective measures of resilience can be measured ecologically using traditional field based natural science methods or socially using observable indicators such as loss of housing or income after a disturbance.

**Table 1:** Approaches for measuring resilience can be either value-explicit or value-free and can measure resilience of ecological or social variables

| | Value-Explicit (Subjective) | Value-Free (Objective) |
|---|---|---|
| **Ecological** | Perceptions of biological diversity within informants' watershed (Allen et al., 2018) | Post-fire tree regeneration in the Rocky Mountains (Stevens-Rumann et al., 2018) |
| **Social** | Perceptions of social capital within a informants' watershed (Allen et al., 2018) | Relative change in housing and tourism from Hurricane Irma (Furman et al., 2021) |

Value-explicit indictors of SES resilience have been measured by a handful of social science studies through surveys and interviews (Allen et al., 2018; Salomon et al., 2019). These studies draw on resilience principles to develop a specific set of indicators for the study context. Resilience principles are the elements needed by a system to maximize resilience and in order to gauge perceptions of resilience (Walker & Salt, 2006). In their seminal work, Walker and Salt identified nine resilience principles (Table 2): biological diversity, ecological variability, modularity, acknowledging slow variables, tight feedbacks, social capital, innovation, overlap in governance, and ecosystem services (Walker & Salt, 2006).

**Table 2:** Nine resilience principles with respective definitions (Walker, Brian, Salt, 2006).

| Principle | Definition |
|---|---|
| 1. Biological Diversity | The number and evenness of species, functional groups, and response to disturbance in the ecosystem |
| 2. Ecological Variability | Natural variability and fluctuations in ecological processes, structures, and populations |
| 3. Modularity | System components are connected to one another so that information is transferred effectively, but not so overly connected that shocks cause disproportionate damage |
| 4. Acknowledging Slow Variables | Incorporation of information about long-term outcomes that result from near-term decision making |
| 5. Tight Feedbacks | Feedbacks among critical system components respond quickly allowing practitioners to avoid dangerous thresholds |
| 6. Social Capital | It comprises the net sum of benefits generated from relationships among components in a system's social network |
| 7. Innovation | Degree of learning, experimentation, education, and locally developed rules to embrace change and creatively improve conditions |
| 8. Overlap in Governance | Institutions have redundancy in their roles and responsibilities |
| 9. Ecosystem Services | Essential and nonessential benefits people obtain from ecosystems |

These nine principles were turned into specific indicators and used to measure subjective perceptions of resilience from stakeholders for four North American watersheds (Allen et al., 2016, 2018). Specifically, researchers used the nine resilience principles and their respective definitions, as shown in Table 2, to draft individual survey questions that targeted indicators for each principle within each informant's respective home watershed (Allen et al., 2018). After administering the survey to stakeholder groups, changes in relative resilience were analyzed across spatial scales (Allen et al., 2018). This study focused on measuring uncertainty of resilience by asking informants to self-assess their uncertainty as well as calculated variance as a proxy for group-level uncertainty (Allen et al., 2018). Self-assigned uncertainty was highest amongst social and governance questions while group-level uncertainty was highest for indicators of ecosystem service and trust (Allen et al., 2018).

An alternative framework of resilience principles was designed to specifically improve the resilience of ecosystem services and tailored towards policy development (Biggs et al., 2012). This alternative framework was used by Salomon et al. (2019) for measuring resilience of the Pacific herring fishery of northwestern Canada (Salomon et al., 2019). Specifically, this study translated resilience principles developed by Biggs et al. (2012) into targeted indicators developed for the Pacific herring fishery of northwestern Canada (Table 3). The authors used a mixed methods approach of surveys and interviews to gather knowledge from stakeholders within the Pacific herring system about these indicators (Salomon et al., 2019). The authors found a decrease in SES resilience due to shifts in governance structure from indigenous led governance to colonial regimes (Salomon et al., 2019).

**Table 3:** Resilience principles operationalized to the Pacific herring fishery of northwestern Canada. Resilience principles come from Biggs et al. (2012), with indicators developed by Salomon et al. (2019).

| **Resilience Principle** | **Indicator** |
|---|---|
| Maintain Diversity & Redundancy | Marine Species & Habitat Diversity |
| | Species Response Diversity |
| | Diversity of Perspectives |
| | Diversity of Livelihoods |

| | |
|---|---|
| | Diversity in Herring Size Structure<br>Diversity in Herring Spawning Season Dates |
| Manage Connectivity | Degree of Information Sharing |
| Manage Slow Variables & Feedbacks | Understanding of Gradual Changes<br>Decisions Updated with New Information<br>Ability of Managers to Respond to Key Changes |
| Foster Complex Adaptive Thinking | Willingness to Embrace Change<br>Preparedness to Cope with Unexpected Events |
| Encourage Learning | Innovation & Willingness to Experiment<br>Sharing of Scientific Resources |
| Broaden Participation | Level of Participation<br>Level of Trust<br>Level of Cooperation |
| Promote Polycentric Governance | Use of Indigenous Knowledge & Stewardship Protocols<br>Distribution of Power in Decision Making<br>Accountability<br>Indigenous Authority to Access Herring<br>Willingness for Conflict Resolution |

Resilience can change over time given a disturbance or change in human management, thus it is important when measuring resilience to include clear temporal bounds as well as spatial bounds to clarify changes in resilience from a pre-disturbance state to post-disturbance state (Carpenter et al., 2001). In one example, researchers used stakeholder informed perceptions through semi structured interviews and historical land ownership documents to retroactively map forest resilience in multi-ownership systems in order to adaptively manage high-frequency fire (Steen-Adams et al., 2017). Such studies have found that informal and formal governing bodies targeting wildfire management merged efforts over time (Steen-Adams et al., 2017). Developing SES histories can explain ecological resilience variation and differences in forest composition over time given changes in ownership and consequential changes in management (Steen-Adams et al., 2017).

Factors that influence resilience in wildfire-prone SES

*Governance Responses and Stakeholder Collaboration*

Each SES has a varying diversity of actors, perspectives, and institutions within its governance structure (Baird et al., 2019). The structure of each SES is unique based on its institutions and the respective disturbances that drive governance responses (Berardo & Lubell, 2016). Improving SES resilience in dynamic systems requires policies and management actions to match the characteristics of the system (Garmestani & Benson, 2013). Greater institutional diversity within an environmental governance structure is thought to improve resilience within SES (Jones et al., 2013). Traditionally, managers have focused on adaptive management, with emphasis on a structured trial and error process that acknowledges incomplete knowledge of the system and embedded uncertainty (Allen & Garmestani, 2015; Cosens & Williams, 2012). Recently this view has come to include adaptive governance, or the "type of governance necessary to allow sufficient flexibility for adaptive management" with its focus on polycentricity, local knowledge, diversity, and redundancy (Cosens & Williams, 2012, p. 2). While adaptive management promotes resilience ecologically, adaptive governance when used in conjunction with adaptive management can offer increased change in resilience to the system as a whole (Cosens & Williams, 2012). In terms of best practices for enhancing the resilience of a SES, focusing on ecosystem services, adaptive management/governance, and polycentric governance may offer the greatest changes (Biggs et al., 2012).

Recently, given the rise of wildfires in the American west, environmental organizations have been partnering and collaborating with the federal and state government, and the private sector, to address the impact of wildfires (Roberts et al., 2019, 2020). These new partnerships are seen as a new form of environmental governance that brings together diverse groups and collectively pools resources (Huber-Stearns, 2015). Individual actors are motivated by their organizations' missions, leadership, and desire for greater impact on wildfire mitigation (Roberts et al., 2019, 2020). Recent studies suggest that wildfire governance needs to change in ways that do not view historic fire regimes as exact predictors, understand SES thresholds, address issues using interdisciplinary approaches, and promote knowledge sharing and collaboration among stakeholders (Steelman, 2016; Timberlake et al., 2020). Well-developed social networks between multiple stakeholders of an SES can improve wildfire mitigation by fostering information sharing and subsequent solution driven planning (Fischer et al., 2016).

*Wildfire Mitigation Actions*

In addition to the environmental governance structure, changes in management actions can contribute to changes in SES resilience. There are several primary management actions agencies can take to mitigate wildfire (Roberts et al., 2019). Before fire, these actions include administering prescribed burns, creating defensible space around communities and homes, thinning at-risk forests, and putting in fuel breaks (Roberts et al., 2019). The creation of defensible space removes fuel around communities and homes intending to make them easier to protect given a fire event as well as reduces the likelihood fire can spread from the forest to human structures (Roberts et al., 2019). Similarly, the creation of fuel breaks aims to stop fire spread through the creation of strips of removed vegetation (Roberts et al., 2019).

Prescribed burns and thinning both aim to remove a portion of fuels from the system thus reducing the risk of high severity fires (Roberts et al., 2019). To foster resilience through their management actions, the U.S. Forest Service prioritizes the presence of frequent, low-severity fires in western wildfire systems (Timberlake et al., 2020). This decision mirrors the current understanding that fuels reduction treatments, particularly in mixed conifer systems, can increase forest resilience in the face of wildfire (Waltz et al., 2014). When the landscape does experience a fire event, it is less severe because of fuel reduction treatments and thus the ecosystem maintains a similar structure and function (Waltz et al., 2014). Application of prescribed fire serves as a management tool that mirrors desired disturbance regimes. However, it is not utilized at preferred scales and frequencies due to social barriers such as limited capacity and funding (Schultz et al., 2019).

After a fire, there are a few primary management actions such as: (1) mulching a burned hillside to prevent erosion into sensitive waterbodies, (2) rehabilitating or restoring an area back to pre-fire condition, which can include planting trees or restoring waterways, and (3) removing trees for salvage logging (Roberts et al., 2019). Additionally, the U.S. Forest Service, alongside county and state firefighting agencies, often suppress fires as a primary form of fire management (Roberts et al., 2019). In many cases, changes to environmental governance and wildfire management actions are correlated in the western U.S., as higher levels of cooperation and collaboration are leading to more resources and more coordination in implementing pre-wildfire management actions (Roberts et al., 2019). Within any given management action, the most effective changes to resilience occur when mitigation and planning actions are done through interdisciplinary approaches (Fischer et al., 2016).

The pre and post wildfire mitigation actions outlined above are being complemented by new tools like Potential Wildfire Operational Delineations (PODs) which serve as a planning tool used to characterize risks across landscapes and improve decision making (Greiner et al., 2020a). This tool is particularly useful for development of incident responses as the boundaries of each POD "are relevant to fire control operations, such as roads, trails, ridgetops, drainages, and fuel transition" (Thompson et al., 2018, p.1). In addition to management tools, there is also the trend of applying actions previously considered outside the scope of wildfire specific management to a system to improve resilience to disturbances more broadly, including those of wildfire. One example of this trend is seen in the increasing support for Beaver Dam Analogues (Fairfax & Whittle, 2020). While their direct impact on wildfire resilience is still an area of ongoing research, initial studies show that given their role in riparian restoration, Analogues can create post-fire refugia by forming pockets of wetter and more wildfire resistant habitats (Fairfax & Whittle, 2020).

While management actions have the potential to increase SES resilience, high severity fire events have the propensity to decrease resilience (Timberlake et al., 2020; Waltz et al., 2014). For the purposes of the present study we are defining fire severity as the amount of organic matter removed by the fire (Keeley, 2009). The increasing severity and intensity of fires in the western U.S. have been linked to decreasing forest resilience especially under the context of climate change (Stevens-Rumann et al., 2018). This is because these high severity and intensity wildfire events abruptly alter the ecosystem's state and few elements, such as structure or function, are maintained post-disturbance (Johnstone et al., 2016). However, while it is the common belief that wildfire events decrease SES resilience, this is not always the case, especially if frequent, low severity fires that offer the potential for maintained resilience over time are allowed (Stevens-Rumann & Morgan, 2016). Thus, in some cases, a wildfire may foster SES resilience depending on the context (McWethy et al., 2019).

## Chapter Three: Methods

Study area

*Geographic area*

This study focused on the Poudre River watershed and the Big Thompson River watershed in northern Colorado. Both watersheds flow eastwards from the northern Colorado Rockies. Both watersheds have headwaters in Rocky Mountain National Park and eventually flow into the South Platte River, a tributary of the Mississippi River. The Poudre watershed is 1,219,038 acres and has population centers in Greely, Windsor, and Fort Collins (Coalition for the Poudre River Watershed, 2020). The Big Thompson watershed is 270,000 acres and has population centers in Estes Park and Loveland (USDA, 2010).

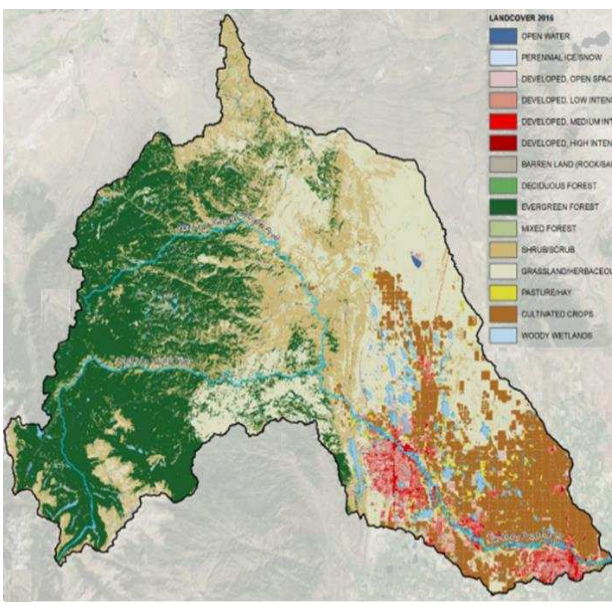


**Figure 1:** Land Use in the Poudre River watershed (Coalition for the Poudre River

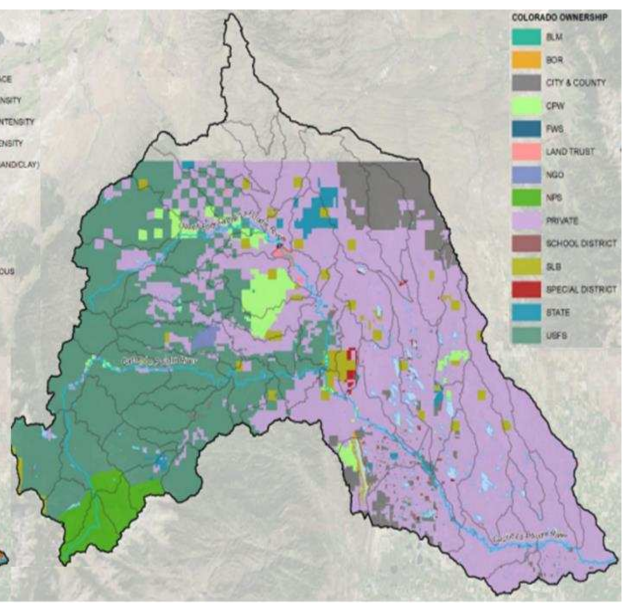


**Figure 2:** Colorado Land Ownership of the Poudre watershed (Coalition for the Poudre River

The Poudre watershed collectively contains nine reservoirs and serves as a water supply for households and agriculture operations of the northern Front Range (Coalition for the Poudre River Watershed, 2020; USDA, 2010). Within the Poudre watershed, the majority of land is forested, followed by agricultural use and grasslands (Figure 1). However, there are significant pockets of low-intensity development with centers of high-intensity development. The Poudre River has 46 miles designated as wild and scenic and is the only river with that designation within the state. Figure 2 shows the primary Colorado land ownership types of the watershed with primarily private ownership, followed by the U.S. Forest Service, and county or city ownership. The drainage's most popular state park is the State Forest State Park in Walden, which spans 71,000 acres of high alpine terrain off of Cameron Pass (Colorado Parks and Wildlife, 2022).

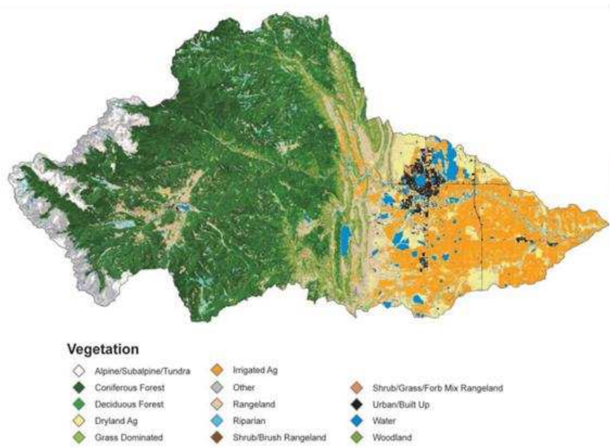


**Figure 3:** Land Use in the Big Thompson watershed (USDA, 2010)

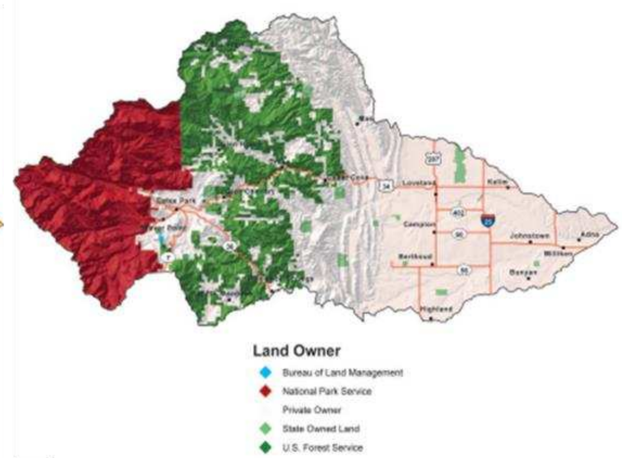


**Figure 4:** Land Ownership of the Big Thompson watershed (USDA, 2010)

Similar to the Poudre watershed, within the Big Thompson watershed the majority of land is forested, followed by agricultural use and grasslands with significant pockets of low-intensity development with centers of high-intensity development (Figure 3). While the top of the Poudre watershed lies in Wyoming, the Big Thompson watershed to the south runs within Colorado for its entirety (USDA, 2010). Figure 4 shows the primary land ownership types of the watershed with primarily private ownership, followed by U.S. Forest Service and National Park Service for Rocky Mountain National Park (USDA, 2010).

*Human component*

Both the Poudre and Big Thompson watersheds have major population centers. Within the Poudre River watershed, the major population center is Fort Collins with 169,810 people (U.S. Census Bureau, 2020). The major population center of the Big Thompson watershed is Loveland with a population of 76,378 (U.S. Census Bureau, 2020). Fort Collins and Loveland are located within the dense population strip of the Colorado Front Range that runs to the west of the I-25 corridor across the state. To the west of these population centers are the foothills and then the Rocky Mountains. To the east of these population centers is primarily agricultural land with limited human populations. The wildland urban interface (WUI) refers to locations where human developments abut wildlands (Liu et al., 2015). Within the entirety of the Colorado Front Range, the WUI is expanding as the development corridor grows (Liu et al., 2015). This is of particular concern for expansions to the west, where developments now abut forested landscapes with a high propensity for fire (Liu et al., 2015). Both Fort Collins and Loveland follow this pattern of expanding WUI and consequential greater risk of fire to communities especially within the context of climate change (Liu et al., 2015).

*Wildfire-water component*

The Poudre River watershed and the Big Thompson River watershed are of particular interest for this study because they have both experienced largescale wildfires in recent years. In the Poudre watershed, the Cameron Peak Fire burned from August to December of 2020 and burned 208,913 acres on the Arapaho and Roosevelt National Forests (*Cameron Peak Fire Information - InciWeb the Incident Information System*, n.d.). The East Troublesome Fire burned simultaneously with the Cameron Peak Fire and burned 193,812 acres before it was contained in November of 2020. Both fires were fueled by drought conditions and high winds (*East Troublesome Post-Fire BAER Information - InciWeb the Incident Information System*, n.d.). The East Troublesome Fire was of particular concern in the Big Thompson watershed, because of the extended evacuation it caused for Estes Park and Rocky Mountain National Park. In 2012, both of these watersheds experienced impacts from the High Park Fire, which burned

87,284 acres in 2012 (*Cameron Peak Fire Information - InciWeb the Incident Information System*, n.d.; *East Troublesome Post-Fire BAER Information - InciWeb the Incident Information System*, n.d.). Figure 5 shows the boundaries of the Poudre River watershed, the Big Thompson River watershed, the High Park Fire, the Cameron Peak Fire, and the East Troublesome Fire; illustrating the recent fire history impacting these watersheds. Within the study area, wildfire events have impacted the water supply and ecosystem services of the area (Writer et al., 2014). After the High Park Fire, disinfection by-products (DBP) and organic matter were higher in the Poudre River watershed and water treatment processes were needed to effectively address the increase in DBP and organic matter in local water supply (Writer et al., 2014). Statewide, wildfire events have proved to impact many elements of the water supply system including reservoirs and diversions that limit water storage capabilities (Jones et al., 2022).

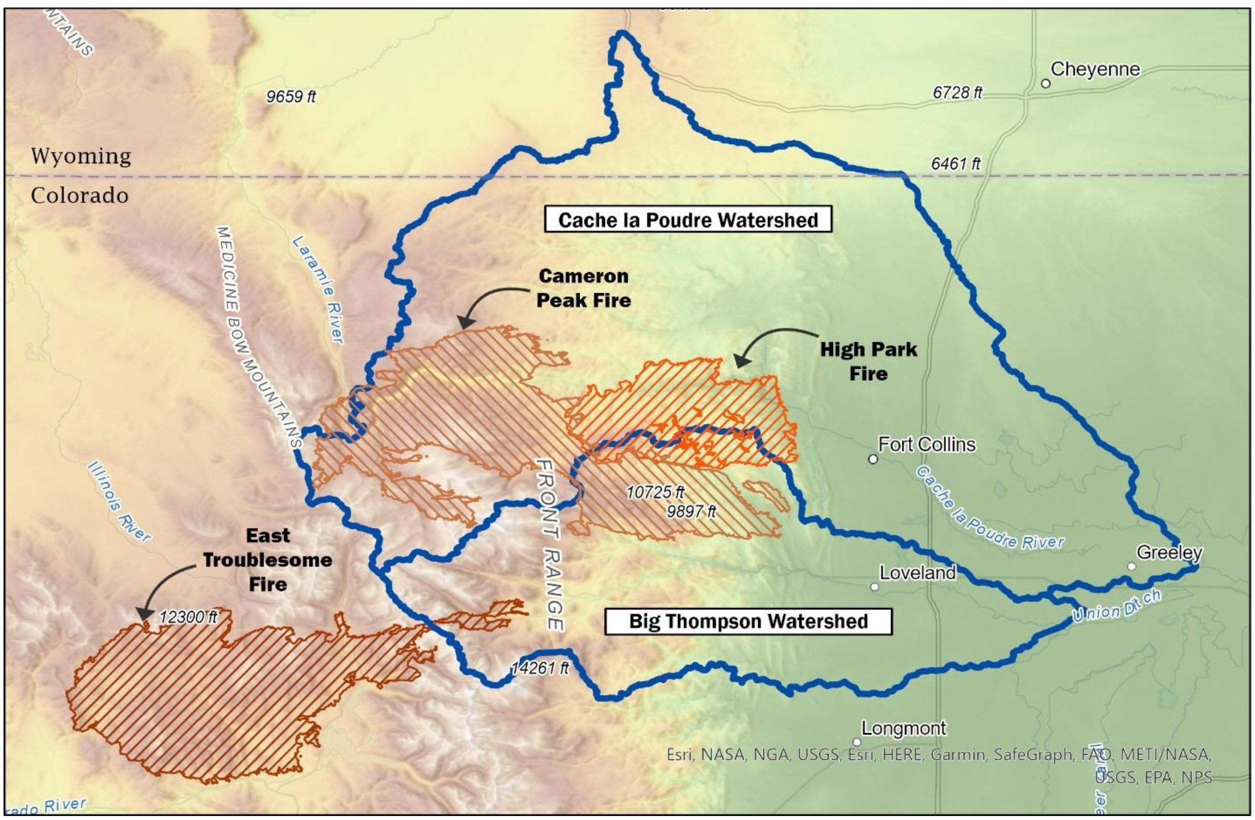


**Figure 5:** Boundaries of the Poudre River and Big Thompson River watershed and the total burn areas of the Cameron Peak Fire, East Troublesome Fire, and High Park Fire (Cheney & Zeelar, map created for write up)

*Governance and Management Response*

With the rise of wildfires and their impacts to society in the American west, partnerships and collaborations have begun between government agencies, utilities, coalitions and non-governmental organizations (NGOs), research groups, cities and counties, and private businesses to address the impact of these events (Roberts et al., 2019, 2020). This is occurring in the Poudre River and Big Thompson River watersheds and focuses on collaboration and prioritization of wildfire mitigation efforts. Within these partnerships and organizations, there are 7 major wildfire mitigation actions that are being invested in both pre- and post-fire: (1) administering prescribed burning, (2) creating defensible space, (3) thinning forests, (4) making fire breaks, (5) mulching post fire landscapes, (6) rehabilitating forest landscapes to pre-fire conditions, and (7) rehabilitating stream systems to pre-fire conditions (Roberts et al., 2019). For the purpose of this study, we will focus on pre- wildfire mitigation and post- wildfire mitigation actions. Pre-wildfire mitigation action included administering prescribed burning, creating defensible space and thinning forests (by hand and mechanical). Post-wildfire mitigation actions included mulching post-fire landscapes, reforesting post-fire landscapes, and stream restoration and stabilization projects post-fire.

<u>Data Collection Overview</u>

A mixed methods approach was used in this project. A qualitative approach was used first to provide depth and nuance to characterize SES resilience. This data was gathered through interviews with leaders of key organizations involved in pre- or post-fire mitigation. A quantitative approach was used to measure perceptions about specific indicators of SES resilience. Quantitative data was collected through an online survey administered to multiple stakeholders across several organizations. Both the surveys and interviews went through the human subjects' research IRB approval process (IRB: #3584, Appendix A). Both qualitative and quantitative elements of the project focused on stakeholder knowledge. We focused on stakeholders because stakeholder perceptions can provide expert knowledge about resilience that the general public would lack, and information gathered from stakeholders can directly inform the decision-making process, thus making this a particularly relevant population to target for research on management changes (Ban et al., 2013; Reed, 2008).

*Resilience Principles and Indicators Development*

Table 4 overviews the resilience principles that were used to inform interviews and surveys in this study. The principles draw on those of Salt and Walker (2006) and Biggs (2012). In areas of overlap, principles were combined, but in areas without overlap, individual principles were retained. This method was chosen to include the greatest total number of principles. The total number of merged principles is eight and can be seen in Table 4 below, that identifies where merges occurred.

**Table 4**: Selected resilience principles and merged principles for this study. *Green for principle with origin from Biggs, 2012 and mirrored in the Stockholm Resilience Center's Wayfinder tool. Blue for principle with origin from Salt and Walker, 2006.*

| **Merged Resilience Principles** | **Original Resilience Principles** |
|---|---|
| Ecological Diversity | Biological Diversity<br>Maintain Diversity & Redundancy |
| Ecological Variability | Ecological Variability |
| Ecosystem Services | Ecosystem Services |
| Manage Connectivity | Modularity<br>Manage Connectivity |
| Manage Complex Variables & Feedbacks | Manage Slow Variables & Feedbacks<br>Acknowledging Slow Variables<br>Tight Feedbacks |
| Foster Complex Adaptive Thinking | Foster Complex Adaptive Thinking<br>Encourage Learning<br>Innovation |
| Linking and Bonding Social Capital | Social Capital |
| Governance | Overlap in Governance<br>Promote Polycentric Governance<br>Broaden Participation |

Using this set of resilience principles, we developed specific indicators through a literature review and expert knowledge that reflect each principle and the study focus of wildfire and water. As a starting point we used two recently published papers that developed subjective measures of resilience (Allen et al., 2018; Salomon et al., 2019). We then expanded on these indicators as needed using expert knowledge of local systems. Through this process we developed a first draft of indicators for the eight principles. We vetted this draft with five experts in the field, two from our thesis committee and three from the National Science Foundation (NSF) grant that this project is a component of. Experts covered various backgrounds including hydrologist, environmental economist, ecologist, social scientist, and forester. This breadth of background allowed for the review to comprehensively reflect needed refinements across all the principles and indicators. We incorporated all expert feedback to develop our final set of principles and indicators. Table 5 shows the final resilience principles, indicators, and definitions used in this study.

**Table 5:** Final resilience principles and indicators with subsequent definitions

| | |
|---|---|
| Ecological | **Ecological Diversity:** The number and evenness of species and ecosystem types, and their ability to respond to disturbance<br>• *Ecosystem diversity*: the presence of a healthy variety of ecosystem types (e.g., alpine, forest, woodland, shrub, riparian, meadow)<br>• *Forest diversity:* the presence of a healthy variety of tree species (e.g., aspen, ponderosa pine)<br>• *Habitats Disturbance Response*: the ability for plant and animal habitats to respond to ecological disturbances |
| | **Ecological Variability:** Natural variability and fluctuations in ecological processes, structures, and populations<br>• *Forest structure*: the representation of different size and age classes of forest (a mix of small, medium, and large trees)<br>• *Fire processes variability*: the ability of wildfires (including their frequency, size, and severity) to occur within a healthy level of variability and fluctuations<br>• *Forest processes variability:* the ability of non-fire processes (e.g., pest outbreaks, wind damage, ice damage) to occur within a healthy level of variability and fluctuations<br>• *Watershed processes variability*: the ability of watershed processes (e.g., maintain stream flows, buffer large floods, support healthy water quality, regulate sediment movement) to occur within a healthy level of variability and fluctuations |
| Ecosystem Services | **Ecosystem Services***:* Adequate provision of essential and nonessential benefits people obtain from nature<br>• *Water quality*: the suitability of the water supply for human consumption (i.e., free of harmful chemical, physical, or biological components)<br>• *Erosion control*: the ability of the watershed to limit hillslope erosion of sediment into receiving streams, and the ability of streams to regulate downstream transport of sediment<br>• *Water regulation*: the ability of the watershed to reduce or buffer downstream flooding |

| | |
|---|---|
| | • *Recreation opportunities*: the ability to meet human demand for recreation opportunities (i.e., hiking, water sports, fishing, hunting)<br>• *Cultural benefits*: the ability of the watershed to support a good quality of life for the people that live within it now and in the future |
| Social Dimensions | **Manage Connectivity:** Decision makers and stakeholders are connected to one another so that information is transferred effectively<br>• *Evidence based decision making:* the integration of evidence-based information into decision making by groups, organizations, communities, and households working on wildfire, forest, and watershed management<br>• *Degree of information sharing:* the degree of information sharing across groups, organizations, communities, and households working on wildfire, forest, or watershed management |
| | **Manage Complex Variables & Feedbacks:** Incorporation of information about long-term outcomes into decision making<br>• *Understanding of gradual changes:* the level of understanding by groups, organizations, communities, and households working on wildfire, forest, and watershed management about gradual, long-term changes to the watershed (e.g., from wildfire, forest or watershed management, climate, human use, etc.) |
| | **Foster Complex Adaptive Thinking:** Degree of learning and experimentation by decision makers and stakeholders in response to ecological and social change<br>• *Willingness to accept change:* the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to accept changes in the watershed (e.g, changing fire regimes, forest or watershed management, or climate) in their management decisions<br>• *Degree of learning and experimentation:* the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to experiment with new management actions or practices (e.g., pre- or post-fire mitigation) in response to changes in the watershed |
| | **Linking and Bonding Social Capital***:* The strength of relationships among decision makers and stakeholders<br>• *Level of coordination:* the level of coordination (i.e., the joint determination of goals) across groups, organizations, communities, and households working on wildfire, forest, and watershed management<br>• *Level of collaboration:* the level of collaboration (i.e., the voluntary helping of others to achieve goals) across groups, organizations, communities, and households working on wildfire, forest, and watershed management<br>• *Trust:* the level of trust across groups, organizations, communities, and households working on wildfire, forest, and watershed management |
| | **Governance**: The level of redundancy in the roles and responsibilities, and the equitable participation of all decision makers and stakeholders<br>• *Institutional redundancy*: the level of overlap in the groups, organizations, communities, and households working on wildfire, forest, and watershed management<br>• *Distribution of power:* the equitable distribution of power across all groups, organizations, communities, and households working on wildfire, forest, and watershed management |

| | |
|---|---|
| | • *Accountability*: the level of accountability (i.e., following through on responsibilities) among all groups, organizations, communities, and households working on wildfire, forest, and watershed management<br>• *Participation*: the level of participation in decision-making across all groups, organizations, communities, and households about wildfire, forest, and watershed management<br>• *Diversity of perspectives*: the diversity of perspectives (e.g., ideas, views, opinions) that inform decision-making about wildfire, forest, and watershed management |

Qualatative Data Collection

*Interview Development*

Semi-structured interviews were developed to gather detail on how stakeholders characterize resilience of their system, how it has changed over time, and their perceptions about how current management actions are influencing resilience, and whether there are gaps. The interviews were used to gain a nuanced understanding of current resilience and changes in resilience from wildfire events and management actions. To develop the interviews, we outlined priority themes, based on research objectives. These sections included characterizing current resilience, characterizing post 2020 wildfire resilience, influence of 2020 wildfires on changes to resilience, impact of governance and management actions on resilience, and perceptions of future resilience. Using these broad themes, our interview questions aimed to understand:

- How were organizations defining and operationalizing resilience?
- How did stakeholders characterize resilience of their primary watershed presently (in 2022)?
- What was the influence of the 2020 wildfires in changing local resilience as perceived by local stakeholders?
- What management actions are presently being implemented in the study area, what actions are perceived to be the most effective, and did the 2020 wildfires change the scope and or scale of mitigation actions locally?

- How do organizations working on wildfire and watershed management collaborate and coordinate with one another?
- Where do stakeholders want to see their watershed's resilience in the next 5-10 years and what factors are necessary to create that change?

For all sections we developed sub questions asking how the informant perceived resilience in terms of the eight principles and indicators we developed (Table 5). We vetted our first draft of the interview with the thesis committee for review and subsequent edits. After the first two interviews we did a final round of edits to enhance clarity for the interviewees based on feedback in the first two interviews. These recommendations did not change the material substantively, rather merged similar questions and word smithed questions to be shorter and easier for informants to understand. These first two interviews were both included in analysis. The final version of the interview can be seen in Appendix B.

*Interview Database Development*

Our interviews were targeted at stakeholders who operationalize watershed protection through wildfire mitigation actions within the Poudre River and Big Thompson River watersheds. Based on these criteria, we developed an initial database of key stakeholders, organized by the stakeholder types of federal or state government agencies, water utility, coalition or NGO, academic or research group, city or county governments, and private business. Research groups housed under government agencies, such as the Rocky Mountain Research Station for example, were categorized as a research group given their operational role. All other organization types fell clearly into solely one of the organizational groups and don't require any further explanation of delineation. The inclusion of these groups was based on similar works and reflected how other social environmental scientists had defined stakeholder groups in prior studies (Huber-Stearns, 2015; Roberts et al., 2020). This initial database was created through the authors local knowledge, web-based research, and expert elicitation from faculty at CSU's Warner College of Natural Resources.

After developing the complete stakeholder database, an initial calculation was conducted for the target number of interviews across the total number of organizations by stakeholder type. We calculated how many interviews we should request using a weighted representation per organization type. This decision was based on designing the spread of interviews per stakeholder type to reflect the number of total relevant organizations working under each stakeholder type. This calculation was based on a total targeted number of 15 interviews. 15 interviews were designated as an appropriate total number given the total number of organizations was around 37, and that this was a mixed methods study. The initial calculation for interviews requested by the six stakeholder types can be seen below in Table 6. Calculations for column 'number of interviews to request' were determined based on maintaining the percentage representation for each stakeholder type out of the 28 of which were initially identified as key organizations to interview.

**Table 6:** Calculation for determining number of initial interview requests to make by stakeholder type

| Stakeholder Types | Number or initially identified key organizations | Percentage Representation | Number of initial interviews to request |
|---|---|---|---|
| Government Agencies | 6 | 21% | 3 |
| Utilities | 4 | 14% | 2 |
| Coalitions and NGOs | 8 | 29% | 4 |
| Research Groups | 3 | 11% | 2 |
| City and Counties | 3 | 11% | 2 |
| Private Businesses | 4 | 14% | 2 |
| TOTAL | 28 | 100% | 15 |

*Requesting Interviews*

Using the targeted number of interviews (Table 6) we selected stakeholders from each organization type for our first round of interview requests. In this first round of interview requests, we reached out to employees in managerial or director positions. If they recommended a different staff member more suited to answer our questions, we shifted to pursue the interview with the recommended staff member. We first reached out to potential interviewees at the end of June 2022 (6/27/2022). If we did not hear back, a first reminder was sent one week after initial contact and a second reminder was sent two weeks after initial contact. If a potential informant did not respond after two reminders, we moved on to tier two candidates from the same organization group.

Tier one stakeholders were selected based on our personal knowledge about which stakeholder groups within each stakeholder type would have the most knowledge on SES resilience within the two watersheds of interest. The same question drove the prioritization for tier two interview informants with the caveat that the pool was from remaining practitioners who had not yet been interviewed and not yet been sent a request with two subsequent reminders.

We were able to reach our target of 15 interviews but as Table 7 highlights, we had to make changes from our targeted spread of interviews across stakeholder types. Specifically, we were unsuccessful in having private businesses included. Table 7 shows the breakdown of stakeholder type representation for the 15 conducted interviews. The final list of organization that participated in an interview can be seen in Appendix C.

**Table 7:** Final breakdown by stakeholder type for conducted interviews

| Stakeholder Types | Calculated Initial Requests | Interviews Conducted | Net change |
|---|---|---|---|
| Government Agencies | 3 | 4 | +1 |
| Utilities | 2 | 2 | n/a |
| Coalitions and NGOs | 4 | 4 | n/a |
| Research Groups | 2 | 3 | +1 |
| City and Counties | 2 | 2 | n/a |
| Private Businesses | 2 | 0 | -2 |

Previous works identified local busiensses, specifically breweries, as key funders in watershed management initiatives in these watersheds (Roberts et al., 2019, 2020). However, in reaching out to breweries for interviews, we learned that due to internal staff changes and priority shifts, they did not have the knowledge of SES resilience we were seeking to characterize in this study. We had also identified a few engineering firms who had worked on watershed projects in the study site in the past. However, due to the long span in time since their work, when we asked them to participate in the study they had insufficient knowledge on current resilience to participate in an interview. In both cases, the private businesses themselves recommended we seek other groups for the interviews. Thus, in the end, the two targeted interviews (Table 6) were redistributed with one to government agencies and one to research groups (Table 7). These two groups were chosen as replacements because throughout the first interviews, informants stressed the crucial role they played in the development and implementation of wildfire mitigation.

*Conducting interviews*

Interviews were conducted from July through August 2022. Interviews were conducted either on Teams or in person depending on the interviewee's preference. Interviewees were given consent forms and informed that interviews were recorded. Consent forms were sent one week prior to the interview and requested to be returned the day of the interview. A table of all principles and indicators was also sent one week prior to the scheduled interview along with the list of questions for the interview (Appendix B). This allowed informants to come with any questions they might have as well as provide thorough and well thought out responses. During the interview, the table of principles and indicators as well as the written interview questions were provided as reference. This helped interviews stay on track and assisted informants who preferred visual prompts over auditory ones.

Interviews concluded with asking informants who else they believed was a priority to include in our resilience study. We asked this question to gather additional information for contacts internally within their organization as well as for contacts outside their organization. Their responses were added to our database of stakeholders identified for survey dissemination only after confirming through online research that the newly identified informant still worked within one of the two study area watersheds on wildfire, forest, or watershed management. By conducting the interviews first, we were able to add to the stakeholder database for survey dissemination and identify new key informants for survey dissemination through interviewee knowledge. Additionally, the use of internal recommendations for surveys was expected to increase the survey response rate.

Quantatative Data Collection

*Survey Development*

An online survey was developed using Qualtrics. The survey contained six sections: (1) overview, (2) current resilience, (3) resilience before the 2020 wildfire events, (4) influence of 2020 wildfire events on resilience, (5) the influence of management actions on resilience, and (6) future scenarios. The resilience indicators in Table 5 were used to generate the survey questions about resilience in sections 2-5. The final survey can be found in Appendix D.

In the overview section (1) we asked stakeholders to consent to taking the survey and asked them to identify their respective organizational group, role, and time in their position. To effectively learn about each watershed and acknowledge answers might vary between watershed, this section concluded by explicitly asking informants which watershed they would be responding for-the Poudre River or Big Thompson River watershed. For current resilience (2), we asked respondents to rank, using 5-point Likert scales, each indicator-question developed from the eight resilience principles, for the current year (2022). For resilience before the 2020 wildfire events (3), informants were asked the same indicator-questions in the same 5-point Likert scale, but for before the 2020 wildfire events. These sections collectively served to characterize past and current perceptions of resilience.

In the section on influence of 2020 wildfire events on resilience (4) the same indicator-questions were asked but using an altered 5-point Likert scale targeted at level and direction of influence rather than quality of watershed state. This section serves a crucial role for understanding if changes to perceived SES resilience are attributed to the wildfire events or other occurrences. This section combined with the two previous sections allowed us to understand how recent wildfire events have impacted resilience of the SES system.

The management actions section (5) asked informants to rank the effectiveness of three pre-wildfire mitigation actions as defined by administering prescribed burns, creating defensible space, and tinning forests both mechanically and by hand. Using these same three pre-wildfire mitigation actions, we asked informants how influential these mitigation actions were on influencing each of the indicators, using the same 5-point Likert scale as the 2020 wildfire events influence. The ranking of management effectiveness and collective impact on SES resilience questions were repeated for three post-fire mitigation actions as defined by mulching, reforesting post-fire landscapes, and stream restoration and stabilization projects.

The final section focused on future resilience (6). In this section we aimed to understand what wildfire related impacts concerned stakeholders the most, as well as what factors they thought would have the largest potential to improve resilience. We also asked informants to suggest any management strategies we had not yet considered that they would like to see implemented in the future. The survey concluded by asking if informants wanted a copy of the project results or had any further comments or questions.

The survey was refined through iterative edits and vetting from multiple experts before reaching our final product. A first round of vetting was conducted with the thesis committee to ensure that survey questions sufficiently answered research questions. A second round of vetting was conducted with the CSU Stats lab. This round of edits focused of finalizing the Likert scales and focused on using two scales- one for quality of watershed and one for influence on watershed. In this stage a five-point scale with a middle neutral was selected. A third stage of vetting focused on increasing clarity in flow and wording. For this stage the survey was sent to a post doctorate researcher at the Warner College of Natural Resources with specialty in survey development. From this stage we merged a few sections based on recommendations to improve flow and length of the survey. Additionally, in this stage we removed the phrase resilience and replaced it with ecological and social health to limit jargon and allow for all relevant stakeholders to engage with the survey. Next, we sent the survey out to two local experts to take the survey. The feedback we received after this pretest focused on finalizing wording and tailoring the wording to the stakeholder knowledge we aimed to capture. Finally, the researchers went through the final survey to remove any kinks in the presentation on Qualtrics, ensure wording was correct, and finalize the visual presentation.

*Survey Dissemination*

For survey dissemination we used the database initially produced for the interviews and bolstered from interviewee recommendations on other stakeholders. The complete list of organizations that received the disseminated survey can be seen in Appendix E. All stakeholders in the database hold roles in watershed or wildfire management. In cases where multiple employees at a target organization work on watersheds and/or wildfire, we included all relevant employees in the database. By the twelfth interview when we asked for recommendations of internal and external stakeholders to survey, we did not receive any new recommendations showing a comprehensiveness to the survey dissemination database.

Many interviewees who recommended a specific stakeholder or coworker to fill out the survey requested that we send the survey to them directly to share with their suggested contacts. In these instances, we sent the survey link to the interviewee to forward to their respective contact. Both the interviewee and the stakeholder receiving the forwarded survey were included in the stakeholder database. For all other stakeholders, we sent them the survey link from Qualtrics directly to their work email. Initial requests for the survey were sent on August 15, 2022. Reminders were sent on August 23, 2022, and September 1, 2022. The survey was closed on September 12, 2022.

## Data Analysis

### *Qualitative Analysis*

After the interviews were conducted, interviews were transcribed from audio recordings into written transcriptions using the application Otter ai. Transcripts were then spot checked and cleaned into a final analyzable form. The original interview recording, the Otterai transcription, and the final cleaned interview were all saved in a password locked application and kept for reference by the primary investigator throughout analysis. A saved output of top summary words created by the Otterai software as well as researcher's notes on the tone and top themes were saved alongside the transcript.

Written transcriptions were then uploaded to the qualitative analysis platform, Dedoose. The qualitative analysis used systematic thematic coding based in a thematic analysis methodology, where segments of data are coded thematically and then broader concepts are created from synthesizing codes (Thornberg & Charmaz, 2014). During this process, I went through the data systematically and assigned relevant codes to each data section. As additional codes emerged, I created new codes and grouped together similar codes based on common themes. Codes were generated on topical content rather than by question for almost all questions as is appropriate for thematic analysis of semi-structured interviews (Thornberg & Charmaz, 2014). Two exceptions were made. The first question asked informants to explain how their organization was defining and operationalizing resilience. Another question asked informants to provide their five-to-ten-year vision for a more resilient watershed. These two questions were analyzed on their own because they were asking for specific definitions or visions. Additionally, qualitative data was used to provide a nuanced understanding of if changes to the system pre and post 2020 were attributed to wildfire. As new codes on wildfire influence came to the surface in the coding process, influence codes were separated into different parent codes of positive and negative influence and denoted as social, ecosystem service, or ecological changes to best lend themselves to comparison with quantitative findings.

Throughout the coding process, I kept detailed notes of transcription and left memos indicating data segments to return to. To ensure the first few interviews included all relevant codes, I returned to the first third of interviews after generating all my codes. Thematic coding was chosen as the best option for analysis because it allows for themes and patterns of the data to come to the surface in a systematic and methodical way (Braun & Clarke, 2006). For particularly relevant individual vignettes, I included individual narratives to add depth and nuance in relevant areas through a narrative analysis (Riessman, 2008). Keeping informants' quotes in-tact can provide a nuanced depth to a storyline (Lavoie et al., 2019).

Only after all interviews had been coded and the earliest interviews double checked for the inclusion of newer codes, did I remove codes no longer deemed important to the narrative. Codes with three or fewer assigned excerpts were deemed insufficiently supported to be incorporated into the final write up. Thus, all codes with three or fewer assigned relevant excerpts were not included in final analysis. This left a total of 67 codes (Appendix F). The final 67 codes included at least four assigned excerpts up to 26 assigned excerpts.

*Quantitative Analysis*

The survey was analyzed quantitatively, below the respective analysis methods for each section of the survey are outlined.

*(A) SES Resilience Pre and Post 2020 Fires*: To assess changes in resilience, we assigned values to the Likert scale questions (Allen et al., 2018). For quality questions these quantifiations translate to Very Poor (1), Somewhat Poor (2), Neutral (3), Somewhat Good (4), Very Good (5). We then calculated mean scores for relative resilience of current 2022 resilience and resilience before the 2020 wildfires

for all of the resilience indicators. These relative resilience means were mapped for each indicator on a spider web graph for visual comparison of resilience pre and post 2020 wildfire across indicators. To test for statistical differences between current 2022 resilience and resilience before the 2020 wildfires we conducted a paired Wilcoxon Sign-Rank test. This test was chosen because it can be tailored for paired data, allows for ordinal Likert-scale data, and does not require the assumption of normality (McCrum-Gardner, 2008). This methodology was chosen over other statistical methods used in assessing relative resilience such as logistic ordinal regression because we wanted to isolate the single dependent variable of passage of time as a proxy for wildfire occurrence.

(B) *Differences in Resilience Across Watersheds:* Mean resilience for present day watersheds was recalculated using the same methodology outlined above, but with separate calculations for each watershed. These relative resilience means were mapped for each indicator on a spider web graph for visual comparison of present-day resilience between the Poudre and Big Thompson watersheds. We did not conduct any statistical tests for inference on these means, given the small number of respondents for the Big Thompson watershed (n=12).

(C) *Influence of 2020 Wildfires on Resilience*: The same numeration process was done for questions of wildfire influence on resilience. For influence questions these quantifiations translate to Strong negative influence (1), Slight negative influence (2), No influence (3), Slight positive influence (4), Strong positive influence (5). Using this ordinal scale, means and standard deviation of wildfire influence were calculated for all resilience indicators. Bar charts with standard deviation bars were developed for all significant indicators from the paired Wilcoxon Sign-Rank test. Significant indicators with a mean influence score of less than three, noted from the ordinal data transformation as 'No influence', were grouped together as indicators that had negative influence from the 2020 wildfires. Within this grouping, mean influence scores closer to one indicate the greatest negative influence from the 2020 wildfires on that resilience indicator. Significant indicators with a mean influence score of more than three, were grouped together as indicators that had negative influence from the 2020 wildfires. For this grouping, mean influence scores closer to five indicate a larger positive influence from the 2020 wildfires on that resilience indicator. Calculating these mean influence scores and applying them to indicators with significant change pre and post fire allowed us to see if the post fire change was perceived by stakeholders as a result of the wildfire events. Graphing indicators with statistically significant change pre to post fire in groups of positive and negative perceived influence allowed us to compare strength of perceived influence across key indicators.

(D) *Pre-Wildfire & Post-Wildfire Mitigation Actions:* To explore the influence of management actions on perceived resilience, the influence Likert scale was again translated to an ordinal scale using the qualifications described in part A above. Using this ordinal scale, mean influence for all indicators was calculated for both groupings of pre and post wildfire mitigation actions. To compare pre-wildfire and post-wildfire mitigation actions perceived influence on SES resilience, mean influence scores were mapped on a spider web graph for a visual comparison of mitigation strategy effectiveness across all the SES resilience indicators. To analyze ranked effectiveness of pre-wildfire mitigation actions (administering prescribed burns, creating defensible space, and thinning forests both mechanically and by hand) a count of each action was created for the perceived ranking of most effective, second most effective, and third most effective. These findings were presented graphically as segmented bar charts to show the breakdown of each action across ranked order. Additionally, for the most effective category, actions were additionally listed in order of rank based on informant responses. The same methodology was used to analyze the ranked effectiveness of post-wildfire mitigation actions (mulching post-fire landscapes, reforesting post-fire landscapes, and stream restoration and stabilization projects post-fire).

*(E) Future Resilience:* Lastly, the future resilience section of the survey was analyzed. For the first question of this section, we asked respondents how concerned their organization was about the impact of future wildfire on local forests and watersheds. To create a mean level of concern, values were assigned to responses of concern as (1) Not concerned, (2) Somewhat concerned, (3) Concerned, and (4) Very concerned. Using these numerical assignments, a mean level of concern was calculated for all respondents. Secondly, to analyze the top impacts of concern for forests and watersheds locally we totaled all responses and sorted by top responses to produce a list of top concerns for future resilience. To understand which factors stakeholders perceived to be the most impactful on improving ecological and social health we sorted the factors by response. While the instructions asked stakeholders to select the top three factors of influence, many selected more than three. For this reason, responses were broken down into those who reported more than three top factors and those who reported the recommended three factors. After sorting and listing the top factors for both groups, we found that the top six factors for both groups were the same. These top six factors were then presented as an ordered list with respective counts for each factor. Finally, the management strategies informants provided in the 'other' category of mitigations actions for future resilience were compiled and presented as a list.

## Chapter Four: Results

<u>Qualitative</u>

*Defining Resilience*

All interviewees reported using the term in their work. When asked to define resilience, some informants provided a vision driven definition while others brought up metrics for measuring resilience. Many informants provided both a vision driven definition and specific resilience metrics. Table 8 provides excerpts for all the vision driven definitions of resilience that interviewees provided. Most focus on the system's ability to bounce back to its previous state following a disturbance. Many definitions used proxy words such as "watershed health" or "watershed strength" in their definitions.

**Table 8**: All the vision driven definitions of resilience provided by interviewees

| Theme | Example Quotes |
| --- | --- |
| Resilience Definitions | 'The ability to persist in some form or another through disturbances and change.'<br>'We define resiliency plans, the ability of the watershed to bounce back after an impact, like a future fire or flood event.'<br>'Resilient forests, to me, it's just a healthy forest, it's able to withstand disturbances.'<br>'The ability of our watershed to respond to any sort of disturbance and rebound.'<br>'The stability of that, that landscape to accommodate those land uses that are on it.'<br>'That the community can survive and be intact after fire.'<br>'An ecosystem's ability to bounce back after a disturbance.'<br>'The ability to absorb and recover from disturbance.'<br>'A system's ability to absorb and recover from disturbances such as wildfire without a real fundamental change in ecological process function.'<br>'Forest strength and watershed strength.'<br>'Its adaptive management… it's how we see the landscape 100 years down the road.'<br>'The ability of a landscape to absorb disturbance without changing ecosystem function and moving to an alternative state.'<br>'A state of health whereby it can be resilient to the impacts of severe wildfire.' |

Informants provided a wide range of metrics for increased local resilience. Metrics can be broken down into forest metrics, watershed metrics, social metrics, and mixed metrics. All provided resilience metrics can be seen in in Table 9. The most referenced resilience metrics informants provided were that of water quality, water supply, and wildfire mitigation actions.

**Table 9:** Resilience metrics offered within resilience definitions informants provided

| Forest | Watershed | Social | Mixed |
|---|---|---|---|
| Forest heterogeneity | Aquatic health | Visitor experience | Ecosystem health |
| Fuels treatments | Water supply | Fire adapted communities | Wildfire mitigation actions |
| Forest health | Watershed strength | Evacuation Preparedness | Ecosystem services |
| Forest strength | Water quality | | |
| Wildlife habitat | | | |
| Vegetation re-growth | | | |

Lastly, when providing definitions of resilience and any subsequent resilience metrics, a few informants provided descriptor words to accompany resilience. Such resilience descriptors can be viewed as tailored views on resilience that highlight an organization's resilience focus. Specific forms of resilience included SES resilience, collaborative resilience, logical resilience, social resilience, landscape resilience, ecological resilience, watershed resilience, and forest resilience.

*Mitigation Actions*

Interview informants listed a variety of management actions currently occurring in their watersheds including thinning (mechanically and by hand), mulching, replanting, stream restoration, home hardening, and mixed methods actions which blend two or more actions congruently. Informants identified the major driving factors behind the development and implementation of mitigation actions as being driven by neighboring communities, water supply or watershed priority, and further needs identified through the monitoring of past mitigation efforts. Many informants perceived improvements in mitigation actions over time in that they are increasing in scale and are utilizing wildfire as a treatment through the use of tools such as Potential Operational Delineations (PODs). On the social side, informants mentioned improving social license as defined by the public's willingness and acceptance of mitigation action implementation.

Many stakeholders identified improvements in the use of out of the box solutions for mitigation actions. Examples of out of the box solutions included the creation of web-based tools or collaborative maps. Such projects included the creation of collaborative mapping tools of existing projects, web-based tools that identify high risk areas, outcome tracking software, and watershed investment tools. In terms of on-the-ground activities, multiple informants brought up the use of beaver dam analogs as an out of the box treatment.

Prescribed fire as a treatment type came up repeatedly in conversation as the most effective management action. Informants described the effectiveness of prescribed fire on three major fronts. Firstly, informants perceived that when used with thinning it can have combined effects and allows for the treatment of multiple forest types and forests with strong suppression legacies. Secondly, informants discussed that prescribed fire offers a cost-effective way to treat at scale. Lastly, informants noted that no other treatment type serves as a natural analogue to wildfire and thus prescribed fire offers landscapes a unique set of ecological benefits that mirror natural processes.

*Influence of 2020 Wildfires on Resilience*

Interviews unveiled two types of discussions surrounding the influence of the 2020 wildfires on resilience. While all informants spoke of the role the wildfires played in changing the SES, some spoke to fire related ecological changes while others focused on social variables that wildfire had served as a catalyst for improving.

In terms of ecological degradations associated with the 2020 wildfire events, the top three degradations informants discussed included post-fire flood cycles, climate change, and water quality/supply degradation. The comments around post-fire flood cycles highlighted the damages to properties, loss of recreation opportunities, and increasing concerns for public safety surrounding the floods that follow wildfires. Many informants who discussed this point brought up the flood of 2013 that followed the High Park Fire as well as flooding following the 2020 wildfire season. Narratives around climate change focused on both the changing way forests respond to wildfire and creating forest conditions with increased susceptibility to wildfires. Concerns around water quality and supply focused on the role wildfires play in altering the water quality of local source water systems. Example quotes of these top themes can be seen below in Table 10. Other fire related ecological concerns included perceptions of degraded ecosystem services, density of fuel loads, increasing fire severity, presence of insect and beetle kill trees, and limited regeneration in burn areas.

**Table 10**: Example quotes for fire reflated ecological degradations including post-fire flood cycles, climate change, and water quality/supply degradation

| Theme | Example Quotes |
|---|---|
| Post-Fire Flood Cycles | 'I think the floods that happen post fire are huge. I know that a lot of the work in the Poudre is for post-fire flood recovery. The floods have a large impact on ecological health and the watersheds as a whole.'<br>'The 2013 food is a big thing that happened and changed the systems and how ecologically the riparian areas and water interact.'<br>'From a social and ecological standpoint, of course the fires of recent memory and the floods of recent memory. Those two events are huge in shaping these watersheds.'<br>'The aftereffects of flooding and erosion… [they] certainly impact the landscape and water quality and health of our rivers and all the species that live in them.' |
| Climate Change | 'The 2020 wildfire was just unprecedented. This is the new normal in a lot of ways and this is what we're going to be facing in the future. We need to really think about our work in the context of that future, climate, future fire behavior, |

| | |
|---|---|
| | and what we can do, even in the face of that pretty extreme event to enhance and foster resilience.'<br><br>'There's lots of wildfire now… I continue to more worried about them with climate change in the ways we're seeing wildfire behave differently. And forests respond differently after wildfire.'<br><br>'Ecologically, I would say climate change is a huge factor… and all the related issues associated with climate change, earlier runoff, drier forests…Just kind of the stage is set for big fires.'<br><br>'The most concerning thing that looms is climate change. I don't think that we're going to see conditions that improve in terms of wildfire susceptibility. That's got to be the most concerning and may not be specific to wildfire events, but that contributes to their likelihood.' |
| Water Quality/ Supply Degradation | 'I think the biggest concern is the impacts to water quality, there's long term impacts and then impacts to public safety as well.'<br><br>'Water Supply is very concerning to me. We already don't have enough water where we live and have been experiencing drought for many years. Compromised water quality is a big concern of mine too.'<br><br>'From a water quality perspective, we're concerned about pollution, we're concerned about damaged infrastructure cost, having to shuffle between we have to water supplies.'<br><br>'Our number one priority is water quality and quantity and making sure we're supplying water to our customers the best water that we can. I would say the ecological health of the watershed it's good and bad. The Poudre is a really pristine water supply… with mostly undeveloped or low impact land up there. On the other hand, we've experienced a couple of, giant wildfires in the last 10 years, being High Park and Cameron Peak.' |

Throughout the interviews, there was one theme that came out regarding the wildfire's ecological impacts in a positive way. Many informants percieved the wildfires as creating increased ecological variability and heterogeneity across the watersheds. Some informants noted that this can improve habitats for foraging species such as Mule Deer and Elk. Many informants also saw a positive ecological impact from the 2020 wildfires in some low severity burn areas where the wildfires acted as a mitigation treatment would have. Throughout the conversations, many informants brought up the notion that these watersheds are fire adapted systems, and that fire is a process embedded in this landscape.

Other codes on response to wildfire focused on improved social variables that wildfire had served as a catalyst for. The top three of these catalysts included perceived positive changes for funding, partnerships, and public attention and support. The theme of wildfire as a catalyst for funding focused on new funding options opening up after natural disasters such as wildfire. The theme of wildfire as a catalyst for partnerships highlighted how the wildfire events strengthened existing collaborations and brought together new partnerships. The theme of wildfire as a catalyst for public attention and support can be synthesized as higher levels of public's knowledge of and support for mitigation treatments after wildfire events. Example quotes of these top themes can be seen in Table 11. A fourth code of wildfire serving as a catalyst for ramping up mitigation actions was also found within the interviews. It can be viewed as a sub-code to wildfire as a catalyst for funding and for public support of mitigation actions because higher fundings and public support was framed by some stakeholders as the wildfire events establishing the necessary conditions for translating mitigation plans into on the ground actions.

**Table 11**: Example quotes of wildfire as a catalyst for improved social variables including increased funding, partnerships, and public attention/support

| Theme | Example Quotes |
|---|---|
| Catalyst for Funding | 'What it (Cameron Peak) did do is money. That's one thing that any crisis event will bring with it. Response money and funding.'<br><br>'These fires un-corked a pile of new funding.'<br><br>'Anytime one of these wildfire events takes place there, a lot of funding becomes available, so the scale definitely ramps up.'<br><br>'Overall, the 2020 wildfire season brought us together much more and helped highlight the urgency of the work. Since then, we've seen a lot of really good investment, at that state level with increases in funding to our state grant programs.' |
| Catalyst for Partnership | 'We try to collaborate and really stretch out our resources as best we can. I think that these events seem to strengthen those collaborations… that's definitely an outcome of the fires.'<br><br>'The fires have just increased the collaborative nature of these different kind of actions across the board in northern Colorado.'<br><br>'This manage connectivity indicator has skyrocketed since those fires. I think those fires really highlighted the importance of people at different organizations collaborating and working together, rather than duplicating |

| | |
|---|---|
| | efforts and competing with each other. Because we have so many shared risks and shared goals.'<br><br>'The fires just strengthened our resolve to work more closely together and increase the pace and scale.' |
| Catalyst for Public Attention and Support | 'People have seen these destructive fires happening in their backyards, and it's really kind of lit a fire under people to take action. And since the Cameron peak fire we've made community wildfire protection plans in the Poudre River Watershed.'<br><br>'I've been surprised by some community members…who have just been more receptive to some of these conversations around fire adapted communities. I think a big part of that is seeing these fires and realizing we live in the forest and the forest is changing and evolving and we need to change and adapt with it.'<br><br>'Based on my experience, working with those communities now and talking to folks that have lived in the area for a while, it seems like there has been a paradigm shift. I've seen a shift of people being more accepting of prescribed fire and pile burning, because they realize fire is inevitable and either they can do it in a more controlled way, or they can wait for a wildfire to come through.'<br><br>'Before the East Troublesome fire, we already had some social license from the High Park fire. Even though it was 10 years ago people still remember it.' |

*Partnership Across the Study Area*

A variety of themes emerged from the interview data around local partnerships. For example, stakeholders suggested partnerships are motivated by differing or adjacent land ownerships as well as aligned organizational goals. Partnership formations were described as taking a long time to build but once established, withstanding setbacks. Benefits from partnerships were described as building organizational capacity, improving social license, and facilitating the spread of funds across organizations. For these reasons, some informants spoke at length about the importance of stakeholder connectivity with one informant saying "Our partnerships and collaborations impact all of the resilience principles. It feels mandatory, how we work is in a collaborative fashion and I would hope the other agencies have a similar answer." Finally, the most applied code about partnerships in the watersheds was for the strength of partnerships. Table 12 shows example quotes for this top theme.

**Table 12**: Example quotes for strength of partnerships

| Theme | Example Quotes |
|---|---|
| Strength of Partnerships | 'The commitment to collaboration in these watersheds continues to grow and deepen.'<br>'I feel like Northern Colorado is a really progressive place when it comes to organizations collaborating with each other rather than competing with each other because we just realized that like, there's not enough resources to get this work done. And the more we can collaborate and pool resources, the more effective we can be.'<br>'All of this has really benefited from the cross jurisdictional planning and cross jurisdictional investments, which would not be possible but for these partnerships and collaborations. I think these connections have been really important for building resilience, because collectively we can take a pretty holistic view at these resilience principles.'<br>'It feels like it's a real functional collaborative, with really good strong relationships. Everyone is on the same page with the work that we need to be doing.'<br>'We have good plans and good partners at the table.'<br>'I think there is a remarkably high degree of strength within those relationships among the decision makers and stakeholders. There's a high level of coordination, a high level of collaboration, and a pretty high level of trust.' |

*Barriers and Future Needs*

When asked what elements of ecological and social health should be prioritized in the next five to ten years, interviewees had a wide range of answers. Tier 1 indicates themes that 27% of informants discussed, tier 2 indicates themes that 20%, and tier 3 indicates themes that 13% of informants discussed. The top three priorities for the next five to ten years were described as the priority to protect water quality and water supply, maintain and improve stakeholder relationships, and remove barriers to prescribed fire (Table 13).

**Table 13:** Top priorities for improving ecological and social health in the next five to ten years

| |
|---|
| **Tier 1** |
| Protect water quality and water supply |
| Maintain and improve stakeholder relationships |
| Remove barriers to prescribed fire |
| **Tier 2** |
| Improve and protect ecosystem services |
| Develop more wildfire adapted community plans |

| |
|---|
| Deploy unique tools such as beaver dam analogs |
| **Tier 3**<br>Improve ecological diversity and variability<br>Limit post-fire flooding destruction<br>Focus on adaptivity and connectivity |

In the discussions of what factors are necessary to create these changes, many informants first set the stage by discussing current barriers and difficulties. Informants listed a variety of barriers and difficulties presently that prevent the types of mitigation actions they would like to see implemented- including barriers based on land ownership. For public land ownership, informants cited policies limiting treatments in wilderness areas as a top concern. On private lands they saw limited connectivity of projects and the need for individual land ownership buy-in and initiative as major barriers. For mitigation on both private and public lands, informants expressed frustration at limited treatment sizes. The most common theme for both land types was that of barriers to prescribed fire. Table 14 shows example quotes of barriers to prescribed fire. Barriers included forest's structure being too dense to receive fire safely, limits to social license, and policy or insurance barriers.

**Table 14**: Example quotes for theme barriers to prescribed fire

| Theme | Example Quotes |
|---|---|
| Barriers to Prescribed Fire | 'There's a couple of policies sort of around prescribed fire and viability who can and can't do prescribe fire. Some of those kinds of things that I think could be changed and helped.'<br>'You probably heard about the challenges with insurance.'<br>'We need someone to step with prescribed fire on non-federal lands. Many agencies have tried and failed… there's still a void of who's coordinating and leading a lot of prescribed fire and non-federal lands and adding that capacity.'<br>'I think from a public perception, people will say they believe in prescribed burning, but will tend to not in my backyard it.'<br>'We've got a lot of work to do there still in terms of creating that social license, and really getting fire on the ground in the way that we need to.'<br>'First burns are really difficult without some sort of mechanical help. We could do it without mechanical help, but you're going to get mortality and things that socially wouldn't be acceptable.' |

| | |
|---|---|
| | 'There have been some challenges with burning with prescribed burning… it's because of policies rather than desire… [we] need better laws and insurance for implementing prescribed burns.'<br><br>'Due to climate change and social licensing, the window of opportunity to implement prescribed fire is becoming ever narrower… People just don't want to see smoke in the air. They don't want to see fire near their communities.'<br><br>'Prescribed fire is another important tool that is in the toolbox that we need to begin to use more often. Of course, with that comes a little bit of a risk, but the risks always there…How do you want to take your risk? Do you want to take it on the highest, hottest day in August? Or do you want to do it in a more controlled way?'<br><br>In an ideal world… we would go in and thin the forests, build and burn piles and get these forests back to a place where we can reintroduce fire and actually do broadcasts burning. But we're a long ways from that, there's just too much fuel that we have to get rid of before we can reintroduce fire.' |

Interviewees also discussed barriers and difficulties beyond those associated with management actions. Broadly they identified legacy settlement effects, expanding Wildland Urban Interface (WUI) populations, growing populations of residents and tourists across the state, and differences between the Big Thompson and Poudre watersheds as difficulties. In respect to the latter, informants suggested there was less collaboration, coordination, and information sharing in the Big Thompson watershed as compared to the Poudre watershed. A few informants suggested that this difference was because a smaller portion of the Big Thompson burnt in the High Park Fire (Figure 5). Thus, Big Thompson stakeholders had not been through the process of forming social links that pre 2020 wildfires fostered in the Poudre watershed.

In response to these barriers, informants offered solutions related to social and financial needs. The top three needs identified were changes in partnerships, increases/changes to funding sources, and citizen acceptance and buy-in to mitigation actions. Example quotes for each of these three top needs can be seen in Table 15. Other identified needs included the desire for greater adaptivity and willingness to learn from practitioners, increased incorporation of science into decision making, and enhanced staff capacity across involved organizations.

**Table 15**: Example quotes for identified needs of changes in partnerships, increases/changes to funding, citizen acceptance and buy in to mitigation actions

| Theme | Example Quotes |
|---|---|
| Changes in Partnerships | 'Implementation wise, it would be awesome to have an army of different agencies working at different and larger scales.'<br><br>'We need to continue to increase the amount of coordination because certain agencies can only manage certain private, federal or state lands and things. Continuing to have them coordinate across boundaries…would continue to improve the resilience.'<br><br>'I don't think we have a lot of redundancy in roles and responsibilities. I think we're probably a little thin in that in that aspect.'<br><br>'The nonprofits in particular, thinking about how they can, at the very least, continue to work really closely together, but also contemplating the possibility of merging their organizations might be worth thinking about.'<br><br>'I've seen in a very limited way a bit of cross watershed collaboration, but not as much as I would like to see. There's still more separate than they really should be.'<br><br>'We need to go to our partners and ask them what do you value? [Identify], we have aligned goals, let's do it. Then expand that out from there. That's, my vision.' |
| Increases/Changes to Funding | 'There are changes that I would like to make [to] some of the government organizations to make funding come down easier. If there could not be so much red tape to getting things done.'<br><br>'Given the amount of federal ownership and in these two watersheds, just to allocate more resources to it, that's the big one.'<br><br>'Of course, insufficient federal funding, that looms over all of this is funding.'<br>'I'd like to see a little bit more ownership from funds through the adaptive management process.'<br><br>'What I've heard over and over again, is that somebody has to write the grant proposals, somebody has to organize, somebody has to do fundraising. We need to invest in those, somebody's.'<br><br>'Shared resources that, that is still a stumbling block, especially with the federal government. We have been able to share funds with some of our partners...but there are definitely strings attached.' |
| Citizen Acceptance and Buy In | 'I think that continuing [outreach and education] can really help our public's acceptance and understanding of, what these watersheds need ecologically. I think there's been great strides made in that regard... I just think that continued outreach and trying to generate a higher understanding among our public will continue to be important to gain support for some of these activities.'<br><br>'We really have to educate and engage the public… The more we do get the public involved and give them buy in, I think we're going to see some real change happen.' |

| | |
|---|---|
| | 'We've got a lot of work to do there still in terms of creating that social license, and really getting fire on the ground in the way that we need to.'<br>'Bringing the private landowners and citizens in to get more buy in would be huge.'<br>'We put a lot of emphasis on the ecological and forest management and wildfire management, I think more emphasis on changing human behavior as far as reducing human wildfire ignitions… I think we need to change human behavior, reduce human ignitions, and change the publics expectation towards burns in order to build resilience.' |

<u>Quantitative</u>

*Survey Responses*

The survey link was sent out to a total of 108 emails, this includes the stakeholders to which it was forwarded on the research team's behalf. Of these 108, seven emails were undeliverable to our intended recipients even after the email address was confirmed. An additional three informants had retired leaving a total of 98 surveys sent to valid emails of active stakeholders. 61 stakeholders of the 98 opened the survey for an engagement rate of 62%. 37 stakeholders completed the survey in its entirety for a completion rate of 38%. Of these 37 informants, 12 reported the Big Thompson as their primary watershed, 24 reported the Poudre as their primary watershed, and one did not confirm a primary watershed. Table 16 shows the breakdown of completed surveys by stakeholder type. Government agencies were the top group to complete the survey and made up almost half of completed responses. Informants who felt they fit into the "other" organization type, reported themselves as water providers, conservation districts, and river engineers.

**Table 16:** Breakdown of completed surveys by organizational group type

| **Organization Type** | **Completed Surveys** | **Percentage of Surveys Completed** |
|---|---|---|
| Academic or Research Group | 2 | 5% |
| City or County Government | 4 | 11% |
| Coalition or NGO | 8 | 22% |
| Government Agency | 17 | 46% |

| | | |
|---|---|---|
| Private Business | 3 | 8% |
| Other | 3 | 8% |
| Total | 37 | 100% |

*SES Resilience Pre and Post 2020 Fires*

Figure 6 shows the mean scores for current 2022 resilience and resilience before the 2020 wildfires for all resilience indicators. Water quality and recreation opportunities had the highest means for all indicators at a level of 4.27 before the 2020 wildfires. Pre 2020 fire processes variability and present 2020 fire processes variability had the lowest means for all indicators at a level of 1.92. In Figure 6, the greatest differences between mean resilience pre and post fire is seen for the ecosystem service principle showing lower mean resilience after the 2020 fires for indicators of water quality, erosion control, water regulation, and recreation opportunities. With the exception of the indicator of watershed processes variability, there was limited change for pre and post fire for principles of ecological diversity and ecological variability as can be seen in the overlap of present 2022 and pre 2020 wildfire lines in the upper right corner of Figure 6. The left side of Figure 6 shows a higher mean score for relative resilience from pre 2020 wildfires to present 2022 for all indicators of principles manage connectivity, manage complex variables & feedbacks, foster complex adaptive thinking, linking and bonding social capital, and governance except for the power distribution indicator.

The results from the paired Wilcoxon Sign-Rank test can be seen for each indicator in Table 17. Using an alpha of 0.05, 14 different indicators had statistically significant changes in perceived resilience before and after the 2020 wildfires. These indicators spanned all of the principles, with the exception of ecological diversity. Of the 14 statistically significant indicators, eight indicators were significant with perceived positive influence from the wildfire events including Information sharing, understanding gradual change, degree of learning & experimentation, level of coordination, level of collaboration, trust, institutional redundancy, and participation (Figure 8). An additional six indicators were significant with a perceived negative influence from the wildfire events including watershed processes variability, water quality, erosion control, water regulation, recreation opportunities, and cultural benefits (Figure 8).

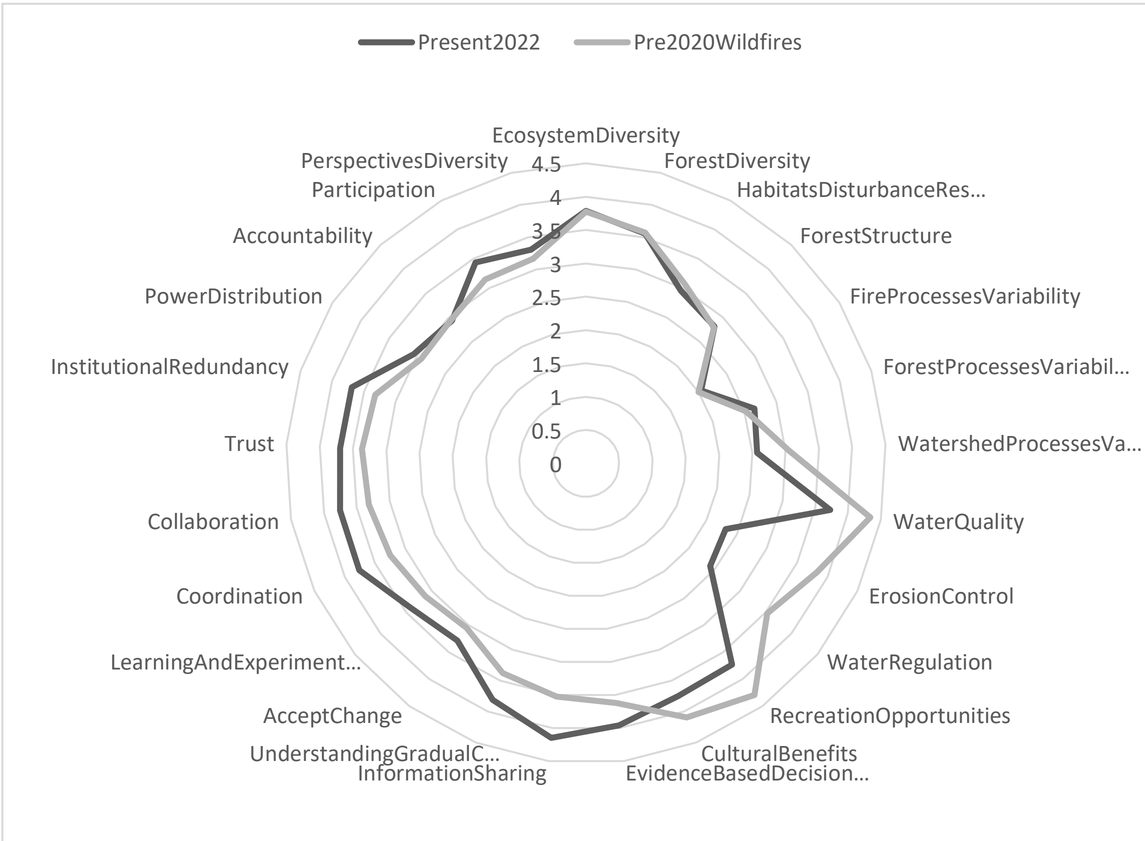


**Figure 6:** Mean scores for current 2022 resilience and resilience before the 2020 wildfires for all resilience indicators

For the principles of ecosystem services, all indicators were significantly different pre and post fire, with mean influence scores under three, noting a perceived negative influence on resilience from the 2020 wildfire events (Figure 8). This contrasts to the principles of manage complex variables & feedbacks and linking and bonding social capital. For these principles, all indicators were significantly different pre and post fire, with mean influence scores above three, noting a perceived positive negative influence on resilience from the 2020 wildfire events (Figure 8).

**Table 17:** Results from the paired Wilcoxon Sign-Rank test for difference in resilience from present day 2022 and before the 2020 wildfires for all resilience indicators from 37 respondents. The asterisk (*) indicates statistical significance using a alpha of <0.05.

| Type | Principle | Indicators | P-value |
|---|---|---|---|
| Ecological | Ecological Diversity | | |
| | | Ecosystem Diversity | 0.795 |
| | | Forest Diversity | 1.000 |
| | | Habitats Disturbance Response | 0.428 |
| | Ecological Variability | | |
| | | Forest Structure | 0.830 |
| | | Fire Processes Variability | 0.916 |
| | | Forest Processes Variability | 0.187 |
| | | Watershed Processes Variability* | 0.002 |
| Ecosystem Services | Ecosystem Service | | |
| | | Water Quality* | 0.001 |
| | | Erosion Control* | <0.001 |
| | | Water Regulation* | <0.001 |
| | | Recreation Opportunities* | <0.001 |
| | | Cultural Benefits* | 0.007 |
| Social Dimensions | Manage Connectivity | | |
| | | Evidence Based Decision Making | 0.078 |
| | | Degree of Information Sharing* | 0.001 |
| | Manage Complex Variables & Feedbacks | | |
| | | Understanding Gradual Changes* | 0.003 |
| | Foster Complex Adaptive Thinking | | |
| | | Willingness to Accept Change | 0.102 |
| | | Degree of Learning & Experimentation* | 0.016 |
| | Linking and Bonding Social Capital | | |
| | | Level of Coordination* | 0.002 |
| | | Level of Collaboration* | 0.001 |
| | | Trust* | 0.011 |
| | Governance | | |
| | | Institutional Redundancy* | 0.017 |
| | | Distribution of Power | 0.120 |
| | | Accountability | 0.260 |
| | | Participation* | 0.014 |
| | | Diversity of Perspectives | 0.432 |

*Differences in Current Resilience Across Watersheds*

Differences between watersheds can be seen in Figure 7, which shows the perceptions of current 2022 resilience for all resilience indicators for each watershed separately. In the Poudre watershed, the highest resilience indicator for 2022 was degree of information sharing with a mean of 4.3. In 2022, in the Big Thompson watershed, the highest resilience indicator was water quality with a mean of 4.1. For both watersheds, the lowest resilience indicator was fire processes variability with a mean of 2.0 in the Poudre and a mean of 2.2 in the Big Thompson. Erosion control was the indicator with the largest difference between watersheds with a difference in means of 1.0. The indicator that was most similar across watersheds was the habitats disturbance response indicator with difference in means of less than -0.01

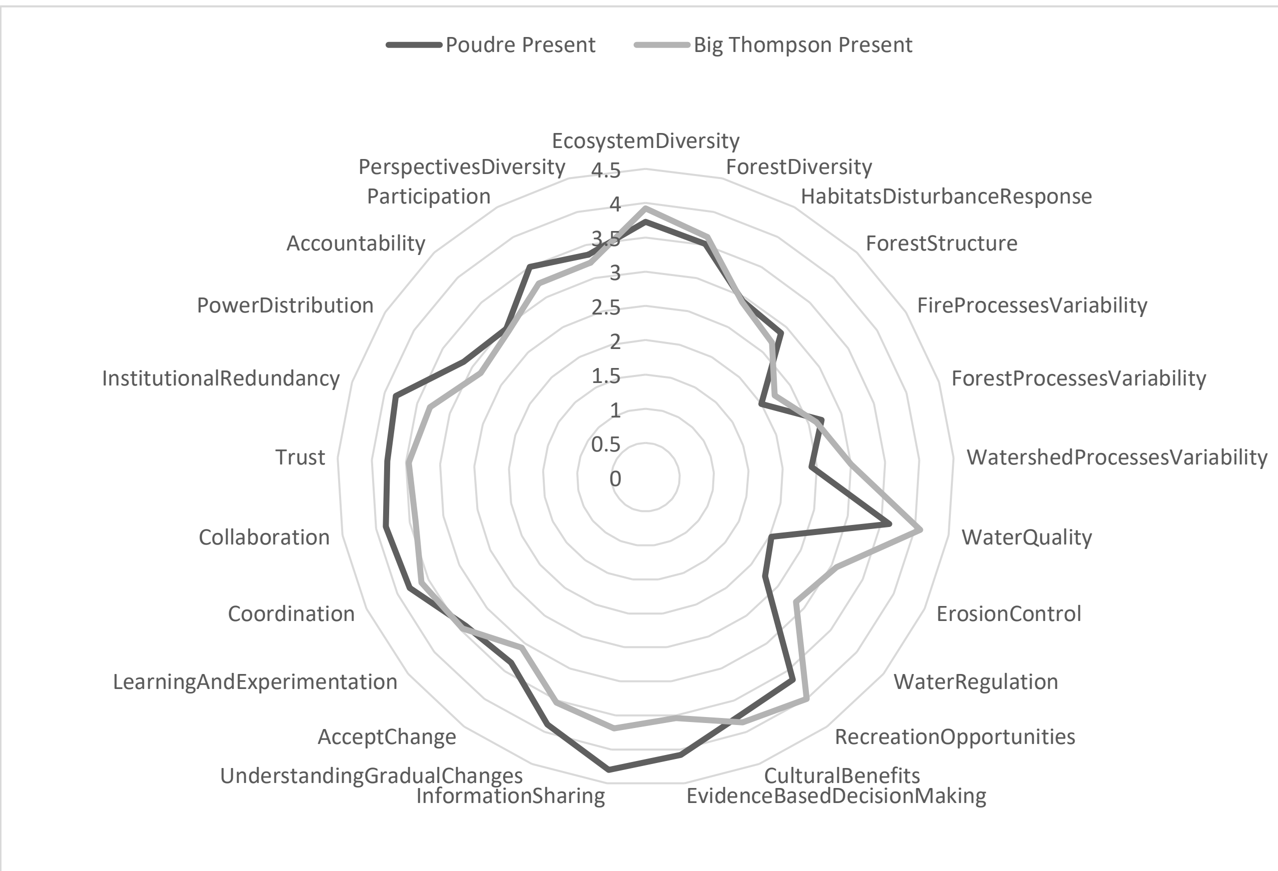


**Figure 7:** Mean scores for current 2022 resilience for all resilience indicators comparing the Poudre (N=24) and Big Thompson (N=12) watersheds

*Influence of 2020 Wildfires on Resilience*

Figue 8 shows the significant indicators from the paired Wilcoxon Sign-Rank test grouped by perceived positive and negative influence of the 2020 wildfires on these indicators. The 2020 wildfires were perceived as having a positive influence on level of collaboration, level of coordination, understanding of gradual changes, degree of information sharing, institutional redundancy, degree of learning and experimentation, participation, and trust. These indicators have calculated mean influence scores above three, which was the “no influence” option from the Likert scale questions prior to ordinal transformation. Influence means closest to five on the graph show a higher degree of positive influence from the fires. Degree of information sharing shows the greatest perceived positive influence from the fires with a mean influence score of 4.22. It is important to note that trust was statistically significant from the paired Wilcoxon test, but had a high standard deviation, that brought its lower standard deviation bound below the critical line of no influence drawn at three. Thus, post- fire changes in trust are potentially not a result of the wildfire events alone.

The 2020 wildfires were perceived as having a negative influence on cultural benefits, erosion control, recreation opportunities, water quality, water regulation, and watershed processes variability. These indicators have calculated mean influence scores are below three, indicating perceived negative influence from the wildfire events where influence means closest to one show a strong perceived negative influence. Of these indicators, erosion control shows the greatest perceived negative influence from the 2020 wildfires with a mean influence score of 1.39. Cultural benefits and recreation opportunities had high standard deviations and because of this their upper standard deviation bounds passes the critical line of no influence drawn at three. Thus, post- fire changes in cultural benefits and recreation opportunities are potentially not a result of the wildfire events alone.

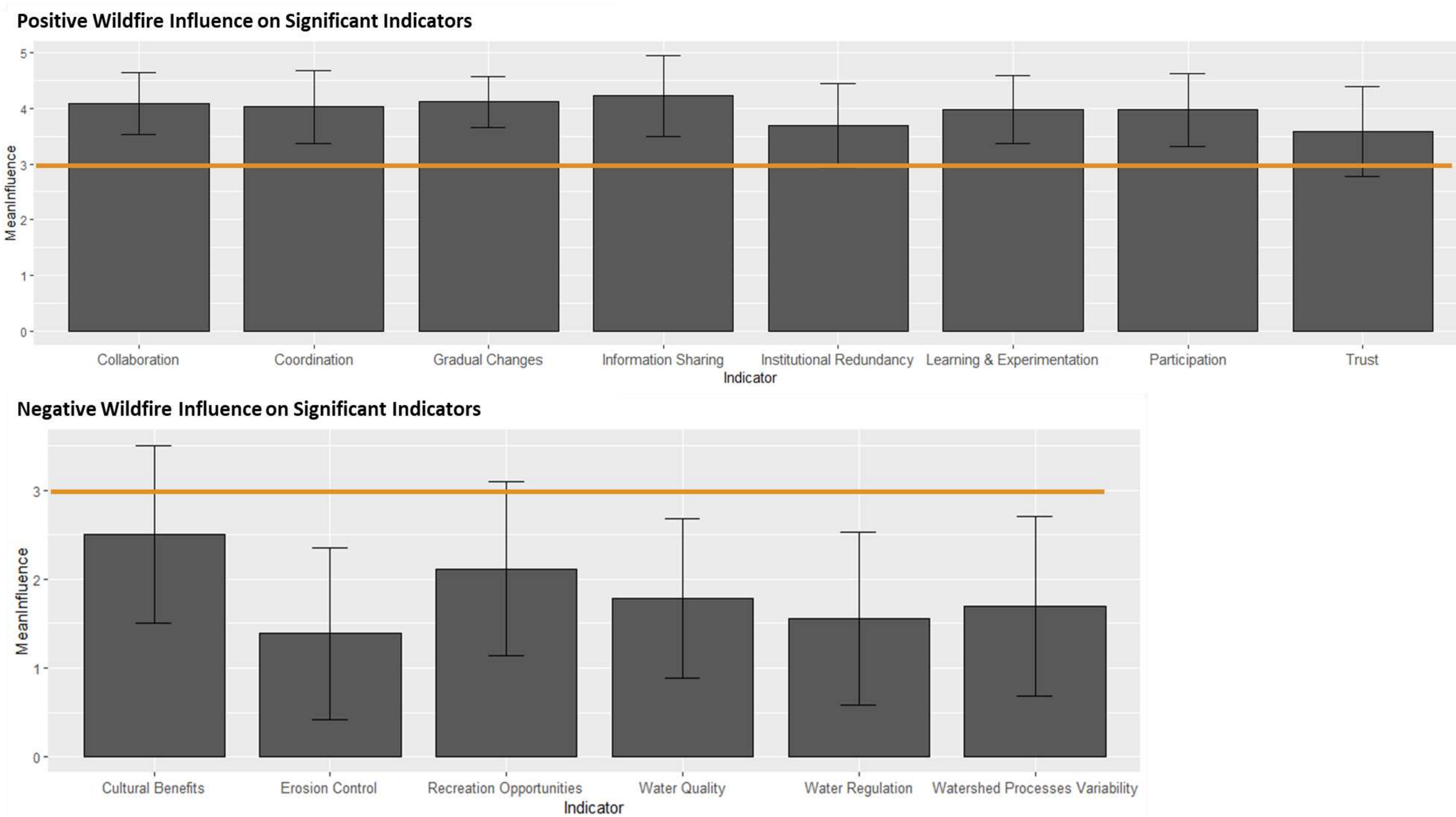


**Figure 8:** Effect of 2020 wildfires on resilience indicators used to assess change in the resilience of the Poudre and Big Thompson watersheds social-ecological system (mean ± standard deviation)

*Influence of Pre-Wildfire & Post-Wildfire Mitigation Actions on Resilience*

Comparisons of mitigation treatments can be seen in Figure 9. Figure 9 shows mean influcence for pre-wildfire (administering prescribed burns, creating defensible space, and thinning forests both mechanically and by hand) and post-wildfire mitigation actions (mulching post-fire landscapes, reforesting post-fire landscapes, and stream restoration and stabilization projects post-fire). The top right of Figure 9 shows greater perceived influence on resilience from pre-fire mitigation actions for indicators of forest structure, fire process variability, and forest process variability. The bottom right of Figure 9 shows greater perceived influence on resilience from post-fire mitigation actions for indicators of watershed process variability, water quality, erosion control, water regulation, and recreation opportunities. The left side of the spider chart shows limited differences between pre and post mitigation actions across social resilience indicators.

Out of the designated pre-wildfire mitigation actions informants identified administering perscribed burns as the action with the greatest potential for increasing ecological and social health of the watersheds followed by thinning forests and creating defensible space respectively. Out of the designated post-wildfire mitigation actions informants identified reforesting post fire landscapes as the action with the greatest potential for increasing ecological and social health of the watersheds followed by mulching and stream restoration/stabilization projects respectively. Figure 10 shows the spread of ranked pre and post mitigation actions. While certain actions had higher ranking from stakeholders than others, all three designated actions received votes for the most effective at increasing social and ecological health locally.

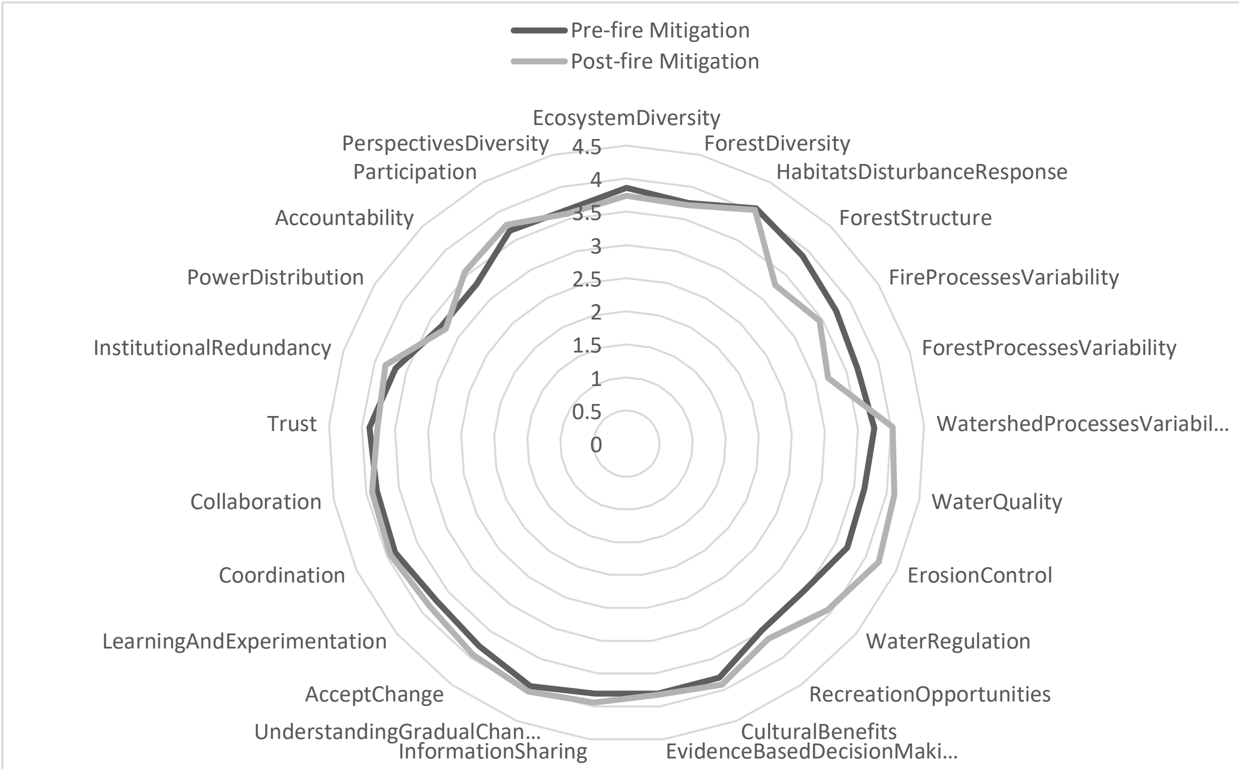


**Figure 9:** Mean scores for perceived influence of pre and post wildfire mitigation actions on resilience for all resilience indicators. Pre-wildfire actions include administering prescribed burns, creating defensible space, and thinning forests both mechanically and by hand. Post-wildfire actions included mulching post-fire landscapes, reforesting post-fire landscapes, and stream restoration and stabilization projects post-fire.

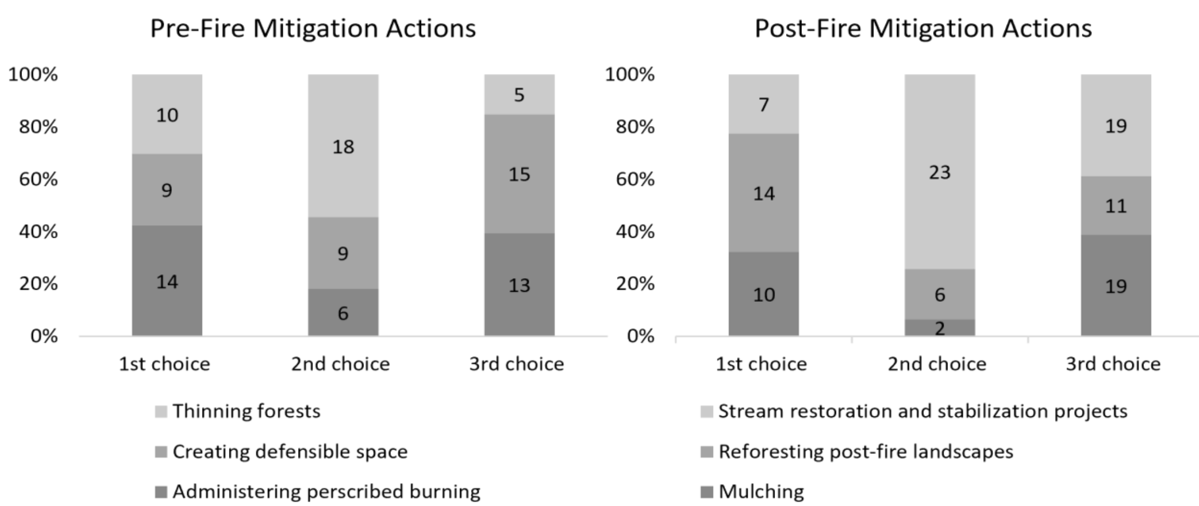


**Figure 10:** The spread of ranking for pre and post wildfire mitigation actions by survey informants. The spread of preferred mitigation actions ranges across first, second, and third preferred choice across stakeholders

*Future Resilience*

Through the application of assigned values of (1) Not concerned, (2) Somewhat concerned, (3) Concerned, and (4) Very concerned, a mean level of concern for direct and indirect impacts of future wildfires on forests and watersheds was calculated to be 3.5. Only one informant reported 'no concern' for direct and indirect future impact of wildfire on forests and watersheds. In respect to concerns about future wildfire-related impacts, informants where most concerned with water quality impacts (n=34) followed by infrastructure impacts (n=33). 67% of informants reported being concerned with all five future wildfire-related impacts (water quality impacts, infrastructure impacts, hydrologic impacts, forest impacts, and recreation impacts).

Of the provided factors for improving social and ecological health of forests and watersheds moving forward, informants perceived administering more prescribed fire as the most influential factor. Table 18 shows the top factors for perceived improvements to social and ecological health of forests and watersheds with their respective counts. When asked if any other factors could be used to improve social and ecological health of forests and watersheds, informants had a variety of responses including seed collection and tree planting, landscape scale climate mitigation, linked and large-scale firebreak treatments, systems-based restoration of streams, increased collaboration, tours for public engagement in restoration efforts, and noxious weed management particularly for cheatgrass.

**Table 18**: Ranked factors for influencing social and ecological health of forests and watershed by informant counts of perceived influence

| Ranking | Action | Count |
|---|---|---|
| 1 | Administering more prescribed fire | 17 |
| 2 | Thinning more forests | 15 |
| 3 | Additional funding | 14 |
| 4 | Allowing more wildfires to burn (if life or property are not in danger) | 14 |
| 5 | More stream restoration and stabilization projects post-fire | 12 |
| 6 | Beaver restoration | 12 |

# Chapter Five: Discussion and Conclusion

## Contextualizing Mixed Methods Findings

Our methodology is rooted in SES resilience research that compares resilience across time and space through the characterizing of subjective views stakeholders hold on system resilience (Allen et al., 2018; Nemec et al., 2014; Salomon et al., 2019). Similarly, our methodologies are rooted in the application of subjective measures of SES resilience to western wildfire issues (Higuera et al., 2019). To our knowledge, no other studies consider subjective measures of wildfire driven changes to SES resilience within a spatially and temporally bound system. This mixed methods approach allowed us to characterize SES resilience across principles and indicators while understanding the nuanced narratives behind the changes to resilience before and after the large-scale wildfire events of 2020 in the Poudre River and Big Thompson River watersheds.

First, through our mixed methods analysis, we find a narrative that (1) with the exception of watershed processes variability, the wildfire events did not significantly influence ecological principles of SES resilience, (2) wildfire events had strong negative impacts on the ecosystem service principle of SES resilience and (3) wildfire events had positive impacts on social principles of SES resilience. Second, our mixed quantitative and qualitative findings on the role of mitigation activities in influencing SES resilience point to a strong desire for increased use of prescribed fire across the system. This was coupled with other mitigation goals of increasing connectivity of new and existing fuel treatments, mixing use of thinning and prescribed fire to foster safe conditions for prescribed fire as well as continued use of mulching as a post-fire protection of water supplies. Barriers and limitations were noted such as insurance barriers to prescribed fire, challenges surrounding land ownership, and heightened restrictions attached to funding mechanisms. Finally, in regards to future actions to improve SES resilience at the system level, informants stressed the need for utilization of risk management tools such as PODs as well as out of the box solutions such as watershed restoration through beaver dam analogues. Continued strengthening and deepening of partnerships was seen as a current source of resilience as well as a priority for fostering future resilience.

Below, we combine these findings with stakeholder feedback on what actions are needed to improve future SES resilience in the study area to lay out management and policy implications. Additionally, we summarize the key implications derived from the quantitative findings about current resilience and changes to resilience due to fire events and use our qualitative analysis to illuminate explanations for these findings. We compare these mixed methods findings on perceived resilience using our contextualized resilience principles and indicators to existing research in the fields of ecology, ecosystem services, and social dimensions of natural resources.

## Current Resilience and Changes in Resilience from the 2020 Wildfire Events

### *Ecological*

In our quantitative findings, stakeholders did not perceive changes pre and post 2020 wildfire events for most of the indicators in the ecological principles of ecological diversity and ecological variability. The one exception to this was perceptions of negative changes to watershed processes variability. In our qualitative data, informants noted many negative degradations resulting from the 2020 wildfire events. These data elucidated degradations of habitat loss, particularly in aquatic and riparian areas. Some informants had concerns about the severity of the 2020 burns, with worries about the ability for regeneration of forests in high severity burn areas. Conversely, informants noted that wildfire had served as a catalyst for ecological variability, fostering greater heterogeneity of habitat and forest types across the landscape. Lastly, many informants viewed the wildfires as a type of mitigation treatment, given their reduction of fuel loads and ability to mitigate impacts from future wildfires. Thus, while all the indicators from the ecological diversity principle and most indicators from the ecological variability principle were not statistically significant in our quantitative analysis of changes pre and post fire, this likely reflects the counterbalance created by both positive and negative perceptions of changes in the ecological system resulting from the 2020 wildfire events.

Such counterbalances have been seen in existing research. In terms of the resilience principle ecosystem diversity, existing literature highlights both positive and negative influences on diversity resulting from wildfire events. For example, severe wildfires alter sediment transportation, flow levels, and water temperature, thus changing aquatic species composition and the capacity for habitat disturbance response (Rieman & Clayton, 1997). In some cases, limited habitat disturbance response results in mortality or endemic extinction, indicating fire would negatively impact our resilience principle of ecosystem diversity (Rieman & Clayton, 1997). However, to build resilience to wildfire, ecosystem and forest diversity are vital to fostering resilience in wildlife habitats, which suggests that wildfire could increase the resilience principle of ecosystem diversity (Kelly & Brotons, 2017). Furthermore, increased variation of fire severity between events has been shown to promote biodiversity and provide niche habitats particularly for avian and pollinator species (Kelly & Brotons, 2017; Kotliar et al., 2007).

Similar juxtapositions can be seen for indicators of the resilience principle of ecological variability. Wildfires help regulate forest process variability through the management of pest populations (Pausas & Keeley, 2019). In cases of low severity frequent fire, wildfires can regulate fire processes variability by maintaining understory density at levels that decrease frequency in large-scale high severity fire (Pausas & Keeley, 2019). Similarly, shorter fire return intervals have been linked to increased heterogeneity of forest types and stand variability (Baker, 2014). Inversely, wildfire has also been linked to lesser levels of ecological variability. Wildfire events catalyze forest composition changes and in some cases lead to state transitions away from forest systems (Collins & Roller, 2013; Miller et al., 2012). Wildfires can catalyze state transitions from forest to non-forested landscapes, highlighting weak resilience of the forested state (Coop et al., 2020). In cases of wildfire-driven forest conversion, systems experience losses to many resilience principles including weakened forest processes variability. These conversions and subsequent lowered ecological metrics of resilience are catalyzed by high severity fire that alter system functions such as tree regeneration (Coop et al., 2020). Similarly, high severity fires have been linked to reduced recovery and limited representation of different size trees within the forest structure (Rhoades et al., 2011). Lastly, climate change and subsequent longer fire seasons and increased predicted burn areas will continue to alter fire processes variability (Collins & Roller, 2013; Westerling et al., 2011).

Thus, the limited perceived change in ecological indicators in the present study likely reflects a nuanced influence of both positive and negative changes from the 2020 wildfire events. Qualitative data suggest this nuanced influence is a product of heterogeneity of burn severity in the present study- where up to 36% of the impacted area is considered high severity burn (*Cameron Peak Fire Information - InciWeb the Incident Information System*, n.d.). While many of the indicators positively influence resilience under low severity fire, the influence may be reversed in high severity burn areas. Further application of SES resilience indicators to systems with clearly delineated low and high severity burn areas is recommended to tease out how severity alters subjective measures of SES resilience using ecological indicators.

The narrative of the wildfires both positively and negatively impacting the system ecologically does not apply to the indicator of watershed processes variability. In terms of this indicator, stakeholders perceived the 2020 wildfire events as weakening the watershed's ability to maintain stream flows, buffer large floods, support healthy water quality, and regulate sediment movement within a healthy level of variability and fluctuations. This finding affirms existing literature about wildfire impacts on watershed processes. In a 2019 review of the influence of wildfire on water quality and watershed processes, researchers reviewed the known impacts within the existing body of knowledge (Rhoades et al., 2019). Researchers highlight the role fire plays in water quality contamination, loss of sediment regulation processes, alterations to streamflow, and aquatic habitat degradation (Rhoades et al., 2019).

Thus, stakeholders currently perceive the ecological health of their systems with nuance and variety. Informants perceived aquatic ecological health as negative but saw strength in the wildfire's protection of current resilience. A large current threat to ecological health was seen in increasing climatic pressure and their cascading effects on the ecosystem. Qualitatively, informants perceived ecological resilience in the Poudre watershed as higher than the Big Thompson watershed, noting higher levels of dense stands that remain in the Big Thompson thus weakening current resilience to future wildfire events. However quantitively, the resilience indicator of watershed process variability was notably lower in the Poudre watershed as compared to the Big Thompson.

*Ecosystem Services*

Unlike the ecological principles, for the ecosystem service principle, stakeholders perceived changes in all indicators before and after fire events. Specifically, stakeholders perceived that all ecosystem service indicators were negatively influenced by the wildfire events in the quantitative analysis. This perceived negative change was expressed in a variety of ways in our qualitative data. Through the thematic code of post-fire flood cycles, stakeholders highlighted the damages to properties, loss of recreation opportunities, and increasing concerns for public safety surrounding the floods that follow wildfires. Stakeholders were also highly concerned about water quality in particular; many informants highlighted concerns about the altered water quality of local water source systems that resulted from the 2020 wildfire events.

The strong level of stakeholder concern about ecosystem services and high levels of perceived loss of ecosystem services is likely a result of the fact that the study watersheds hold high cultural and recreational significance as well as serve as a local source of water to downstream populations. In the

Poudre watershed, recreators seek the multiuse trails, campsites, whitewater opportunities, and backcountry of the watershed (United States Department of Agriculture Forest Service, 2016). On the Big Thompson, Rocky Mountain National Park brings in large amounts of tourists every year for driving excursions, site seeing, and wildlife viewing with roughly 4.5 million visitors annually (National Parks Conservation Association, n.d.). The embedded importance of recreation locally and the loss in quality of existing recreation opportunities from post fire impacts is likely the reason why stakeholders perceived such significant losses in recreation-based ecosystem service measures of resilience. Similar findings have been seen where local recreational values and subsequent social norms affect perceived losses post fire (Edgeley & Paveglio, 2017).

Our findings that wildfire events negatively impacted cultural values, or the ability of the watershed to support a good quality of life for the people that live within it now and in the future, mirror other bodies of work that show that the values of local populations dictate perceptions of post-fire degradations and often influence perceptions of the recovery (Edgeley & Paveglio, 2017). Water holds a wide variety of cultural values including but not limited to aesthetic, spiritual, artistic, cognitive, and philosophical values (Burmil et al., 1999). Such values are heightened in arid western landscapes where water is seen as a valuable and defining landscape feature (Burmil et al., 1999). Beyond water based cultural values, cultural values in favor of protected areas, wildlife, and biodiversity protection are rising across the western U.S. (Manfredo et al., 2021). While most of these cultural values that support strong attachment to local ecosystem services are lower with the occurrence of a wildfire event, some research indicates that fire increased the cultural values of knowledge systems by fostering heightened academic assessments of the system (Vukomanovic & Steelman, 2019).

Our findings that wildfire events decrease resilience through the loss of ecosystem services of erosion control, water quality, and water regulation are congruent with findings of existing works of literature. Wildfires are known to bear many social costs, many from the loss of watershed based ecosystem services (Jones et al., 2022; Kinoshita et al., 2016). Wildfire is costly to society through the loss of ecosystem services, especially the loss of clean water supplies (Kinoshita et al., 2016). The post-fire flood cycle and subsequent degradation of water quality within source water supplies is not new to our study area. Wildfires in the Colorado Front Range cause negative impacts to water provisioning and regulating services through the altering of nutrient and sediment regulating cycles (Rhoades et al., 2011; Vukomanovic & Steelman, 2019). Changes in water quality from wildfire in headwater systems of the Rockies impact Front Range communities through altered water provisioning (Vukomanovic & Steelman, 2019). After the High Park fire, post-fire floods came with significant water quality degradation of source waters (Writer et al., 2014). These degradations and subsequent treatment costs led to the water municipalities using multiple water supplies (Writer et al., 2014). Impacts of post-fire erosion are well known (Robinne et al., 2020) with wildfire increasing sedimentation in spring runoffs (Wohl et al., 2022).

Thus, stakeholders currently perceive the ecosystem service health of their systems as somewhat poor, with the lowest perceived resilience for the resilience indicators of erosion control and water regulation. Throughout interviews, a tone of fear and loss regarding the current threat of flooding and recent loss of life as well as damage to current recreation and sense of place arose. Across quantitatively calculated relative resilience, the Poudre has lower current resilience for all ecosystem service indicators when compared to the Big Thompson. However, qualitative data illuminated strength of system redundancies within the source water systems that serve residents of the Poudre drainage.

*Social Dimensions of Natural Resources*

For the 13 social indicators, stakeholders perceived a statistically significant increase in eight indicators since the 2020 wildfire events, with positive changes perceived within each of the five social principles of resilience. The narratives provided through qualitative data analysis offer a potential rationale for this finding. Throughout interviews, informants focused on the role of wildfire in catalyzing beneficial change to social variables such as improved funding, strengthened partnerships, and increased public attention and support for mitigation treatments. Individual informants noted the trend that the wildfires brought partners together out of necessity and strengthened their ability to collaborate. Furthermore, areas that had already experienced the previous High Park Fire felt their social capital had been built and trialed in earlier fires, thus fostering a greater sense of preparedness in the 2020 wildfire events given their previously built social connectivity.

While our analysis shows a positive influence from the 2020 wildfire events to many of the social resilience indicators, it is notable that all of the indicators under the linking and bonding social capital principle were highly statistically significant. Qualitative data reiterated that wildfire events increased collaboration and coordination efforts and served to build social capital across the system. Social capital theory applied through a wildfire lens suggests multiple stakeholders build connections, trust, and act collectively to respond to disturbance events in an engaged way that fosters innovation and greater levels of information sharing (Fischer & Jasny, 2017). Previous research underscores the relationship between strength of existing social capital - including strength of stakeholder connectivity- and improved wildfire preparedness (Bihari & Ryan, 2012; McCaffrey, 2015). While the connection between social capital and wildfire preparedness is established in the literature, wildfire serving as a catalyst for improved social capital post-fire is relatively novel. Existing research illustrates that post-fire collective efforts foster an enhanced sense of community and post-fire cohesion benefits future hazard response across stakeholder groups (Edgeley & Paveglio, 2017). Additionally, increased collaboration between stakeholders improves post-fire recovery and facilitates higher levels of inter-agency trust (McCaffrey, 2015).

Our findings highlight an improved degree of information sharing as well as increased levels of learning and experimentation within the SES. Qualitative data suggest that connections between the heightened level of social capital facilitated the increased degree of information sharing. This finding reiterates the highly interconnected nature of SES resilience indicators where cooccurrence is common in studied systems (Biggs et al., 2012). Similarly, learning from past wildfire events improves adaptive capacity for future wildfire events and subsequent management (Fischer & Jasny, 2017). Highlighting additional linkages, wildfire adaptive capacity is influenced by levels of trust and quality coordination (Paveglio et al., 2012). While the direct influence of wildfire events on fostering increased information sharing and experimentation is an area ripe for additional research, similar findings have been seen with prescribed fire where successful management of prescribed fire opens the way for new learning and experimentation through the use of PODs on subsequent wildfire events (O'Connor & Calkin, 2019).

Quantitative and qualitative datasets showcased that the wildfire events of 2020 catalyzed greater levels of institutional redundancy and participation in the system. Quantitative analysis highlighted room for improved distribution of power, accountability, and diversity of perspectives. This opportunity for improvement within the system's governance structure is crucial to flag given the known role polycentricity along with adaptive governance offer in improving local SES resilience (Biggs et al., 2012; Cosens & Williams, 2012). While the improved institutional redundancy and increased participation post-fire engenders confidence that the social networks are moving towards polycentric formations with subsequent heightened resilience, the limited change in power, accountability, and diversity of perspectives is not a surprising finding. Homogeneity within wildfire management social networks is not new, but rather reflects the siloed nature of disturbance response, policy barriers across land ownership types, and social connections built on a basis of local geographies (Fischer & Jasny, 2017).

Quantitative data also illuminates that the wildfire events catalyzed a greater level of understanding of gradual changes within the system. Such changes include long term changes to the watershed from wildfires, management action, climatic influence, or human use. Qualitative data highlighted an increased understanding of fire as a natural process within the study area and a need to foster fire adaptivity on a systems level. Furthermore, qualitative data showcased stakeholder's desire to recognize the role of climate change in potential system state transition and adjust expectations accordingly. These findings are in line with the movement beyond limiting wildfire specific resilience perspectives to traditional and ecologically bound definitions of resilience that focus on returning to a previous system state (McWethy et al., 2019). Rather, researchers are encouraging consideration of adaptive resilience and transformative resilience which acknowledge unequivocal changes within the system (McWethy et al., 2019).

Thus, stakeholders currently perceive the social health of their systems as strong with high levels of institutional redundancy, collaboration, coordination, and information sharing. Informants noted the interconnectedness of indicators of social resilience and stressed the current strength of the individual indicators as well as the strengths of connections across indicators. Current strength in willingness to accept change and understanding of gradual changes within the system harken back to a theme of accepting new adaptive forms of management and conceptualization of resource management more broadly (McWethy et al., 2019). In general, current relative resilience was higher in the Poudre watershed compared to the Big Thompson. Qualitative data suggest that this difference is a result of the deep level of connections within the Poudre that were made in response to earlier wildfire events.

Management Implications and Future Resilience

Findings related to how mitigation actions influence resilience and what future actions are needed to improve resilience provide management suggestions for wildfire and watershed decision makers. Through the quantitative component, informants ranked administering prescribed fire as the most effective at fostering forest and watershed resilience over thinning forests and creating defensible space. Additionally, informants viewed administering prescribed fire as the most important management action for positively influencing social and ecological health of forests and watershed.

Through the qualitative component of our research, informants noted a strong preference for prescribed fire as a treatment within the study area, given that it (1) produces preferred forest composition especially when combined with thinning, (2) provides a cost-effective way to treat at scale, and (3) offers a natural analogue to wildfire with subsequent ecological benefits. Enthusiasm for prescribed fire as a strategy to foster SES resilience locally was stated alongside a list of barriers to implementing such projects. Barrier's informants noted included the forest's structure being too dense to receive fire safely, limits to social license, and policy or insurance barriers.

Our findings surrounding preferred pre-fire mitigation reiterated many known narratives in the literature. Stakeholders' goal to prioritize prescribed fire is likely rooted in the known role prescribed fire has on decreasing the size and intensity of future wildfires if an existing treatment and a new wildfire overlap spatially (Kalies & Yocom Kent, 2016; Restaino & Peterson, 2013). In the short term, prescribed fire reduces surface fuels and fire hazards and furthermore can decrease tree mortality (Kalies & Yocom Kent, 2016; van Mantgem et al., 2016). Prescribed fire is unmatched in its surrogacy to wildfires and alone provides the most comparable analogue (Stephens et al., 2012). While informants noted these many strengths of prescribed fire, they additionally highlighted known barriers to the treatment, in particular insurance, liability, and policy barriers, which reflect the present narrative in the existing literature (Schultz et al., 2019; Wonkka et al., 2015).

While stakeholders were most interested in developing more ways to get fire back onto the landscape, they also stressed the vital role of investing in other forms of mitigation as well. Continuing pre-fire thinning projects was a priority and serves an important role in pre-wildfire mitigation in that it has fewer barriers and is crucial to get local forests back in a state of density to withstand burns. This sentiment of pro mixed methods mitigation treatments is reiterated in the literature in particular to the increased effectiveness of treatments when combined and upkept (Stephens et al., 2012). Both prescribed fire and thinning when applied alone provide short term benefits to resilience by reducing fuels, thus making the system less susceptible to high severity fire (Stephens et al., 2012). However, when applied in a predetermined combination, mixed actions help meet specific and locally contextualized management objectives (Stephens et al., 2012). In terms of management objectives of reduced total fuel mass and increased species richness, treatments that combine thinning and prescribed fire foster these outcomes most effectively (Schwilk et al., 2009). Furthermore, many informants wanted to see more thinning across the study site and stressed the benefits of increased maintenance of and connectivity between existing treatment sites (van Mantgem et al., 2016).

Within the discussion of post-fire priorities, a large contingency of stakeholders suggested prioritizing the protection and restoration of ecosystem services, and many focused specifically on improvements to water quality and water supply. Stakeholders noted desired continuation of existing methods with heightened focus on continued post-fire aerial mulching as well as stream restoration and stabilization with respective goals of sediment stabilization. Mulching is accepted as an emergency treatment of sloped landscapes to lessen post-fire erosion and subsequent impacts to water supplies (Cerda & Robichaud, 2009). Mulching increases ground cover and thus reduces sedimentation for the first few years post-fire when watersheds are at heightened risk (Cerda & Robichaud, 2009; Wagenbrenner et al., 2006). However, while mulching is accepted as highly useful in facilitating vegetation growth, preventing erosion, and limiting flood impacts, the mitigation treatment has difficulties standing up to larger storm events (Wagenbrenner et al., 2006). Similar to mulching, the use of physical barriers within streams and hillsides have been used to limit the impacts of post fire erosion and sedimentation (González-Romero et al., 2022).

Informants viewed reforesting post fire landscapes as a vital factor to positively influence social and ecological health of forests and watersheds. This sentiment is reflected in the literature as a desired post-fire mitigation action, particularly in regions that burned at high severity where natural regeneration is limited (North et al., 2019). However, in practice, many reforestation efforts are designed and implemented homogenously, thus limiting their impact on resilience (North et al., 2019). Stakeholders additionally noted the desire to employ out of the box restoration actions for riparian resilience. Many of these comments centered around interest in deploying unique tools and many stakeholders underscored the example of beaver dam analogs. While the impact of beaver dam analogues as a post-fire mitigation treatment on resilience is an area of present exploration, their use pre-fire has been linked to increased pockets of intact riparian refugia in the face of wildfire, thus offering a potential role in fostering post-fire resilience (Fairfax & Whittle, 2020).

In addition to on-the-ground mitigation actions, stakeholders identified many future actions around planning, development, and funding, needed to improve future resilience. Stakeholders perceived a need for developing more fire adapted community plans. Such plans need to consider local housing associations with subsequent social norms, vegetation preferences, and preexisting perceptions (Paveglio et al., 2016). There is a need to employ social sciences further in the effective development of fire adapted communities (Paveglio et al., 2016). Furthermore, stakeholders stressed the need for incorporating existing and new science into decision making processes across the board. However, literature suggests that collaborative management is most effective when it draws on both scientific knowledge as well as local knowledge (Kemmis, 2002). Some informants stressed the need to maintain and improve relationships between stakeholders. Specifically, the need to connect across watersheds and collaborate further with agencies of differing types were identified as needs by stakeholders. Such a collaborative approach is crucial for effective disturbance response and improves pre-fire planning efforts including the establishment of fire adapted communities (Schultz & Moseley, 2019). Collaboration should be employed further in the study site to leverage the desired levels of increased connectivity and maintenance of existing mitigation treatments.

The need to foster improved relationships with the public was perceived as a vital part of developing citizen acceptance and buy in for implementing mitigation actions. Strength of citizen acceptance for mitigation actions has been linked to the public's familiarity with the intended mitigation action and trust in the implementing agency (McCaffrey et al., 2013) and a further focus on these two variables would aid further development of social license for wildfire treatments locally. In terms of funding needs, stakeholders noted the need for increases in funding as well as changes to funding, specifically the widening of permitted tasks within administered funds. Lastly, throughout implementation of on-the-ground mitigation actions and planning tasks, stakeholders perceived a need for adaptivity and promotion of continued learning amongst practitioners (McWethy et al., 2019).

## Limitations

The purpose of this study was to understand stakeholder perceptions of SES resilience and offer managers and policymakers a more comprehensive understanding so that they could better plan for wildfire in the face of climate change. As a result, this study did not include all stakeholders impacted by wildfire, such as the general public, so it does not provide an exhaustive view of perspectives on resilience. Perceptions of resilience may have differed if the general public participated in the study.

Additionally, while we tried to include perceptions of all organizations involved in wildfire and watershed resilience, there is also the potential for selection bias within the present study because the measured perceptions only reflect the subset of stakeholders who were willing to fill out the survey. We disseminated the survey to all recommended key stakeholders and used best practices, including multiple follow-up attempts, to ensure all stakeholders had sufficient opportunity to share their perspectives. However, certain types of organizations are represented more strongly, like that of government agencies, than others in our collected data. Perceptions of resilience may have differed if this composition of participating stakeholders had represented existing stakeholder networks more exactly.

A limitation in data analysis is that there was only one coder for the qualitative analysis of this project. This is a result of the project being a master's thesis project. However, best practices were used to minimize error, including cross-referencing survey responses with interview responses and using a triangulation methodology to check that findings hold similarities and ensure the validity of findings (Moon et al., 2016). However, single coder bias could result from the single coder for the qualitative elements of this project. Qualitative results could have varied if a different coder or group of coders had been used based on the professional background, lived experience, and philosophical lens that any qualitative coder implicitly brings to a set of qualitative data.

Externally, there are challenges for generalizing our findings to the greater western U.S. given that our study area is small and resilience conditions may not translate to other areas. However, the purpose of this study was to characterize resilience for a specific spatial extent at specific points in time, which is very context specific to an individual system. Thus, to inform resilience planning, we first must understand resilience at the local level. However, the development of resilience indicators and information on how management actions influence resilience, is applicable to a broader audience. The resilience indicators and principles applied to this study are applicable to resilience research of similar systems across the western U.S.

## Significance and Future Research

This research fills a gap in applied understanding of how large-scale wildfires impact the resilience of their respective communities and ecosystems through a SES framework (Higuera et al., 2019). We developed a set of locally contextualized SES resilience indicators that can be used in the context of improving wildfire management actions for both ecosystems and communities. Findings offer managers the ability to see in which ways wildfire is most impacting SES resilience as well as what specific management actions are perceived to foster the greatest resilience. This knowledge can be used as an input into future management decisions to increase local relative resilience that is temporally relevant. No studies, to our knowledge, characterize perceived SES resilience within the temporal and spatial bounds of our study site. Our work addresses a need for applied resilience principles for a specific disturbance event by describing the relative resilience across spatial or temporal dimensions (Allen et al., 2018; Angeler & Allen, 2016; Nemec et al., 2014; Salomon et al., 2019).

Our set of indicators can be adopted in future research and management by drawing on mixed methods and engaging stakeholder perspectives in characterizing resilience. Application of our resilience indicators to a study that compares SES resilience across high severity and low severity burned areas could fill the gap on the role of severity on SES resilience principles of ecological diversity and variability. Systems that would most easily lend themselves to the adoption of our set of indicators would be other forested watersheds. The set of indicators lends itself to application of SES resilience studies with disturbances other than just wildfire. Future studies could apply the indicators to characterize changes in resilience resulting from floods, windfall events, landslides, or pest outbreaks. Additionally, indicators could be applied to understand changes in resilience before and after the development of water system infrastructure or changes in governance regimes (Nemec et al., 2014; Salomon et al., 2019). Our set of SES resilience indicators could be applied to groups of the general public to determine if community perspectives reflect or differ from stakeholder perspectives on perceived resilience. In our interviews, informants underscored the interconnected nature of social indicators and recommended streamlining these indicators given the heightened level of connectedness between social indicators (Biggs et al., 2018). Future studies employing our indicators could consider merging some of the social indicators given this established interconnectedness.

## Conclusion

Wildfire prone systems of northern Colorado are a classic example of SES with myriad interactions between ecological based and human derived elements of the system. SES resilience frameworks allow practitioners to understand how wildfire as a disturbance alters different elements of the system. Through the development and application of temporally and spatially contextualized resilience indicators, we explored how the large-scale wildfires of 2020 impacted SES resilience in the Poudre and Big Thompson watersheds and how management actions could be utilized to foster greater future resilience. Through a mixed methods approach we found the 2020 wildfires did not significantly influence perceived resilience of most ecological indicators, with the exception of watershed processes variability. The lack of perceived change in the other indicators capturing ecological diversity and variability principles is most likely not a result of no change, but rather a nuanced and complex perception of the influence of wildfire at varying scales and in varying directions on these indicators. We suspect this is because of the heterogeneity of burn severity of the fire, where in high severity burn areas ecological variability and diversity decreased, whereas in low severity patches the fire served analogous roles to a mitigation treatment.

All ecosystem service indicators were negatively influenced by the 2020 wildfires with qualitative analysis highlighting water quality in local water supply and the dangerous post-fire flood cycle as top concerns. Qualitative data highlighted stakeholder prioritization of ecosystem service protection in future restoration activities. Many social indicators of resilience were perceived as positively influenced by the 2020 wildfires with qualitative themes emerging about increased interagency collaboration and greater levels of information sharing due to wildfire events. While the connection between heightened social capital and wildfire preparedness is well established, our finding that wildfire events catalyze social capital is relatively novel. Results from this study reinforce previous literature that highlights that wildfire often lacks a clear delineation of good or bad and is highly contextualized to the severity and locality of the disturbance as well as the vitality and adaptability of existing social networks.

In terms of mitigation actions and future resilience, the results of this study suggest there is a greater need for prescribed fire even in the face of existing social, policy, and insurance barriers to the practice. Qualitative data suggest that the continued use of thinning is vital to get forest structure into a safe composition for prescribed fire. Quantitative data suggests continued use of post-fire mulching is needed for water source protection. Qualitative analysis highlights the desire among stakeholders for a higher level of maintenance and connectivity across individual treatment areas for increased system resilience. Stakeholders thought approaching out of the box solutions such as beaver dam analogues and employing new risk management tools such as PODS were vital to increase future resilience. While desire for increased partnerships, particularly in soliciting funding mechanisms, was highlighted by many informants, there was also the theme of strength of and pride in existing collaborative efforts throughout the watersheds.

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Appendices

Appendix A - IRB Approval

Appendix B - Interview Guide

Appendix C - Interviewed Organizations

Appendix D - Survey Instrument

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## Appendix A - IRB Approval



PROTOCOLS

kuali

COLORADO STATE UNIVERSITY

**The protocol listed below has been approved by the CSU IRB SBER Fort Collins on Wednesday, June 22nd, 2022.**

PI: Jones, Kelly W

Submission Type and ID: Initial 3584

Title: Measuring Socio-Ecological Resilience in Fire Prone Systems of Northern Colorado

Approval Date: Wednesday, June 22nd 2022

Continuing Review Date: no date provided

Expiration Date: Monday, June 21st 2027

The CSU IRB (FWA0000647) has completed its review of protocol 3584 Measuring Socio-Ecological Resilience in Fire Prone Systems of Northern Colorado. In accordance with federal and state requirements, and policies established by the CSU IRB, the committee has approved this protocol under Exempt review.

Any additional comments regarding this approval are included below. If you have additional questions about this please contact RICRO IRB Staff.

**Please note:**

- This protocol will need to undergo Continuing Review and approval prior to no
- date provided. Any additional changes to this approved protocol must be obtained prior to implementation of those changes, by submitting an amendment request to the CSU IRB for review/approval.

Good luck in your research endeavors!




Initial exempt determination has been granted to recruit subjects with the approved recruitment and consent procedures. The above-referenced research activity has been reviewed and determined to meet exempt review criteria by the Institutional Review Board under exempt review category [2(ii)] of the 2018 Requirements. The study was assessed as being in accordance with §46.111(a)(7). Continuing review is not required.

Risk Level: Not greater than Minimal

Funding: Federal

## Attachments

**Appendix B - Interview Guide**

**Stakeholder interview to characterize SES resilience**

**Consent Form**

Dear Informant,

My name is Aly Cheney and I am a master's student in the Human Dimension of Natural Resources Department at Colorado State University. I am requesting an interview with you as part of a larger research project funded through Colorado State University, exploring the social and ecological resilience of the Big-Thompson and Poudre River Watersheds.

You have been selected for this interview because of your work in watershed protection and/or wildfire mitigation in the Big-Thompson and/or Poudre River Watersheds. Our study focuses on the perceptions of stakeholder that work in this field and after creating a database of relevant organizations, we have identified you a key informant given your occupational role in watershed resilience. The purpose of this interview is to gain insight into how you characterize past, present, and future resilience in your watershed and understand more about actions that alter resilience. While there is no direct benefit to you from participating, we will use the knowledge gained from this interview to provide recommendations that we hope can help improve resilience. We will share the final results with you upon completion of the research project.

Your participation in this interview is voluntary and you can stop the interview at any time. Your responses will remain confidential, as all write-ups of the data will exclude individual and organizational names or potential identifiers. We will keep all materials that link your responses with your name in a secure location. This interview should take approximately 30-60 minutes.

You signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, and that you have received a copy of this form.

Print Name____________________________________
Signature_____________________________________ Date ___________

We would like to record the interview today with an audio recording device. Recording the interview will allow us to utilize direct quotes and to avoid misinterpretation.
Do we have your permission to record this interview? Yes___ No___

Feel free to contact either myself Alyson.cheney@colostate.edu or Dr. Kelly Jones at kelly.jones@colostate.edu, with any questions or concerns you may have about our research.

**Stakeholder interview questions to characterize SES resilience**

Thank you for your willingness to speak with me today. I really appreciate you input and hearing your insights will help our research greatly. Do you have any questions before we start the interview?

**Introduction:**

| **Principle** | **Definition** | **Example Indicators** |
|---|---|---|
| Ecological Diversity | The number and evenness of species and ecosystem types, and their ability to respond to disturbance | • Ecosystem diversity<br>• Forest diversity<br>• Population response/changes |
| Ecological Variability | Natural variability and fluctuations in ecological processes, structures, and populations | • Forest structure<br>• Fire processes variability<br>• Forest processes variability<br>• Watershed processes variability |
| Ecosystem Services | Adequate provision of essential and nonessential benefits people obtain from nature | • Water quality<br>• Erosion control<br>• Water regulation<br>• Recreation<br>• Cultural benefits |
| Manage Connectivity | Decision makers and stakeholders are connected to one another so that information is transferred effectively | • Decisions updated with new information<br>• Degree of information sharing |
| Manage Complex Variables & Feedbacks | Incorporation of information about long-term outcomes into decision making | • Understanding of gradual changes |
| Foster Complex Adaptive Thinking | Degree of learning and experimentation by decision makers and stakeholders in response to ecological and social change | • Willingness to accept change<br>• Degree of learning and experimentation |
| Linking and Bonding Social Capital | The strength of relationships among decision makers and stakeholders | • Level of coordination<br>• Level of collaboration<br>• Trust |
| Governance | The level of redundancy in the roles and responsibilities, and the equitable participation of all decision makers and stakeholders | • Institutional redundancy<br>• Distribution of power<br>• Accountability<br>• Participation<br>• Diversity if perspectives |

1. Can you state your name, and briefly describe your organization and your role in your organization?
    a. What watershed(s) does your organization focus on?
2. In your work do you use the term resilience, and if so how do you define it?
3. How would you characterize the ecological and social health of your watershed(s) today (2022) using the following eight resilience principles?
    a. What factors or events do you think have shaped the ecological and social health of your watershed(s) today?

**Wildfire Events and Resilience:**

4. Can you tell me about the ecological and social health of your respective watershed(s) before the Cameron Peak and East Troublesome Fires of 2020?
    a. Specifically, how have the eight resilience principles changed due to these specific wildfire events, if they have changed at all?

**Governance, Management Actions, and Resilience:**

5. What type of pre- or post-wildfire mitigation actions (e.g., thinning, mulching, etc.) are being implemented in your watershed(s)?
    a. Did the Cameron Peak and East Troublesome Fires of 2020 change the type or scale of mitigation actions?
    b. How do you think these different mitigation actions influence the ecological and social health of your watershed(s)?
    c. Are there some mitigation actions that have more influence on these resilience principles than others?

6. How would you describe the relationship between your organization and other organizations working on wildfire in your watershed(s)? Is there collaboration and coordination amongst your organization and others, and or any joint or shared resources?
    a. Have there been any changes in these relationships before and after the Cameron Peak and East Troublesome Fires of 2020?
    b. How do you think these relationships between organizations working in your watershed(s) influence the eight resilience principles?

**Future Resilience:**

7. What concerns your most about wildfire events in your watershed(s)? What concerns you less about wildfire events in your watershed.

8. Can you describe to me where you would like the ecological and social health of your watershed(s) to be in 5-10 years? Are there any principles or indicators you like to see prioritized in the next 5-10 years?

9. What factors, management actions, or policies would most likely help you get to this level of ecological and social health in your watershed(s)?

a. Are there changes in the use of pre- or post-wildfire mitigation actions that you think could improve the resilience of your watershed(s)?
b. Are there any additional actions, not currently being used, that you think could improve future resilience (e.g., climate assisted tree migration)?
c. Are there changes in relationships across organizations that you think could enhance future resilience in your watershed(s)?

**Final Reflection and Next Steps:**

10. In the next step of our research, we want to send a survey on these indicators to other stakeholders who work on watershed and wildfire mitigation in the Poudre River and Big Thompson River Watershed. Is there anyone within your organization you would recommend we send this survey to?
    a. If so, would you be willing to provide us with their contact information
11. What organizations do you recommend we prioritize surveying?
    a. Do you have a contact you are willing to share at that organization?

**Appendix C - Interviewed Organizations**

Only one staff member per organization participated in an interview.

| **Government Agencies** |
|---|
| Colorado Parks & Wildlife |
| Arapahoe Roosevelt National Forest |
| Rocky Mountain National Park |
| Colorado State Forest Service |
| **Utilities** |
| Fort Collins Utilities |
| Northern Water |
| **Coalitions and NGOs** |
| Peaks to People Water Fund |
| Coalition for the Poudre River Watershed |
| The Nature Conservancy |
| Ember Alliance |
| **Research Groups** |
| Colorado Forest Restoration Institute |
| Northern Colorado Fireshed |
| Center for Collaborative Conservation |
| **City and Counties** |
| Larimer County |
| City of Fort Collins |

**Appendix D - Survey Instrument**

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Start of Block: Default Question Block

Thank you for your interest in this survey. The purpose of this survey is to gain insight into how you characterize past, present, and future resilience in your watershed and understand more about management actions that alter resilience. Results from this survey will be analyzed with responses from others working on watershed management and wildfire mitigation in these watersheds.

Please keep in mind that your participation is voluntary, and your responses will remain confidential, as we will not attach your name or organization to your responses. We estimate that this survey will take less than 30 minutes to complete. <u>By clicking “yes” below, you indicate that you have read and understand the information provided above, that you willingly agree to participate, and that you may withdraw your consent at any time</u>. Feel free to contact either Alyson Cheney at alyson.cheney@colostate.edu or Dr. Kelly Jones at kelly.jones@colostate.edu, with any questions or concerns you may have about our research.
Do you consent to taking this survey?

○ Yes (1)

○ No (2)

*Skip To: End of Survey If Q1 = No*

End of Block: Default Question Block

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Start of Block: Introduction

Which of the following best characterizes your organization? Please select the most applicable.

○ Government Agency (1)

○ Private Business (2)

○ Coalition or NGO (3)

○ Academic or Research Group (4)

○ City or County Government (5)

○ Water Utility (6)

○ Other (7) ________________________________________________

What is your role in your organization? Click as many that apply.

- ▢ Managerial (oversee operations, manage projects, etc.) (1)
- ▢ Carry out on the ground management actions (administer restoration projects, conduct field work, etc.) (2)
- ▢ Mainly planning based (draft plans, conduct environmental impact statements etc.) (3)
- ▢ Develop funding (pool funds, connect with donors, administer funds, etc.) (4)
- ▢ Outreach/ education (educate public on watershed issues, educate stakeholders on projects, etc.) (6)
- ▢ Research (develop and implement research projects, etc.) (7)
- ▢ Other (5) ________________________________________________

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About how many years have you worked for this organization?

________________________________________________________________

---

For the purpose of this study we are interested in the **Big Thompson River and Poudre River watersheds**. In order to most effectively learn about each watershed, we ask that for this survey you pick the watershed you are more familiar with for your responses. Which watershed will your answers focus on?

- ○ I will be responding for the Big Thompson watershed (1)
- ○ I will be responding for the Poudre watershed (2)

End of Block: Introduction

---

Start of Block: Current Resilience

In this section, we aim to understand how you view present day (2022) resilience in your primary watershed. For the following table, please read each statement and answer how you rank the health or the current state of your watershed.

**Presently, in 2022**, how would you rank the average or general state of each of the following indicators in the watershed you selected to report on?

**Scale:** Very Poor (1) Somewhat Poor (2) Neutral (3) Somewhat Good (4) Very Good (5)

(clickable grid) with indicators of:

- the presence of a healthy variety of ecosystem types (e.g., alpine, forest, woodland, shrub, riparian, meadow) (1)
- the presence of a healthy variety of tree species (e.g., aspen, ponderosa pine) (2)
- the ability for plant and animal habitats to respond to ecological disturbances (3)
- the representation of different size of age classes (a mix of small, medium, and large trees) (4)
- the ability of wildfires (including their frequency, size, and severity) to occur within a healthy level of variability (5)
- the ability of non-fire processes (e.g., pest outbreaks, wind damage, ice damage) to occur within a healthy level of variability (6)
- the ability of watershed processes (e.g., maintain stream flows, buffer large floods, support healthy water quality, regulate sediment movement) to occur within a healthy level of variability (7)
- the suitability of the water supply for human consumption (i.e., free of harmful chemical, physical, or biological components) (8)
- the ability of the watershed to limit hillslope erosion of sediment into receiving streams, and the ability of streams to regulate downstream transport of sediment (9)
- the ability of the watershed to reduce or buffer downstream flooding (10)
- the ability to meet human demand for recreation opportunities (i.e., hiking, water sports, fishing, hunting) (11)
- the ability of the watershed to support a good quality of life for the people that live within it now and in the future (12)
- the integration of evidence-based information into decision making by groups, organizations, communities, and households working on wildfire, forest, and watershed management (13)
- the degree of information sharing across groups, organizations, communities, and households working on wildfire, forest, or watershed management (14)
- the level of understanding by groups, organizations, communities, and households working on wildfire, forest, and watershed management about gradual, long-term changes to the watershed (e.g., from wildfire, forest or watershed management, climate, human use, etc.) (15)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to accept changes in the watershed (e.g, changing fire regimes, forest or watershed management, or climate) in their management decisions (16)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to experiment with new management actions or practices (e.g., pre- or post-fire mitigation) in response to changes in the watershed (17)

- the joint determination of goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (18)
- the voluntary helping of others to achieve goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (19)
- the level of trust across groups, organizations, communities, and households working on wildfire, forest, and watershed management (20)
- the level of overlap in the groups, organizations, communities, and households working on wildfire, forest, and watershed management (21)
- the equitable distribution of power across all groups, organizations, communities, and households working on wildfire, forest, and watershed management (22)
- the level of accountability (i.e., following through on responsibilities) among all groups, organizations, communities, and households working on wildfire, forest, and watershed management (23)
- the level of participation in decision-making across all groups, organizations, communities, and households about wildfire, forest, and watershed management (24)
- the diversity of perspectives (e.g., ideas, views, opinions) that inform decision-making about wildfire, forest, and watershed management (25)

**End of Block: Current Resilience**

---

**Start of Block: Wildfire Changes**

In this section we want to understand your thoughts on how wildfires impact the resilience and health of your primary watershed. There will be two tables in this section. The first asks about health and functionality of your primary watershed before the 2020 wildfires (*Cameron Peak Fire and East Troublesome Fire*). The second asks about how influential the 2020 fires were for creating changes to the health and functionality of your primary watershed.

**BEORE** the 2020 wildfires (*Cameron Peak Fire and East Troublesome Fire*) how would you rank the current state of each of the following indicators in your watershed?

**Scale:** Very Poor (1) Somewhat Poor (2) Neutral (3) Somewhat Good (4) Very Good (5)

(Clickable grid) with indicators of:

- the presence of a healthy variety of ecosystem types (e.g., alpine, forest, woodland, shrub, riparian, meadow) (1)
- the presence of a healthy variety of tree species (e.g., aspen, ponderosa pine) (2)
- the ability for plant and animal habitats to respond to ecological disturbances (3)
- the representation of different size of age classes (a mix of small, medium, and large trees) (4)
- the ability of wildfires (including their frequency, size, and severity) to occur within a healthy level of variability (5)

- the ability of non-fire processes (e.g., pest outbreaks, wind damage, ice damage) to occur within a healthy level of variability (6)
- the ability of watershed processes (e.g., maintain stream flows, buffer large floods, support healthy water quality, regulate sediment movement) to occur within a healthy level of variability (7)
- the suitability of the water supply for human consumption (i.e., free of harmful chemical, physical, or biological components) (8)
- the ability of the watershed to limit hillslope erosion of sediment into receiving streams, and the ability of streams to regulate downstream transport of sediment (9)
- the ability of the watershed to reduce or buffer downstream flooding (10)
- the ability to meet human demand for recreation opportunities (i.e., hiking, water sports, fishing, hunting) (11)
- the ability of the watershed to support a good quality of life for the people that live within it now and in the future (12)
- the integration of evidence-based information into decision making by groups, organizations, communities, and households working on wildfire, forest, and watershed management (13)
- the degree of information sharing across groups, organizations, communities, and households working on wildfire, forest, or watershed management (14)
- the level of understanding by groups, organizations, communities, and households working on wildfire, forest, and watershed management about gradual, long-term changes to the watershed (e.g., from wildfire, forest or watershed management, climate, human use, etc.) (15)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to accept changes in the watershed (e.g, changing fire regimes, forest or watershed management, or climate) in their management decisions (16)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to experiment with new management actions or practices (e.g., pre- or post-fire mitigation) in response to changes in the watershed (17)
- the joint determination of goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (18)
- the voluntary helping of others to achieve goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (19)
- the level of trust across groups, organizations, communities, and households working on wildfire, forest, and watershed management (20)
- the level of overlap in the groups, organizations, communities, and households working on wildfire, forest, and watershed management (21)
- the equitable distribution of power across all groups, organizations, communities, and households working on wildfire, forest, and watershed management (22)
- the level of accountability (i.e., following through on responsibilities) among all groups, organizations, communities, and households working on wildfire, forest, and watershed management (23)
- the level of participation in decision-making across all groups, organizations, communities, and households about wildfire, forest, and watershed management (24)

- the diversity of perspectives (e.g., ideas, views, opinions) that inform decision-making about wildfire, forest, and watershed management (25)

Page Break

In this section we want to understand your thoughts on how influential the 2020 wildfires were on changes in social and ecological health.

The **influence** of the 2020 wildfires (*Cameron Peak Fire and East Troublesome Fire*) on each of the following indicators has been…

**Scale**: Strong negative influence (1) Slight negative influence (2) No influence (3)Slight positive influence (4) Strong positive influence (5)

(Clickable grid) with indicators of:

- the presence of a healthy variety of ecosystem types (e.g., alpine, forest, woodland, shrub, riparian, meadow) (1)
- the presence of a healthy variety of tree species (e.g., aspen, ponderosa pine) (2)
- the ability for plant and animal habitats to respond to ecological disturbances (3)
- the representation of different size of age classes (a mix of small, medium, and large trees) (4)
- the ability of wildfires (including their frequency, size, and severity) to occur within a healthy level of variability (5)
- the ability of non-fire processes (e.g., pest outbreaks, wind damage, ice damage) to occur within a healthy level of variability (6)
- the ability of watershed processes (e.g., maintain stream flows, buffer large floods, support healthy water quality, regulate sediment movement) to occur within a healthy level of variability (7)
- the suitability of the water supply for human consumption (i.e., free of harmful chemical, physical, or biological components) (8)
- the ability of the watershed to limit hillslope erosion of sediment into receiving streams, and the ability of streams to regulate downstream transport of sediment (9)
- the ability of the watershed to reduce or buffer downstream flooding (10)
- the ability to meet human demand for recreation opportunities (i.e., hiking, water sports, fishing, hunting) (11)
- the ability of the watershed to support a good quality of life for the people that live within it now and in the future (12)
- the integration of evidence-based information into decision making by groups, organizations, communities, and households working on wildfire, forest, and watershed management (13)
- the degree of information sharing across groups, organizations, communities, and households working on wildfire, forest, or watershed management (14)

- the level of understanding by groups, organizations, communities, and households working on wildfire, forest, and watershed management about gradual, long-term changes to the watershed (e.g., from wildfire, forest or watershed management, climate, human use, etc.) (15)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to accept changes in the watershed (e.g, changing fire regimes, forest or watershed management, or climate) in their management decisions (16)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to experiment with new management actions or practices (e.g., pre- or post-fire mitigation) in response to changes in the watershed (17)
- the joint determination of goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (18)
- the voluntary helping of others to achieve goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (19)
- the level of trust across groups, organizations, communities, and households working on wildfire, forest, and watershed management (20)
- the level of overlap in the groups, organizations, communities, and households working on wildfire, forest, and watershed management (21)
- the equitable distribution of power across all groups, organizations, communities, and households working on wildfire, forest, and watershed management (22)
- the level of accountability (i.e., following through on responsibilities) among all groups, organizations, communities, and households working on wildfire, forest, and watershed management (23)
- the level of participation in decision-making across all groups, organizations, communities, and households about wildfire, forest, and watershed management (24)
- the diversity of perspectives (e.g., ideas, views, opinions) that inform decision-making about wildfire, forest, and watershed management (25)

End of Block: Wildfire Changes

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Start of Block: Management Actions

In this section we would like to understand your opinion and perception on how **administering pre-wildfire mitigation actions** in your watershed has influenced the current level of ecological and social health for your watershed. Pre-wildfire mitigation actions include:

•administering prescribed burning
• creating defensible space
• thinning forests (by hand and mechanical)

The influence of **pre-wildfire mitigation actions** on each of the following indicators has been…

**Scale**: Strong negative influence (1) Slight negative influence (2) No influence (3)Slight positive influence (4) Strong positive influence (5)

(Clickable grid) with indicators of:

- the presence of a healthy variety of ecosystem types (e.g., alpine, forest, woodland, shrub, riparian, meadow) (1)
- the presence of a healthy variety of tree species (e.g., aspen, ponderosa pine) (2)
- the ability for plant and animal habitats to respond to ecological disturbances (3)
- the representation of different size of age classes (a mix of small, medium, and large trees) (4)
- the ability of wildfires (including their frequency, size, and severity) to occur within a healthy level of variability (5)
- the ability of non-fire processes (e.g., pest outbreaks, wind damage, ice damage) to occur within a healthy level of variability (6)
- the ability of watershed processes (e.g., maintain stream flows, buffer large floods, support healthy water quality, regulate sediment movement) to occur within a healthy level of variability (7)
- the suitability of the water supply for human consumption (i.e., free of harmful chemical, physical, or biological components) (8)
- the ability of the watershed to limit hillslope erosion of sediment into receiving streams, and the ability of streams to regulate downstream transport of sediment (9)
- the ability of the watershed to reduce or buffer downstream flooding (10)
- the ability to meet human demand for recreation opportunities (i.e., hiking, water sports, fishing, hunting) (11)
- the ability of the watershed to support a good quality of life for the people that live within it now and in the future (12)
- the integration of evidence-based information into decision making by groups, organizations, communities, and households working on wildfire, forest, and watershed management (13)
- the degree of information sharing across groups, organizations, communities, and households working on wildfire, forest, or watershed management (14)
- the level of understanding by groups, organizations, communities, and households working on wildfire, forest, and watershed management about gradual, long-term changes to the watershed (e.g., from wildfire, forest or watershed management, climate, human use, etc.) (15)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to accept changes in the watershed (e.g, changing fire regimes, forest or watershed management, or climate) in their management decisions (16)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to experiment with new management actions or practices (e.g., pre- or post-fire mitigation) in response to changes in the watershed (17)
- the joint determination of goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (18)
- the voluntary helping of others to achieve goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (19)
- the level of trust across groups, organizations, communities, and households working on wildfire, forest, and watershed management (20)
- the level of overlap in the groups, organizations, communities, and households working on wildfire, forest, and watershed management (21)

- the equitable distribution of power across all groups, organizations, communities, and households working on wildfire, forest, and watershed management (22)
- the level of accountability (i.e., following through on responsibilities) among all groups, organizations, communities, and households working on wildfire, forest, and watershed management (23)
- the level of participation in decision-making across all groups, organizations, communities, and households about wildfire, forest, and watershed management (24)
- the diversity of perspectives (e.g., ideas, views, opinions) that inform decision-making about wildfire, forest, and watershed management (25)

In this section we would like to understand your opinion and perception on how administering **post-wildfire mitigation actions** in your watershed has influenced the current level of ecological and social health for your watershed. Post-wildfire mitigation actions include:

• mulching post-fire landscapes
• reforesting post-fire landscapes
• stream restoration and stabilization projects post-fire

The influence of **post-wildfire mitigation actions** on each of the following indicators has been…

**Scale**: Strong negative influence (1) Slight negative influence (2) No influence (3)Slight positive influence (4) Strong positive influence (5)

(Clickable grid) with indicators of:

- the presence of a healthy variety of ecosystem types (e.g., alpine, forest, woodland, shrub, riparian, meadow) (1)
- the presence of a healthy variety of tree species (e.g., aspen, ponderosa pine) (2)
- the ability for plant and animal habitats to respond to ecological disturbances (3)
- the representation of different size of age classes (a mix of small, medium, and large trees) (4)
- the ability of wildfires (including their frequency, size, and severity) to occur within a healthy level of variability (5)
- the ability of non-fire processes (e.g., pest outbreaks, wind damage, ice damage) to occur within a healthy level of variability (6)
- the ability of watershed processes (e.g., maintain stream flows, buffer large floods, support healthy water quality, regulate sediment movement) to occur within a healthy level of variability (7)
- the suitability of the water supply for human consumption (i.e., free of harmful chemical, physical, or biological components) (8)
- the ability of the watershed to limit hillslope erosion of sediment into receiving streams, and the ability of streams to regulate downstream transport of sediment (9)
- the ability of the watershed to reduce or buffer downstream flooding (10)
- the ability to meet human demand for recreation opportunities (i.e., hiking, water sports, fishing, hunting) (11)

- the ability of the watershed to support a good quality of life for the people that live within it now and in the future (12)
- the integration of evidence-based information into decision making by groups, organizations, communities, and households working on wildfire, forest, and watershed management (13)
- the degree of information sharing across groups, organizations, communities, and households working on wildfire, forest, or watershed management (14)
- the level of understanding by groups, organizations, communities, and households working on wildfire, forest, and watershed management about gradual, long-term changes to the watershed (e.g., from wildfire, forest or watershed management, climate, human use, etc.) (15)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to accept changes in the watershed (e.g, changing fire regimes, forest or watershed management, or climate) in their management decisions (16)
- the willingness and ability of groups, organizations, communities, and households working on wildfire, forest, and watershed management to experiment with new management actions or practices (e.g., pre- or post-fire mitigation) in response to changes in the watershed (17)
- the joint determination of goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (18)
- the voluntary helping of others to achieve goals across groups, organizations, communities, and households working on wildfire, forest, and watershed management (19)
- the level of trust across groups, organizations, communities, and households working on wildfire, forest, and watershed management (20)
- the level of overlap in the groups, organizations, communities, and households working on wildfire, forest, and watershed management (21)
- the equitable distribution of power across all groups, organizations, communities, and households working on wildfire, forest, and watershed management (22)
- the level of accountability (i.e., following through on responsibilities) among all groups, organizations, communities, and households working on wildfire, forest, and watershed management (23)
- the level of participation in decision-making across all groups, organizations, communities, and households about wildfire, forest, and watershed management (24)
- the diversity of perspectives (e.g., ideas, views, opinions) that inform decision-making about wildfire, forest, and watershed management (25)

Please rank the level of influence you think these three post-wildfire mitigation actions have had on increasing ecological and social health in your watershed. Click and drag them into a new rank order of 1, 2, and 3 (where 1 indicates the action has had more of a positive influence on ecological and social health).

______ mulching post-fire landscapes (1)
______ reforesting post-fire landscapes (4)
______ stream restoration and stabilization projects post-fire (5)

**End of Block: Management Actions**

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**Start of Block: Future Scenarios**

In this final section we want to understand your concerns about the future and how resilience could be improved in your primary watershed.

How concerned is your organization about the impact future wildfire could have in the forests and watersheds where you work? Impacts can be either direct (e.g., damaging infrastructure, destroying habitat) or indirect (e.g., altering water quality, reducing biodiversity).

○ Not concerned (1)

○ Somewhat concerned (2)

○ Concerned (3)

○ Very concerned (4)

*Skip To: Q29 If Q24 = Not concerned*

Which of the following future wildfire-related impacts are of concern for the forests and watersheds where you work? Please select all that apply.

- ☐ Water quality impacts (e.g., turbidity, ash, nutrients, dissolved oxygen, algal blooms, etc.) (1)
- ☐ Forest impacts (e.g., changes in biodiversity, species recovery, soil water retention, etc.) (2)
- ☐ Hydrologic impacts (e.g., channel scouring or sedimentation, timing or volume of runoff, etc. ) (3)
- ☐ Infrastructure impacts (e.g., damage to homes, equipment, reservoir sedimentation, etc.) (4)
- ☐ Recreation impacts (e.g., damage to trails, rivers, campgrounds, etc.) (5)
- ☐ Other: (6) ________________________________________________

Which of the following factors do you think would have the most impact on improving the ecological and social health of the forests and watersheds where you work? **Please select the top three that you think are most important.**

- ☐ administering more prescribed burning (1)
- ☐ creating more defensible space (2)
- ☐ thinning more forests (by hand and mechanical) (3)
- ☐ suppressing more active wildfire (4)
- ☐ mulching more post-fire landscapes (5)
- ☐ reforesting more post-fire landscapes (6)
- ☐ more stream restoration and stabilization projects post-fire (7)
- ☐ beaver restoration (8)
- ☐ climate assisted tree migration (9)
- ☐ allowing more wildfires to burn (if life or property are not in danger) (10)
- ☐ additional funding (11)
- ☐ improved collaboration and coordination in wildfire mitigation planning (12)
- ☐ changes to building codes on how homes are built (13)
- ☐ changes to zoning codes on where homes can be built (14)
- ☐ more education and outreach to private land managers (15)
- ☐ better integration of science into decision-making (16)

☐ monitoring outcomes of management actions (17)

☐ changes in dynamics of political influence in natural resource management (18)

---

Are there any other management strategies or inputs not listed above that you think would be useful for improving resilience in the future in the watersheds where you work?

________________________________________________________________

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Do you want us to send you a write up of the project results when they are ready?

○ Yes, please provide preferred email address (1)
__________________________________________________

○ No (2)

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Thank you for your time and input. Your insights are very valuable to our research team. If you have any additional comments or questions please leave them here.

________________________________________________________________

**End of Block: Future Scenarios**

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**Appendix E - Survey Dissemination List**

Organizations that received the disseminated survey

All relevant staff members at any given organization received the disseminated survey.

| **Government Agencies** |
|---|
| Colorado Parks and Wildlife |
| US Forest Service (Arapahoe and Roosevelt) |
| Natural Resource Conservation Service |
| Bureau of Land Management |
| US Fish and Wildlife |
| Rocky Mountain National Park |
| Colorado State Forest Service |
| Colorado Water Conservation Board |
| United States Geological Survey |
| **Private Businesses** |
| Lynker |
| Otak |
| Stillwater Sciences |
| Johnson Environmental Consulting |
| JW Associates |
| **Utilities** |
| Fort Collins Utilities |
| Loveland Utilities |
| Greeley Utilities |
| Northern Water |
| Soldier Canyon Utility |
| **Coalitions and NGOs** |
| Peaks to People Water Fund |
| Coalition for the Poudre River Watershed |
| Big Thompson Watershed Coalition |
| Colorado Water Trust |
| The Nature Conservancy- CO |
| Ember Alliance |
| Fire Adapted Colorado |
| Big Thompson Conservation District |
| Estes Valley Watershed Coalition |
| Estes Valley Fire |
| **Research Groups** |
| Colorado Forest Restoration Institute |

| |
|---|
| Northern Colorado Fireshed Collaborative |
| The Center for Collaborative Conservation |
| Rocky Mountain Research Station |
| Colorado Natural Heritage Program |
| **City and Counties** |
| City of Fort Collins |
| City of Greeley |
| Larimer County |

**Appendix F - Code Tree**

| Themes | Parent Codes | Descriptor Codes |
|---|---|---|
| 5/10 vision | | |
| Defining resilience | | |
| Barriers/difficulties | | |
| | Barriers to prescribed burning | |
| | Differences between watersheds | |
| | Expanding WUI population | |
| | Legacy settlement effects | |
| | Limited treatment size | |
| | Navigating policy | |
| | Population and tourism boom | |
| | Land ownership barriers | |
| | | Private landowners |
| | | Public land barriers |
| Mitigation actions | | |
| | Driving factors | |
| | | Driven by communities |
| | | Driven by monitoring past management |
| | | Driven by water supply / watershed priority |
| | Effectiveness of prescribed fire | |
| | | Combined effects with thinning |
| | | Cost-effective |
| | | Ecologically most beneficial |
| | Improving in | |
| | | Increasing in scale |
| | | Creative solutions |
| | | Social license |
| | | Wildfire as a treatment including use of PODs |
| | Types of mitigation actions | |
| | | Home-hardening |
| | | Mixed method |
| | | Mulching |
| | | Replanting |
| | | Stream restoration |
| | | Thinning |
| Needs- social | | |
| | Adaptivity and learning by practitioners | |
| | Changes in partnership | |
| | Citizen acceptance and buy in | |
| | Increases in funding/ changes to funding | |
| | Science backed decision making | |

Staff capacity

Negative ecological impacts

2013 floods/ fire flood cycles

Climate change

Degraded ecosystem services

Fuel loads

Increasing fire severity

Insects and beetle kill

Limited regeneration

Water quality/ supply degradations

Partnership

Based on different land ownership

Build capacity

Can withstand setbacks

Driven by aligned goals

Facilitating social license

Facilitating spread of funds

Importance of stakeholder connectivity

Strength of partnerships

Take time to build

Wildfire as a catalyst

For ecological variability

For funding

For partnership

For public attention and support

For ramping up mitigation actions