Exploring Multiple Understandings of Western Wildfires in Support of Knowledge Co-Production Practices

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Environment and Sustainability)
in the University of Michigan
2023

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Dedication

To my children, Oliver, Madrona, and Liat.

May you know when to fight for what is hard and when to take it easy.

Acknowledgments

The journey that brought me here has been long and meandering. I am incredibly grateful for the influential mentors I have had the privilege to work with along the way. Dr. Paige Fischer has been a wonderful mentor and friend. Her discipline and persistence proved invaluable as she helped me navigate multiple unexpected detours. She took this journey alongside me and stayed by my side, always with encouragement and dedication to excellence.

My sincerest appreciation to my incredible committee. Dr. Maria Carmen Lemos, a renowned scholar of knowledge co-production whose charm and wit enliven our program. Dr. Steve Yaffee, a staunch advocate for teaching and making scholarship relevant to practice. Dr. Susan Simkins, whose support and insight enabled me to stray into the world of team cognition. Dr. Laurie Lachance, who helped reinforce the importance of this work and got me excited to get out there. Finally, I am indebted to Dr. Heidi Huber-Stearns for endless support, compassion, and humor. I would not be here without you.

In addition to my committee, I continue to be inspired and challenged by my academic mentors from Seattle and Cambridge. Dr. Marina Alberti planted the seed for this dissertation over a decade ago. She always gave me light and room to grow. Dr. Larry Susskind never saw obstacles, only opportunities. And Dr. Shafik Islam's bold ideas and intellect brought so much life into our IGERT community.

I also want to acknowledge my student colleagues from UERL, MIT, Water Diplomacy, WFFI, and Dana. Their willingness to talk through ideas or to just let me 'process it out loud' have been my favorite parts of this journey.

I want to thank the University Network for Collaborative Governance and the Fire Adapted Communities Learning Network for opening their doors to me and grounding me in what great practice looks like.

Lastly, I owe a great debt to my family, who has been the support system that kept me going financially, technically, emotionally, and physically. My husband Michael, always the yin to my yang. My parents, Hanna and Baruch, who would have written this for me if they thought it would help. Oliver, for forgiving the endless mistakes I made learning to be a "working mother." Madrona, who has stepped in as our second mother. And Liat, who brings us all back together again.

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Abstract

Addressing society's most pressing and complex sustainability challenges requires a more productive collaboration between research and practice. Environmental governance increasingly turns to knowledge co-production, a collaborative and participatory process in which teams of researchers, policymakers, practitioners, and other relevant actors jointly produce knowledge to inform decision-making. Transdisciplinary research teams reflect multiple understandings, drawing from their members' diverse perspectives, experiences, cultures, and ways of knowing. A scholarly principle of knowledge co-production is recognizing and legitimizing those multiple understandings. However, *how* practice can (and should) attend to those multiple understandings (i.e., recognize, include, respect, and sustain) remains unclear.

This dissertation aims to improve how knowledge co-production practices attend to multiple understandings within the context of western wildfire challenges. I report on a mixed methods investigation that responds to the following three research questions:

(1) How can knowledge co-production practices identify and characterize multiple understandings of western wildfire challenges?

(2) How can knowledge co-production practices quantify the distribution of and explore the relationship between multiple understandings of western wildfire challenges?

(3) What model of team learning could help transdisciplinary teams continue to take advantage of their multiple understandings?

Western wildfires represent a complex and rapidly changing sustainability challenge. Co-production among diverse actors has been identified as necessary to inform collective actions to manage wildfire risks more effectively. However, practitioners need better approaches to attend to multiple understandings. In Chapter 2, I present an empirical narrative analysis based on semi-structured interviews with sixty influential actors. I construct nine social narratives that capture actors' shared stories about the causes, consequences, and solutions to western wildfire challenges. I find narrative analysis to be a pragmatic approach to characterize the strategies and scales that distinguish between actors' understandings while retaining the language and power embedded in those understandings. In Chapter 3, I present the findings of an online survey that explores the understandings of a purposive sample of one hundred and fifty-three (153) highly influential wildfire actors. My analysis suggests that actors' understandings are nuanced, overlapping, and do not align with actor types. Research findings emphasize the importance of elicitation techniques that capture the complexity of actors' understandings and prompt dialog and reflexivity. In Chapter 4, I present a perspective on how transdisciplinary teams working on complex sustainability challenges can sustain integrative and iterative team learning to continue to take advantage of their multiple understandings. I synthesize literature in team science to characterize the relationship between team learning and team cognitive structure, i.e., the pattern by which knowledge is organized, represented, and distributed within a team. I offer a conceptual model of a resilient team cognition necessary to sustain knowledge co-production practices. I provide insight on the features that characterize and factors that facilitate resilient team cognitions.

In this dissertation, I present approaches to advance how practice attends to multiple understandings. The qualitative and quantitative empirical findings emphasize the importance of

capturing the language, power, and rich complexity embedded in actors' understandings of sustainability challenges. The literature synthesis advances understanding by situating knowledge co-productions' aspirational ideas about team learning within emergent literature about the role of team cognition.

Chapter 1 Introduction

1.1 The need to attend to multiple understandings

The Anthropocene marks a period of great acceleration, where the severity and complexity of sustainability challenges are increasing (Berkes, 2017; Steffen et al., 2007). Challenges such as climate change, flooding, wildfires, and drought, reflect complex, uncertain, and problematic interactions between social and ecological systems, leading to increasingly urgent yet intractable problems (Chapin et al., 2010; Fischer et al., 2016). These challenges require coordination across various boundaries and scales, among actors with diverse knowledge and capacities, and amidst ambiguity and disagreement (Bodin, 2017; Cash et al., 2003; Pregernig, 2014). Environmental governance practices addressing these challenges necessitate many different types of knowledge (Kates & Clark, 1996; Plummer et al., 2013). Environmental governance scholars have long emphasized the importance of collaborations between researchers and affected actors to improve the way society manages natural resources, informs policy, and collects and interprets evidence (Armitage et al., 2009; Berkes, 2017; Bodin, 2017; Diduck et al., 2010; Lee, 1993; Van Kerkhoff & Lebel, 2006; Wondolleck & Yaffee, 2000). Traditionally, that diversity was captured by interests or 'stakes' (Reed et al., 2009). Recent scholarship asserts the importance of bringing a mix of scientific, economic, social, and political understandings to produce the knowledge needed to address complex sustainability challenges (Bremer & Meisch, 2017; Dilling & Lemos, 2011; Norström et al., 2020; Van Kerkhoff & Lebel, 2006). Environmental governance increasingly turns to knowledge co-production, a collaborative and participatory process in which teams of researchers, policymakers, practitioners, and other

relevant actors jointly produce knowledge to inform decision-making (Lemos, 2015; Mach et al., 2020; Norström et al., 2020; Steger, Klein, et al., 2021). The normative aspirations of these transdisciplinary co-production practices are bold and numerous (Table 1.1). To achieve those aspirations, a core principle of knowledge co-production is recognizing and legitimizing multiple understandings (Norström et al., 2020). Understandings are here defined as how actors construct meaning, interpret, or make sense of knowing, drawing from their diverse perspectives, experiences, cultures, and ways of knowing (Appendix A).

Co-production may fall short of meeting its own aspirations (Mach et al., 2020). Specifically, how practice currently attends to, i.e., recognizes, includes, and respects, multiple understandings may be insufficient. There remains conceptual ambiguity around what is meant by understandings and its relationship to knowledge (Harris & Lyon, 2014; Page et al., 2016). The way understandings are recognized in practice is not well-articulated or only internally documented with little transparency (Horcea-Milcu et al., 2022; Lebel et al., 2006; Steger et al., 2021). Selection practices for project participants are often ad-hoc or designed for convenience (Butler et al., 2015; Reed et al., 2009). Methods to identify representation are also poorly resourced, i.e., not much time and money is invested into this initial exploratory design stage (Horcea-Milcu et al., 2022; Steger et al., 2021). One of the major criticisms of co-production is the failure of groups to acknowledge the inherent power dynamics associated with the inclusion of different perspectives (Klenk & Meehan, 2015; Miller & Wyborn, 2018). However, there is no established framework or approach for ensuring that power inequities are addressed (Djenontin & Meadow, 2018; Gray et al., 2022; Horcea-Milcu et al., 2022; Ratner et al., 2022; Yua et al., 2022). Getting the representation of multiple understandings right remains a top challenge (Ansell et al., 2020; Chakraborty et al., 2022).

Table 1.1 Normative aspirations of knowledge co-production

Description	References
Process, knowledge, and decisions that are more	
Just. Co-produced knowledge is more equitable, inclusive, respectful, legitimate, and socially responsible. The process ensures that different voices and knowledge systems are included in the production of knowledge and ultimately reflected in decisions. Process design balances power inequities, valuing, legitimizing, and incorporating the knowledge and experiences of marginalized or underrepresented groups.	Miller & Wyborn, 2018; Steger et al., 2021; Brouwers et al., 2022; Brugnach & Ingram, 2012; Mach et al., 2020
Salient. Co-produced knowledge is more relevant to the needs and concerns of affected communities. It is place-based, context-specific, and pragmatic. It bridges the gap between science and society.	Cash et al., 2003; Djenontin & Meadow, 2018; Pitt et al., 2018; Caniglia et al., 2021
Credible. The process for co-producing knowledge is more rigorous, robust, and systematic, adhering to established and collectively agreed upon methods. Diverse perspectives, expertise, and experiences support collaborative rather than instrumental rationality resulting in knowledge that is more comprehensive, addresses biases and blind spots, and leads to wiser decisions.	Cash et al., 2003; Steelman et al., 2021; Wyborn et al., 2019; Kettle, 2019; Jagannathan et al., 2020
Actionable. Co-produced knowledge informs policy, practice, or community action. It contributes to positive societal outcomes. Knowledge co-production results in knowledge that is useful, usable, actionable, and effective.	Arnott et al., 2020; Hakkarainen et al., 2022; Mach et al., 2020; Armitage et al., 2011; Lemos, 2015
Durable. The knowledge that is collaboratively produced is less likely to be challenged, it is more stable, durable, and results in action that is more likely to be mutually beneficial.	Muñoz-Erickson et al., 2017; Miller & Wyborn, 2018; Kettle 2019; Susskind, 2010; Emerson et al., 2012
Adaptive. Knowledge co-production processes encourage reflection, critical examination, and challenging assumptions. Processes help teams become more adaptive and resilient. In the context of dynamic and deeply uncertain conditions, it helps teams be more flexible and responsive to changing conditions and new information.	Berkes & Armitage, 2010; Hakkarainen et al., 2022; Bousquet et al., 2017; Lemos, 2015; Jagannathan et al., 2020
Team processes that support	
Learning. Transdisciplinary teams share expertise and exchange ideas. Knowledge co-production supports both individual and team learning. Practices incorporate experimental, experiential, adaptive, collaborative, social, and transformative learning.	Roux et al., 2017; Berkes, 2017; Chambers et al., 2021; Caniglia et al., 2021; Rodela et al., 2019; Ernst, 2019b
Relationship building. Co-production supports dialogue between actors, reciprocal interactions, and empathy that leads to mutual learning, trust, and respect. Co-production helps teams build relationships and social cohesion.	Roux et al., 2017; Greenaway et al., 2022; Djenontin & Meadow, 2018; Berkes, 2017
Capacity building. Processes develop the capacity for communities to work together, identify solutions and mutually beneficial agreements. It improves access to data, and trains team members to negotiate policy and interpret evidence more effectively.	Louder et al., 2021; Reed & Rudman, 2022; Caniglia et al., 2021; Norström et al., 2020; Djenontin & Meadow, 2018
Empowerment. Co-production processes lead to broader engagement, ownership, and accountability among a broader group of actors. Processes can support a more democratic process of representation.	Arnott et al., 2020; Hakkarainen et al., 2022; Mach et al., 2020; Armitage et al., 2011; Lemos, 2015
Outcomes that are more	
Sustainable. Co-production results in better knowledge, which in turn results in better decisions and better actions, which ultimately results in improved social and ecological conditions. Co-production practices can lead to improvements for current and future generations in terms of health and welfare.	Louder et al., 2021; Molinengo et al., 2021; Reed & Human, 2022; Page et al., 2016; Caniglia et al., 2021

1.2 Implications of failing to attend to multiple understandings

Attending to multiple understandings can have substantial implications on the quality of the knowledge produced, relationships built, the extent of learning, decisions agreed upon, resultant actions, and ultimately the social and ecological outcomes (Figure 1.1). When practice does not sufficiently attend to multiple understandings, the resulting knowledge may not be

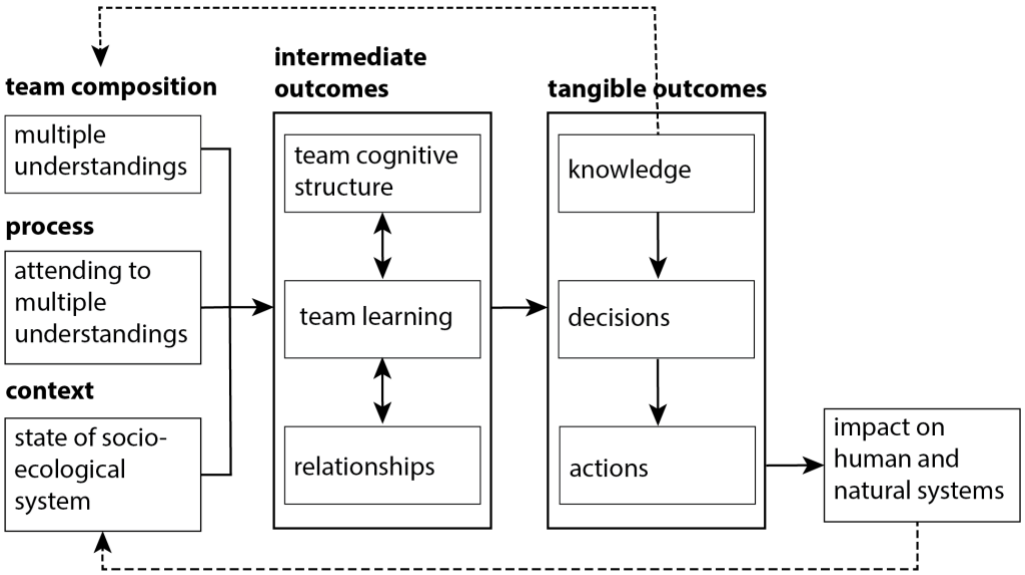


Figure 1.1 Conceptual framework of the role of multiple understandings in knowledge co-production practices

comprehensive or wise (Caniglia et al., 2023; Holling, 1996; Reed et al., 2014), actions may not be adaptive or flexible (Armitage et al., 2011; Burke et al., 2006; Wyborn, 2015), and decisions may marginalize certain actors (Chakraborty et al., 2022; Manuel-Navarrete et al., 2021; Polk, 2015; Rosendahl et al., 2015). Actor groups whose understandings are not attended to may stay involved but feel silenced, walk away from the process, or lose faith in governance practices altogether (Ansell et al., 2020; Carboni et al., 2017). Sometimes, failing to attend to multiple understandings can make the process counterproductive, reinforcing power dynamics (Knapp et al., 2019), eroding trust (Innes & Booher, 2010), polarizing actors (Caniglia et al., 2023), and

increasing the intractability of challenges (Dewulf et al., 2009; Lewicki et al., 2003; Shmueli et al., 2006).

1.3 Situating knowledge co-production and multiple understandings across science fields

Research on knowledge co-production and multiple understandings is an inherently interdisciplinary topic (Harris & Lyon, 2014; Palmer et al., 2016; Tebes, 2018). Similar concepts are brought up in various, often parallel fields and theories with diverse meanings and interpretations (Knapp et al., 2019). I situate my research among four interconnected fields: sustainability science, complexity science, philosophy of science, and team science.

Sustainability science aims to meet the needs of present and future generations through environmental governance practices that improve the interactions between natural and social systems (Bennett & Satterfield, 2018; Glaser, 2004; Horcea-Milcu et al., 2020). Collaborative environmental governance emphasizes collaborative rationality to improve decision-making by including the views of all affected parties (Innes & Booher, 2010). Knowledge co-production is perceived as essential to sustainability science as it supports more just, legitimate, and equitable sustainability actions (Cash et al., 2003; Chakraborty et al., 2022; Cosens, 2013; Miller & Wyborn, 2018).

Complexity science seeks to better understand complex adaptive systems. Complexity science is the foundation for resilience thinking and the management of social-ecological systems (Anderies & Janssen, 2013; Berkes, 2007; Folke, 2006; Gunderson & Holling, 2002). Characteristics of these systems (e.g., contextual, open, relational, dynamic, adaptive, and emergent) (Folke et al., 2003; Levin, 1999; Liu et al., 2007) results in a post-normal science where there is irreducible uncertainty, values are in dispute, and decisions are high stake and

urgent (Funtowicz & Ravetz, 1993; Wyborn et al., 2019). These conditions pose unique challenges for attending to multiple understandings. These challenges include, but are not limited to, information gaps (Gustafsson & Lidskog, 2018), a need for greater flexibility and adaptability (Lockwood et al., 2010; Sellberg et al., 2021; Walker et al., 2004), salience of context-dependence (Berkes, 2009; Norström et al., 2020; Plummer & FitzGibbon, 2007), and the necessity of creating stronger connections between science and practice (Mach et al., 2020; Nowotny et al., 2001).

Philosophy of science, particularly the study of Science, Technology, and Society (STS), engages with alternative epistemologies, ontologies, and research paradigms to examine how knowledge is conceptualized. These paradigms influence how knowledge co-production is conducted and valued (Fazey et al., 2014). Knowledge co-production is primarily situated within the constructivism-interpretivism-qualitative paradigm, which assumes that individuals actively construct and interpret their knowledge and understanding of the world through personal experiences, social interactions, and mental processes (Van der Walt, 2020; McCarthy, 2006; Fazey et al., 2014; Creswell, 2007). This conceptualization defines understandings as plural, partial, and positioned (Albrechts, 2013; Bremer & Meisch, 2017; Chakraborty et al., 2022; Chambers et al., 2022; Gunderson & Holling, 2002; Miller et al., 2008; Schuttenberg & Guth, 2015; Williams, 2014) (Figure 1.2). STS scholars emphasize that all knowledge is simultaneously a product of science and society (i.e., is co-produced), refuting the positivist idea that objective facts can be disentangled from subjective perspectives and that there is a singular reality out there that scientists can discover (Charmaz, 2014; Haraway, 1989; Jasanoff, 2019; Nowotny et al., 2001). Boundary work is a critical component of STS, emphasizing the discursive power embedded in demarcating or drawing boundaries around what counts as

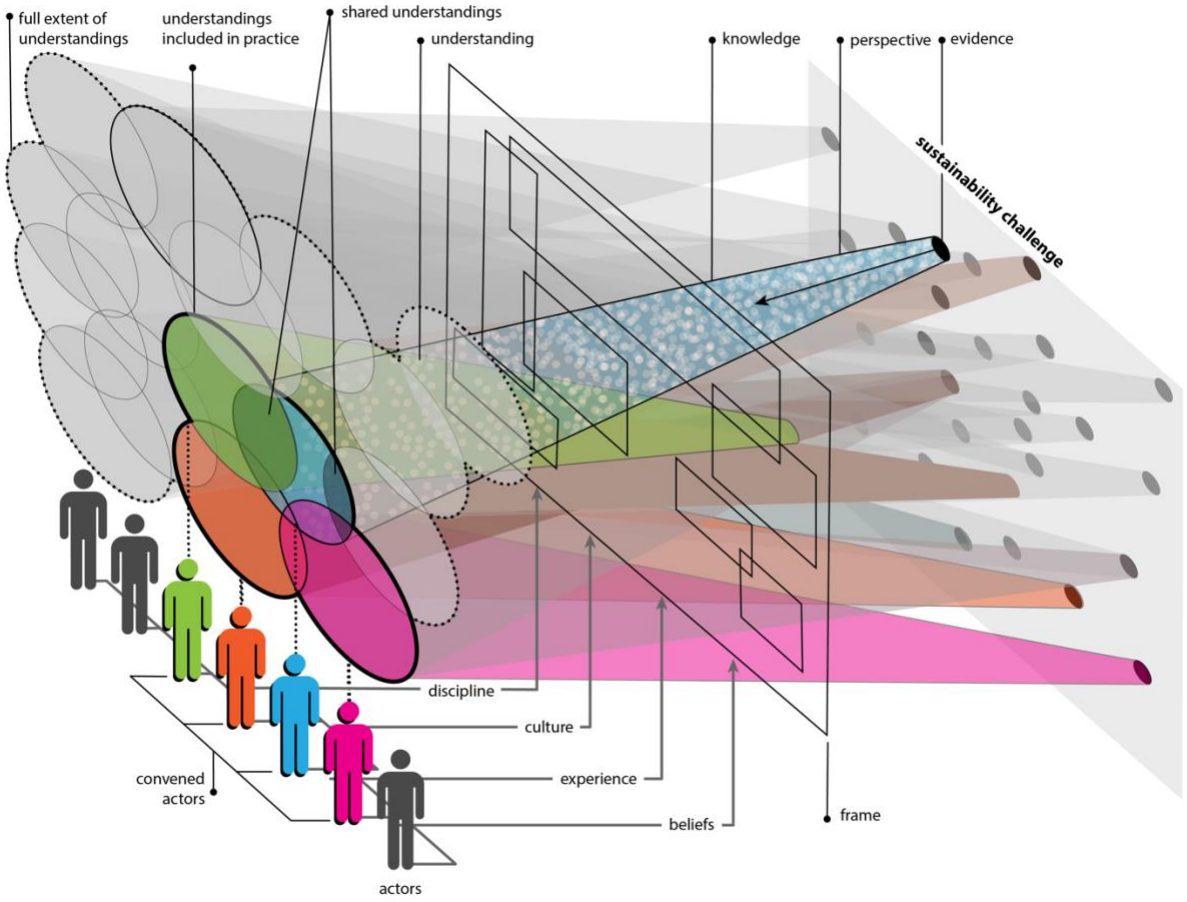


Figure 1.2 Understandings are plural, partial, and positioned

I approach this dissertation from a constructivism-interpretivism research paradigm that suggests that all understandings are partial, positioned, and plural. Understandings are partial as our experiences and disciplinary knowledge are limited, but also based on the frames people apply to make sense of their experiences (Gunderson et al. 2002). Understandings are positioned based on actors' unique perspectives. Two actors can look at the same piece of evidence and understand it differently. Understandings are plural because reality is plural. Reality is not singular and objective, but rather multiple and constructed. Actors with access to the same evidence or who share a disciplinary background, culture, or beliefs may hold overlapping or shared understandings of a complex challenge. While it is unrealistic that practice captures the full extent of different understandings, it may be able to capture sufficient diversity of understandings to mirror the complexity of the sustainability challenge. The graphic illustrates the relationship between convened actors engaged in sustainability practice and a diversity of understandings to mirror the challenge.

knowledge or what views are perceived as legitimate, credible, and salient (Brugnach et al., 2008; Cash et al., 2003; Gieryn, 1995). Constructivism-interpretivism paradigms tend to result in environmental governance practices that encourage mutual learning through multi-stakeholder

interactions and are not simply linear producer-to-end user activities (Fazey et al., 2016). However, while sustainability science promotes a constructivism-interpretivism paradigm, the scholars and practitioners convened in these practices do not necessarily share that view (Fazey et al., 2016). Actors who hold a more positivist view, including the existence of a singular identifiable reality and the primacy of deductive reasoning, may not value recognizing and legitimizing multiple understandings.

Team science is a relatively nascent field that emerged from industrial psychology (Salas et al., 2018) and organizational studies (Salazar et al., 2012; Stokols et al., 2008). It examines the relationship between the composition and interactions of team members and team performance outcomes (DeChurch & Mesmer-Magnus, 2010; Ilgen et al., 2005; Kozlowski, 2018; Mohammed et al., 2017; Wildman et al., 2012). Scholarship emphasizes the role of cognitive biases and the inherent tension between multiple and shared understandings in terms of communication, innovation, and efficiency (DeChurch & Mesmer-Magnus, 2010; Mannix & Neale, 2005; Mesmer-Magnus et al., 2017; Salazar et al., 2012; Van den Bossche et al., 2006). Furthermore, the pattern by which knowledge is organized, represented, and distributed within the team (i.e., team cognitive structure) has been shown to have an important relationship with team learning (Bowers et al., 2017; Burke et al., 2006; DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2021).

The intertwined disciplinary roots of multiple understandings and knowledge co-production introduce conceptual ambiguity and research redundancy. However, they also introduce interesting insights into the areas of overlap for cross-pollination between fields. For example, the role of reflexivity in facilitating adaptation to uncertain and dynamic conditions among team science and complexity science (Bixler et al., 2022; Boon et al., 2014; Lorenz,

2013; Slater & Robinson, 2020; Uitdewilligen et al., 2010; West, 1996) or a focus on addressing power and justice among philosophy of science and sustainability science (Brugnach & Ingram, 2012; Caniglia et al., 2021; Chambers et al., 2021; Hakkarainen et al., 2022; Tengö et al., 2014).

1.4 Dissertation roadmap

Scholars' theoretical conceptualizations and normative aspirations do not always carry meaning and value into practice (Goldman et al., 2018). Attending to multiple understandings can seem too abstract, overwhelming, or even inappropriate for practitioners who wish to address complex sustainability challenges (Chambers et al., 2022; Fallon et al., 2021; Kowarsch et al., 2017; McIlroy-Young et al., 2021; Van Kerkhoff & Lebel, 2006; Whitney et al., 2017). In this dissertation, my praxis is constructing pragmatic and authentic approaches to attend to multiple understandings to improve sustainability practices.

1.4.1 Research questions

This research aims to improve how knowledge co-production practices attend to multiple understandings within the context of western wildfire challenges. To support this aim, I ask three research questions:

(1) How can knowledge co-production practices identify and characterize multiple understandings of western wildfire challenges?

(2) How can knowledge co-production practices quantify the distribution of and explore the relationship between multiple understandings of western wildfire challenges? and,

(3) What model of team learning could help transdisciplinary teams continue to take advantage of their multiple understandings?

1.4.2 Investigation of multiple understandings within the context of western wildfire challenges

I investigate multiple understandings within the context of forest fires in the American West (Figure 1.3). Wildfires are historically native to most western temperate forests and are critical to maintaining ecosystem health (Ecowest, 2019; Prichard et al., 2021; Reilly et al., 2022). However, due to a legacy of forest and fire management (e.g., grazing, silviculture, suppression), wildfires are more severe and faster moving, and larger wildfires are occurring over a longer fire season (Dunn et al., 2020; Safford et al., 2022; Weber & Yadav, 2020). Climate change and development in high-risk fire areas exacerbate these trends (Hessburg et al., 2019; McWethy et al., 2019; Prichard et al., 2021). Current wildfire regimes result in undesirable or pathological conditions (Fischer et al., 2016; Schumann et al., 2020) - more smoke, communities disrupted, lives lost, money spent, forest species lost, and ecosystem functions impaired (Safford et al., 2022; Thomas et al., 2017). Model trajectories show that if substantial changes are not made, wildfire risks will increase exponentially over the next few decades (Westerling, 2016; Williams et al., 2019).

Strategies for addressing western wildfire challenges require complex cross-boundary coordination among diverse actors with different roles, capacities, perspectives, disciplines, cultures, interests, experiences, and beliefs (Huber-Stearns et al., 2021; Paveglio, 2021). Despite significant investments in research, policy change, and management, including hundreds of collaborative efforts across a range of scales, wildfire risks continue to escalate (Fischer et al.,

2016; McWethy et al., 2019; Olson et al., 2015). Western wildfires represent a salient scholarly moment to investigate how knowledge co-production can attend to multiple understandings and a practical opportunity to inform a complex sustainability challenge.

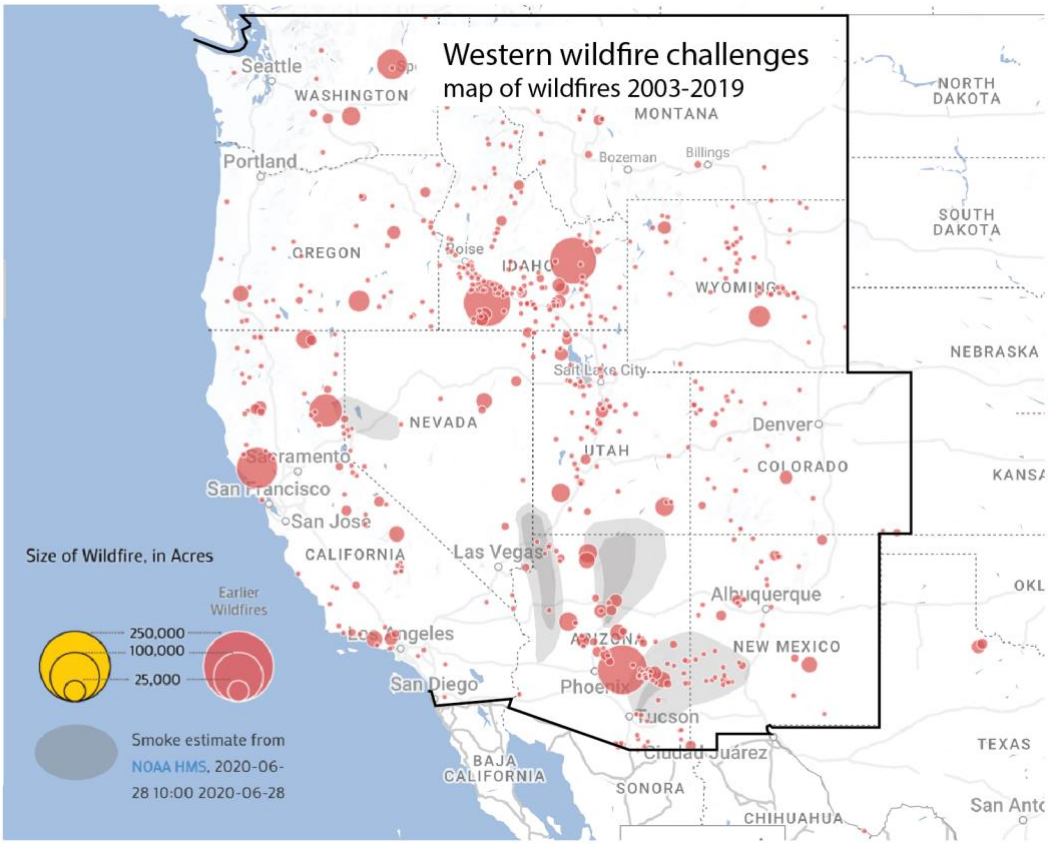


Figure 1.3 Map of western wildfires

1.4.3 A mixed-methods research design

This dissertation reports on research following an exploratory sequential mixed methods research design (Figure 1.4). Exploratory sequential designs start with qualitative research emphasizing a richer exploration of the meaning and language embedded in a poorly researched phenomenon. Qualitative findings inform subsequent quantitative research to investigate the phenomenon among a larger segment of the population (Creswell & Plano-Clark, 2011; Fetters et al., 2013). The first research phase included a qualitative investigation of the social narratives

of influential actors' understandings of western wildfire challenges. Influential actors represent the type of actors generally sought in knowledge co-production practices - recognized experts from multiple disciplines and actors with informed understandings outside of academia who are shaping public discourse and thinking around these challenges. In the second phase, I built on social narratives and sentiments expressed by interview participants to design an online survey that empirically quantified the distribution and explored the relationship between actors' understandings. Lastly, I synthesized theory in both sustainability science and team science to provide insight on the features that characterize and factors that facilitate the capacity of

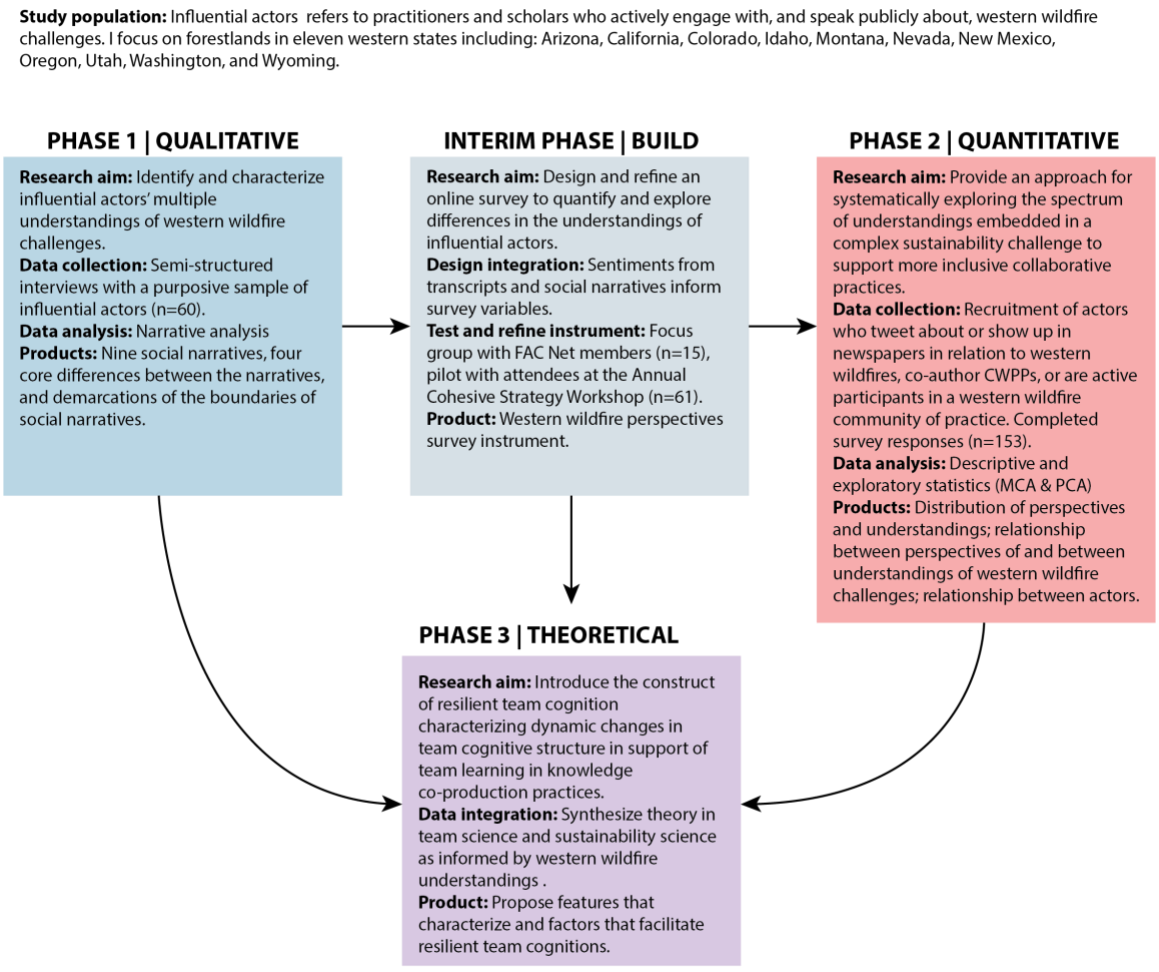


Figure 1.4 A mixed methods research design

transdisciplinary teams working on complex sustainability challenges to co-produce knowledge more effectively while remaining open to new knowledge.

1.4.4 Overview of the chapters

In Chapter 2, I report on an empirical narrative analysis to investigate multiple understandings within the context of western wildfire challenges. Based on sixty semi-structured interviews with influential actors, I identified nine social narratives that capture distinctions in the connections actors make between the causes, consequences, and solutions to wildfire challenges, in the spatial and temporal scale they emphasize, in the way they frame the challenge, and in the language they use. I also found differences in how actors demarcate social narratives' credibility, legitimacy, and salience. This research suggests that the analysis of social narratives fills an essential gap in practice by providing a pragmatic exploratory process for identifying and characterizing actors' multiple understandings.

In Chapter 3, I report on the findings of an online survey that explores the understandings of a purposive sample of one hundred and fifty-three (153) influential wildfire actors. Survey findings are examined in terms of their implications for informing the selection of project partners such that they mirror the distribution of understandings across the broader population, informing process design to consider important distinctions and conflicts between actors' understandings, and informing partner selection criteria to better represent understandings. This research contributes to knowledge co-production practice and scholarship through insights about the importance of elicitation techniques that capture the complexity of actors' understandings and prompt dialog and reflexivity.

Chapter 4 examines the role of integrative and iterative team learning within knowledge co-production practices. I synthesize literature in team science to characterize a relationship between team learning and team cognitive structure - the pattern by which knowledge is organized, represented, and distributed within the team (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2021). I offer a conceptual model of resilient team cognition that accommodates dynamic structural changes to support team learning within knowledge co-production practices. I provide insight into the features that characterize and the factors that facilitate resilient team cognition. I close with a summary of the scope and significance of this framework for knowledge co-production practice.

In the concluding chapter, I summarize the findings across the three chapters to present insights and recommendations. The qualitative and quantitative empirical findings emphasize the importance of capturing the language, power, and rich complexity embedded in actors' understandings of sustainability challenges. The literature synthesis advances understanding by situating knowledge co-productions' aspirational ideas about team learning within emergent literature about the role of team cognition. This dissertation can inform conversations among researchers and practitioners about bringing together actors with multiple understandings pragmatically and authentically in support of more meaningful collective action.

Chapter 2 Wildfire Narratives: An Empirical Investigation of the Multiple Understandings of Western Wildfire Challenges

2.1 Introduction

Addressing society's most pressing and complex sustainability challenges requires a more productive collaboration between research and practice. Environmental governance practices have long promoted bringing together affected parties, decision-makers, and technical experts to inform, make decisions about, and even co-manage socio-ecological systems (Bodin, 2017; Chaffin et al., 2016; Chapin et al., 2010; Folke et al., 2005; Lee, 1993; Plummer et al., 2013; Wondolleck & Yaffee, 2000). Environmental decision-making intended to address these challenges is frustrated by irreducible uncertainty, values in dispute, high stakes, and urgency (Funtowicz & Ravetz, 1993; Wyborn et al., 2019). In these contexts, traditional knowledge production modes, where research is intentionally separated from practice, may be insufficient (Jagannathan et al., 2020; Nowotny et al., 2001). Instead, environmental governance is increasingly turning to practices where scientists from multiple disciplines and local and indigenous actors co-produce knowledge to inform decision-making (Lemos & Morehouse, 2005). Knowledge co-production is conceptualized as a collaborative and interactive strategy to construct knowledge that is more place-based and action-oriented by intentionally bringing together actors with a plurality of understandings (Armitage et al., 2011; Jagannathan et al., 2020; Norström et al., 2020) (Table 2.1).

A scholarly principle of knowledge co-production is recognizing and legitimizing those multiple understandings (Brouwers et al., 2022; Klenk & Meehan, 2015; Knapp et al., 2019;

Norström et al., 2020). The "pluralistic principle" (p.187) states that as all knowledge is inevitably situated and partial, ensuring a range of perspectives on a given issue is both practically and ethically important (Norström et al., 2020). Research on complex socio-

Table 2.1 Key Terms

Definitions	References
Knowledge systems, or **ways of knowing:** Frameworks, principles, or methods that inform how actors acquire and interpret knowledge about a particular phenomenon.	Meppem & Bourke, 1999; Berkes, 2008; Rathwell et al., 2015; Cash et al., 2003
Perspective: An actor's point of view. It is shaped by their experience, beliefs, context and shapes how they perceive evidence.	Holmes 2020
Knowledge: Evidence positioned relative to an actor's or institute's perspective. It is what is perceived to be viable or justifiable by actors, and distinguished from reality, fact, or truth.	Chapman & Schott, 2020; Latulippe & Klenk, 2020; Roux et al., 2017
Understandings: How actors construct meaning, interpret, or make sense of knowledge, drawing from their diverse perspectives, experiences, cultures, and ways of knowing. Understandings go beyond what is to include what ought to be. Shared understandings refers to the knowledge and ways of knowing that is shared, or common, among actors.	Daly, 2016; Norström et al., 2020; Davenport, 2018; Carroll et al., 2011; Jasanoff, 2004
Frames: Frames shape understandings by emphasizing certain knowledge while minimizing other knowledge. Frames are constructed by implicit and explicit **boundaries** actors formulate about what knowledge is credible, legitimate, and relevant knowledge	Entman, 1993; Nisbet & Mooney, 2007; Bremer & Meisch, 2017
Boundary work: The process of demarcating or drawing boundaries around what counts as knowledge, or what views are perceived as legitimate, credible and salient	Brugnach et al., 2008; Cash et al., 2003; Gieryn, 1995
Competitive boundary work: The process of maintaining, reaffirming, and defending boundaries around shared understandings.	Langley et al., 2019
Collaborative boundary work: The process of blurring, bridging, or dissolving boundaries between multiple understandings.	Langley et al., 2019
Boundary management: The process of facilitating knowledge sharing and integration among actors with multiple understandings by blurring or simply recognizing boundaries	Jerneck & Olsson, 2011
Knowledge co-production: a collaborative and interactive strategy to construct knowledge that is more place-based and action-oriented by intentionally bringing together actors with a plurality of understandings	Armitage et al., 2011; Jagannathan et al., 2020; Norström et al., 2020

ecological systems with large uncertainties harbor multiple epistemically sound scientific perspectives suggesting a need for processes that attend to multiple scientific viewpoints (Chambers et al., 2021). Beyond scientific knowledge, actors' tacit and experiential knowledge of socio-ecological systems holds lessons for responding to change and nurturing diversity (Folke et al., 2003). Capturing a representative breadth of understandings is expected to support the more comprehensive knowledge necessary to address these challenges (Page, 2010; Susskind, 2010). It is also expected to support more just and inclusive practices (Wyborn, 2015). Intentionally involving diverse actors in a decision-making process implies accepting that there can be multiple legitimate ways of understanding a problem and finding solutions (Brugnach & Ingram, 2012). However, how knowledge co-production currently attends to multiple understandings may be insufficient (Mach et al., 2020; Meadow et al., 2015; Page et al., 2016; Reed & Abernethy, 2018).

Co-production practices are often criticized for not being inclusive of multiple understandings (Brugnach & Ingram, 2012; Chakraborty et al., 2022; Jagannathan et al., 2020), not recognizing important differences between understandings (Chambers et al., 2022; Hakkarainen et al., 2022), and failing to address discursive power, i.e., control over what (and whose) understandings are valued and used to inform decisions (Djenontin & Meadow, 2018; Klenk & Meehan, 2015; Knapp et al., 2019; Maclean et al., 2022; Miller et al., 2008; Muñoz-Erickson, 2014; Zurba et al., 2022). A failure to recognize and legitimize multiple understandings, i.e., the pluralistic principle, has been found to perpetuate power inequities (Gray et al., 2022), marginalize certain voices (Purdy & Jones, 2012; Tengö et al., 2014), erode trust (Ansell et al., 2020), destabilize agreements (Cosens, 2013), and make conflicts more intractable (Dewulf et al., 2009; Lewicki et al., 2003). To facilitate the recognition of multiple understandings, practitioners require an initial exploratory process for identifying and

characterizing actors' multiple understandings of complex sustainability challenges (Chakraborty et al., 2022; Proctor, 2020; Tengö et al., 2014). To legitimize multiple understandings, practices must examine the implicit boundaries that shape how actors define what counts as knowledge (i.e., what knowledge is legitimate, credible, and salient, and what knowledge is not) (Brugnach & Ingram, 2012; Daly, 2016). However, practice lacks a framework, guidance, or approach for supporting this principle. This chapter proposes an approach to support the pluralistic principle within knowledge co-production practices.

This research study aims to identify and characterize influential actors' multiple understandings of increasingly severe wildfires in the US West, hereafter referred to as "western wildfire challenges." Influential actors represent the type of actors generally sought in knowledge co-production practices - recognized experts from multiple disciplines and actors with informed understandings outside of academia shaping public discourse and thinking around sustainability challenges. We represent actors' understandings in terms of narratives, explicit and coherent stories about what is happening and what should be done (Fischer, 2003). We elicited the narratives of sixty influential actors and analyzed them to identify social narratives representing shared stories of common experiences and interpretations (Rawluk et al., 2020; Shenhav, 2015) of wildfire challenges. Our three research questions address three challenges for recognizing and legitimizing multiple understandings in practice. First, to identify a representative breadth of understandings of the challenge in practice, we ask - what are the social narratives of western wildfire? Second, to explicitly characterize differences in understandings in practice, we ask - what are the important differences between influential actors' social narratives? Third, to address discursive power by legitimizing multiple understandings in practice, we ask - how do influential actors demarcate the boundaries of credible, salient, and legitimate social narratives regarding western wildfire challenges?

2.2 Background

2.2.1 Conceptualizing multiple understandings

Bringing together diverse actors with different interests, experiences, capacities, and values has long been integral to managing environmental challenges (Ostrom, 1990; Rittel & Webber, 1973). Recent knowledge co-production scholarship highlights a growing emphasis on inclusive diversity of actors' understandings (going beyond traditional diversity measures of interests and affiliation) (Ansell & Gash, 2008; Chakraborty et al., 2022; Emerson et al., 2012; Muñoz-Erickson, 2014). However, as knowledge co-production has expanded, so have interpretations of what is meant by multiple understandings (Chapman & Schott, 2020; Steger, Klein, et al., 2021). This conceptual ambiguity may exacerbate procedural limitations and impact practice design and evaluation (Fazey et al., 2014)

This research focuses on "multiple understandings" to capture differences in how actors interpret and make sense of knowledge. Knowledge co-production scholars use terms such as ideas, information, perceptions, and evidence (Brunner & Steelman, 2005; Dilling & Lemos, 2011; Louder et al., 2021; Pahl-Wostl, 2006; Proctor, 2020) to characterize what is being integrated. Knowledge co-production also refers to recognizing and legitimizing knowledge types (tacit, local, and scientific knowledge), knowledge systems, ways of knowing, epistemic pluralism, ontological understandings, and view or worldviews (Armitage et al., 2011; Aspøy & Stokland, 2022; Brugnach & Ingram, 2012; Caniglia et al., 2021; Chambers et al., 2021; Davis et al., 2021; Folke et al., 2005; Goldstein & Butler, 2010; Klenk & Meehan, 2015; Rathwell et al., 2015) which represent deeper levels of comprehension. We use the term understandings to reinforce knowledge co-production's aims to go beyond providing more information or knowledge (Goldman et al., 2018; Hakkaraiunen et al., 2022) to co-create new understandings

(Louder et al., 2021). Like rationales, agendas, or logics (Brouwers et al., 2022; Chambers et al., 2022; Goldman et al., 2018; Muñoz-Erickson, 2014; Van Kerkhoff & Lebel, 2006; York et al., 2016), understandings go beyond what is to include what ought to be (Jasanoff, 2004). Understandings consider actors' contexts, experiences, values, and interpretations of knowledge (Muñoz-Erickson, 2014a). Frames further shape understandings by emphasizing and legitimizing specific knowledge while minimizing and delegitimizing others' knowledge (Osaka et al., 2021; Wyborn, 2015).

2.2.2 Challenge #1: Identifying a representative breadth of understandings of the challenge

Integrating multiple understandings into collaborative processes for decision-making while maintaining the integrity and agency of all actors is only sometimes feasible and rarely easy (Rathwell & Peterson, 2012). Capturing a representative breadth of understandings is critical to supporting inclusive and effective co-production practices (Polk, 2015). However, identifying actors' understandings remains a core challenge in practice (Brugnach & Ingram, 2012; Feldman & Ingram, 2009; Horcea-Milcu et al., 2022). Decisions about what diversity to include generally occur during the exploratory initial stages of knowledge co-production (Page et al., 2016; Steger et al., 2021). Initial investments can support systematic knowledge of multiple understandings that inform practice design (Horcea-Milcu et al., 2022). However, while this phase is generally very resource intensive, it is largely underfunded (Horcea-Milcu et al., 2022; Steger et al., 2021). Furthermore, practice lacks established practices to take inventory of the spectrum of understandings and assess their implication for successful outcomes (Devente et al., 2016; Reed & Abernethy, 2018). Existing processes are generally implicit, equivocal, and poorly documented (Boon et al., 2014; Chakraborty et al., 2022; Hakkarainen et al., 2022; Horcea-

Milcu et al., 2022; Klenk & Meehan, 2015; Norström et al., 2020; Tengö et al., 2014; Wyborn et al., 2019). Often, diverse representation is captured by calling for actors to fill specific roles. For example, the Wildland Fire Mitigation and Management Commission has been tasked with informing federal policy recommendations and strategies on ways to better prevent, manage, suppress, and recover from wildfires (USDA, 2021). The commission's twenty-nine members have been selected to represent governmental agencies, Tribal governments, the private sector, 'forestry,' 'social science,' and 'innovation' (USDA, 2021). However, it is unclear whether diverse sectors and interest-based representation capture a representative breadth of understandings of the challenge. Recent evidence suggests that differences in actor type may not indicate differences in perspectives (Cuppen et al., 2010, as cited by Brouwers et al., 2022).

2.2.3 Challenge #2: Explicitly characterizing differences in understandings

The engagement of actors with diverse understandings can better connect knowledge and action (Lopez et al., 2019; Shackleton et al., 2019), but it can also function as a source of project-related tension and inefficiencies (Djenontin & Meadow, 2018). While some differences in understandings can foster creativity and flexibility (i.e., are complimentary), differences can also cause miscommunication, disagreements, and conflicts (i.e., are conflicting) (Mannix & Neale, 2005; Salazar et al., 2012). The benefits of complementary differences rarely emerge spontaneously and necessitate accommodation in project design (Rathwell et al., 2015). Practice must go beyond identifying a breadth of multiple understandings to characterize differences between them. Efforts to clarify actors' understandings remain an important need in practice (Fazey et al., 2014). These characterizations can inform process design and influence project success. Finding parallels between, for example, indigenous and scientific knowledge systems

can enhance the legitimacy and credibility of both (Rathwell et al., 2015). Alternatively, when differences stem from deeper conflicts, turning to evidence may unintentionally reinforce existing tensions and inhibit collective action, making challenges more intractable (Lewicki et al., 2003; Mannix & Neale, 2005; Wyborn, 2015). There are also times when differences should be recognized but not reconciled. For example, scholars have challenged the impact of integration (i.e., adding together) of diverse perspectives as coercing indigenous or local knowledge to align with scientific standards and values associated with Western scientific understandings (Goldman et al., 2018; Klenk & Meehan, 2015).

2.2.4 Challenge #3: Addressing discursive power by legitimizing multiple understandings

Scholars of co-production have raised questions about how practice determines whose voice counts, who are the gatekeepers, and what it means to integrate knowledge (Fazey et al., 2013). Demarcating or drawing boundaries around what counts as knowledge (i.e., boundary work) can yield substantial discursive power (Pregernig, 2014). On par with power over territories and resources, discursive power shapes whose perspectives are reinforced and what evidence is considered to inform decisions (Goldstein & Butler, 2010; Purdy & Jones, 2012; Rawluk et al., 2020; Shenhav, 2015). Actors with shared experiences, disciplines, cultures, and personal beliefs may have access to the same evidence, hold similar perspectives, or frame issues similarly, resulting in shared understandings about what counts as knowledge. When the boundaries actors set around an issue become commonly accepted, they can become embedded within institutions and reinforced as the 'right' view of a policy problem (Stone, 1997). The way actors frame or create boundaries around an issue can preclude other perspectives and pre-empt many considerations from entering the debate (Jerneck & Olsson, 2011).

Reinforced and exclusionary boundaries may lead actors with different understandings to avoid the process (Carboni et al., 2017; Wondolleck et al., 2003) or engage in a more muted or limited manner (Chambers et al., 2022; Paveglio et al., 2015; Purdy & Jones, 2012; Tengö et al., 2014). However, few studies have directly investigated the relationship between understandings and boundary work to expose the discursive power relations that shape collaborative knowledge-making (see Daly, 2016; Muñoz-Erickson, 2014; Wyborn, 2015 for notable exceptions). Recognizing the boundaries that demarcate legitimate understandings may not solve power dynamics, but it can reveal bias and facilitate a greater capacity for change (Caniglia et al., 2021). Chambers et al. (2022) suggest that recognizing multiple understandings can elevate marginalized agendas, challenge assumptions, foster learning and mutual respect, and prompt reflexivity.

2.2.5 Narratives, social narratives, and narrative analysis

Narratives represent explicit and coherent stories about what is happening and what should be done (Fischer, 2003). Actors construct narratives to give meaning to or interpret their experiences and knowledge (Polkinghorne, 1998). In this way, narratives reflect understandings of complex environmental phenomena (Innes & Booher, 2010; Paveglio, 2021). Social narratives are a particular type of narrative that captures shared experiences and interpretations of an event or phenomena (Rawluk et al., 2020; Shenhav, 2015). When narratives are told and retold, they multiply, disperse, and transform, i.e., they become social narratives (Shenhav, 2015).

Pervasive social narratives are widely perceived as conveying truths, gaining dominance over other narratives (Shenhav, 2015). “Dominant narratives are not called stories. They are called reality” (McKinnon 1996 235). One of the more enduring and impactful narrative

elements concerns how particular ideas are framed or bounded (Paveglio, 2021). Boundaries that demarcate the legitimacy, credibility, and saliency of understandings are not self-evident but can be revealed based on language and meaning embedded in narratives (Rein & Schön, 1996). Narratives presuppose selection, i.e., "what is told marginalizes what remains untold" (Shenhav, 2015 p3).

Narrative analysis may aid the initial exploration stage of co-production. Narrative analysis is used in public policy to better understand how actors make sense of conflicts; uncover nuances and details of people's experiences and understandings; and identify many truths rather than finding one generalizable truth (Feldman et al., 2004; Hunter, 2010). Narratives analysis is a language-focused interpretive approach providing researchers with a schema of understandings (Fischer, 2003; Jerneck & Olsson, 2011). In line with previous research, by analyzing social narratives, practice can reveal important differences in shared understandings of sustainability challenges and their relationship to discursive power (Rawluk et al., 2020; Shenhav, 2015).

2.3 Western wildfire challenges

Western wildfires present a complex socio-ecological challenge characterized by more severe fires and increasing socioeconomic impacts (Burke et al., 2021; Dunn et al., 2020; Safford et al., 2022). Despite significant investments in research, policy change, and management, wildfire risks continue to escalate (Fischer et al., 2016; McWethy et al., 2019; Olson et al., 2015). The intractability of these challenges arises from the intricate interplay between social and ecological systems (Fischer et al., 2016; Steen-Adams et al., 2017). Knowledge co-production represents a critical need for wildfire management in complex landscapes (Paveglio, 2021). Western wildfires are an appropriate context for investigating multiple understandings given the

salience of wildfires, the diversity of entities engaged with wildfire risk management, and well-recognized tensions between various actors (Huber-Stearns & Cheng, 2017).

Various social narratives have influenced Western wildfire management, ranging from tribal spiritual narratives to militaristic and institutionalized narratives focused on combating fires (Butler, 2009; Paveglio, 2021; Pyne, 1995). In response to a series of recent devastating fires, there has been an increase in the representation of wildfire narratives in blogs, podcasts, symposiums, films, and media coverage (Ingalsbee, 2017). Social scientists have investigated the perspectives of different actors, including residents, scientists, project partners, and the media, regarding key wildfire themes (Champ et al., 2012; Jacobson et al., 2021; Moritz et al., 2018). Several studies have specifically researched wildfire narratives (Crow et al., 2017; Hall et al., 2015; Morehouse & Sonnett, 2010; Moskwa et al., 2018).

Research characterizing wildfire narratives suggests a convergence toward a unified co-produced narrative emphasizing a landscape-scale ecological fire restoration (Brenkert-Smith et al., 2017; Goldstein & Butler, 2010). This narrative has been "reproduced and told through social interaction" (Butler 2009, pg. 137) and it "silently articulates assumptions and expectations, shaping who they [fire managers] are, what practices they engage in, and how they judge the actions of others" (Butler 2009, pg. 138). This narrative has been successfully circulated among the Fire Learning Networks (Goldstein & Butler, 2009), the National Cohesive Strategy, and federal agencies such as the USDA Forest Service (Brenkert-Smith et al., 2017) and at a local level, through Community Wildfire Protection Plans (Abrams et al., 2015; Brummel et al., 2010).

Despite its ubiquity, implementation of activities aligned with this narrative continues to be opposed, litigated, and abandoned (Brenkert-Smith et al., 2017; Paveglio, 2021), and suppression tactics continue to dominate wildfire risk management actions (Ingalsbee, 2017;

Schultz et al., 2019). The fire restoration narrative is often depicted as dichotomous or conflicting with other narratives about the role of fire in the landscape (Butler, 2009; Carroll et al., 2006; Crow et al., 2017; Edwards & Gill, 2016; Ganey et al., 2017). For example, the dichotomy emphasizing fire as a beneficial and necessary component of ecological processes in fire-prone landscapes to one which emphasizes the destruction and devastation caused by wildfires (Morehouse & Sonnett, 2010); and the dichotomy emphasizing fuels reduction treatments as necessary to reduce the risk of high severity wildfire and its negative impacts on habitat (e.g., spotted owl) or an opposing narrative that suggests that high severity wildfire is neither uncommon nor a threat to habitat (Ganey et al., 2017); or, the dichotomy between this narrative and a "resistance" narrative that emphasizes air quality, escaped fires, and aesthetic impacts as issues with prescribed burning in wildland urban interface (WUI) (Brenkert-Smith et al., 2019). These competing narratives are broadly depicted as posing a challenge to advancing collective cross-boundary action (Morehouse & Sonnett, 2010), emphasizing the importance of finding common ground or shared understandings (Davis et al., 2021; Moritz et al., 2018; Paveglio, 2021). Building on these works, our research seeks to identify and characterize multiple understandings of western wildfire challenges and their representation through social narratives.

2.4 Methods

We employed a narrative analysis to empirically investigate influential actors' multiple understandings regarding western wildfire challenges. We ask three research questions:

(1) What are the social narratives of western wildfire challenges?

(2) What are important differences between influential actors' social narratives?

(3) How do influential actors demarcate the boundaries of credible, salient, and legitimate social narratives of western wildfire challenges?

Narrative analysis follows a qualitative research approach that seeks to explain a complex phenomenon by constructing deep and nuanced characterizations that capture actors' experience, language, and meaning (Charmaz, 2014; Dupraw, 2018; Crewell, 2007). Our process was iterative, returning to data collection after each round of analysis (Creswell, 2007). We analyzed our data as it was being collected and used saturation, the point at which no new themes emerged, as the criterion for stopping data collection (Creswell, 2007; Nowell & Albrecht, 2019; Oliver, 2012). In both our data collection and analysis, we set out to treat all participants equally, regardless of whether we agreed with their understandings, i.e., symmetry (Fischer, 2000) and emphasized their point of view, i.e., empathetic understanding (McIlroy-Young et al., 2021).

2.4.1 Data collection

2.4.1.1 Study population, sampling, and recruitment

This research examines fires in forested landscapes in western US states. We focused on actors working on western wildfires whom we considered influential because they are recognized as experts in their field and engaged in public discourse around the challenge at a regional or national level. We elicited diverse perspectives from individual practitioners and scholars as representatives from various governmental and non-governmental organizations. We followed a purposive sampling strategy to maximize the saliency and diversity of perspectives (Schreier, 2018). We first sampled individuals from internet searches and our research team's expert knowledge of prominent actors working on wildfire topics in western forestlands (Patton, 2014).

We then used snowball sampling, identifying recommendations based on the interviewee's social networks (Parker et al. 2019). In the last iteration of interviews, we emphasized actors who could speak to voices and themes that came up as potentially marginal or excluded (Kristensen & Ravn, 2015; Osaka et al., 2021; Sievert et al., 2022; Wang, 2017). For example, actors who work in the energy sector, emergency management directors, and community housing. Our sample included diverse geographies, sectors, scales, and topical areas (Table 2.2). We recruited actors through personalized email requests for interviews (69% positive response rate).

2.4.1.2 Interviews

The research team, consisting of the authors, conducted sixty interviews over the phone or via video conferencing between August 2021 and August 2022. Interviews were semi-structured to conversational (Patton, 2014) and guided participants to discuss (1) the causes of the western wildfire problem (i.e., how did we get here?), (2) the consequences or impacts (i.e., why we should care?), and (3) potential solutions (i.e., what we should do about it?) (Appendix B). We started each interview by asking participants to briefly describe their role in relation to western wildfires. For each interview, the interviewer took detailed notes by hand and recorded the conversation. We transcribed notes and recordings and conducted a content analysis (Saldaña, 2008) with NVivo qualitative analysis software.

2.4.2 Data analysis

2.4.2.1 Constructing social narratives

We constructed the social narratives by starting with participants' individual narratives and looking across those narratives for repeated themes (Polkinghorne, 1995; Shenhav, 2015). We first analyzed participants' interview transcripts and notes for a priori categorical codes

Table 2.2 Interviewee characteristics

a) Professional sector and scale

	Local	**State**	**Regional**	**National**
Government	1	7	5	6
NGO	4	1	8	10
Tribal	1	0	1	1
Private	1	3	1	5
Academia	0	6	6	4

b) Topics of expertise

(n)	**Topic**
16	Natural resource management & watershed protection
14	Fire ecology, restoration, & forest health
12	Climate change, atmosphere, & carbon
12	Conservation & wilderness
11	Environmental law & policy
10	Built environment, land use codes, & utilities
10	Business innovation & partnerships
10	Rural livelihoods & economic sustainability
10	Computational models & assessment
10	Fuels management (inc. Rx fire & workforce development)
9	Collaboration & conflict resolution
6	Timber industry & silviculture
6	Traditional fire culture
5	Community development & planning
5	Hazards & risk management
4	Environmental justice & equity
4	Insurance
4	Public health
4	Firefighting and incident command (inc. suppression)
3	Education, learning, & communication
2	Cultural assets, parks, & recreation

based on the interview guide (identifying causes, consequences, and solutions) (Gibson & Brown, 2009). We illustrated conceptual models of each participant's individual narrative depicting participants' characterization of the relationships between causes, consequences, and solutions. (Figure 2.1). We used these models as a first step in scaling up to social narratives. We then conducted an inductive analysis to identify key themes that organize each participant's story (Ryan & Bernard, 2003). We developed an analytical memo with a summary of each participant's individual narrative. We applied a constant comparison process to compare, contrast, and distill emergent themes, patterns, and categories across individual interviews (Glaser & Strauss, 1967). We captured areas of agreement and disagreements between the individual narratives repeated across transcripts (McAdams, 1997).

We identified four categories of themes that distinguished between the narratives:

(1) **Strategies** stem from the conceptual models, looking for repeated patterns in the way actors related or provided a rationale for their solutions based on the causes and consequences (See Figure 2.1a for a more detailed explanation).

(2) **Scales** emphasize different spatial and temporal scales, for example, focusing on local short-term strategies or place-based generational knowledge.

(3) **Frames** represent participants' emphasis on specific knowledge, indicating how they are making sense of the complexity of the challenge (e.g., economic lens or traditional ecological knowledge).

(4) **Language** captures the distinct terms or phrases actors used, representing communities of practice (Lave & Wenger, 1991; Ryan & Bernard, 2003).

We conducted axial coding to identify themes within each category and compared them across the individual narratives. We wrote an analytical memo for each theme, continuing to look for repeated and relationships (Creswell, 2007; Thornberg et al., 2013).

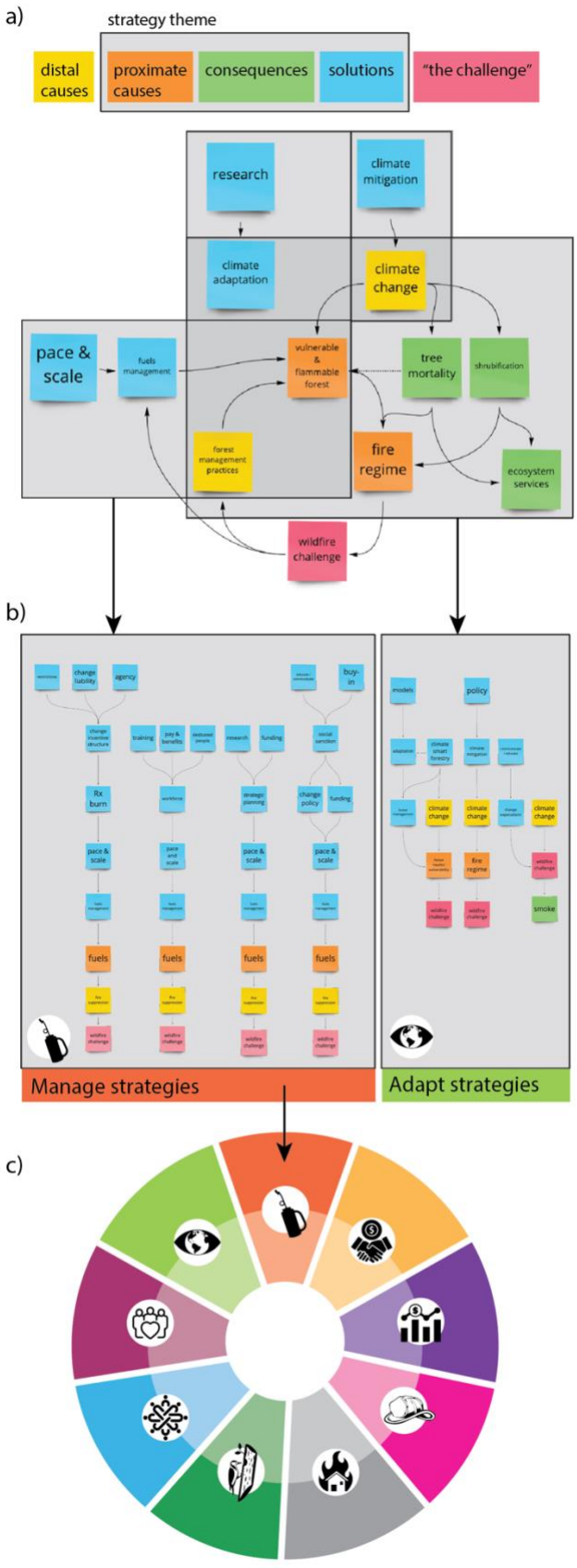


Figure 2.1 Social narratives analysis

a) The research team created a conceptual model based on the transcript or interview notes of each interviewee. Conceptual models illustrate expressed relationships (arrows) between distal and primal causes of, consequences of, and solutions to wildfire challenges. Emergent strategic themes (bound by rectangular gray frame) capture patterns of connections between causes, consequences, and solutions heard across multiple subjects.

b) The research team merged similar strategic themes and clustered together themes that were repeatedly heard together. These clusters of themes represent different elements of the same story. This process of moving between transcripts and clusters of themes was highly iterative.

c) The team constructed nine clusters of strategic themes. We combined these clusters with emergent themes that capture how interviewees conceptualize the space and time scale of western wildfire challenges, how they frame the challenges, and the particular language they use to characterize challenges. Together, these four core elements (strategies, scale, frame, and language) were used to inform the development of the nine social narrative. The process of moving between clusters of themes and narrative analysis was highly iterative, looking for shared language and meaning across subjects.

We clustered the strategies, scales, frames, and language themes to construct a set of social narratives (Figure 2.1b). These analyst-constructed social narratives become our unit of analysis, allowing us to identify multiple social narratives within each transcript (Ryan & Bernard, 2003). We then analyzed each social narrative to identify the way actors justified the legitimacy, saliency, and credibility of their perspectives, i.e., how they demarcated the boundary of the narrative. The process of constructing social narratives from individual narratives was highly iterative, involving repeatedly checking back against the original data to test and reconfigure themes and clusters of themes (Wang, 2017).

2.4.2.2 Evaluating and verifying the social narratives

We refined the narratives based on established criteria, aiming for the following:

(1) **Inclusive representation:** the full breadth of narratives is included (Meppem & Bourke, 1999).

(2) **Resonance and internal validity:** the narratives resonate with practitioners as what they see in their work (Creswell, 2007; Fischer, 2003; Herrick, 2004).

(3) **Integrity and respect:** narratives use language and meaning as portrayed by subjects to sustain the integrity and authenticity of the told experience (Kearns & Fontana, 2007). They further honor and respect all ideas without judgment (Collins et al., 2020).

(4) **Distinction and coherence:** All narratives are internally consistent, i.e., it makes sense that these things are together (Riessman, 2016) and minimally overlapping or redundant (Fischer, 2003).

(5) **Compelling:** all narratives are concise, illustrative, interesting, and engaging to the reader (Kim, 2019)

We triangulated our narratives against supplementary materials (publications, podcasts, conferences) for consistency and breadth (Yin, 2011). These materials helped confirm that no other social narratives are circulating, informing our decision about saturation. In addition to repeated interrogation of the interview data, we refined and finalized the narratives' selection and characterization based on feedback from multiple sources. We shared the draft narratives with interview participants for their feedback and elicited input from six experts from boundary-spanning organizations who could speak to various facets of western wildfire challenges (Davis et al., 2021; Morgan, 2014).

2.5 Results

2.5.1 Nine social narratives

In response to research question 1, what are the social narratives of western wildfire challenges, we introduce nine social narratives that capture coherent storylines reflecting shared or common experiences and interpretations of the challenges across the participants we interviewed. These social narratives suggest the multiple understandings to be recognized in co-productive practice addressing western wildfire challenges. Although we focused on the differences between the social narratives, we also heard evidence of common ground across the interviews. These are perspectives that are true for all nine of the social narratives. First, we heard that western wildfires threaten both social and ecological values, and we need to act now to reduce impacts. Second, we heard how conditions on the ground have changed, requiring new strategies to manage risks. Third, we heard that the challenge is complex and needs solutions to match that complexity.

Each of the nine social narratives captures a different way actors are making sense of the complexity of western wildfire challenges.

- 'Manage' emphasizes wildfire challenges as primarily a fuels management issue,
- 'Work' focuses on the financial sustainability of timber management to reduce risks,
- 'Market' employs an economic lens to highlight the role of insurance in both signaling and managing risk,
- 'Control' prioritizes efficiency and safety to protect against fire hazards,
- 'Regulate' points to the important role of where and how people build to mitigate wildfire challenges,
- 'Conserve' prioritizes forest health and restoration to reduce wildfire risks,
- 'Revitalize' speaks to traditional fire culture and the importance of our relationship with fire,
- 'Justice' stresses the uneven distribution of wildfire burden on vulnerable populations and marginalized communities,
- 'Adapt' underscores the criticality of climate change as a key driver shaping future wildfire management pathways.

We provide summaries of each storyline in Table 2.3. We wrote these summaries to reflect the language and meaning we heard in the interviews. To highlight important distinctions, we include unique keywords for each narrative. These keywords came after we constructed and segmented the transcript in relation to the nine narratives. We conducted a keyword analysis focusing on the most frequently used nonoverlapping keywords associated with each narrative (Table 2.3).

Table 2.3 Narrative summaries

MANAGE
Key quote: "We know what to do, and we just need that partnership on the ground to get it done"
Keywords: fuels, pace and scale, scientific consensus, risk management strategy, (mis)perceptions, & (learning to) live with fire
Summary: Over the past decade, we have seen more frequent, high intensity, extensive, and fast-moving fires that threaten forest ecosystems and human communities. The Western wildfire crisis is driven by denser, more fuel-filled forests due to a century of poor forest management practices. Wildfire risks are exacerbated by climate change and development in the wildland urban interface. To manage wildfire risks, we need to dramatically increase the pace and scale of landscape-scale fuel treatments. Foremost, we need to be strategic about prioritizing areas where we combine mechanical thinning with prescribed burning. There is broad scientific agreement about these ideas. However, agency budgets and liability standards continue to benefit suppression over preventative measures; we lack the capacity to scale up; and misunderstandings preclude the social license to get the work done. We need better outreach and education to communicate the science and inform policy and practice.
WORK
Key quote: "The west doesn't have a fire problem, it has a tree problem, and our solution is getting the trees out."
Keywords: timber, products, biomass, sustainable economies, rural communities, jobs, and regulations
Summary: Nineties environmental regulations crippled much of the timber industry out West. Forests became overgrown, and the rate of mortality rose higher than the rate of harvest. Increased fuels and reduced access led to greater fire risks. The forest is like a garden, it needs to be tended. Ongoing forest maintenance must pay for itself. 'Let it burn' policies waste valuable resources, so we must stop all fires as soon as possible. The value of our lands standing green is much higher than black. We can utilize trees to sequester carbon, generate sustainable products, and to reinvest in our rural communities. Alternatively, a scorched landscape has no benefits to the forest and wildlife, and smoke from wildfires has enormous impacts on public health. We need to address policies that prevent work from happening, sustain funding to build infrastructure while reducing risks, create partnerships across lands, and look for ways to innovate.
MARKET
Key quote: "If we let the market do its magic, residents would bear the true risk they impose, and wildfire risks would go down."
Keywords: insurance, risk, price, models, accurate, and burden
Summary: The Western wildfire crisis precipitated in 2018 when the insurance industry saw $25billion in losses. Three factors played a role in the crisis (1) a lack of understanding, due to inadequate models, (2) restrictions of accurate premiums, and (3) prohibitively expensive risks. Wildfire models are complicated by the complexity, unpredictability, and changing nature of wildfires. The insurance industry has the financial incentive to develop the best models, so their assessments are the most accurate price signal of risk. It is not feasible to restrict development in harm's way. However, development in the WUI increases risk exposure and is the responsibility of homeowners. People can understand, a ten-fold insurance premium increase means their home is 10-times riskier. When regulators cover up that price signal, they hinder effective decision making and incentivize building in harm's way. Insurance regulation causes a destabilizing market distortion. Mitigation measures such as home hardening and defensible space are an important part of the solution. However, more data is needed to prove their short-term actuarial benefits.

CONTROL

Key quote: "The cost of suppressing fires when they are small is much smaller and less risky than letting them get big and then trying to suppress them."

Keywords: suppression, emergency, line, incident command, firefighters, ignitions, problem, and attack

Summary: When you sit and watch a town burn to the ground in six hours, you get a different opinion about putting out fires. We need to protect life and property. Strategies and tactics on suppression have changed from direct attacks to indirect attacks. Part of the reason is fire dynamics are changing. However, this concept of 'managed' fire has slipped in, moving the line back too far, allowing the fire to get too big. With these hotter and faster fires, with assets closer into the woods, nobody has the expertise to manage wildfires and prescribed burns. Indigenous practices, from a thousand years ago don't make sense now. The 10am-10 acre policy is intended to put fires out before suppression costs get too big. The USFS is using natural wildfires to tap into unlimited funding and firefighting resources to achieve resource benefit objectives. These unplanned ignitions are happening at the wrong time, without pre-treatment, and without the necessary regulatory and fiscal oversight. The risk of escapes, health implications, carbon emissions, toll on firefighters, far outweighs the benefits.

REGULATE

Key quote: "If suddenly I was made king of the world, one of the first things I'd do is say 'no more houses in the WUI"

Keywords: harm's way, code, plans, standards, hardening, and utilities

Summary: Today, millions of people live in high fire-risk forests increasing the likelihood that wildfire response includes expensive structural protection and the chance for accidental fire starts. Regulating development in the WUI, building more fire-resistant homes, investing in egress and standards; if you do these things, you don't have a fire problem. The evidence is just so strong - they're putting themselves at risk. Telling communities that the problem is that federal lands are not well enough taken care of reduces the responsibility that communities have. We are putting too much emphasis on managing our way out of the forest. Instead, we need to regulate and incentivize how and where we develop. It's not an attractive conversation. There is a lack of political will; standards are set on a local scale; retrofitting millions of older homes is cost prohibitive; and there remains gaps in knowledge about what tools work where and in what combinations.

CONSERVE

Key quote: "There is a risk of using fuel reductions as an excuse for forest exploitation. Fuels management that needs to make a buck for somebody is likely to be counterproductive"

Keywords: logging, ecology, restoring, intensity, protecting, and species

Summary: Western forests have evolved with mixed severity fires. However, we have high-graded most of our forests; changed species composition; grazed, mined, and developed the land; and suppressed fires. These actions have left the forest more vulnerable. While many climate-driven fires are higher in severity, we are still operating in a fire deficit and seeing much needed low and mixed severity fires. Proper fuels treatments can reduce fire intensity, however fuels management that is tied to profit, has a corrupting influence with unintended, even counterproductive effects. When large trees are removed, the canopy is broken removing shade and moisture and increasing wind penetration; thinning operations leave behind slash, and pile burning damages soil horizons. Instead of trying to prevent damage, we should: invest in long term ecological fire restoration; use ignitions under good conditions to restore function; enhance biodiversity, pyro-diversity, and forest resiliency; leave wilderness and protected areas alone; focus our investments in the WUI; and learn to value the role wildfires play in ecosystem health, watershed stability, and carbon storage.

REVITALIZE

Key quote: "All of us have a role, and all of us can revitalize our productive relationship with fire."
Keywords: cultural, place, relationship, indigenous, process, stories, stewardship, learning, and generation.
Summary: Since time immemorial, indigenous peoples have been inseparable from fire and the landscape. They didn't just live with fire, they magnified its role; they burned and reburned landscapes to move animals and water across the landscape, and produce food, fiber, medicines, and regalia. The current wildfire crisis is driven by the elimination and criminalization of that fire culture. Our culture of fear sustains an industry of disaster capitalism. We are destroying cultures and ecosystems without any environmental oversight. We need to change our relationship to fire. Each community needs to be empowered to steward fire. We need to mainstream and democratize fire though a groundswell of understanding, advocacy, and direct action. We need to learn from native people who have managed fire in the West for millennia; support and facilitate the tribes in employing traditional practices; and carve out space for non-Western science. We need to engage in authentic collaboration with all stakeholders and rights-holders, recognizing the trauma of past actions, taking action that everyone agrees to, co-managing across jurisdictions, co-producing knowledge, and supporting learning and experimenting.

JUSTICE

Key quote: "We must address the fact that these kinds of disasters have the most dire impacts on communities already most affected by policy inaction."

Keywords: Equity, social, community, smoke, health, impacts

Summary: The real reason we care about wildfires today is that people are being affected in unprecedented ways. Our wildfire problems are tied to core socio-economic problems around housing, poverty, and race. The public impact of wildfires is dramatically undercounted, with the communities most affected least likely to recover from the long-term financial stress following a disaster. Whatever policy we put in place; justice must be at the center. As global fire risks escalate, we must examine who is bearing the costs of wildfire. Property owners' shoulder greater costs for insurance and retrofits; entire communities are rebuilt; and residents are impacted by smoke and trauma. Vulnerable populations including outdoor workers, pregnant women, young children, the elderly, those with pre-existing respiratory and cardiac disorders, low-income communities with limited mobility, and non-native English speakers bear a disproportionate burden. We need to invest in our communities and establish relationships before the disaster occurs. We're going to have to spend an order of magnitude more than we're currently spending and do a better job identifying vulnerable populations and directing investments there.

ADAPT

Key quote: "We literally have to be thinking about ways to adapt the landscape in ways that there may not be any analog for."
Keywords: future, transitions, expectations, existential, and uncertainty

Summary: It's not just about the forest becoming thicker, it's the climate signal. We are seeing drier, hotter, longer summers, with more lightning and strong winds. We are facing an existential crisis. Western wildfires contribute about a quarter of the PM 2.5 emissions into the atmosphere. Conservative models show fire risk doubling, with more than half of Western forests and the species that depend on them disappearing this century. Massive type conversions, forestlands becoming grasslands and shrublands, reducing the capacity to sink carbon in our landscape and amplifying climate change. Fire and smoke conditions get much worse before they get better. We are entering a no analog situation with massive uncertainty. People need to understand this is the new normal. We must prioritize emissions reduction. Fuels management will help up to a point, but some of these wildfires are so severe they will burn through anything. And we must adapt forest practices to changing conditions.

The narrative wheel (Figure 2.2) illustrates the relationship between the narratives. While the wheel depicts the nine narratives as mutually exclusive, it is important to note that elements of the social narratives are interrelated and overlapping. Adjacent narratives are generally more

Figure 2.2 Social narratives of western wildfire challenges

This wheel illustrates the relationship between nine social narratives of western wildfire challenges. Narratives that are adjacent are more similar or complimentary while narratives that are on opposing sides are more divergent or conflicting.

similar and share more overlap or synergy. For example, both ‘Manage’ and ‘Work’ prioritize removing fuel from forests to reduce wildfire risks. However, where ‘Work’ focuses on monetizing fuel management to support rural livelihoods, ‘Manage’ focuses on large-scale treatments on public lands. Conversely, ‘Manage’ and ‘Adapt’ both emphasize science-based technical expertise. However, while ‘Adapt’ highlights the uncertainty in scientific understandings, ‘Manage’ emphasizes scientific consensus and certainty. Narratives positioned opposite from each other are generally more divergent and conflicting. For example, where ‘Revitalize’ emphasizes the importance of increasing the role of fire on the landscape and democratizing fire management, ‘Control’ emphasizes stopping fires while they are still small and investing in our firefighter workforce.

While the nine social narratives reflect distinctions between common or shared understandings of western wildfire challenges, the actors we interviewed combined multiple social narratives into their characterizations. Furthermore, the actors' individual narratives did not combine social narratives in consistent ways. For example, a handful of participants combined elements of 'Manage' and 'Conserve' to emphasize a more ecological restoration facet of fuels management while remaining skeptical about larger-scale logging and thinning operations. Alternatively, a handful of participants combined elements of 'Manage' with the 'Work' narrative, emphasizing the important role of partnerships between federal land managers and industry to scale up fuel reductions. We also found that interview participants from the same organization or actor group did not consistently align with the same social narratives.

2.5.2 Differences between the narratives

We report on the four core elements or categories of themes along which narratives differed to characterize important differences between social narratives (research question 2)

2.5.2.1 Strategies

Interviews focused on the causes, consequences, and solutions to western wildfire challenges. Strategies reflect the way actors relate or provide a rationale for their solutions based on a set of causes and consequences. Strategies reflect actors' logic or how their ideas intend to achieve a specific aim or address an underlying issue (Table 2.4). For example, 'Regulate' centers on exposure and hazards associated with development within high-risk fire zones (cause). It focuses on impacts on communities in terms of loss of infrastructure and assets and homeowner and municipality costs of building back (consequences). Responding to these causes and consequences, 'Regulate' solutions emphasize home hardening, managed retreat, defensible space, and reforming utility infrastructure to change where and how actors develop.

Table 2.4 Different understandings of the causes, consequences, and solutions to western wildfire challenges

	Causes	Consequences	Solutions
Manage	suppression, history of forest management that led to more fuel-dense forestlands	focus on forestlands, mega-fires, larger more frequent and more destructive fires; exponential rise in cost of suppression	increase pace & scale of fuels management (e.g., thinning, Rx, & managed wildfire); change incentive structure; prioritization models and risk assessments; workforce development, research and funding, outreach and communication, social sanction
Work	environmental regulations; loss of timber management	focus on financial viability, loss of profit, rural communities and livelihoods, and regulatory uncertainty	streamline regulations; connect jobs to actions; innovations; partnerships; biomass utilization, access road and fuel breaks
Market	unknown (or poorly understood) change in risk, insurance reform so premiums don't match risk, risk too expensive	focus on costs; cost to taxpayers, emphasis on loss of assets (value in home), loss of stable insurance (exiting), lack of certainty for both homeowners and insurers	let premiums reflect actual risk signal, minimize insurance regulation, investments in more accurate catastrophic models, cross-state model reviews, CBA of household risk mitigation strategies.
Control	human ignitions, managed wildfire practices, lack of swift initial attack, letting wildfires get out of control	focus on health and safety, firefighters, assets, whole communities, cost of fire management	direct attack, quick initial attack, 10 am / 10 acre rule, strategic use of trained workforce, investments in workforce; evacuations, forest management practices
Regulate	development in harm's way; increase exposure and hazards; utility design	focus on WUI communities, loss communities and assets; cost to restore/build back; utilities and infrastructure systems	how communities and houses are designed and where development occurs, local policy changes, zoning, development codes, plans, community engagement, retrofits and redesign, defensible space, regulation of public utilities, and managed retreat
Conserve	extractive forestry practices	focus on forest health and resiliency, watershed health;	ecological fire restoration; passive management in wilderness, forest protections, conservation, environmental regulations, managed wildfires
Revitalize	criminalization of cultural burning and traditional fire practices	focus on culture, spiritual connections, food, safety, and identity	indigenous training; cultural burning, greater rights and access to manage lands, authentic collaboration
Justice	historic socio-economic and environmental inequities, lack of protective measures to mitigate public risks, global patterns of crises	focus on marginalized and vulnerable communities, unequal burden; affordable housing, smoke, public health impacts, and loss of reliable utilities	community planning and engagement; vulnerability and adaptation plans, build relationships, smoke management including monitoring, communication, and treatments, more research on health impacts, affordable housing, standards for outdoor labor

Adapt	climate signal, hotter temperatures, drier conditions (vapor pressure and drought), winds, natural ignitions	longer fire seasons, change in landscape patterns (shrubification, zombie forests), emissions, greater instability	reduce emissions (climate mitigation), adaptation; change expectations, integrated predictive models

2.5.2.2 Scales

As interviewees described their strategies, they referenced different temporal and spatial scales (Figure 2.3). For example, 'Market' is oriented around annual state-level practices, e.g., *"If you're an insurance broker and you're selling this policy, the premium is based on the risk*

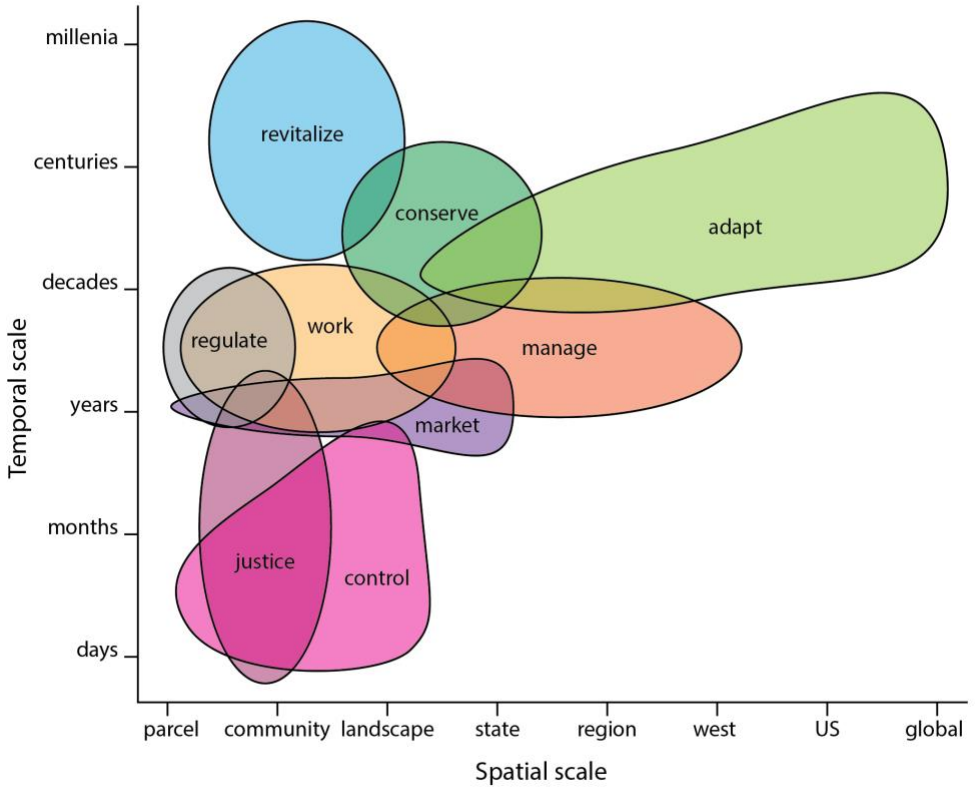


Figure 2.3 Time and space scale of western wildfire narratives

This Stommel diagram (Clark, 1985) represents the unique time and space scales of each of the nine narratives. Differences in scale among actors may help explain some mismatch between their understandings. Time and space scales correspond with the strategic elements of each narrative, characterizing the scale at which causes, consequences, and solutions are conceptualized.

this year; efforts outside this year are harder to quantify." Alternatively, 'Regulate' operates at a multi-year community level, e.g., *"our long-term strategy will need to be ongoing for decades, and it needs to be scaled down to the community level to be effective."* Differences in spatial and temporal scales characterize differences in priorities or emphases. For example, some actors contrasted longer-term and large-scale planning aligned with the 'Manage' narrative to the shorter-term response of 'Control,' i.e., *"there's a 24-hour mentality on a fire that's going to be on a landscape for two months."*

2.5.2.3 Frames

Frames are shaped by actors' disciplines, cultures, experiences, and beliefs. Frames shape understandings by emphasizing certain knowledge while minimizing other knowledge. Diverse frames explain differences in planning approaches, differences in expectations regarding outcomes, and differences in the success of different processes (Burns and Cheng, 2007; Williams et al., 2012; Gray, 2003). For example, actors who framed the western wildfire challenge as an economic challenge were more likely to look at market-based solutions like supporting the timber industry, monetizing co-benefits of wildfire risk reductions, or setting insurance premiums. Alternatively, actors who framed it as an ecological challenge were more likely to focus on ecosystem functions, intrinsic values, and more extended returns on investments. Sometimes, frames were mentioned directly, for example, *"I keep approaching this from an economic standpoint."* However, at other times the frames were more implicit. For example, *"right now we have a government monopolization of fire and government does not have enough person power or resources to do it all, given the scale of it, so breaking that monopolization, democratizing fire management and including communities, that's the source of labor power."* The implicit frame we saw here was about workforce and ownership. In

constructing the narratives, we looked at the frames that distinguish between storylines. For example, ‘Adapt’ framed the western wildfire challenge as a future problem while ‘Conserve’ framed the problem in relation to past events; ‘Regulate’ framed the problem in more technical terms, while ‘Justice’ framed the problem in terms of social justice and equity; ‘Manage’ and ‘Control’ framed the challenge through a more paternalistic view of nature, while ‘Revitalize’ emphasizes a more synergistic relationship to nature.

2.5.2.4 Language

The unique language actors used is important in revealing their understandings. Indigenous or emic terms and phrases help reveal taken-for-granted assumptions and different communities of practice (Butler, 2009; McIlroy-Young et al., 2021)). For example, “pace and scale,” “no analog conditions,” “culture of fear,” and “let it burn” came up as common linguistic patterns that helped distinguish between the social narratives. Specific terms signify parts of narratives that anchor actors and connect them to one another. They reveal the elements that are multiplied by social narratives and help distinguish between them. In addition, sometimes, participants explicitly called out differences in language. These parts of the transcripts were important to portray parts of stories that they feel are getting left out, simplified, or misunderstood. For example, a handful of actors emphasized the oversimplification between the terms “cultural burning” and “prescribed burning,” distinguishing the diversity of methods, objectives, and spiritual intentions involved in cultural burning. Other actors distinguished between perceptions of biomass as fuel or vegetation, i.e., *"They call it fuels, I call it vegetation because its habitat not just fuels."* Others referenced biomass as a commodity, resource, or product, i.e., *"How do we keep our resources from burning up?"* Similarly, both referring to responses to unplanned ignitions, ‘Manage’ aligns with the view that “managed wildfire” is

essential to reducing fuels at the scale necessary to achieve risk reduction objectives. ‘Conserve’ aligns with the view that “letting fires burn” is too risky and a misappropriated usage of federal funds. These distinctions may be necessary for practitioners to consider when designing inclusive practices.

2.5.3 Demarcation of the boundaries of credible, salient, and legitimate social narratives

In our analysis of the transcripts, we found about two dozen ways participants demarcate, justify, or legitimize their narrative and, conversely, minimize or disregard other narratives. We further found that different social narratives correspond with different demarcation strategies (Table 2.5). For example, ‘Revitalize’ legitimizes knowledge through long land tenure (e.g., "since time immemorial") and inter-generational place-based experience (e.g., *“the average five-year-old Karuk child knew more about fire than 99.9% of the current population of the United States. They were taught by their elders from a very young age how to use fire”)*. Sometimes boundaries can conflict. For example, ‘Adapt’ emphasizes the importance of scientific expertise and empirical evidence to make knowledge credible (e.g., *"agreement or majority among scientists")*. Alternatively, the ‘Control’ narrative tends to question academic perspectives as *"they have never been on the fire line." Instead, it emphasizes* the credibility of *“boots-on-the-ground”* and *“end-of-a-Pulaski-with-my-kids-on-the-fire-line”* knowledge.

Some social narratives were characterized in a more negative light by some actors. Judgments were placed on the ethics, motivations, and credibility of actor groups presumed to go along with those narratives. For example, a few actors with a high correspondence to the ‘Conserve’ narrative stated that they were *"worried that the timber industry and the Forest Service are going to use all of these factors to increase harvesting and*

Table 2.5 Demarcation strategies.

We analyzed the segmented transcript text associated with each narrative to examine how actors justified the legitimacy, credibility, and salience of their conceptualization of western wildfires and the language they used to exclude other conceptualizations as not credible, salient, or legitimate.

Justifications	**Terms, phrases, and quotes**	**Representative narratives**
Credibility [scientific]	scientific expertise, discipline, facts, measurements, evidence, "expert systems"	Manage, Conserve, Adapt
Credibility [practice]	"I've been doing this a long time", "how things are done", "common sense"	Work, Control
Reality	"obviously", "based on real data", rationality	Market
Neutrality	view from nowhere, neutrality, not biased	Regulate
Ethical	morality, the right thing to do, for people, protector of the environment	Conserve, Revitalize, Justice
Agreement	scientific consensus, certainty, known	Manage
Legitimacy	direct, first-hand, personal experience, boots on the ground or Pulaski in hand (in contrast to academics), "I was there", seeing the impact up close, "I have family here", "interacted in a very intimate way"	Work, Control
Affected	skin in the game, financially bound, dependent, victim	Work, Market, Revitalize, Justice, Justice
Tenure	number of years living in a community or at a job; ancestral knowledge, intergenerational ties, since time immemorial; stature within the community	Revitalize, Control
Collaborative rationality	working with others, collaborative	Manage, Justice
Humble	admitting uncertainty, humble, "I'm not an expert at this, but", emphasis of knowledge gaps, Does anyone really know?	Adapt
Recognized	position, title, accolades, rank, number of publications, number of people who attended their lecture, "I'm who they go to", supported by the academic community	Conserve
Saliency	relevancy, importance	Regulate, Saliency
Best	most accurate, best data, most effective, most important, most significant	Market, Regulate
Exclusions		
Minority	few, small group, distractions, marginal, alone, slim	
Unscientific	outside of science, "there is no evidence", "I don't see any scientific validity in what they're saying"	
Uninformed	under informed, "they don't understand", "they don't understand the importance of fire on the landscape"	
Wrong	false, not true, simply not true, not reality	
Biased	biased by politics, financial incentives, not neutral, agenda	
Illegitimate	having never seen a fire, theory-based or not rooted in practice	
Unethical	Perpetrator, "operating under the pretense of false collaboration"	
Othering	They, them, there are some…	
Unrealistic	"They want to have it both ways, they want everyone to have insurance and they want it cheap"; "They start with a legitimate argument and then they take it into ridiculous places"	

massive clear cuts." In contrast, participants with high alignment to the 'Work' narrative characterized the timber industry as representing *"one of the best solutions to some of the biggest problems of our time."* Meanwhile, participants aligned with the 'Work' narrative characterized the 'Conserve' narrative in a negative light, stating that *"this laissez-faire type of idea where you can just leave everything to its own devices out there and still have a healthy forest ecosystem, this is just not correct."*

Demarcations establish, negotiate, and maintain boundaries between science and practice. For example, one participant maintained the boundary between science and practice by remarking that - *"too often solid science across a range of disciplines is conflated with feelings and partial truths that render them less than useful to further discourse."* We also heard about boundaries that participants felt were imposed on them. For example, boundaries can come from organizational culture, e.g., *"If you don't get in line, you are not a team player. If you question the mission, your career gets hurt".* Peer review explicitly maintains the boundary of different disciplines (Miller et al., 2008). However, sometimes the boundary is more implicit. For example, one participant noted *"a warning for when you write an article, make sure to say within the first paragraph: wildfires are getting worse because of fuels buildup due to 100 years of fire suppression, climate change, and the ever-expanding wildland urban interface". Another participant* emphasized that *"if you want to get the grant, you need to use the right language."* While we saw evidence of boundary maintenance, we also saw evidence of collaborative boundary work, i.e., blurring, bridging, or dissolving boundaries between multiple understandings (Gieryn, 1995; Jasanoff, 2004; Langley et al., 2019). Participants combined multiple social narratives suggesting that the boundaries between social narratives have blurred.

2.6 Discussion

While knowledge co-production practices aspire to recognize and legitimize multiple understandings (Norström et al., 2020), identifying and characterizing actors' understandings remains a core challenge in practice (Devente et al., 2016; Gray et al., 2017; Horcea-Milcu et al., 2022). This research presents narrative analysis as a pragmatic and linguistic approach to identify and characterize influential actors' multiple understandings of western wildfire challenges. Based on our interviews, we identified nine social narratives, characterized differences between the narratives across four categories of themes, and revealed the boundaries actors use to demarcate what makes each social narrative credible, salient, and legitimate. In this section, we discuss what our findings mean regarding western wildfire challenges and broader implications for practice and scholarship.

2.6.1 Implications of research for addressing western wildfire challenges

2.6.1.1 A multitude of social narratives

While numerous prior characterizations of wildfire narratives have depicted understandings in terms of their dichotomy, e.g., (Butler, 2009; Crow et al., 2017; Ganey et al., 2017); conflict (see (Brenkert-smith et al., 2019; Crow et al., 2017; Edwards & Gill, 2016), or unity (Brenkert-Smith et al., 2017; Butler, 2009) our findings reveal a multitude of overlapping ways actors are engaging with these challenges. For example, both the 'Manage' and 'Conserve' narratives emphasize the importance of more wildfire on the landscape and de-emphasis of suppression tactics, aligned with the 'Control' and 'Work' narratives. However, both the 'Manage' and 'Work' narratives emphasize the more active treatment of fuels in forested landscapes in contrast to a greater emphasis on passive management aligned with the 'Conserve'

narrative. Similarly, in contrast to the 'Manage', 'Work,' and 'Adapt' narratives that focus on treatments in forested landscapes, 'Justice', 'Regulate', and 'Market' focus on the role of wildfire in high-risk forested communities.

Our finding of nine social narratives suggests that taken-for-granted understandings of western wildfire challenges are being renegotiated and reconceptualized (Jasanoff, 2003). This moment may be catalyzed by the increased salience of the challenge and the influx of political and economic investments being made (Burke et al., 2021). Hazards can function as a focusing event (Birkland, 2009; Crow et al., 2017) or a window of opportunity catalyzing institutional change (Chapin et al., 2010; Newig et al., 2019; Wyborn et al., 2019). While 'Manage,' 'Control,' 'Conserve,' 'Regulate,' and 'Work' have been around for decades, other narratives, including 'Revitalize,' 'Justice,' 'Market,' and 'Adapt' have likely popularized in response to recent wildfire catastrophes. The multitude of narratives suggests that this is an especially important time to invest in exploring actors' multiple understandings.

2.6.1.2 Differences to inform the design of collaborative wildfire practices

Differences among actors' perspectives on wildfire challenges shape collaborative wildfire risk management (Abrams et al., 2016; Brenkert-Smith et al., 2017; Paveglio et al., 2018). We identified four categories of themes that capture differences in social narratives: strategies, scales, frames, and language. These themes resonate with previous findings. For example, Williams et al. (2012) identified scale and frame differences as critical in shaping involvement and the direction of Community Wildfire Protection Plans. Similarly, Steelman et al. (2016) and Brenkert-Smith et al. (2017) identified differences in the scale with which actors view the challenge as an important factor influencing wildfire risk management. Recognizing

differences in how actors perceive trade-offs embedded in different spatial and temporal scales can play an important role in designing wildfire management practices (Hamilton et al., 2019).

Actors from different agencies, disciplines, and roles can reflect differences in understandings. We found that differences in the types of strategies mentioned largely align with disciplinary backgrounds and agency capacity. For example, ‘Manage’ broadly aligns with the disciplinary backgrounds (forestry) and agency capacity (large-scale landscape treatments) of the USDA Forest Service. In contrast, ‘Market’ largely aligns with insurance companies' disciplinary backgrounds (finance) and agency capacity (setting insurance premiums). Collaborations that intentionally bring in diverse disciplines and roles with complementary differences can result in more inclusive and innovative plans. This has been evidenced in numerous Collaborative Forest Landscape Restoration Projects (Schultz, 2012) and Community Wildfire Protection Plans (Abrams et al., 2016).

Alternatively, conflicting differences reflect differences in actors’ understandings that can delay or derail collaborative practices. Conflicting differences may stem from identity challenges (Dewulf et al., 2009; Shmueli et al., 2006) or deeper differences across incommensurable institutions (Goldstein et al., 2010). Identity challenges can be identified through defensive posturing and negative characterization of opposing groups (Dewulf et al., 2009). We found examples of negative characterizations and defensive posturing suggesting identity challenges between the 'Work' and 'Conserve' and, to a lesser extent, between the 'Revitalize' and 'Manage' narratives and the 'Market and Justice' narratives. These identity conflicts may reflect lingering resentments from historical conflicts, like the ‘Timber Wars,’ criminalization of traditional fire practices, and discriminatory practices, respectively (Davis & Lewicki, 2003; Tedim et al., 2021).

In line with prior research (Burns & Cheng, 2007; Vaughan & Seifert, 1992), we found evidence of conflicting differences stemming from actors' positions, where risk perception and core values are in play. For example, a positional conflict about using unplanned ignitions to manage resources was revealed in the different language actors used (e.g., 'managed wildfire' or 'letting wildfire burn'). Rhetoric emphasizing distinct language and meaning may also help detect more muted or latent conflicts (Plastina, 2022). For example, while the 'Market' narrative includes language around residents choosing to locate in "harm's way," 'Justice' emphasizes how regional and global trends increase the "burden" imposed on residents living in high-risk fire areas. Although not necessarily conflicting, these differences can harbor seeds of conflicts that ultimately impede substantive progress (Nowell, 2010; Schön & Rein, 1995).

Complimentary and conflicting differences between social narratives have different implications for practice. Explicitly identifying and characterizing differences can influence the design of practice (Chambers et al., 2022; Devente et al., 2016; Hakkarainen et al., 2022). For example, in terms of complimentary differences, having actors recognize and discuss these differences before taking action may help anticipate or prevent conflict later on (Lang et al., 2012). Facilitating conversations where people acknowledge these differences can further build relationships, trust, and collaborative capacity (Innes & Booher, 2016). Alternatively, resolving identity conflicts may require skilled mediation and relationship-building efforts (Gray, 2004; Santos et al., 2022; Shmueli et al., 2006). Collaborations may first want to start with more complimentary differences to build relationships and momentum (Butler & Schultz, 2019).

2.6.1.3 The complexity of actors' understandings may be getting overly simplified and minimized.

The process of constructing the social narratives revealed simplifications participants used to characterize other actors' understandings. Simplifications are often referenced when actors use the term "they." For example, "*They* are almost always painted as the bogeyman. *They* are the reason we have pine beetle at all" (Friberg, 2019), or "*They* asserted that the human tragedies caused by these fires were the result of "overgrown" forests, too many dead trees and environmental laws that restricted the logging industry and national land management agencies … *They* claimed that logging would have curbed or stopped the fires" (Hanson, 2021) (emphasis ours). These simplifications in published literature align with some of the language we found in our conversations. For example, *"They call it fuels. I call it vegetation because it is habitat, not just fuels,"* or *"they have never been on the fire line."*

These simplifications did not line up with the complexity of understandings we saw among our participants. Participants recognize western wildfire challenges as being complex and therefore requiring complex understandings. However, participants' assumptions about other actors' understandings fail to capture this complexity. This finding aligns with other research showing that the dialogue around wildfire can be unfairly simplistic (Friberg 2019). It also aligns with a broader tendency among policy and practice to treat diverse actors as a homogenous group despite a growing body of research that suggests significant heterogeneity (Paveglio, 2021).

Our findings show evidence of actors' understandings as complex in two ways. First, while actors emphasized important distinctions between the social narratives, they hybridized and overlapped multiple narratives in unique patterns. The combination of different narratives may reflect a change or shift in understandings (Brenkert-Smith et al., 2017; Jaworsky, 2016)

and the adaptation of actors to the conflict (Turner, 2008; Rein & Schön, 1996; Cornelissen & Clark, 2010; Kaire & Wahhwani, 2010). Second, we found that actors associated with the same functional groups, interest groups, or actor types (e.g., industry, environmentalist, state forest manager) do not necessarily align with the same set of narratives. This aligns with others' findings that actor type does not necessarily predict perspective (Cuppen et al., 2010; Goldman et al., 2016). It further corresponds with research indicating that actors representing traditionally separate or polarized positions exhibit increased heterogeneity by traversing, transforming, and dismantling distinctions in unexpected ways (Langley et al., 2019). This makes sense given wildfire risk management practices that increasingly promote collaboration and transdisciplinary efforts that span across multiple boundaries (Colavito et al., 2019; Davis et al., 2021; Hamilton et al., 2019). For example, groups such as the Joint Fire Science Program (2023), California's Wildfire Climate Institute (CWI, 2022) and Fire Adapted Communities Learning Network (2023) all emphasize connecting actors with diverse understandings to engage in shared learning and actionable science.

The complexity of actors' understandings has important implications for how wildfire practice depicts and measures differences among actors. Traditional ways to identify project partners often use actor types as a proxy for diversity (i.e., stakeholder analysis) (Reed et al., 2009). However, our findings suggest that actor types may not capture the diversity in actors' understandings of western wildfire challenges. Logically, it is more likely that representatives of an actor type who already align with the understanding and discourse of a collaborative effort will be selected and agree to participate in these efforts, while actors with conflicting understandings are more likely to opt-out. For example, while the federal Wildland Fire Commission includes non-federal representation of a non-profit environmental organization, that representation is more likely aligned with the 'Manage' narrative than the 'Conserve' narrative.

For wildfire practices to be more inclusive of multiple understandings, intentional boundary management may be necessary (Davis et al., 2021; Huber-Stearns et al., 2021). Boundary management can help facilitate mutual understanding and enhance collaborative capacity by explicitly recognizing and reflecting on the boundaries between multiple understandings (Langley et al., 2019).

2.6.2 Broader implications for practice and scholarship

Recognizing and legitimizing multiple understandings is a principle in knowledge co-production scholarship (Brouwers et al., 2022; Klenk & Meehan, 2015; Knapp et al., 2019; Norström et al., 2020), but how well is practice supporting this aim? Critiques of knowledge co-production suggest it may not be doing it well (Brugnach & Ingram, 2012; Djenontin & Meadow, 2018; Jagannathan et al., 2020; Zurba et al., 2022). To better support this principle, we suggest that practice should explicitly identify and characterize actors' multiple understandings and examine the implicit boundaries that shape how actors define what counts as knowledge. Our research suggests that the analysis of social narrative fills an important gap in practice by providing a pragmatic approach to identify and characterize multiple understandings and reveal their boundaries.

Characterizing social narratives can aid the initial exploration stage of co-production (as depicted by Steger et al., 2021). Narrative analysis captures both the breadth of knowledge and the complimentary and conflicting differences between understandings. While traditional narrative analysis generally corresponds one entity with one narrative (Creswell, 2007; Fischer, 2003), our findings suggest that this simplification may overlook important overlaps between actors' narratives. We further found that it is important to distinguish between the understandings

of individuals and their organizations and between individuals and their interest groups. While unified and simplified understandings may be easier to represent and interpret, they may not represent the complexity of actors' understanding of complex sustainability challenges. When actors are brought into a process to represent a way of understanding the problem, it may prevent them from sharing the complexity of their understanding with the team. This highlights the need for research and practice to engage more deeply with and to think more explicitly about the complexity of understandings when designing knowledge co-production practices (Fazey et al., 2013)

Explicitly revealing demarcation boundaries suggests ways to bring them into conversations. Our focus on the demarcation of social narratives revealed how different social narratives are supported by different types of boundaries (e.g., scientific credibility, ethics). This suggests that focusing on just one type of boundary may exclude multiple understandings. Collaborative environmental governance practices increasingly emphasize using evaluation metrics to determine what evidence should count in knowledge co-production practices (Fazey et al., 2014; Meadow et al., 2015; Wall et al., 2017). Given the diversity of boundaries, if practices are to recognize and legitimize multiple understandings, the process of determining those criteria needs to be done with all actors early on, and in a collaborative and safe environment (Chakraborty et al., 2022; Dale & Armitage, 2011; Tengö et al., 2014).

2.6.3 Research limitations

This paper adopts a constructivist-interpretive approach, prioritizing influential actors' perceived reality of what are the right or most appropriate interpretations (Morse, 2017) of current western wildfire challenges. Narratives are inherently subjective. There is no concrete

phenomenon to validate or confirm findings against. The social narratives reflect common experiences and interpretations of individuals who are actively working in and well versed in western wildfire challenges. They do not capture the social narratives of residents or politicians, may carry little relevance as conditions on the ground and social norms shift, and may not apply to wildfire in non-forested landscapes such as grasslands. Given our non-representative sample and the qualitative nature of our semi-structured interviews, validation strategies like intercoder reliability and nonparametric statistics are unsuitable (Morse, 2017). For example, as we did not ask participants the same questions in the same way, quantifying the extent to which they discuss different narratives or extrapolating the distribution of narratives to the broader population would be inappropriate. We further recognize that our analyst-constructed social narratives are a simplification and not an accurate representation of any one narrative out there. Instead, we see them as an approach to facilitate a conversation in which actors discuss differences in understandings and reflect on the role of discursive power in process design (Rathwell et al., 2015).

2.6.4 Future research directions

We see a few ways in which this research can be built upon:

Broader distribution of narratives: Further exploration is needed to quantify the distribution of social narratives among the population of actors engaged with western wildfire challenges. For example, a larger random sample and a more structured questionnaire or survey would be required to determine which narratives are more common or more marginal and relatedly, for which perspectives there is more agreement, and for which there is a greater divergence of perspectives.

Relationship between narratives: Among the influential actors we spoke to, we heard significant mixing of multiple social narratives in diverse ways. Future research could examine which narratives correspond more closely with one another (i.e., are often told together) and which are more in conflict. It could also identify the emergence of a new hybrid narrative among actors whereby the same set of narratives are consistently told together.

Selection of representation: Social narratives represent shared understandings among like-minded actors or groups. However, it needs to be clarified to what extent social narratives align with interest groups, disciplines, or other attributes. How might practice determine selection criteria if social narratives do not correspond with interest groups such as industry, NGOs, or academia? To be inclusive of multiple understandings in practice, conveners must establish a clear connection between selection criteria and more implicit understandings of actors (Ansell et al., 2020).

2.7 Conclusion

When managers reflect on the limitations of cross-boundary wildfire risk management, it is not the need for more technical knowledge and tools but rather the task of bringing together diverse populations with different values, worldviews, or abilities that is described as a critical limiting factor (Paveglio, 2021). If knowledge co-production practice is to promote bringing together multiple understandings, a critical precondition informing the design of collaborative practice should be greater transparency about what those understandings are. In this study, we construct social narratives to identify and characterize multiple understandings of western wildfire challenges. We propose that social narrative analysis may be a valuable approach to inform the exploratory stage of knowledge co-production practices by more explicitly

characterizing multiple understandings. Furthermore, by examining how actors describe the credibility, legitimacy, and relevance of social narratives, this study sheds light on the relationship between multiple understandings and discursive power.

The understandings actors bring into a process can have a great bearing on the quality of the knowledge produced and, ultimately, on the decisions informed by that knowledge (Berkes, 2009; Norström et al., 2020; Mach et al., 2020). Identifying and characterizing multiple understandings is only the first step. Each understanding provides unique contributions (Rathwell et al., 2015). However, differing understandings can also result in miscommunication, inefficiencies, and conflict, derailing co-productive practices. Beyond explicitly recognizing what the multiple understandings are, teams engaged in knowledge co-production practices need to explicitly reflect on the role they want multiple understandings to play. To effectively recognize and legitimize multiple understandings, actors will need to reveal and reflect on the complex patterns of their understandings. Beyond identifying and characterizing multiple understandings, engaging with multiple understandings will require changes to incentive structures through changes in funding, publications, and institutional missions. Further, sustained engagement practices must value and incentivize multiple understandings and ways of knowing rather than focus on shared understandings.

Chapter 3 Understandings of Western Wildfire Challenges. In Support of More Inclusive Collaborative Environmental Governance Practices

3.1 Introduction

Practitioners increasingly turn to collaborative governance practices to tackle complex sustainability challenges (Mach et al., 2020). A foundational tenet of collaborative governance is inclusivity, "including a broad enough spectrum of stakeholders to mirror the problem'' (Gray, 1989, pg.155). Increasingly, sustainability science scholarship emphasizes actors' multiple ways of knowing or understandings as an important dimension of inclusivity (Mach et al., 2020; Norström et al., 2020). Including multiple understandings is expected to support decisions that are more comprehensive, robust, innovative (Berkes & Armitage, 2010; Jagannathan et al., 2020), responsive (Bousquet et al., 2017; Lemos, 2015), socially acceptable (i.e., perceived as legitimate, credible, and salient by those affected by the decision) (Cash et al., 2003) and just (Mach et al., 2020; Miller & Wyborn, 2018). Traditional stakeholder analysis is designed to systematically identify actors with diverse interests and influence (Reed et al., 2009). However, there is a lack of guidance on how practitioners should identify actors who can represent sufficiently diverse *understandings* of the challenge (Horcea-Milcu et al., 2022; Reed et al., 2014; Steger et al., 2021). This chapter aims to provide an approach for systematically exploring the spectrum of understandings embedded in complex sustainability challenges to support more inclusive collaborative practices.

We investigate actors' understandings within the context of western wildfire challenges. Western wildfires represent an increasingly salient and complex sustainability challenge.

Western wildfires regimes, i.e., the frequency, severity, size, and duration of wildfires, are changing (Safford et al., 2022). The need for immediate cross-boundary cooperation to manage associated risks is well documented (Bixler, 2023; Calkin et al., 2014; Davis et al., 2021; Paveglio, 2021). Cooperative efforts require collaboration between dispersed actors working at various scales and capacities and reflecting diverse interests, roles, backgrounds, and perspectives (Huber-Stearns et al., 2021; Paveglio et al., 2018). Differences in what actors perceive needs to happen, even what caused the challenge in the first place, can hinder collective action (Brenkert-Smith et al., 2017; Crow et al., 2017; Paveglio et al., 2015). Over the past two decades, numerous collaborative efforts have convened to mitigate cascading and long-term ecological, economic, social, health, and climate effects from wildfires (Abrams et al., 2015; Fleeger, 2008; Hadley et al., 2022; Schultz et al., 2014; King & Scott, 2018). However, even as diverse actors agree that urgent action is needed, differences in actors' understandings of these challenges continue to stymie efforts (Fischer et al., 2016; Smith et al., 2016; Westerling, 2016; Ager et al., 2015). Despite widespread recognition of this limitation, practice lacks a comprehensive assessment of the diverse understandings of practitioners and scholars addressing western wildfire challenges.

To address this gap, we suggest three ways collaborative wildfire risk management practices can be more inclusive. First, the distribution of understandings represented by project partners ought to mirror the distribution of understandings across the broader population. Second, process design should consider important distinctions and conflicts between understandings. Third, representation should effectively reflect understandings, i.e., ensure relationships between selection criteria and understandings. In support of these three inclusivity parameters, we designed an online survey to answer three research questions,

1. What is the distribution of understandings of wildfire challenges?
2. What are the relationships between understandings of wildfire challenges?
3. What are the relationships between actors and their understandings of wildfire challenges?

The survey builds directly on a narrative analysis study (Chapter 2), in which the authors construct nine social narratives that identify and characterize the understandings of sixty influential actors embedded in western wildfire challenges. Social narratives refer to common stories that capture shared experiences, disciplines, cultures, and beliefs. Each social narrative corresponds with multiple perspectives about wildfires. Perspectives are represented by distinct statements, sentiments, or segments of interview transcripts that retain research participants' language and meaning. To investigate actors' understandings, the survey collects data on the perspectives and corresponding narratives that resonate with respondents. The survey was administered to a purposive sample of 153 actors and analyzed with descriptive statistics and exploratory correspondence analyses.

3.2 Theoretical background

3.2.1 The importance of inclusive representation in collaborative environmental governance practices

Environmental governance scholars have long emphasized the importance of collaborations between researchers and affected actors to improve the way society manages natural resources, informs policy and collects and interprets evidence (Armitage et al., 2009; Berkes, 2017; Bodin, 2017; Diduck et al., 2010; Lee, 1993; Van Kerkhoff & Lebel, 2006; Wondolleck & Yaffee, 2000). These collaborative practices emphasize the importance of

inclusive representation of the diversity of actors (Emerson & Gerlak, 2014). Theory suggests that when actors engage in inclusive dialogue and open and transparent communication, they build relationships, foster trust, support mutual learning, and produce knowledge and decisions that help problem-solve and reduce conflicts (Ansell & Gash, 2008; Emerson et al., 2012; Gray, 1989; Hakkarainen et al., 2022). Alternatively, inadequate representation can result in the exclusion of potentially valuable ideas, the perpetuation of power asymmetries, the marginalization of voices, and the exacerbation of conflicts (Greenaway et al., 2022; Li & Yarime, 2017; Reed et al., 2014; Rosendahl et al., 2015; Shmueli et al., 2006). These challenges have been identified as key failures of collaborative environmental governance practices (Devente et al., 2016; Knapp et al., 2019).

3.2.2 A lack of systematic and explicit approaches for ensuring inclusive representation

Collaborative environmental governance practices generally start with an exploration of the issues and identification of representative actors (Page et al., 2016; Steger et al., 2021). Typically, conveners or project managers identify a selection of team members that represent the larger population of actors (Innes & Booher, 2010). Agreed upon approaches for getting inclusion right at this early stage are really important (Meadow et al., 2015; Page et al., 2016). However, while traditional representative democracy has established rules for representation (Nabatchi, 2010), the process by which collaborative environmental governance practice decides representation lacks systematic and explicit approaches. Representation is context-specific, inconsistent, ad hoc, and lacks established guidelines (Coleman et al., 2021; Horcea-Milcu et al., 2020; Reed et al., 2014; Reed et al., 2009; Steger et al., 2021). Representation may focus on different interest groups and actors with influence at different scales and sectors, for example,

state, local, and federal governments, private and non-governmental organizations, or simply concerned individuals, (Ansell & Gash, 2008; Koontz & Thomas, 2006; Monroe & Butler, 2016; Ozawa & Susskind, 1984). Membership may be voluntary, systematic, mandated, or motivated by politics or convenience (Brummel et al., 2010; Imperial & Koontz, 2007; Purdy & Jones, 2012). Membership rules can be poorly documented and ambiguously defined (McIntyre & Schultz, 2020; Rosendahl et al., 2015). Furthermore, selection processes are generally poorly resourced (Horcea-Milcu et al., 2022; Klenk & Meehan, 2015; Steger et al., 2021).

What inclusive representation looks like is highly case-specific (Brugnach & Ingram, 2012; Horcea-Milcu et al., 2022). An idealized 'inclusion of all actors' (Habermas, 1962) is likely unrealistic and problematic (Innes & Booher, 2010). However, alternative determinations, e.g., balance, sufficient, and adequacy (Devente et al., 2016; Gray, 1989; Van Der Walt, 2020) are vague. There is tension in defining sufficient inclusion. Overly restrictive or inadequate representation can marginalize groups or exclude important information (Chambers et al., 2022; Fazey et al., 2013). However, excessively expansive inclusion can lead to inefficiencies, create conflicts, or reduce the credibility or legitimacy of a process (Fazey et al., 2014; Mannix & Neale, 2005). Collaborative processes may be more successful if inclusion is more strategic and selective (Ansell et al., 2020). However, to inform strategic selection, conveners or project leaders must first gain a pragmatic understanding of what the spectrum of diversity to be represented entails (Steger et al., 2021).

3.2.3 Stakeholder representation

While most representation practices are inconsistent and ambiguous, representation practices that are more systematic, documented, and resourced, generally try to identify actors

based on types of stakeholders (Knapp et al., 2019). Stakeholders refer to actors who affect or are affected by a decision (Freeman, 1984, as cited by Reed et al., 2009). Stakeholder groups reflect formal or informal communities or networks of actors that share a common interest, or stake, specifically an interest in a particular outcome (Reed et al., 2009). For example, particular outcomes may focus on more workforce development funding or wilderness area protections. Stakeholder assessments are a formalized way of determining the different interests associated with a challenge (Brugha & Varvasovszky, 2000; Grimble & Wellard, 1997; Reed et al., 2014). While in some cases, stakeholder groups select their own representation (Susskind, 1989), most often, representation is determined through actors' affiliation with specific disciplines, sectors or agency types, or interest groups (e.g., environmentalists, private industry, tribes, state land management agency, health department). Stakeholder terminology is ubiquitous among collaborative environmental governance practices; however, in this chapter, we avoid the term due to its colonial roots (Reed & Rudman, 2022). Instead, we use the term actors to represent individuals who affect or are affected by a sustainability challenge.

3.2.4 From interests to understandings

Interests are one way to capture diversity. Another approach is to focus on diverse understandings, worldviews, perspectives, or ways of knowing (Cash et al., 2003; Champ et al., 2012; Gray et al., 2022; Klenk & Meehan, 2015; Pregernig, 2014; West et al., 2019; Williams et al., 2020). Fundamental to the deliberative turn in scientific debates about sustainability challenges is the recognition of the legitimacy of different understandings (Fischer, 2000; Harris & Lyon, 2014; Innes & Booher, 2010). Collaborative environmental governance is built on the assumption of collaborative rationality, whereby the rational or best solution reflects the active

collaboration of actors who represent a variety of points of view (Habermas, 1962; Innes & Booher, 2010). Collaborative rationality aims to capture not "a tainting of pure scientific discovery" but rather "a more accurate representation of how knowledge is co-produced (i.e., simultaneously constructed and influenced by the society and culture" (Jasanoff, 2019; Meadow et al., 2015).

3.2.5 Representation and discursive power

The knowledge used to inform decisions affects how problems are identified and defined, the capacity for innovative and practical solutions, and the relevance, legitimacy, and credibility of decisions among communities of actors (Fazey et al., 2014; Reed & Abernethy, 2018). Decisions about whose understanding is reinforced, what evidence is considered, and how different knowledge claims and perceptions of evidence are reconciled reflect substantial discursive power (Butler & Goldstein, 2010; Mach et al., 2020; Purdy & Jones, 2012; Rawluk et al., 2020). Those who wield socially acceptable knowledge have considerable power in shaping research and practice outcomes (Fazey et al., 2014). Power imbalances can undermine processes by limiting considerations, marginalizing certain groups, biasing results, and destabilizing outcomes (Daly, 2016; Gray et al., 2022; Reed et al., 2009). They may also mean that actors with different understandings avoid the process (Carboni et al., 2017; Wondolleck et al., 2003). Collaborative environmental governance scholarship emphasizes the importance of paying attention to the tendency for powerful framings to dominate (Pregernig, 2014). However, critiques suggest that these normative aspirations do not necessarily translate to practice (Carter, 2013; Chambers et al., 2022; Fazey et al., 2014; Latulippe & Klenk, 2020).

3.2.6 Limited approaches to capturing multiple understandings

Representing the heterogeneity of actors' perspectives and understandings is far from simple (Scolobig & Lilliestam, 2016). Collaborative environmental governance practices rarely reflect the diversity of meaning and interpretations among actors (Feldman & Ingram, 2009). Most collaborative practices emphasize differences in actor types. However, there is no evidence to suggest that groups of actors with similar interests adequately align with groups of like-minded actors (i.e., actors who share perspectives or understanding of the challenge). Little has been written about capturing the diversity of actors' understandings to inform inclusive representation when addressing sustainability challenges (Page et al., 2016; Reed et al., 2009; Steger et al., 2021). Further, qualitative and quantitative research that characterizes the diversity of understandings among the public rarely informs explicit membership rules.

3.2.7 Conflicts in understandings

Differences between actors' understandings of sustainability challenges may facilitate innovation and flexibility (Berkes & Armitage, 2010; Muñoz-Erickson et al., 2017), but they often challenge and delay (or derail) practices (Daniels & Walker, 2001). There is growing evidence that differences between actor groups are becoming more distinct and conflictual, i.e., groups are becoming more polarized (Boxell et al., 2020; Iyengar & Krupenkin, 2018). Scientific arguments used to advocate for decisions aligning with different interests may strengthen conflicts rather than resolve them (Adler, 2014; Meppem & Bourke, 1999; Ozawa & Susskind, 1984; Pregernig, 2014). Media outlets tend to dramatize conflicts, potentially exacerbating them (Bolsen et al., 2014; Druckman et al., 2013; Klepper, 2023) (Box 3.1). In practice, differences between actor groups get overly simplified, reinforcing assumptions about correspondence

between perspectives, i.e., actors who think one way on one issue are likely to feel similarly on this other issue. To investigate the diversity of understandings embedded in sustainability challenges, practice needs a systematic approach to identify the distribution of understandings and connect them to actor groups and examine the relationship more carefully between actors' perspectives or the complexity of their understandings.

Box 3.1 Depictions of views of wildfire in research, practice, and media

People's perceptions about wildfire have been the focus of much attention, increasingly so as the saliency of wildfire challenges increases in the west. Wildfires have always captured media attention (in terms of films, podcasts, newspaper and magazine articles, and blogs), however while traditional coverage has sensationalized the damage, more recent coverage is also sensationalizing the conflict between residents, scientists, and politicians (Crow et al., 2017; Jacobson et al., 2021; Morehouse & Sonnett, 2010; Walker et al., 2020). Quantitative assessments of perceptions about wildfire include surveys from local to national scales and focusing on residents (McCaffrey et al., 2008), scientists (Tedim & Leone, 2020; Moritz et al .,2018) and decision makers, and looking at views about specific topics (e.g., prescribed fire). A recent review of barriers to science use in wildland fire management suggests that people's views about wildfire are perceived by wildfire managers as the largest barrier to getting stuff done (Hunter et al., 2020). Views are represented as: a lack of public awareness of science, a lack of support for fire management approaches, a perception by managers that science conflicts with policy or political agendas, a perception that science is politically motivated, and concerns that new approaches will be litigated. Diversity of views, not just among the public, but in professional practice is recognized as contributing to diverse narratives of wildfire (Edwards & Gill, 2016). Dichotomous views are discussed in terms of forest restoration (Ganey et al., 2017), fuels management (DellaSala et al., 2022), risks associated with controlled burns (Hamilton & Salerno, 2020), and smoke (Fowler et al., 2019). While certainly not always (Burns & Cheng, 2007; Champ et al., 2012; Hartter et al., 2020), much of the depictions of wildfire views center on conflict (Brenkert-Smith et al., 2019; Carroll et al., 2006; Paveglio et al., 2015).

3.3 Methods

This study presents an approach for supporting collaborative environmental governance practices to represent an inclusive understanding of complex sustainability challenges. We investigate understandings within the context of wildfire challenges. We ask:

1. What is the distribution of understandings of wildfire challenges?
2. What are the relationships between understandings of wildfire challenges?
3. What are the relationships between actors and their understandings of wildfire challenges?

Each question is defined by a set of data collection and analysis objectives (Table 3.1).

Table 3.1 Research questions and objectives

Objective #	Description
Research question 1a What is the distribution of perspectives of wildfire challenges?	
Objective 1a	Identify majority perspectives
Objective 1b	Identify minority perspectives
Objective 1c	Identify divergent perspectives
Objective 1d	Identify areas of nuance, ambiguity, or uncertainty
Research question 1b What is the distribution of understandings of wildfire challenges?	
Objective 1e	Quantify affiliation with different social narratives of western wildfire challenges
Research question 2a What are the relationships between perspectives of wildfire challenges?	
Objective 2a	Identify areas of conflicting perspectives
Objective 2b	Identify agreement among perspectives
Research question 2b What are the relationships between understandings of wildfire challenges?	
Objective 2c	Find associations between social narratives of western wildfire challenges
Objective 2d	Explain variation among actors' social narratives of western wildfire challenges
Research question 3a What is the relationship between actors and their perspectives of wildfire challenges?	
Objective 3a	Quantify number of agreements in perspectives between pairs of actors
Research question 3b What is the relationship between actors and their understandings of wildfire challenges?	
Objective 3b	Characterize spread of actors in terms of their understandings of wildfire challenges
Objective 3c	Test differences in understandings between interest groups

3.3.1 Data collection

3.3.1.1 Survey design

We designed the Western Wildfire Perspectives Survey to capture actors' understandings of western wildfire challenges in terms of both perspectives through their selection of statements, and understandings through their affiliation with nine social narratives (Table 3.2). The survey design builds directly on the narrative study discussed in Chapter 2 that identified nine social narratives (Figure 3.1) describing alternative sets of perspectives about what has caused wildfire challenges (how did we get here), what are the consequences of wildfire challenges (why should we care), and what are appropriate solutions to western wildfire challenges (what should we do about it). The selection of perspectives used in the survey aims to capture important distinctions between social narratives. Each perspective is represented by a statement that maintains the language research participants use in their description of western wildfire challenges (Table

Table 3.2 Key terms and their application in the survey

Term	Definition and application in the survey
Understandings	Understandings refers to how actors construct meaning, interpret, or make sense of knowledge, drawing from their diverse perspectives, experiences, cultures, and ways of knowing (Pritchard, 2009). In this study, we look at two levels of understandings - perspectives (finer) and social narratives (broader).
Perspectives	An actor's point of view, i.e., the vantage point from which a piece of evidence or an event is seen (Holmes, 2020). Perspectives included in the study came from sentiments, or segments of interview transcript from a prior study (Russo et al., in prep).
Social narrative	Common stories that capture shared experiences, disciplines, cultures, and beliefs (Polkinghorne, 1995; Shenhav, 2015). Social narratives included in the survey came from a set of nine social narratives constructed in a prior study (Russo et al., in prep). The nine narratives are summarized in Figure 3.1. Each social narrative is characterized by multiple perspectives (Appendix C)

Manage emphasizes the wildfire crisis as primarily a fuels management issues, seems to play a central role in how scholars and practitioners depict the western wildfire challenge.
Work focuses on the financial sustainability of timber management as a means to reduce risks.
Market employs an economic lens to highlight the role of insurance in both signaling and managing risk.
Control prioritizes efficiency and safety to protect against fire hazards.
Regulate points to the important role of where and how people build as a way to mitigate the wildfire crisis.
Conserve prioritizes forest health and restoration as a means to reduce wildfire risks.
Revitalize speaks to traditional fire culture and the importance of our relationship to fire.
Justice stresses the uneven distribution of wildfire burden on vulnerable populations and marginalized communities.
Adapt underscores the criticality of climate change as a key driver shaping future wildfire management pathways.

Figure 3.1 Social narratives of western wildfire challenges

Nine social narratives were constructed based on empirical qualitative research (see Chapter 2 for a full description of narratives and their construction). The wheel represents the relationship between the narratives, where narratives represented closer together are more similar or complimentary.

3.3). The full set of statements used in the survey and their correspondence to social narratives is included in Appendix C. We validated the correspondence between statements and social narratives by going back to the transcript data (Morse et al., 2002) and through discussions with topic experts (Morgan, 2014).

The survey included perspectives, multiple-choice demographics, and open-ended feedback questions (Appendix D). We used a forced choice format, where respondents were asked to select the perspective that resonated with them more among thirty-one opposing pairs of perspectives (Dolnicar et al., 2011; Whitaker & Fitzpatrick, 2013). The order of the pairs was randomized to minimize bias (Morii et al., 2017). We opted for forced choice over two alternative survey designs that capture differences in perspectives: Likert-scale, where respondents rate how much they agree with statements, from low (1) to high (5) (Whitaker & Fitzpatrick, 2013) and Q-sort, where analysts identify groups of respondents who sort a

Table 3.3 Development of survey questions

The statements used in the survey to represent perspectives came directly from sentiments expressed by interview participants in the narrative study (Russo et al., in prep).

Shorthand	Q3L | Incentivize Rx	Q3R | Rx is a liability
Survey perspective	Liability reform is needed to incentivize prescribed burning practices.	Escaped fires from prescribed burning are too high of a liability
Original sentiments	"We've been talking about this a long time, let's have more fire, but, you know, the air regulations in California, the training and liability issues are extremely difficult. It's very hard to bring this stuff to scale without removing some of those barriers. If I'm lighting a prescribed fire and I'm personally responsible and it blows up and takes out a community. I mean, what's my incentive?"	"They're going to continue to escape, they're going to continue to do damage to resources and private property, and they're going to create an environment where you have all your firefighters tied up on these fires, and now you have other fires you want to put out, and you don't have fire fighters to put them out."
	"If you want to talk about a major barrier, much more than air pollution, there is no available commercial insurance for prescribed fire.	"I'm not against prescribed burning. But I'm saying, right now does anybody have the expertise to do prescribed burning."
	"Currently all the incentives are to engage in fire suppression."	"The relative risk of an escape is so high that you wouldn't have a fire in the first place."

representative set of subjective statements into similar arrangements (Brown, 1993; Valenta & Wigger, 1997). We selected the binary forced choice format over the Likert scale to nudge respondents to take a clear position on their preferred perspective. Compared to the Likert scale, forced-choice formats are less susceptible to response biases like social desirability and acquiescent responding (Whitaker & Fitzpatrick, 2013).

We used multiple methods to evaluate and refine the survey. We shared an early version of the survey with participants from the narrative study and obtained their feedback on the overall concept. Before administering the survey, we further consulted with a handful of field experts to gather their comments on the survey's design, validity, and utility. To refine the list of perspectives and examine the overall validity and reliability of the survey, we conducted a focus

group with Fire Adapted Communities Learning Network members, a professional group of people and communities working on wildfire resilience (FAC Net, 2023). Focus group participants took the survey and engaged in a facilitated discussion while on the call (Ryan et al., 2012). We further refined the survey based on a pilot with attendees at the Annual Wildfire Cohesive Strategy Workshop (USDA, 2014). Based on feedback, we altered the survey, allowing respondents to select neither or both perspectives. The resulting format was a hybridized forced-choice multiple response. Although this complicated the analysis, it allowed respondents to express ambiguity, uncertainty, or nuanced differences between perspectives (Ernst, 2019; Brown, 1993; Valenta & Wigger, 1997). Despite Q-sort's advantages in factor analysis, we opted for forced choice due to limitations in sample size (Brown, 1993) and negative feedback from focus group and pilot participants regarding its tedious and lengthy nature.

A part of the survey design was sharing real-time results with survey respondents. After selecting among the perspectives, respondents received a personalized results page that visually demonstrated how their selections corresponded to nine social narratives. Results were provided in real-time, using a polar diagram with nine axes (Figure 3.2). Respondents were directed to our research website for additional narrative information and regularly updated survey results (WFFI, 2023). We then asked respondents to reflect on their results in relation to their perspectives on the wildfire situation and any potential opportunities and challenges in utilizing the nine narratives and this approach in their work. Their feedback informed our evaluation of the survey as an approach to systematically explore understandings to support more inclusive practice.

Figure 3.2 Real-time survey results

After completing the perspective selection portion of the survey, respondents received a visual representation of their results in relation to the nine social narratives. Narrative descriptions were provided through a website link.

3.3.1.2 Population and sampling

The study population consisted of influential practitioners and scholars actively addressing western wildfire challenges. The term western in this study refers to eleven western states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. While grasslands play a significant role in wildfires, this study specifically focuses on perspectives regarding wildfires in forestlands (wildlands) and adjacent communities (wildland urban interface or "WUI").

Our survey sampling strategy aimed to include a diversity of influential actors, going beyond mainstream actors, to capture prominent yet more marginal perspectives working on western wildfires. To achieve this, we utilized a previously constructed dataset identifying individuals who have tweeted about western wildfire (2020-2021), frequently appeared in newspapers related to western wildfire topics in any of the 11 states (2020-2021), or co-authored

Community Wildfire Protection Plans (CWPPs) within those states (2011-2021) (Holm & Fischer, 2023) (Table 3.4a). We sampled individuals who were highly active or engaged, i.e., tweeted ten or more times, mentioned in newspapers within the state more than 90% of actors, were in newspapers in multiple states, or co-authored three or more CWPPs from the dataset (n=1,672) (Table 3.4b). Additionally, our sample included a network of western fire service professionals associated with the Daily Dispatch (Western Fire Chiefs Association, 2023).

3.3.1.3 Recruitment, response, sample characteristics

We sent an invitation to participate in the survey to 1,074 individuals. Invitations were sent via email. We identified email addresses for selected individuals through an online search of names and keywords. We removed individuals for whom we could not find a functional email, or where there was a conflict of interest (e.g., they were involved in the narrative study or survey validation). Of 804 individuals who received the survey, 130 completed it (16% response rate). We followed up on the survey invitation with two email reminders to individuals with uncompleted surveys (Van Selm & Jankowski, 2006). Additionally, we promoted the survey through a flyer in the Western Fire Chiefs Association's Daily Dispatch newsletter from December 6, 2022, to February 15, 2023. Due to the wide dissemination of the flyer, we cannot determine a response rate accurately (Vaske et al., 2022). However, we observed that among the forty fire service members who accessed the survey link, 23 completed at least 80% of the survey.

We administered the survey online through the Qualtrics platform, with an estimated completion time of 10 minutes. We omitted surveys where respondents did not select either

Table 3.4 Survey respondent characteristics

a) The sample of survey respondents was based on database of influential actors. We selected a sub-sample of highly influential actors to include. In addition, we sampled a network of wildfire chiefs who subscribe to the Daily Dispatch. (b) Recruitment was based on a survey link shared by email to actors from the sub-sample whose email we could identify and a broad distribution via flyer to the Daily Dispatch network. (c) Survey respondents reflect 153 completed surveys.

(a) Survey sample	
15,384	identified actors database
1,672	highly influential (sub-sample)
	comprised of:
257	actors who tweeted about western wildfire topics 10 or more times between 2021-2022
377	top ten percent of actors identified in newspapers with regards to western wildfires
96	actors who appear in the newspaper in multiple western states
663	actors who have co-authored 3 or more CWPPs between 2011-2021
279	actors who show up in more than one medium (e.g., newspaper and CWPPs).
+	Wildfire chiefs who subscribe to the western addition of the Daily dispatch
(b) Recruitment	
from highly influential actors sub-sample	
804	identified actors who received survey link
176	individuals who started the survey
130	respondents who completed 80% or more (16% response rate)
from Daily dispatch sample	
40	respondents who started the survey via Daily dispatch link
23	completed 80% or more (response rate NA)
(c) Survey respondents	
153	complete and usable surveys

comprised of: 18 (12%) twitter, 39 (25%) newspaper, 34 (22%) CWPP, 39 (25%) multi-media, 23 (15%) chiefs

Respondent characteristics

**Respondents were able to select more than one option, so # do not add up to total*

State		Scale		Topics	
69 (45%)	CO	106 (69%)	State	119 (78%)	Environmental protections
51 (33%)	CA	104 (68%)	Local	109 (71%)	Landscape treatments
50 (33%)	OR	57 (37%)	Regional	108 (71%)	Preparation and mitigation
36 (24%)	WA	47 (31%)	National	106 69%)	Planning and local policy
30 (20%)	ID	Sector		100 (65%)	Wildfire response
30 (20%)	MT	107 (70%)	Government	75 (49%)	Research
27 (18%)	WY	38 (25%)	NGO	51 (33%)	Infrastructure
24 (16%)	NM	37 (24%)	Academia	46 (30%)	Recovery
23 (15%)	AZ	19 (12%)	Private	40 (26%)	Public health
23 (15%)	UT	8 (5%)	Tribal	37 (24%)	Equity
22 (14%)	NV			35 (23%)	Industry
				32 (21%)	Traditional fire culture
				17 (11%)	Regulation & insurance

statement for more than 30% of the pairs as incomplete. We obtained a total of 153 completed surveys. The distribution of respondents was skewed towards individuals who primarily work in Colorado, California, and Oregon, at a local or state scale, in the government sector, and on environmental protections, landscape treatments, or mitigation (Table 3.4c). We categorized respondents into ten different interest groups (e.g., federal forestland managers, local planners) based on a combination of their demographic information (sector, scale, topics worked on), recruitment method (Twitter, newspaper, CWPP, fire chiefs), and their email domain extensions (.com, .gov, .edu, or .org) (Table 3.5).

Table 3.5 Survey respondent interest groups

We assigned each respondent into an interest group based on their response about scale, scope, topic, mode of influence (e.g., twitter, CWPP), and email domain extensions (e.g., .org, .com, .edu).

% of sample	Interest group
40 (26%)	Fire fighter or fire chief (link from western fire chief distribution)
29 (19%)	Academic (inc: @.edu, scientists, modelers)
21 (14%)	Federal land manager (inc. (email USDA, USGS, BLM)
15 (10%)	Local planner (@.gov, scale local)
13 (8%)	State government (@.gov with state name)
12 (8%)	Private industry professional (inc. timber, innovation sector) (@.com)
4 (3%)	Other
7 (5%)	Firewise councilmember (scale local, known entities)
9 (6%)	environmental NGO professional (email @.org)
3 (2%)	Tribal manager (sector tribal)

3.3.2 Data analysis

We analyzed survey data by research questions (RQ). Each research question was further divided to reflect both perspective-level data and understanding-level data. Analysis was further organized into respective objectives (O) (Table 3.1).

3.3.2.1 RQ.1a What is the distribution of perspectives of wildfire challenges?

To quantify the distribution of perspectives, we looked at four categorical options for respondent selections across the 31 pairs of perspectives, where P_L, P_R refers to the proportion of respondents who resonated more with the left or right perspective, respectively, and $P_{neither}$, P_{both} refers to the proportion of respondents who selected neither or both perspectives, respectively.

O.1a Identify majority perspectives

Within a pair of perspectives, this perspective resonated more than the other for more than two-thirds of respondents; max(P_L,P_R >= 75%) X^2 test.

O.1b Identify minority perspectives

Within a pair of perspectives, this perspective resonated more than the other for less than a tenth of respondents; max(P_L,P_R <= 10%) X^2 test.

O.1c Identify divergent perspectives

Within a pair of perspectives, this perspective resonated more for more than a quarter of respondents while the other perspective resonated more for another quarter or more of respondents; min(P_L, P_R >=25%) X^2 test.

O.1d Identify areas of nuance, ambiguity, or uncertainty

Within a pair of perspectives, more than one-fourth of respondents did not select either perspective, or more than one-fourth of respondents selected both perspectives; $P_{neither}$ >=25%, P_{both} >=25 Z test one-tail normal distribution.

3.3.2.2 RQ.1b What is the distribution of understandings of wildfire challenges?

To quantify the distribution of understandings among respondents, we calculated the percent affiliation (0-100%) across nine social narratives based on presumed correspondence between statements and narratives (Appendix C).

O.1e Quantify affiliation with different understandings of western wildfire challenges

Among the nine social narratives, which narratives resonated with respondents the most and the least; comparison of the difference in mean across the nine social narratives (ANOVA).

3.3.2.3 RQ.2a What are the relationships between perspectives of wildfire challenges?

To explore the relationships between perspectives, we first prepped the data by converting the categorical selection of 31 paired perspectives to a binary selection of 62 perspectives (0 for unselected and 1 for selected). We then conducted a multiple correspondence analysis (MCA) of the perspectives and plotted them as points in a biplot. Multiple correspondence analysis (MCA) is an exploratory statistical method commonly used to identify patterns in the correlations between multivariate categorical data (Khangar & Kamalja, 2017). Social science researchers often employ this method to better understand actors' perspectives (Scolobig & Lilliestam, 2016). The significance of MCA biplots is a matter of interpretation based on relative positions, distances, and context of points (Kaya et al., 2021). We utilized R-packages FactoMineR (Le et al., 2008) and Factoextra (Kassambara & Mundt, 2020) to perform and visualize the MCA (Appendix E).

O.2a Identify areas of conflicting perspectives

To identify pairs of perspectives that conflict or negatively correlate with one another, we represented pairs by a connecting line in the biplot. We identified pairs where points are in

opposing quadrants (e.g., top left, bottom right) and distant from the origin (0,0) to represent perspectives that are important in distinguishing between actors.

O.2b Identify agreement among perspectives

To identify perspectives often selected together, we looked at clusters of points that are close together and distant form the origin (0,0).

3.3.2.4 RQ.2b What are the relationships between understandings of wildfire challenges?

We conducted a principal component analysis (PCA) of the nine social narratives (9 continuous variables, 0-100% for each) to explore the relationships between actors' understandings of wildfire challenges. PCA is often used within environmental social science research to infer hidden relationships between numeric data (Joliffe 2002; Fritz and Koch 2019) (Appendix F).

O.2c Find associations between different understandings of western wildfire challenges

We looked at which social narratives have (1) a close association or are interdependent with one another, (2) are negatively associated with one another, or (3) are independent of one another. We represented the narratives as nine variable vectors around the biplot. We compared the angle of vectors to determine association (Acute angles = close association, obtuse angle = negative association, right angle = independence) (Fritz & Koch, 2019).

O.2d Explain variation among actors' understandings of western wildfire challenges

We calculated the factors explaining the greatest variation in actors' affiliation with the nine social narratives. We identified the two factors that explain the greatest variation in dataset (top 2 eigenvalues, represented by the x and y axes in a biplot).

3.3.2.5 RQ.3a What are the relationships between actors and their perspectives of wildfire challenges?

O.3a Quantify the number of agreements in perspectives between pairs of respondents

We measured the level of agreement among actors' selection of perspectives. We first prepared the data by creating a one-mode adjacency matrix of respondents-respondents. Each cell value equaled the number of agreements such that if both respondents resonated with the left perspective, they get a point, if both do not resonate with left, they get a point; but if one resonates with left and the other with both, they do not get a point. We then calculated the overall mean, min, and max number of connections between respondents.

3.3.2.6 RQ.3b What is the relationship between actors and their understandings of wildfire challenges?

O.3b Characterize the spread of actors in terms of their understandings of wildfire challenges

We looked at the distribution of respondents across the two major factors explaining variability in social narratives. Using the PCA, we represented the 153 respondents as (x,y) coordinates in the biplot. The x values represented respondents' understandings along the first factor, and the y values represent respondents' understandings along the second factor. We described the distribution of x values and y values across 153 entities in terms of their skew (are respondents' views skewed more in one direction or the other), modality (where a bimodal distribution is indicative of polarity while a unimodal distribution is indicative of more moderate views), and height (where a flatter curve reflects a more even distribution of views).

O.3c Test differences in understandings between interest groups

To test whether the understandings of one interest group are significantly different from other interest groups, we assigned each respondent a categorical value (1-10) associated with their interest group type (e.g., NGO, state land manager, fire chief) (see methods). We then calculated the difference in mean of x and y values across the ten groups. We tested for significance with a one-tail ANOVA.

3.4 Results

The results are reported in relation to the research questions and objectives. Perspectives are associated with a question number (Q1-Q31) and letter (L for left, R for right). Each social narrative is associated with its title and distinguished by single quotes (e.g., 'Manage', see Figure 3.1 for descriptions) while single quotes and italics distinguish perspective statements. Tables reference perspectives in shorthand. The complete list of perspectives and their correspondence to social narratives are included in Appendix C.

3.4.1 Distribution of perspectives of wildfire challenges (RQ.1a)

3.4.1.1 Areas of agreement in perspectives (O.1a)

For nine pairs of perspectives, a majority of survey respondents resonated with the same perspective (Table 3.6a). The majority of respondents (84%) agreed with the perspective that *'co-benefits of fuels reduction measures are enormous; we need to better account for these benefits instead of trying to make fuels reduction measures pay for themselves.'* Eighty-three percent (83%) of respondents agreed with the perspective '*To put fire back in balance, we need to use all the tools available to us to invite more fire to the landscape',* and eighty-two percent

(82%) of respondents agreed with the perspective '*We should use unplanned ignitions under good conditions as an opportunity to restore ecological function.'*

3.4.1.2 Minority perspectives (O.1b)

Majority perspectives distinguish minority perspectives that resonate with less than ten percent of respondents. For example, the ideas that '*fire as a means of fire management is a waste of forest resources*' (3%), '*to put fire back in balance, we need to control and minimize the amount of fire on the landscape*' (4%) or that *'to the extent it is safe, we should try to stop all fires in the wildlands as soon as possible'* (8%) are marginal.

3.4.1.3 Divergent perspectives (O.1c)

Seven pairs of perspectives reflected areas of high divergence or a split in views among 44% of the time, and the perspective *'There are viable management options that allow us to dramatically reduce smoke and emissions due to wildfires'* was selected 42% of the time. Similarly, the perspective the *'Western wildfires pose an existential crisis to our forests. We cannot separate the health of our forests from the impact on communities'* was selected 44% of the time, while *'Fire in wildlands is not a disaster. Fire in homes and communities is absolutely a disaster'* was selected 38% of the time.

3.4.1.4 Areas of nuance, ambiguity, or uncertainty (O.1d)

For five pairs of perspectives, a considerable percentage (>25%) of respondents selected both and for three pairs of perspectives a substantial percentage of respondents selected neither

Table 3.6 Distribution of perspectives

(a) We identified pairs of perspectives for which a majority of respondents selected one perspective over the other). We tested the significance, across each pair, of the perspective being selected more than 75% of the time. Among these perspectives, we identified minority perspectives (highlighted in gray). We tested the significance, across each pair, of the perspective being selected less than 10% of the time. (b) We identified pairs for which there are divergent perspectives. We tested the significance of both perspectives within each pair being selected more than 25% of the time. (c) We identified pairs for which respondents often selected neither or both perspectives. We tested the significance of respondents selecting either neither or both perspectives more than 25% of the time.

Q#	Left statement	Right statement	P_L	P_R	$P_{neither}$	P_{both}
(a) Majority and minority perspectives						
26	fuel reduction / co-benefits	fuel reduction / pay for itself	84%*	5%*	6%	5%
21	fire balance / control & minimize	fire balance / all the tools	4%*	83%*	6%	7%
1	unplanned ignitions / restore ecology	unplanned ignitions / dangerous & costly	82%*	8%	8%	1%
30	fire = protect our forests	fire = waste of forest resources	80%*	3%**	12%	5%
13	let fires burn	stop all fires	78%	8%**	10%	5%
3	Rx a liability	incentivize Rx	5%*	77%	12%	6%
23	restore USFS	decolonize USFS	77%	8%	11%	3%
2	Rx ↑ smoke	Rx ↓smoke	12%	75%	8%	5%
28	$ treatments, ↓ risk	$ treatments, ↑ risk	75%	10%	10%	5%
8	↑ suppress / ↑ risk	↑ suppress / ↓ risk	74%	7%	16%	4%
10	thinning & Rx, best tool	climate mitigation, best tool	72%	7%	3%	18%
11	crisis = forest + climate problem	crisis = WUI problem	72%	8%	12%	17%
27	forest roads ↑ risk	forest roads ↓ risk	8%	59%	16%	17%
20	justice = no disproportionate burden	justice = responsibility of people in WUI	56%	18%	19%	8%
(b) Divergent perspectives						
17	unrealistic to restrict	should restrict in risk zone	29%*	58%*	11%	3%
5	more smoke ≠ inevitable	more smoke = inevitable	42%**	44%**	9%	5%
29	env regulations prevent good work	env regulations now more important	29%**	44%**	12%	15%
12	forest fires pose existential crisis	fire in communities = disaster	41%**	37%**	6%	16%
7	management must be grounded in science	must incorporate multiple types of knowledge	36%**	39%**	4%	21%
9	foremost, harden WUI	foremost, manage wildland forests	26%*	36%*	7%	31%
15	insurance premiums must be regulated	insurance premiums = most accurate model	35%**	31%**	24%	10%
19	communities most affected / responsible for cost	communities most affected / least likely to recover	24%	44%	19%	14%
24	fire managers are expertly trained	fire managers need Indigenous-led trainings	20%	51%	14%	14%

Statements with (*) are significant at p value of 0.05, (**) are significant at p value of 0.01.

Table 3.6 Distribution of perspectives. *continued*

Q#	Left statement	Right statement	P_L	P_R	$P_{neither}$	P_{both}
(c) Areas of nuance, ambiguity, or uncertainty						
4	we must educate the public	we must learn to listen	52%	10%	3%	35%**
31	fire mngt to control wildfire spread	fire mngt for ecology	15%	42%	9%	33%**
6	increase pace and scale	increase place-based solutions	23%	36%	3%	38%**
18	home mitigation practices = most effective	fuels reductions in wildlands = most effective	24%	23%	7%	46%**
9	foremost, harden WUI	foremost, manage wildland forests	26%	36%	7%	31%**
14	socio-economic inequities → wildfire problem	restrictive policy → wildfire problem	19%	30%	30%	18%
16	insurance reform = stabilize & reduce risk	insurance reform = market distortion	41%	24%	33%**	3%
25	salvage logging is necessary	salvage logging should be prohibited	52%	12%	33%**	3%
22	invest in hot shot crews	democratize fire management	17%	46%	20%	16%

Statements with (*) are significant at p value of 0.05, (**) are significant at p value of 0.01.

perspective (Table 3.6c). For example, 46% of respondents chose both the perspective '*Home mitigation practices such as home hardening and defensible space are the most effective means to protect communities from wildfires'* and *'Fuels reductions practices in the wildlands provide firefighters a chance to stop the fire before it reaches the community and is the most effective means to protect communities from wildfires.'* Alternatively, a third of respondents (33%) did not select either perspective regarding themes, including salvage logging, insurance, and wildfire policies.

3.4.2 Distribution of understandings of wildfire challenges (RQ.1b)

3.4.2.1 Affiliation with different understandings of western wildfire challenges (O.1e)

'Manage' resonated with respondents more than any other narrative (76%, Figure 3.3). Perspectives that correspond with the 'Revitalize' narrative were also selected by most survey respondents (64%). The 'Adapt' and 'Conserve' narratives resonated with most respondents

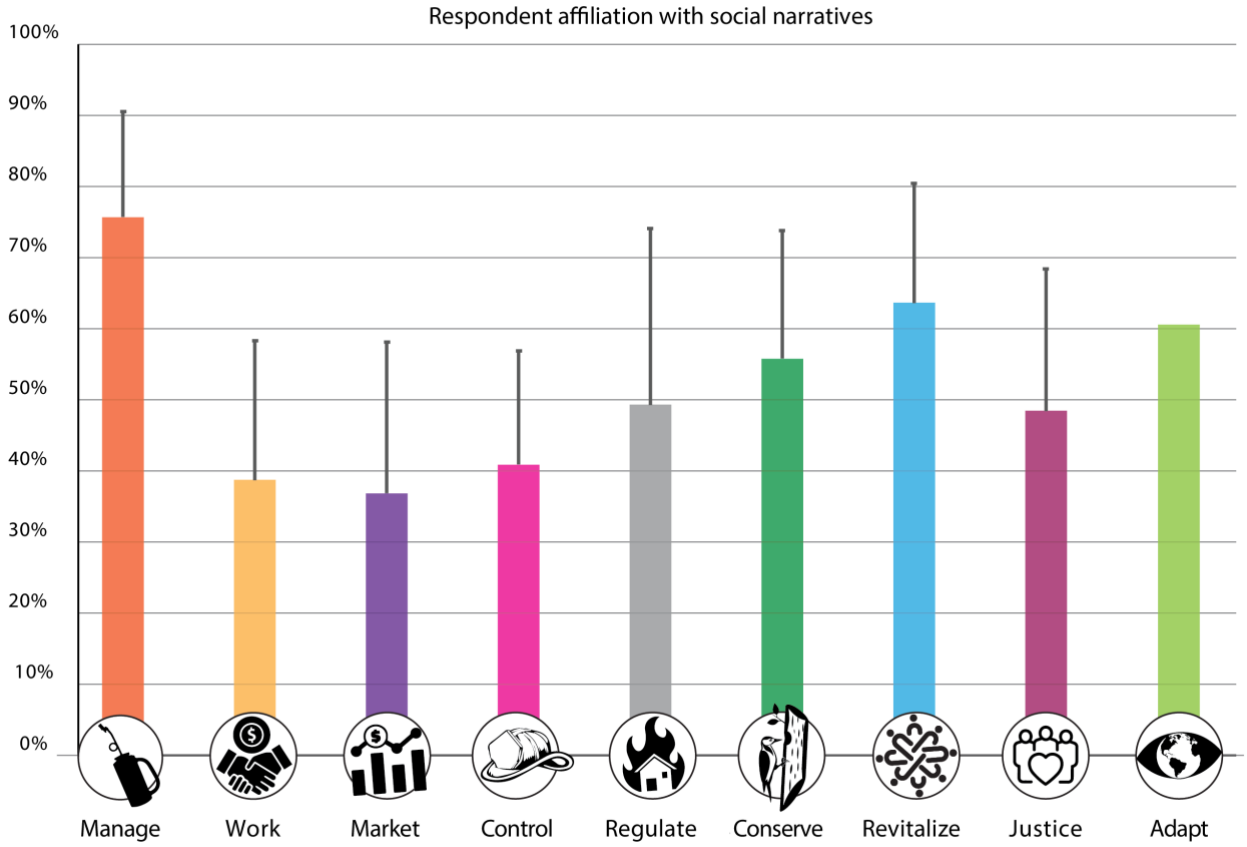


Figure 3.3 Respondents' affiliation with social narratives

Based on a correspondence between each perspective and narrative (Appendix C), we calculated the percent affiliation with each narrative, for each respondent. If the respondent resonated with all the statements that correspond with a narrative, they would receive a 100% along the diagram. Alternatively, if they did not resonate with any of the statements, they would receive a 0% affiliation with that narrative. This graph represents the mean affiliation for all respondents, for each narrative. Black lines represent standard deviation.

(61%, and 56%, respectively). However, we saw more mixed distribution among their corresponding perspectives. For example, the perspective *'we should use unplanned ignitions to burn for resource purposes'* (Q1L), associated with the 'Conserve' narrative reflected a high level of agreement (83%), while the idea that '*we should prohibit salvage logging'* which is also associated with the 'Conserve' narrative, was rarely selected (12%, Q25R). A similar mixed pattern shows up with the 'Adapt' narrative. While 89% of respondents agree that western wildfires represent a climate problem, only 25% agreed that emissions reductions are our best

tool against wildfires (10R). In contrast to these more common narratives, perspectives corresponding to the 'Market,' 'Work', and 'Control' narratives resonated the least with survey respondents (37%, 39%, and 41%, respectively). Overall, the variance in means among the nine social narratives was highly significant (P=2e-16***). Pair-wise differences between Market and the other narratives were not significant.

3.4.3 Relationships between perspectives of wildfire challenges (RQ.2a)

3.4.3.1 Areas of conflicting perspectives (O.2a)

We identified twelve pairs of perspectives that are negatively associated, suggesting they are unlikely to be selected by the same respondent and are more mutually exclusive (Table 3.7a; Appendix E). The pairs of perspectives that are the most negatively associated center on whether we should let fires burn for resource purposes.

3.4.3.2 Interdependence among perspectives (O.2b)

Examining the MCA results, we identified three clusters with high correspondence (Table 3.7b; Appendix E). Cluster 1 reflects perspectives on environmental regulations, inequities, and less freedom for private industries. Cluster 2 reflects perspectives preferencing fire suppression and control. Cluster 3 reflects perspectives favoring looser restrictions and emphasizing free market mechanisms. The remaining perspectives are close to the origin, suggesting that they are not particularly informative in explaining the variation in the data.

3.4.4 Relationships between understandings of wildfire challenges (RQ.2b)

3.4.4.1 Associations between social narratives of western wildfire challenges (O.2c)

Along the PCA biplot, the nine social narratives are depicted as vectors in relation to each other (Figure 3.4). We found acute angles representing the close association between 'Market', 'Work,' and 'Control' as well as between 'Conserve' and 'Justice,' and between 'Adapt' and 'Manage.'

Table 3.7 Correspondence between perspectives (MCA results)

We ran a multiple correspondence analysis (MCA) of the 62 perspective statements (unpaired). We looked to see which pairs of perspectives are (a) mutually exclusive and (b) clusters of individual perspectives that reflect similar selection patterns. Appendix E includes the full results of the MCA analysis including a visual representation of the results.

(a) mutually exclusive perspectives pairs	
1, 8, 10, 13, 14, 21, 25, 26, 27, 28, 29, 30	
(b) clusters of high correspondence perspectives	
Cluster A	10B, 28B, 29B, 25B, 14A
Cluster B	26B, 1B, 8B, 13B, 21A
Cluster C	20B, 29A, 14B, 30B

Representing no association, we found right angles between 'Conserve' and 'Adapt,' between 'Market' and 'Regulate' and between 'Manage' and 'Work.' Lastly, we found a negative association between 'Revitalize', 'Justice,' and 'Conserve' and 'Control,' 'Work,' and 'Market.'

3.4.4.2 Variation among actors' affiliation with social narratives of western wildfire challenges (O.2d)

We found that two factors account for nearly half of the variation when looking at the relationship between actors' affiliation with the nine social narratives. The X-axis depicts 29.1% of the variance (eigenvalue = 2.62). It depicts a view of the role of fire in terms of a desire to

control and minimize fire on the left-hand side and a desire to utilize more fire on the right hand-side) (Figure 3.4, Appendix F). The Y-axis depicts 17.4% of the variance (eigenvalue 1.56) and depicts a view that emphasizes interventions in the forest on the bottom and in communities on the top.

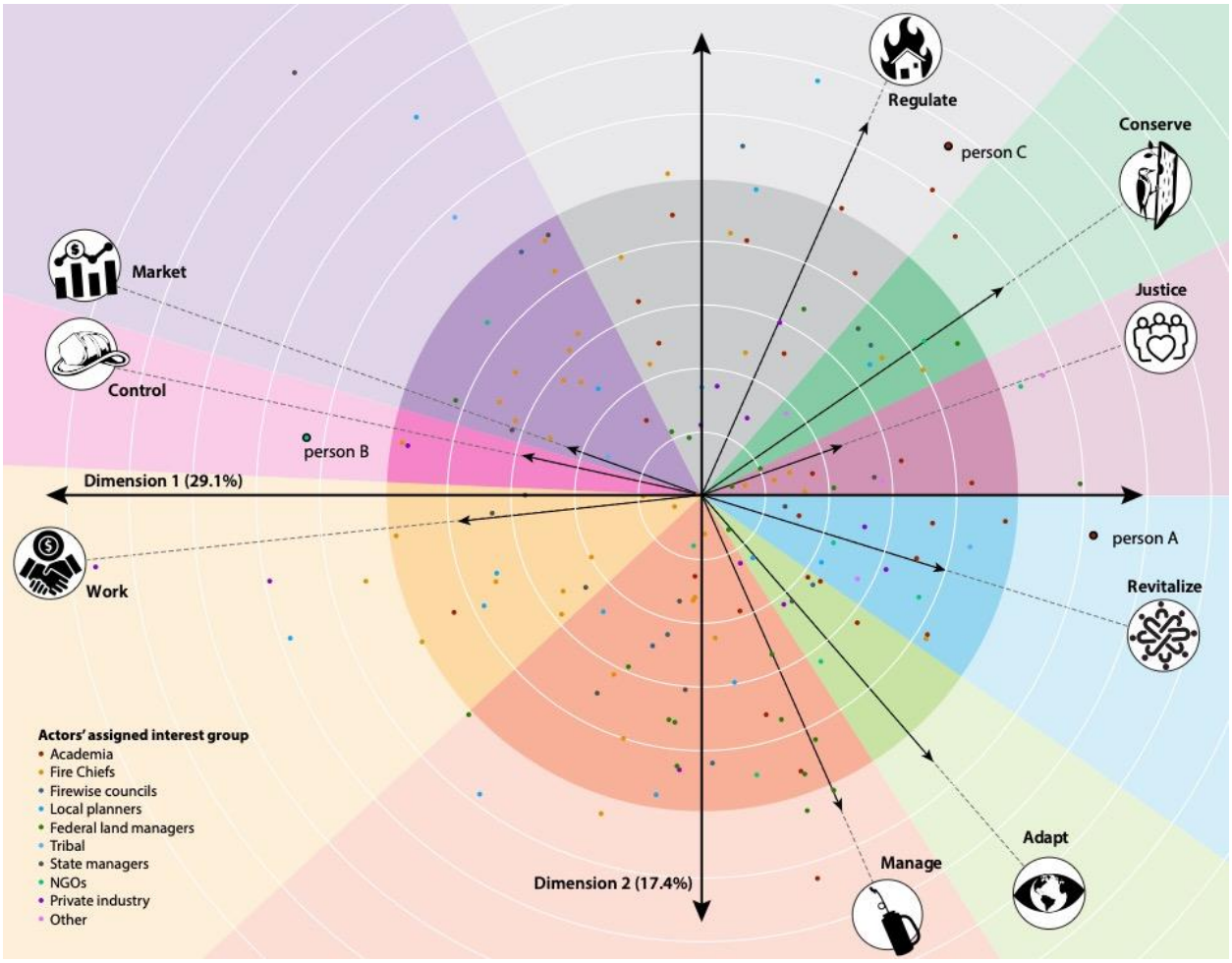


Figure 3.4 Results of the principal component analysis (PCA)

This graphic represents the biplot results of the PCA. The analysis was run on respondents' percent affiliation with each narrative. Each point represents one survey respondent. The two axes represent the two dimensions that explain the greatest variation among respondents' affiliation with the nine narratives. The nine narratives are represented as variables in relation to those two axes. Points that are further from the origin (0,0) are strongly explained by the two dimensions. Points that are closer are more similar. This is also true for narratives. Orthogonal variable (vector) orientation represents an absence of relationship between narratives. Opposing variable orientations reflects opposing relationships. For example, there was no clear relationship between respondents who affiliated strongly with the 'Conserve' narrative and those that affiliated strongly with the 'Manage' narrative. However, respondents who affiliated strongly with the 'Revitalize' narrative were likely to not affiliate with the 'Market' narrative. The color of the points represents respondents assigned interest group category.

3.4.5 Relationships between actors and their perspectives of wildfire challenges (RQ.3a)

3.4.5.1 Agreements in perspectives between actors (O.3a)

We found that, on average, each pair of respondents agreed on about two-thirds of the perspectives (20 pairs of perspectives). On the low end, the two respondents with the most different survey results only agreed on three perspectives. In contrast, on the high end, the two most similar respondents agreed on 43 perspectives (suggesting that they selected 'both' perspectives for at least a dozen pairs). Lastly, each respondent agreed with at least one other respondent on 19 or more perspectives.

3.4.6 Relationships between actors and their understandings of wildfire challenges (RQ.3b.)

3.4.6.1 Spread of actors' views of wildfire challenges (O.3b)

Among the 153 respondents, we found moderate differences in views about the role of fire on the landscape, as indicated by a unimodal distribution (Figure 3.5a). We found that most views were centered (or moderate), with a right-skew suggesting that individuals resonate more with a view that preferences utilizing more fire. We also found moderate differences in views about whether interventions should be prioritized in the forest or communities (Figure 3.5b). Most views were centered, with a minor right-skew preferencing a focus on interventions in communities.

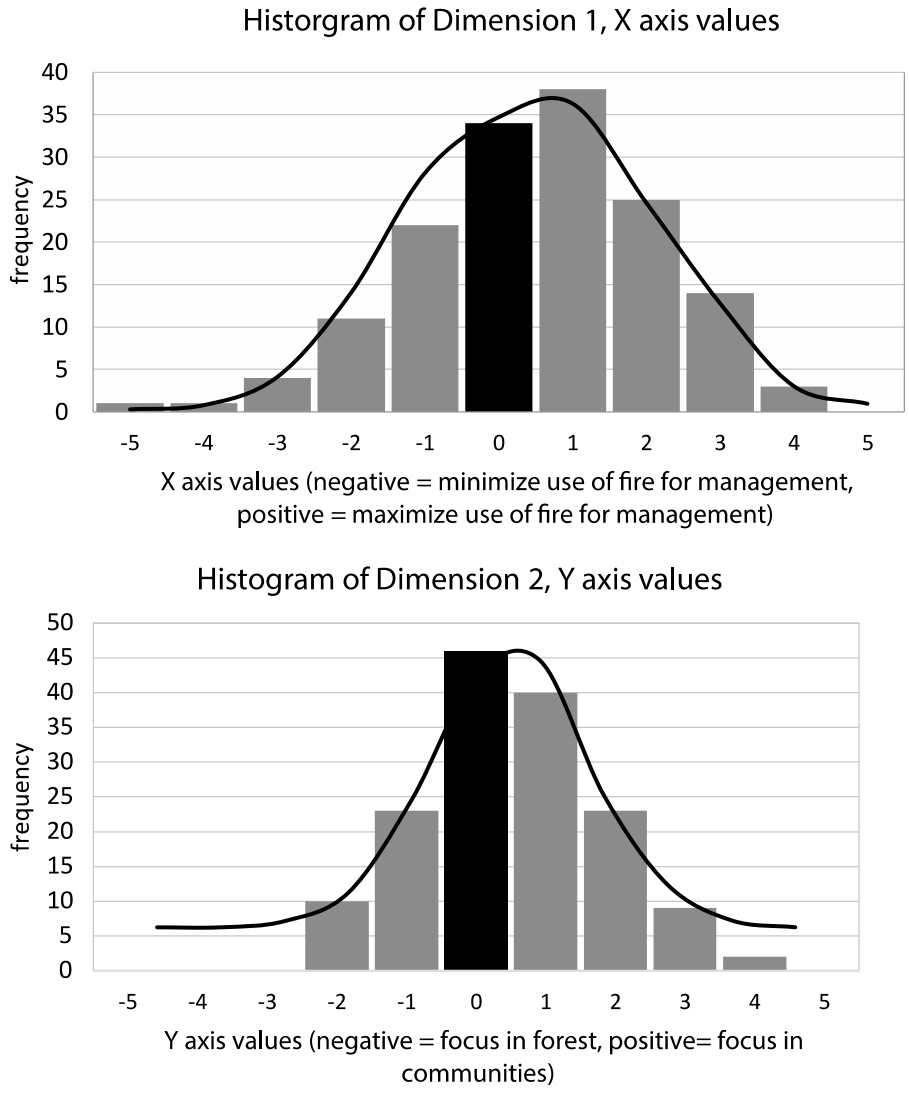


Figure 3.5 Distribution of views among respondents

a) Histogram of dimension 1, X-axis values. The frequency of respondent values along the x-axis represents views about the use of fire for management purposes. The PCA is designed to place the mean at zero. A high value of zero suggests that, for many respondents, this is not a strong predictor of views. There is a skew to the right, representing a slight affiliation with a moderate view that we should maximize the use of fire for management purposes. Low frequencies at the tails represent few extreme views. b) Histogram of dimension 2, Y-axis values. The frequency of respondent values along the y-axis represents views about where to focus interventions. High values at zero suggest this is not a strong predictor of views for many respondents. There is a strong skew to the right, representing a slight affiliation with a moderate view that we should focus on interventions in communities.

3.4.6.2 Differences in understandings between interest groups (O.3c)

To compare interest groups' views about the role of fire and views about the location of interventions, we ran an analysis of variance (ANOVA) on mean values along each factor. We did not find any significant variation across the means of the ten groups for views about the location of intervention. When examining the distribution across interest groups in relation to views about the role of fire, the initial ANOVA test was significant. However, the only pairwise significance in variation was between academics and the other interest groups. A Levene's Test of Homogeneity of Variance did not confirm significance ($P = 0.5304$).

3.5 Discussion

3.5.1 Summary of major findings for collaborative risk management of western wildfires

Survey findings suggest that differences in actors' understandings of western wildfire challenges are primarily explained by their views about the role of fire (should fire play a larger or smaller role) and where interventions should be placed (in communities or forestlands). The majority of influential actors resonate with perspectives that correspond with the 'Market,' 'Revitalize,' and 'Adapt' narratives. While there are substantial and often conflicting distinctions between actors' perspectives, for the most part, differences are moderate, and actors agree on more perspectives than they disagree. Overall, distinctions are blurred as understandings are overlapping, complex, and do not correspond with interest groups.

Our research describes an approach for systematically exploring the spectrum of influential actors' understandings of western wildfire challenges to support more inclusive

collaborative risk management practices. In the introduction, we laid out three ways in which this approach can help practice be more inclusive:

(1) Inform the selection of project partners to mirror the distribution of understandings across the broader population.

(2) Inform process design to consider important distinctions and conflicts between actors' understandings.

(3) Inform partner selection criteria to better represent understandings.

Below, we discuss how our findings can inform the selection and design of practices relative to these three aspects. To do so, we look at the finding holistically rather than in the order of their analysis.

3.5.1.1 Informing the selection of project partners such that they mirror the distribution of understandings across the broader population

Reducing the variability

With sixty-two perspectives and nine social narratives, mirroring the diversity of understandings can seem daunting. However, our findings reflect some ways that variability can be reduced. First, to inform partner selection, the PCA suggests that nearly half of the variation in understandings can be explained by two views. First, a view about the role of fire in terms of a desire to control and minimize fire vs. a desire to utilize more fire. Second, a view that emphasizes interventions in the forest vs. in communities. These factors align with previous research findings that suggest that these are important distinctions between influential actors' understandings (Paveglio et al., 2015). At a minimum, a team should include representation of both sides of both views. Second, in addition to the views mentioned above, we found important

distinctions relative to perspectives about environmental restrictions (a preference for more protections versus a preference for fewer barriers) and perspectives about social justice (emphasis on agency, or responsibility at an individual level versus structure, or responsibility at a societal level). The three MCA clusters (Table 3.7) suggest overlaps among those perspectives. While each cluster of perspectives should be represented, reflecting variability within these clusters may be less important. Third, we found substantial nuance in our results. Respondents selected neither or both statements for eight of the pairs of perspectives. The MCA further suggests that about a third of the perspectives do not explain variation among respondents (identified as points close to the origin, Appendix E). Selecting actors relative to their thoughts on these perspectives is likely less important.

Dominant and marginal narratives

Survey results show 'Manage' as the dominant social narrative. Associated perspectives emphasizing the importance of fuels management using a combination of thinning, prescribed burning, and utilizing natural ignitions to manage forest resources resonated with more than three-quarters (75%) of survey respondents. This finding is not surprising, given the alignment of those perspectives with the National Cohesive Wildland Fire Strategy, professional conferences, and scientific literature (Ager et al., 2015; Dunn et al., 2020; Moritz et al., 2014). However, our findings suggest that some of the narratives depicted as more marginal already resonate with most influential actors. For example, most respondents resonated with statements corresponding with the 'Revitalize' narrative, emphasizing a turn towards traditional fire culture (Q24R), democratizing fire management (Q22R), and integrating non-Western science types of knowledge (Q7R). Bringing 'Revitalize' perspectives into common practice is generally discussed as a novel strategy (Long & Lake, 2018). Alternatively, While literature and media

often emphasize ‘Control’ - a more suppression-oriented narrative - as the dominant narrative, (DellaSala et al., 2022; Gabbert, 2022; Miller, 2021), we found it to be among the least common social narratives. The gap between media and our findings may be due to a “rigidity trap” whereby despite wide recognition of the importance of ecological fire restoration, fire suppression still dominates planning and management (Butler & Goldstein, 2010, pg. 1013)

Major and minor agreements in perspectives

We found substantial agreement on about a third of the pairs of perspectives. If the purpose of the collaboration is efficient decision-making and action, minority perspectives that resonate with less than ten percent of the population can be excluded as a distraction. Focusing on majority perspectives can help groups move forward quickly. For example, as a participant in the narrative study remarked – *“You look at this action plan; it has everybody from the timber industry to the environmental community. It was remarkable. There's a surprising level of consensus on what needs to be done. The timber wars are largely—with some isolated examples—behind us. It took less than six months to put together a comprehensive plan that had broad-base support.”* Alternatively, if the purpose of the collaboration is to ensure that all understandings are represented to minimize future litigation or derailment, it is the minority statements that need to be focused on. One surprising finding was that more than half of the survey respondents resonated with at least one minority statement. In other words, when taken together, those seemingly extreme perspectives such as “we need to decolonize fire management” (8%) or “to the extent it is safe, we should try to stop all fires in the wildlands as soon as possible” (8%) aren’t the ideas of a select few, but rather the majority of actors.

3.5.1.2 Informing process design to take into account important distinctions and conflicts between actors' understandings

Recognizing multiple understandings may require being proactive about the distinctions and conflicts between actors' understandings. Understanding the relationship between different perspectives can inform the design of practices, ensuring a more efficient and productive project (Dewulf et al., 2009; Lewicki et al., 2003; Ozawa & Susskind, 1984). Our survey results suggest three types of differences in perspectives – conflicting, divergent, and nuanced. First, the MCA identified twelve pairs of perspectives characterizing polarized views (Table 3.6a). These areas may be better addressed through relationship building, reconciliation, and trained facilitation (Shmueli et al., 2006). A more aggregate way to examine these conflicts is through the negative association between 'Revitalize,' 'Justice,' and 'Conserve' and 'Control,' 'Work,' and 'Market' (Figure 3.2). These differences likely reflect deeper conflicts in the type of stories or ways actors make sense of the western wildfire challenges and the types of evidence they view as credible, legitimate, and salient (Chapter 2). These conflicts may not be ripe for collaboration and may be exacerbated by a reliance on evidence-based discussions (Kern & Murphy, 2022). Second, divergent perspectives (Objective 1. c) characterize substantial divisions in the way actors think about the challenge. These patterns suggest an opportunity to invest in more research or the quantification of tradeoffs (Spicer, 2004; Wara, 2021). These differences may be informed by joint fact-finding or knowledge co-production, emphasizing transdisciplinary research, place-based goals, and local knowledge (Adler & Birkhoff, 2000; Norström et al., 2020). Third are more nuanced or complementary differences. Some groups prefer to start with these less confrontational differences to build collaborative capacity (Butler & Schultz, 2019). Table 3.5c identifies nine nuanced differences in perspectives that are not mutually exclusive. For example,

should we educate the public or learn to listen to communities? Should we focus on increasing the pace and scale of fuels management or emphasize place-based solutions? Or should we invest in hotshot crews or democratize fire management? These might be productive "early wins" to support achievable objectives, create safe spaces, and establish a commitment to the group process (Leith et al., 2016).

3.5.1.3 Informing partner selection criteria to better represent understandings

Understandings are often characterized as dichotomous and polarized (Jacobson et al., 2021; Morehouse & Sonnett, 2010). However, we found actors' understandings to be highly overlapping and moderate. On average, each pair of respondents agreed on about two-thirds of the perspectives. In other words, most actors agree on most of the issues. Despite polarized views on specific perspectives (see above), all respondents agreed with at least one other respondent on the majority of perspectives. Further, while we found that two factors account for nearly half of the variation among respondents' understandings, the distribution of views along those two factors is largely moderate. Most respondents do not have strong views in terms of either one of those factors. This finding emphasizes an important opportunity for collaborative wildfire risk management practices. It suggests that actors are more alike than they might assume. These assumptions may be limiting practice. To reveal these overlaps, practices must invest time for actors to get to know each other better, i.e., relational learning.

In addition to more overlapping and moderate understandings, we found that they do not correspond with interest groups. Public discourse often connects social narratives with interest groups (Crow et al., 2017; Meppem & Bourke, 1999; Morehouse & Sonnett, 2010). For example, environmentalists are connected with the 'Conserve' narrative, fire chiefs are associated with the 'Control' narrative, and local planners are related to the 'Regulate' narrative. However, we found

no significant variation when comparing the interest groups along the two most influential factors (O.3c). As is illustrated in Figure 3.2 (PCA), actors from the same interest group were associated with substantially different understandings. This suggests that stakeholder assessments or selection by interest group is not an effective strategy if the objective is to capture the diversity of understandings. Instead, we heard directly from respondents (in our conversation and through survey open-ended feedback) and indirectly through survey results that their understandings do not fit into analyst-constructed categories. For example, we found that having respondents select a single scale, sector, or topic they work at the most was not appropriate. Instead, respondents felt it was necessary to be able to select multiple choices. This aligns with scholarship that suggests that boundaries between interest groups are blurring (Drummond & Fischhoff, 2017; Reach et al., 2021; Dunlap et al. 2016). It corresponds with what we heard in our interviews – practitioners do not associate with traditional disciplinary and sector boundaries (Chapter 2). This further aligns with previous survey research showing that perceptions about wildfire risks are mainly independent of individual or peer-group politics (Hartter et al., 2020).

3.5.2 Implications of findings for practice and scholarship

Sustainability science increasingly emphasizes practices that recognize the legitimacy of multiple understandings (Mittwede, 2012; Pohl et al., 2021; Whitaker & Fitzpatrick, 2013). There is also a growing effort to ensure respectful, just, and authentic representation of actors whose ways of knowing have traditionally been left out of environmental decisions (B. Cosens et al., 2021; Hakkarainen et al., 2022; Tengö et al., 2014). Supporting these shifts necessitate approaches that more effectively and systematically inform the inclusive selection of project partners. This research provides a step in that direction. Below we describe research limitations,

how the survey's novelty helped capture the complexity of actors' understandings and prompted dialogue and reflexivity through real-time results, and recommendations for future research.

3.5.2.1 Limitations

In designing the survey, we faced several tradeoffs that led to important limitations. First, the survey captured self-reported individual perspectives rather than people's actual perspectives or the perspectives of their affiliated organization. While self-reported data is quicker and easier to gather, it can be biased by respondents' desire to present themselves in a certain way (e.g., social desirability bias) (Perinelli & Gremigni, 2016). Second, while including both and neither selection, options created more flexibility and accuracy, it is challenging to interpret. There are multiple reasons why a respondent might decide to select both or neither statement: (1) they don't know much about a topic, (2) they think statements are too nuanced to be meaningful out of context, (3) both statements resonate, (4) neither resonate, (5) they think options are offensive or biased, or (6) they don't understand one or both of the statements. Third, the binary forced choice format was problematic for several respondents. Based on open-ended feedback in the survey, we heard that it did not reflect actors' views of the complexity of the challenge. This might have deterred some people from completing the survey and thereby biased our sample. Next, while focusing on influential actors who are not immediately visible is a novel approach to be more inclusive (Holm & Fischer, 2023), it may have resulted in a lower response rate and sampling bias in the context of an online survey (Andre et al. 2012). Similarly, the professional network (DailyDispatch) helped us reach a broader group of actors. Still, it may have introduced bias as we do not know who out of this extensive network decided to complete the survey. Lastly, since we do not fully know the population of influential actors in the western wildfire space (Babbie,

2012), we opted for a more descriptive and exploratory research design at the cost of more generalizable and predictive results.

3.5.2.2 Capturing the complexity of actors' understandings

Capturing the complexity of actors' understandings is more challenging but provides an opportunity for greater connection. Inclusivity necessitates selecting project partners that effectively represent different groups. Clear and simple distinctions between groups can facilitate partner selection. It is easier to identify and label representatives when groups are homogenous and distinct. Stereotypes reflect simplifications of actor groups that get perpetuated in casual rhetoric and more professional and academic circles. For example, suggesting that firefighters don't understand the value of fires for ecosystem function, that environmentalists don't want to see any active management in the forest, or that new residents in the wildland urban interface don't understand fire risks. However, these oversimplifications have been shown to create distance between and further polarize groups (Pew Research Center, 2014). Instead, helping seemingly opposing factions recognize a more complex pattern of connections has been shown to help establish connections and reduce polarizations (Voelkel et al., in review).

Member selection that is informed by interest groups can reduce collaborative capacity. When actors are selected to represent an interest in a specific outcome (Reed et al., 2014), it can result in a more positional zero-sum negotiation (Fisher et al., 1991). Instead, studies suggest that actors who do not strongly affiliate with an interest group are more open to learning and interacting with diverse actors (Cheng & Mattor, 2010). Our survey revealed that interest groups do not align with understandings, emphasizing the importance of changing the approach used to inform partner selection. While Western scientific analysis preferences deductive reasoning and

clear demarcations, analysis tools that capture the complexity of actors' understandings represent an important frontier for research (Bernacchi & Peterson, 2018; Daly, 2016; Tengö et al., 2014)

Social narratives are a simplification of actors' understandings. Each of the nine social narratives depicted in Chapter 2 corresponds with a set of perspectives to point to a coherent story about the causes, consequences, and solutions to western wildfire challenges. In the narratives study, we found that individuals characterize wildfire challenges by bringing together perspectives from multiple social narratives. Past narratives studies within environmental planning and policy broadly and examining wildfire perspectives specifically depict monolithic narratives (Crow et al., 2017; Meppem & Bourke, 1999; Morehouse & Sonnett, 2010). We designed the survey to collect data on the mix of narratives each respondent resonates with. We further analyzed the data to explore the relationships between different perspectives and between actors. We found that recognizing how actors connect with multiple narratives resonated with respondents. Some, though not all, respondents noted how the mix of narratives resonated with them and captured important distinctions in how they see the wildfire situation – e.g., *"I believe the results are an accurate reflection of my perspective"* And *"tough to pick between some of those statements, but it looks like it appropriately teased out how I feel about the situation based on my 30+ years of experience."*

3.5.2.3 Dialogue and reflexivity

"Thank you for the visual results. Helps me understand myself better." Survey respondent

In our review of open-ended survey feedback as well as interactions with survey respondents in a professional workshop, we saw evidence of how people's agreement, surprise, and even frustration with the survey results shifted the conversation from what is the 'right' way to address wildfire risk management to what are the multiple ways of understanding the wildfire

challenge. This is aligned with other narrative studies that suggest that, when seen side by side, contesting narratives, each positing claims of reality, get actors to question their assumptions (Meppem & Bourke, 1999).

Reflexivity, prompted by individuals seeing their own multiple narratives through the narrative wheel in the results, seemed an important and unexpected byproduct of the survey. Reflexivity is generally associated with greater self-awareness, (Armitage et al., 2011; Pahl-Wostl, 2006; West, 1996), legitimization of diverse viewpoints, and mutual understanding (Berkley & Beratan, 2021; Roux et al., 2017), increase in open dialogue (Brouwers et al., 2022; Medema et al., 2014) and increased collaborative capacity when addressing complex challenges (Bixler et al., 2022; West, 1996). Reflexivity may allow actors to compare and contrast the extent to which they share understandings with other actors (Brenkert Smith et al., 2017).

> *"We need to find ways to 'daylight' the processes that shape expert panel recommendations as well as the diverging worldviews and problem frames held by expert scientists."* (McIlroy-Young et al. 2021, pg. 32).

When considering the broader implications of this research for practice, we found that the survey was less about accuracy, i.e., getting the narratives precisely right, and more about starting a conversation about multiple understandings. Several respondents noted that the survey provides an opportunity for reflection, to help create a dialogue, to support shared learning, and inform a discussion. Identifying and characterizing diverse perspectives through social narratives can foster dialogue (Baehler & Biddle, 2018) and illuminate what perspectives might be missing or marginalized from the dominant depiction of the challenge (Kim, 2019).

3.5.2.4 Recommendations for future research

We found two aspects of the survey to be especially fruitful, comparing individual perspectives to social narratives and providing real-time results to respondents. These aspects could be expanded on in future research.

Examine the social narratives of organizations: This study examined social narratives among individuals. It would be interesting to examine the role of social narratives among organizations. For example, a document analysis could help measure to what extent organizations are promoting single (rather than mixed) social narratives, aligning with employee narratives, and aligning with their incentive structures.

Assess inclusivity of practice: This research can serve as a foundation for critically assessing the inclusion of diverse understandings among management efforts, i.e., what understandings are included in practice relative to the set of nine narratives, or to what extent are projects operating within an echo chamber? For example, future research can investigate the representation of the identified nine narratives within initiatives such as the National Wildfire Cohesive Strategy Program (USDA, 2014) or the Wildland Fire Mitigation and Management Commission (Wildland Fire Mitigation and Management Commission Act of 2021, 2021).

Test reflexivity*:* It would be informative to test to what degree taking the survey helps individuals be more critically reflective and self-aware (Savin-Baden & Van Niekerk, 2007; Tesler et al., 2018). It would be interesting to see whether taking this survey and actively reflecting on it as a group exercise facilitates greater inclusivity, openness, and collaborative capacity.

3.6 Conclusion

Differences in actors' understandings can hinder collective wildfire risk management goals (Brenkert-Smith et al., 2017). Active participation of actors with diverse understandings within collaborative practices is intended to overcome these barriers. However, practice is often criticized for failing to capture a sufficient diversity of views (Chambers et al., 2022; Goldman et al., 2018; Jagannathan et al., 2020). To address complex socio-ecological challenges more effectively, conveners need more systematic and pragmatic approaches to determine what a sufficiently inclusive representation might look like. In this investigation, we sought to quantify the distribution and relationship between influential actors' understandings of western wildfire challenges. Overall, we found that when it comes to western wildfire, actors' understandings are highly complex, differences in perspectives are often nuanced, and under the surface of a few conflicting perspectives, actors may be more alike than depicted. Our findings challenge widespread assumptions about actors' understandings of western wildfire challenges and, more broadly, the efficacy of common approaches to capture the spectrum of diverse understandings in a population. This research contributes to scholarship by capturing the complexity of actors' understandings and prompting dialogue and reflexivity through real-time results.

Chapter 4 Resilient Team Cognition: A Cognitive Model of Team Learning to Support Transdisciplinary Knowledge Co-Production

4.1 Introduction

To address our most pressing and complex sustainability challenges, practice is increasingly turning to knowledge co-production among transdisciplinary teams (Brandt et al., 2013; Harris & Lyon, 2014; Lang et al., 2012; Nowotny et al., 2001; Plummer et al., 2022). Sustainability scholars have theorized that traditional linear knowledge production modes, whereby research is intentionally separated from practice, are insufficient to address the complexity, uncertainty, and seeming intractability of contemporary sustainability challenges (Bremer & Meisch, 2017; Curtin, 2014; Lemos & Morehouse, 2005; Norström et al., 2020). Instead, knowledge co-production emphasizes participatory and collaborative processes to "*iteratively unite*" (Wyborn et al., 2019, p. 320) diverse understandings or ways of knowing among actors from both research and practice. These processes are expected to result in more actionable knowledge (Arnott et al., 2020; Mach et al., 2020) and more just and sustainable outcomes (Brugnach & Ingram, 2012; Caniglia et al., 2023; Miller & Wyborn, 2018). In this paper, we unpack what it means to iteratively unite diverse understandings. This concept is nearly ubiquitous in normative characterizations of knowledge co-production; however, inconsistently interpreted and rarely addressed in practice.

We propose that iteratively uniting diverse understandings refers to a combination of two team learning functions. Integrative learning is a process whereby multiple or diverse understandings are combined or harmonized to support a shared understanding of the challenge.

Iterative learning is a process whereby collective understandings are challenged, informed, and adapted to new knowledge. These two team learning functions – albeit under numerous titles and conceptualizations – are cited as core principles of knowledge co-production (Armitage et al., 2008; Mach et al., 2020; Norström et al., 2020; Wyborn et al., 2019; Zurba et al., 2022). However, as with other normative principles of knowledge co-production, there may be a significant mismatch between scholarship and practice (Djenontin & Meadow, 2018; Jagannathan et al., 2020; Mach et al., 2020). Unfortunately, past evidence suggests that a large segment of the diversity in team knowledge fails to be recognized, shared, and harnessed among team members (Brugnach & Ingram, 2012; Jagannathan et al., 2020; Mach et al., 2020; Mohammed et al., 2021).

We identify two knowledge gaps associated with integrative and iterative team learning in transdisciplinary knowledge co-production (hereafter, KCP) (Box 4.1). First, it is not clear to what extent teams are even pursuing both learning functions. If teams are pursuing integrative and iterative team learning, it is unclear what it looks like in practice, i.e., how these concepts are being interpreted. If integrative and iterative team learning is an "imprecisely defined concept that inevitably falls short of meeting its own standards" (Mach et al., p42), there should be substantial implications for changing KCP theory and funding. Second, it is unclear to what degree teams successfully sustain both learning functions in practice. If teams are pursuing integrative and iterative team learning but are unsuccessful, i.e., it represents a critical yet very high bar for practice, then pursuing integrative and iterative learning earnestly may require a substantial shift in attention, facilitation, and incentives. If teams are successful, i.e., KCP has 'cracked the nut,' there are critical lessons to be learned that are well worth documenting. Insights extend far beyond KCP as team science, organizational science, and social psychology

have been grappling with this challenge for a long time (March, 1991; Raisch et al., 2009; Smith & Lewis, 2011; Uitdewilligen et al., 2010). However, while there has been an increase in evaluations of KCP in the last decade, they do not look at integrative and iterative team learning. A major limitation to evaluating team learning within KCP practices is a lack of conceptual clarity. Before scholars and practitioners can engage in a meaningful conversation about these knowledge gaps and their implications for transdisciplinary knowledge co-production, there is a need to conceptualize what integrative and iterative team learning entails.

Box 4.1 What is transdisciplinary knowledge co-production?

Knowledge co-production refers to a collaborative and interactive strategy to construct knowledge that is more place-based and action-oriented by intentionally bringing together actors with a plurality of understandings (Armitage et al., 2011; Jagannathan et al., 2020; Norström et al., 2020). In this paper, we discuss transdisciplinary knowledge co-production practices, a subset of knowledge co-production approaches characterized by (1) a team of scientists from multiple disciplines, as well as non-scientists (e.g., practitioners, local community members, decision-makers), (2) who integrate their diverse expertise and methods, (3) engage iteratively to incorporate new ideas and evidence responding to dynamic and uncertain systems, and (4) produce emergent and transformative understandings that transcend the boundaries of individual understandings.

Sustainability science does not have a language for characterizing team learning and cognitive change. Representing the processes and structures associated with integrative and iterative team learning falls squarely in the domain of team science, particularly team cognition. Scholarship in team science suggests that the capacity to support integrative and iterative team learning is largely explained by the structure of team cognition, i.e., the pattern by which knowledge is organized, represented, and distributed within the team (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2021). Teams with a more shared mental model (e.g., more similarity, overlap, and redundancy in how actors conceptualize the problem and how it should

be addressed) have been shown to support a greater capacity for integrating knowledge (Mohammed et al., 2017). Teams with a more distributed team transactive memory system (e.g., diverse cognition, greater awareness of who knows what on the team) have been shown to support a greater capacity for challenging, differentiating among, and transforming understandings in response to new knowledge (Grand et al., 2016; Heavey & Simsek, 2017; Uitdewilligen et al., 2010). Insights about team cognitive structure could help inform our understanding of integrative and iterative team learning within a co-productive practice. Conversely, the complex and adaptive nature of KCP presents a great case study for team science. However, despite numerous analogous interests, the two fields remain largely isolated.

This insight paper offers a perspective on what integrative and iterative team learning in KCP practice entails. We first present a synthesis of the literature in sustainability science to characterize the aspirational ways in which integrative and iterative team learning are being portrayed, i.e., where the bar is being set. We explain why interactive and iterative team learning is very challenging, i.e., why it is a very high bar. We provide a short primer on team cognitive structure and what team science literature suggests about its relationship to team learning. We then introduce the construct of resilient team cognitions (RTC) to suggest what it might look like, in terms of team cognitive structure, to support integrative and iterative team learning. We discuss four factors supporting RTCs: awareness, incentives, facilitation, and cognitive perturbation. We close with a summary of the scope and significance of this framework for knowledge co-production practice.

4.2 Background

4.2.1 Transdisciplinary knowledge co-production practices

Knowledge co-production is a direct response to the failure of conventional science-policy models premised on the idea that more accurate or technical knowledge, placed in the right hands, will be used to inform effective decision-making (Cash et al., 2003; Muñoz-Erickson, 2014a). Instead, knowledge co-production practices emphasize bi-directional ties between science and practice to make knowledge more actionable (Hakkarainen et al., 2022; Knapp et al., 2019; Lemos & Morehouse, 2005; Nowotny et al., 2001). Knowledge co-production processes are generally embedded within a larger set of collaborative environmental governance practices to address complex sustainability challenges. Practices in which teams co-produce knowledge to address complex sustainability challenges vary greatly in interpretation and intention. For example, national-level advisory teams, like the Wildland Fire Commission, that inform policy (Wildland Fire Mitigation and Management Commission Act of 2021, 2021); regional adaptive co-management teams, like the Collaborative Forest Landscape Restoration's Four Forest Initiative that collaboratively manage shared resources (Butler & Schultz, 2019); community-based research teams that connect research to action to address local environmental justice issues and joint fact-finding teams that resolve state-level knowledge-intensive controversies (Chambers et al., 2021; Hakkarainen et al., 2022; Jagannathan et al., 2020; Knapp et al., 2019).

Several review articles have summarized important differences among KCP practices, capturing "when is co-production co-production?" (Mach et al., 2020, pg. 31; Chambers et al., 2021; Meadow et al., 2015). As we describe integrative and iterative team learning, we recognize that there are no 'one-size-fits-all' guidelines for practice. Team learning looks different

depending on the project context and resources. We intend to put forth a model of what integrative and iterative team learning looks like that is, to our best ability, grounded in the established aspirations of KCP scholarship. However, while KCP is commonly depicted as a 'gold standard that is growing in popularity (Lemos et al., 2018; Mach et al., 2020), the normative aspirations we describe are uncommon in practice (Box 4.2). We intend for this model to spark a conversation about how scholars and practitioners interpret team learning to begin addressing this mismatch.

4.2.2 Team learning in knowledge co-production practices, where is the bar set?

Scholarship on collaborative and adaptive environmental governance has long conceptualized integrative and iterative team learning aspects. Most commonly, social learning describes the process of iterative action, reflection, and deliberation of individuals and groups engaged in sharing experiences and ideas to resolve complex sustainability challenges collaboratively (Ernst, 2019b; King & Jiggins, 2002; Lee, 1993; Muro & Jeffrey, 2008). However, also influential are double (and later triple) loop learning, emphasizing learning that challenges not only the strategies and actions taken but also the underlying assumptions and mental models guiding those decisions (Pahl-Wostl, 2009; Steger et al., 2021), collaborative learning (Daniels & Walker, 2001), shared learning (Caniglia et al., 2021), and adaptive learning (Armitage et al., 2008).

Box 4.2 What role does transdisciplinary knowledge co-production have in practice?

Over the past two decades, there has been a proliferation of interest in knowledge co-production in both academia and practice (Chambers et al., 2022; Lemos et al., 2018; Mach et al., 2020; Tedim et al., 2021; Wyborn et al., 2019). However, it would be misleading to suggest that knowledge co-production, especially in how it is represented in scholarship, is a dominant practice influencing environmental decision-making on the ground. Since the establishment of the National Environmental Policy Act (NEPA) in 1970, there has been a growing focus on environmental decision-making based on scientific evidence or best available science (Colavito, 2017). However, realistically scientific information, evidence, and knowledge constitute one of the numerous factors considered when making decisions about environmental policy and management (Butler & Schultz, 2019; Colavito, 2017). Decision-making teams must work within existing regulations, technical considerations, sociocultural and political inputs, and economic constraints (Arnold et al., 2017). When science informs environmental decision-making, it generally comes from traditional, disciplinary, directional, peer-reviewed publications (Hunter et al., 2020; Nowotny et al., 2001). Over the last decade, knowledge co-production has proliferated as a 'gold standard' for practice shifting funding and research interest towards constructing more actionable knowledge (Lemos et al., 2018). As interest has grown, so has the scope of what knowledge co-production is and what it ought to be. The boundaries between practices such as joint fact-finding, social learning, participatory action research, collaborative adaptive management, and transdisciplinary research have blurred, encompassing broader definitions and interpretations (Brandt et al., 2013). Different KCP practices are necessary for different research or management questions, decision-making contexts, and available resources and skills (Meadow et al., 2015). Furthermore, collaborative and participatory knowledge production is not always necessary, practical, or feasible (Lemos et al., 2018). A growing set of critiques suggests that knowledge is not genuinely being co-produced (Jagannathan et al., 2020; Mach et al., 2020; Meadow et al., 2015). Instead, the interaction between scientists and practitioners is fairly superficial, dominated by contractual or consultative modes rather than collaborative or collegial modes (Meadow et al., 2015; Pregernig, 2014). Among more deliberative and authentic KCP projects, the emphasis has been largely on knowledge integration rather than the recognition and legitimization of multiple ways of knowing or understandings (Chambers et al., 2021; Norström et al., 2020). This limitation reflects pragmatic challenges; for example, many actors don't have resources or incentives to be equal partners in producing knowledge (Wall et al., 2017), as well as epistemic challenges from trying to work across different disciplinary standards (Miller et al., 2008). Several critiques suggest that practices perpetuate rather than overcome power inequities between Western science and indigenous knowledge systems (Armitage et al., 2011; Latulippe & Klenk, 2020; Tengö et al., 2014). From the limited set of projects that are explicitly aiming for transdisciplinary KCP that integrates knowledge between researchers and non-academic partners, still, fewer are suggesting supporting long-term adaptive learning whereby partners respond to new insights and challenge their collective understandings of what the problem is and how it ought to be addressed. KCP practices aiming to address systemic structural changes and deeper cognitive reframing of shared understandings represent a minority of cases (Chambers et al., 2021).

More recently, literature in KCP has emphasized integrative and iterative team learning as core principles in practice. For example, “the creation of iterative and inclusive processes, which allow for the development of common ground and trust while building new capacities to address complex problems and ultimately, enhancing the usability of scientific information beyond the academy” (Wyborn et al., 2019) or “to optimize the potential for successful knowledge co-production, scholars recommend reflexive and iterative engagement with ILK holders throughout all stages of knowledge co-production cycles” (Zurba et al., 2022, p457).

4.2.2.1 Integrating multiple understandings

An essential tenet of KCP practice is collaboration through the integration of multiple and diverse understandings to support more inclusive and wise agreements about how to manage the landscape, inform policy, produce knowledge, or allocate funds. “Integration is defined as the extent to which a team combines its distinct expertise and work into a unified whole” (Balakrishnan et al., 2011, p.2, as cited by Salazar et al., 2012). It may include bringing together, harmonizing, reconciling, or connecting between multiple understandings (Box 4.3). Integration reflects a movement from divergent to convergent thinking, from exploring multiple understandings towards alignment and cognitive closure that emphasizes shared or collective understandings (Boon et al., 2014; March, 1991; Paletz & Schunn, 2010). While often the relationship between integrative learning and shared understanding is not made explicit, the construction of shared understanding is an essential feature of knowledge co-production (Armitage et al., 2011; Bezerra et al., 2023; Ernst, 2019b; Glenn et al., 2022; Wall et al., 2017).

4.2.2.2 Iterating among multiple understandings

KCP scholars further recognize the dynamic and uncertain nature of complex socio-ecological systems (Folke et al., 2003). Extending from that, another tenet is that sustaining

Box 4.3 Integrative learning in wildfire risk management

The Collaborative Forest Landscape Restoration Program (CFLRP) is a policy tool that competitively allocates ten years of funding to collaboratively plan, implement, and monitor projects to reduce wildfire risks (Schultz et al., 2021). It represents "one of the most innovative and significant forest policy experiments to take place in recent decades" (Schultz et al., 2012, pg. 382). The program intentionally brings together actors with diverse perspectives and interests. For example, recognizing paradigmatic tensions, project teams generally include both timber industry and forest ecologists (Schultz et al., 2021). However, a central task of CFLRP collaboratives is to produce knowledge that reflects shared understandings among project partners to inform decision-making by the USDA Forest Service (Urgenson et al., 2018). Research suggests that figuring out conflicting viewpoints represents the most significant obstacle to knowledge production (Colavito, 2017).

ongoing flows of information and reflexivity allows for the possibility of new insights, ideas, discoveries, or developments to be identified and considered (Hakkarainen et al., 2022). Iterative learning reflects a process of acquiring knowledge or skills through repeated cycles of learning, practice, reflection, and refinement (Kolb, 1984). Adaptive teams remain flexible, responsive, innovative, and open to change (Burke et al., 2006; Grote et al., 2018; Zajac et al., 2014) (Box 4.4). They don't just co-produce knowledge; they repeatedly come back and challenge their assumptions to update their understandings of the challenge (Cosens et al., 2021; Meadow et al., 2015). Iteration reflects a movement from convergent to divergent thinking, a cognitive opening whereby shared understandings or assumptions are challenged, differentiated, or dismantled into multiple understandings (Holling, 1996; Leeuwis et al., 2002; Pahl-Wostl, 2006; West, 1996). Evidence from co-production practices addressing water and land management challenges demonstrates that groups that challenge assumptions without constructing shared understandings fail as they miscommunicate and impede progress, while groups that construct shared understandings without challenging assumptions fail as they dismiss changing conditions (King, 2000; Pahl-Wostl, 2006). In other words, both integrative and iterative team learning is necessary to support knowledge co-production.

Box 4.4 Iterative learning in wildfire risk management

The Alaska Fire Science Consortium (AFSC) represents a boundary organization focused on co-production of actionable fire science and management knowledge (Colavito et al., 2019). Wildfire risk management is rapidly changing due to both unprecedented changes in socio-ecological factors shaping risk (Westerling et al., 2006) and paradigmatic shifts in societal understandings of the risk (Colavito et al., 2019; Schultz et al., 2019; Ingalsbee, 2017). The AFSC emphasizes a bi-directional long-term relationship between scientists and actors (Colavito et al., 2019). The collaboration was designed with built-in evaluation and feedback to support iterative learning. Over their time together, the consortium increased their collective knowledge of wildfires and shifted their model to emphasize new research needs and co-produce new knowledge. ‘‘The fire management community had gotten to a place and time where they were starting to think critically about how the fire regime might be changing’’ (Colavito et al., 2019, pg. 923).

4.2.3 Supporting both integrative and iterative team learning, a very high bar

Teams addressing complex challenges contend with numerous difficulties due to the nature of knowledge, conflicting interests, and limited resources (Daniels & Walker, 2001; Lemos et al., 2018; Slater & Robinson, 2020). Integrative and iterative team learning may present another substantial barrier to overcome (Armitage et al., 2008; Cooke et al., 2013). The support of integration and iteration requires overcoming substantial obstacles (Allen & Gunderson, 2011; Berkes, 2009; Smith & Lewis, 2011). Balancing or sustaining both functions entails an inherent paradox or socio-cognitive tension (Armitage et al., 2008; Boon et al., 2014). Outside of sustainability science, this tension represents a well-recognized socio-cognitive challenge (e.g., in organizational science, exploration-exploitation (March, 1991; Smith & Tushman, 2005), flexibility-efficiency (Adler et al., 1999), agreement-disagreement (Fiol, 1994), in deliberative democracy - consensus-dissensus (Landemore & Page, 2015); social groups - cohesion-differentiation (Belzung et al. 2016); self-determination-security (Peters & Waterman, 1982), and interdisciplinary science teams - divergence-convergence (Paletz & Schunn, 2010; Salazar et al., 2012).

Integrating diverse types of knowledge to construct collective understandings is a difficult proposition for transdisciplinary teams (Salazar et al., 2012). An institution's desire for stability and progress can create a path dependency and inertia that favors the status quo and overlooks critical evidence (Argyris & Schön, 1980). Decision-makers seldom examine the underlying assumptions or seek alternative explanations or solutions (Curtin, 2014). Getting members to be responsive to novel ideas has proven among the most challenging competencies to achieve through deliberative efforts (Meppem & Gill, 1998). While there is significant tension in challenging collective understandings, the real difficulty may come from sustaining both learning processes, i.e., re-engaging with the tension throughout the process (Boon et al., 2014; Muñoz-Erickson et al., 2017; Voß & Kemp, 2006). Team members are motivated to sustain their shared reality with others (captured in terms including cognitive tunneling, groupthink, and conformity) (Hodgkinson & Healey, 2008; Matz & Wood, 2005; Uitdewilligen et al., 2010). This motivation leads to cognitive rigidity through reduced flexibility and responsiveness, which impedes team learning (Argyris et al., 1985; Edmondson, 1999; Salas et al., 2010). Deeply uncertain or wicked environmental challenges may exacerbate these tensions as boundaries are equivocal and contested, making it challenging to validate accurate knowledge claims and to define success (Kwakkel et al., 2016).

4.2.4 Evaluating integrative and iterative team learning in knowledge co-production practices, are we meeting the bar?

> *"Despite high expectations, team learning processes in sustainability appraisals are poorly conceptualized and empirically understudied"* (Garmendia & Stagl, 2010, pg. 1712)

Supporting integrative and iterative team learning represents a very high bar for KCP teams. However, it needs to be clarified to what extent teams are meeting it. Numerous scholars have claimed that there is a lack of assessments of the extent to which KCP practice is meeting its own normative aspirations in general (Bergmann et al., 2017; Jagannathan et al., 2020; Lang et al., 2012; Mach et al., 2020). Complicating this limitation is a lack of common principles and criteria for guiding evaluations (Belcher et al., 2016). In terms of team learning in particular, scholars have claimed that team learning is largely unsubstantiated in practice (Armitage et al., 2008; Fazey et al., 2007; Folke et al., 2003; Mascarenhas et al., 2021; Reed et al., 2014; Wollenberg et al., 2000). There is insufficient monitoring of team learning (Armitage et al., 2009; Berkley & Beratan, 2021; Cundill & Fabricius, 2009; Fernández-Giménez et al., 2019). Evaluations of team learning in practice are largely implicit or poorly documented (Belcher et al., 2016; Ernst, 2019b; Garmendia & Stagl, 2010). Furthermore, documented evaluations of team learning are conceptually loose and limited (Ernst, 2019b; Lebel et al., 2010; Soto et al., 2021).

At the heel of these claims, there has been substantial growth in interest and effort to evaluate KCP practices and to evaluate team learning more explicitly. Over the past two decades, important contributions to improving the evaluation of team learning include a dozen systematic literature reviews (see in particular Chambers et al., 2022; Djenontin & Meadow, 2018; Ernst, 2019b; Fazey et al., 2014; Lang et al., 2012; Wall et al., 2017), over fifty empirical studies that explicitly examine team learning, and over 20 theoretical frameworks to inform practice (Appendix G). However, our review of these publications, reveals scant explicit evidence of (1) team-level psychological change (i.e., team learning as an emergent phenomenon), (2) integration of multiple understandings (i.e., a convergence of ideas, the construction of shared or

mutual understandings), or (3) differentiation among multiple understandings (i.e., a divergence between ideas, challenging individual or team-level assumptions). Notable exceptions include Soto et al., (2021), who use a combination of fuzzy cognitive maps and social networks to quantify socio-cognitive change, and Mascarenhas et al. (2021), who qualitatively analyze the learning process. A systematic review of the evaluation of team learning in sustainability practices is beyond the scope of this chapter but represents an important research direction. A major limitation to evaluating group cognitive change within KCP practices is a need for conceptual clarity about what group cognitive change looks like. Outside of sustainability science, team science has been grappling with this question for a long time.

4.2.5 Team cognition and its relationship to team learning

Literature in team science can provide insight into the features that characterize and the factors that facilitate team learning in knowledge co-production practices (Boon et al., 2014; Dewulf et al., 2020; Palmer et al., 2016; Stokols et al., 2008; Tebes, 2018). Team cognition has been shown, practically, theoretically, and empirically to have a critical role in mediating team learning processes (Mohammed et al., 2021; Tindale & Sheffey, 2002). Team cognition characterizes both the processes and representations of the degree of convergence of knowledge shared among team members (Mohammed et al., 2021). It further shapes how team members anticipate and execute actions and therefore strongly regulates team performance outcomes, including learning (DeChurch & Mesmer-Magnus, 2010; Giannoccaro et al., 2018).

4.2.6 Team cognitive structure

The structure of team cognition, i.e., the pattern by which knowledge is organized, represented, and distributed within the team, has been shown to have an important relationship with team learning (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2021). Team cognitive structure is often represented in terms of one of two representations, team mental models (TMM) and team transactive memory models (TMS) (Mohammed et al., 2021). The major distinction between the two constructs centers on whether the knowledge is held in common by team members (i.e., a shared team mental model) or largely distributed among team members (Kozlowski, 2018). TMM emphasizes more cognitive consensus, more agreement or overlap, and a greater density of network closure and redundant connections. Alternatively, TMS emphasizes more cognitive diversity, a collective awareness of who knows what on the team, and greater modularity in network structure (Table 4.1) (DeChurch & Mesmer-Magnus, 2010). Team cognitive structure both emerges from and mediates team learning (Grand et al., 2016; Marks et al., 2001; Mohammed et al., 2021). However, empirical evidence suggests that TMM and TMS have different relationships with integrative and iterative learning (DeChurch & Mesmer-Magnus, 2010).

Table 4.1 Structural features of shared team mental models and distributed transactive memory systems

Element	**Team mental models**	**Transactive memory systems**
Degree of convergence	Cognitive consensus	Cognitive diversity
Type of connection	Agreement	Awareness
Network structure	Closed and redundant	Open and modular

4.2.6.1 Integrative learning and shared mental models

Research suggests a reinforcing relationship between TMM and integrative learning (Marks et al., 2001) (Figure 4.1). Integrative learning, whereby team members identify and combine similar contributions or knowledge, generates more shared mental models through the dominance of one mental model over another or the co-production of a collectively agreed upon mental model (Klimoski & Mohammed, 1994). This process reflects the convergence of thinking, a variance-minimizing mode towards a narrower and more overlapped set of perspectives (Mannix & Neale, 2005). The resultant TMM captures consensual and common aspects of the team (DeChurch & Mesmer-Magnus, 2010; Heavey & Simsek, 2017; Kozlowski & Klein, 2000).

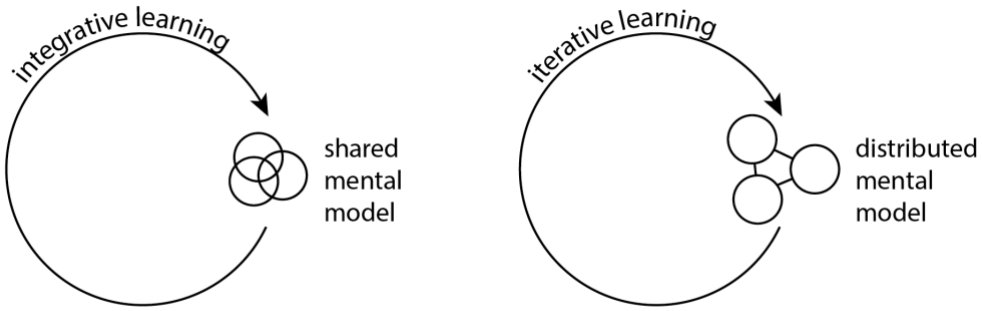


Figure 4.1 Reinforcing relationship between team learning and team cognitive structure.

Reciprocally, shared team mental models facilitate integrative team learning. Greater consensus and agreement and more cognitive connections help teams communicate, coordinate, and enhance the efficiency and execution of plans (DeChurch & Mesmer-Magnus, 2010; Grand

et al., 2016; March, 1991). This, in turn, improves their capacity to integrate knowledge (Cannon-Bowers & Salas, 2001; Gorman et al., 2007).

4.2.6.2 Iterative learning and distributed team models

Team transactive memory systems (TMS) emphasize an awareness of other members' knowledge, i.e., 'who knows what' on the team (Uitdewilligen et al., 2010; Wegner, 1987). Instead of an overlap in understandings, TMS leverage the division of cognitive labor in a team with respect to encoding, storing, and retrieving knowledge from different domains (Lewis et al., 2007). Team transactive memory systems emphasize a divergence of thinking, which maximizes cognitive variance (Kozlowski & Klein, 2000; Mannix & Neale, 2005; Mohammed et al., 2010) through specialization (Wildman et al. 2014) and networked connectivity (DeChurch & Mesmer-Magnus, 2010).

Research also suggests a reinforcing relationship between TMS and iterative learning. Successive series of iterative learning cycles, in which team members' unique understandings and knowledge are differentiated and elaborated on in complex ways, form novel configurations of knowledge that are distinct from the cognitive properties of individuals (DeChurch & Mesmer-Magnus, 2010; Heavey & Simsek, 2017). Reciprocally, greater cognitive diversity, awareness, and an open and modular network structure facilitate the development and exchange of unique and nonoverlapping knowledge rather than shared and possibly redundant knowledge, i.e., iterative learning (Gruenfeld & Hollingshead, 1993; Zajac et al., 2014). Therefore, TMS facilitates challenging collective assumptions, experimentation, and responsiveness to critical evidence (DeChurch & Mesmer-Magnus, 2010; Heavey & Simsek, 2017; March, 1991).

4.2.6.3 Supporting both integrative and iterative team learning through team cognitive structure

Transdisciplinary teams need to co-produce knowledge more effectively while remaining open to new knowledge (Wyborn et al., 2019). To do so, members need to both harmonize diverse and often conflicting understandings to reach an agreement about collective action *and* respond to uncertain and dynamic changes in understandings. As both integrative and iterative team learning are necessary to support sustainability practices, both shared team mental models and distributed team transactive memory systems are needed to support team learning. Historically, the two cognitive representations have been studied independently, though recent work has conceptually integrated across the various constructs and models to leverage their intersections (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2021). However, empirical studies have not combined multiple forms of team cognition (Uitdewilligen et al., 2010), limiting their relevance to complex functions such as those needed by transdisciplinary teams engaged in knowledge co-production (Mohammed et al., 2021).

To support integrative and iterative learning, we propose that teams need a cognitive model that accommodates dynamic structural changes between a more shared mental model and a more distributed transactive memory system. Due to their reinforcing attributes, models of team cognition have traditionally been characterized as emergent stable states (Bourbousson et al., 2011; Cronin et al., 2011; Mathieu et al., 2017; Rosas, 2017; Wildman et al., 2012). However, complex decision-making requires teams to destabilize collective understandings (Curtin, 2014; King & Jiggins, 2002). Despite a growing emphasis on team adaptation and change (Cronin et al., 2011; Grand et al., 2016; Kozlowski & Klein, 2000; Mathieu et al., 2017; Ramos-Villagrasa et al., 2018; Zajac et al., 2014) we could not find any models explaining the dynamic structural

changes necessary to move between the integration of and iteration between multiple understandings among team members.

4.3 Resilient team cognition

We offer a perspective on a resilient team cognition model (RTC) to characterize what it might look like (in terms of team cognitive structure) to support integrative and iterative learning. Teams with a resilient team cognition can accommodate dynamic structural changes between a more shared team mental model and a more distributed transactive memory system necessary to support team learning within knowledge co-production practices. Like other resilient systems, RTC can undergo disturbance and maintain its functions and controls as it is sustained by both cohesion and change (Folke et al., 2003; Holling, 1973). Teams with RTC can recognize novel and critical evidence that challenges prior assumptions about the problem or solution space, even when it requires them to dismantle the significant progress they have made.

Below, we synthesize across scholarship in sustainability science and team science to characterize what a RTC might look like in terms of the three features of team cognitive structure (content diversity, type of connections, and network structure). In the subsequent section, we discuss four factors that support RTCs, awareness, incentives, facilitation, and cognitive perturbation.

4.3.1 Features of a resilient team cognition

The adaptive cycle provides a useful heuristic for thinking about the ongoing structural changes necessary to support integrative and iterative learning (Figure 4.2). Resilient team cognition supports integrative and iterative learning through two structural transitions. Along the front loop (orange), teams engage in integrative learning and move from the initial exploration of multiple understandings (e.g., brainstorming) toward greater alignment of knowledge, shared understandings, and cognitive closure. This process aligns with a structural change from low connectivity and cognitive diversity to greater connectivity and greater cognitive consensus, i.e.,

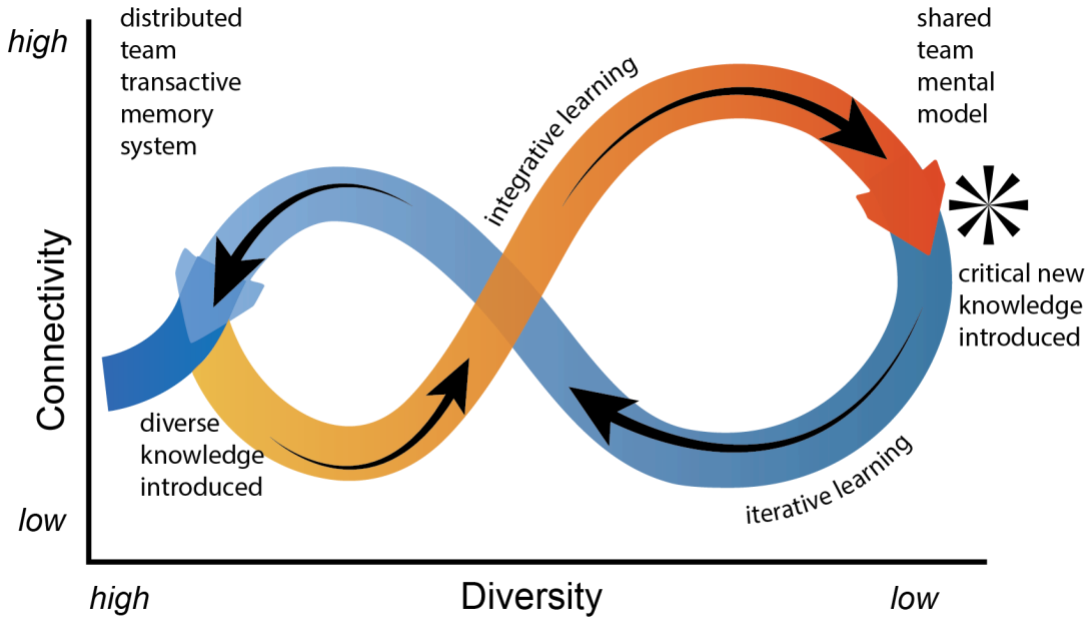


Figure 4.2 The adaptive cycle of resilient team cognitions

Teams with a resilient team cognition accommodate structural change from a shared mental model to a distributed transactive memory system. In the front loop (orange), teams support integrative learning to move from disconnected multiple understandings to a shared understanding. However, when critical knowledge is introduced, teams challenge their assumptions, release their connected cognitive structure, and explore new ideas. In the back loop (blue), teams differentiate and elaborate in complex ways, resulting in new multiple understandings. Teams with a resilient team cognition can recognize novel and critical evidence that challenges prior assumptions about what the problem or solution space looks like, even when it requires them to dismantle the significant progress they have made.

a shared team mental model. Along the back loop (blue), teams engage in iterative learning and move from the conservation and cohesion of shared understandings towards challenging assumptions and greater differentiation among understandings. A cognitive opening or release changes the team's cognitive structure from redundant and shared to a more diverse and distributed team transactive memory system.

4.3.1.1 Content diversity: Balance between cognitive diversity and consensus

Teams are more likely to be able to engage in integrative and iterative team learning if they are balanced in terms of the diversity of their knowledge (Figure 4.3). Diversity is promoted to support innovation and adaptation (Mannix & Neale, 2005; March, 1991; Page, 2007). In complex and dynamic contexts, cognitive diversity may also increase accuracy and robustness

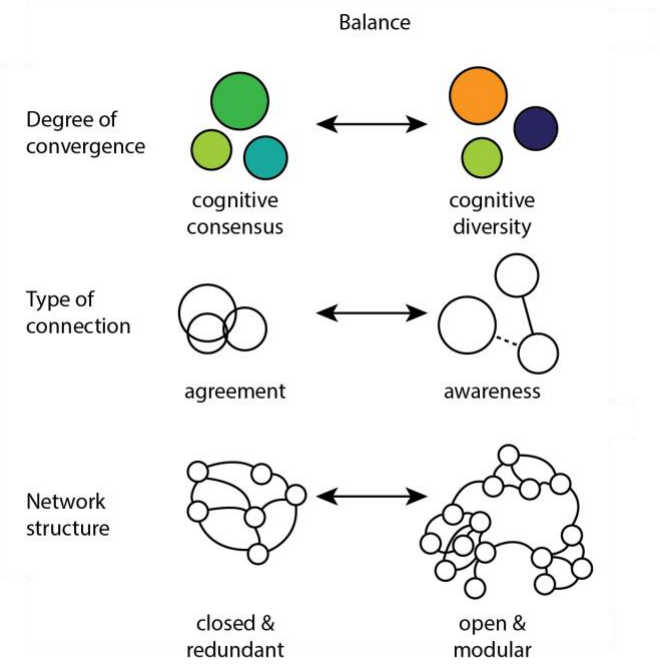


Figure 4.3 Features that characterize a resilient team cognition

(Page, 2010), innovation, and creativity (Boon et al., 2014) and provide necessary insurance for uncertainty and surprise (Low et al., 2002). However, too much diversity can breed miscommunication (Boon et al., 2014), disjoint action (Wagemans, 2002), as well as outright conflict (Cockburn et al., 2019). Sufficient cognitive consensus, i.e., the similarity among team members' knowledge (Mohammed & Ringseis, 2001), is necessary to provide a common ground for discussion and action (Ernst, 2019b; Mohammed & Ringseis, 2001; Van Kerkhoff & Lebel, 2006) (Box 4.5).

Box 4.5 Balancing cognitive diversity in wildfire risk management.

The current dominant narrative for understanding wildfire challenges in the western U.S. emphasizes a shift from a 'war on fire' to 'living with fire' (Tedim et al., 2021). This narrative aims to be both inclusive of multiple ways of knowing while embodying a coherent set of assumptions and (Goldstein & Butler, 2009). The Fire Learning Network reinforces and transmits these ideas while not imposing any values and prescriptions at a site level (Goldstein & Butler, 2009). However, as an influential actor suggested, *"If we really push down to that fundamental assumption, is fire good or fire bad, should we be using fire actively, I have trouble wrapping my head around how we can really co-produce with someone who has a perspective of no, the 10 am policy is right, we need to eliminate and fight fire. I just don't see any evidence that that's a good perspective"* (Russo et al., in prep). A balance was struck between lower-order cognitive diversity among interests, specializations, and scales with a high-order cognitive consensus about promoting 'good fire' for ecological restoration and wildfire management.

When addressing complex sustainability challenges, the type or scale of cognitive diversity matters. Evidence suggests the importance of more agreement on higher-order dimensions and more differences among lower-order dimensions of the problem. Higher-order dimensions include overarching goals (Cockburn et al., 2019; Daniels & Walker, 2001), problem framing (Pahl-Wostl, 2006; Schäfer et al., 2016), focal issue (Ansari et al., 2013), meta-agreements, meta-consensus (Dryzek & Niemeyer, 2006), or cohering logic (E. P. Weber & Khademian, 2008). Agreement on higher-order dimensions is especially important when facing highly contentious and deeply uncertain challenges (Enserink et al., 2013). Lower-order

dimensions include strategic positions, specialized knowledge, and local experiences. Evidence from practice addressing complex sustainability challenges suggests that it is within these lower-order dimensions that cognitive diversity is essential (Cooke et al., 2013; Salmon et al., 2010).

There is a temporal component to balancing cognitive diversity as well. Literature suggests that more cognitive diversity is needed at the beginning of a process, and more consensus is needed at the end (Mohammed & Ringseis, 2001). However, for teams needing to engage in iterative learning, that cycle needs to continue, i.e., the end of one cycle marks the beginning of the next (Paletz & Schunn, 2010; Salazar et al., 2012; Uitdewilligen et al., 2010). Teams need to maintain sufficient cognitive diversity to remain open to not only outcomes of actions (e.g., adaptive management) but changes to the environment and novel ideas (Armitage et al., 2008).

4.3.1.2 Type of connection: Balance between agreement and awareness

Two types of connections characterize how team members 'share' their knowledge. First is agreement, i.e., an overlap in members' thinking. This is often referred to as shared understanding or common ground. Second is awareness, i.e., team members distribute, discuss, or disseminate knowledge (Cannon-Bowers & Salas, 2001). Other members don't necessarily agree with it, but they become aware of it. Teams need a balance of both agreement and awareness.

The construction of shared understandings is the most well-known approach to team learning (Converse et al., 1991) and the most well-cited norm of environmental governance (Ansell & Gash, 2008; Muro & Jeffrey, 2008). Substantial knowledge production performance benefits are associated with groups whose members overlap in their understandings (Cannon-Bowers & Salas, 2001; Wildman et al., 2012). Shared understandings facilitate interpreting,

describing, predicting, coordinating, and communicating knowledge among members (Cannon-Bowers & Salas, 2001; Mathieu et al., 2008; Mohammed et al., 2010). However, shared understandings have a 'dark side' within the context of complex decision-making (Gargiulo & Benassi, 2000; Kallis et al., 2009; Klimoski & Mohammed, 1994). The benefits of shared understandings under stable and predictable contexts may unintentionally hinder challenging assumptions under dynamic and unpredictable conditions(Uitdewilligen et al., 2010). Teams with extensive overlap in mental models may overlook, neglect, or dismiss novel, critical, or disconfirming evidence (Daniels & Walker, 2001; Emerson et al., 2012; O'Connor & Weatherall, 2019). Furthermore, in highly contested spaces, the construction of shared understandings is unlikely to result in equitable and sustainable landscape stewardship (Cockburn et al., 2019).

Agreement is not always necessary. Mutual understandings refers to members' ability to recognize and respect the understandings of other members, even if they do not agree with (or share) those understandings (Emerson et al., 2012). Mutual understanding may produce high levels of empathy and trust, which supports clear communication (Alliger et al., 2015; Cash et al., 2003; Innes & Booher, 1999) and motivates ongoing collaboration (Emerson et al., 2012). Transactive memory is another example of awareness. Here, team members become aware of other team members' knowledge, although they don't necessarily know much about that knowledge. These types of connections are especially important in complex decision-making, where there is significant volume and diversity in knowledge, and it is not possible for everyone to know the same thing (Kozlowski & Ilgen, 2006). Boundary-spanning or bridging organizations can support greater awareness when agreement is unnecessary (Koehrsen 2017). However, to co-produce knowledge, teams need to move beyond gathering and sharing

knowledge (i.e., awareness) and reach agreements about integrating, interpreting, and applying that knowledge (Armitage et al., 2011).

4.3.1.3 Network structure: Balance between redundancy and modularity

Network structure refers to a higher order of connections between knowledge. Networked organizational structures have long been recognized as important to environmental governance (Argyris & Schön, 1980; Curtin, 2014; Senge, 1997). However, most empirical research has focused on connections between individuals or organizations, not knowledge (see Mohammed et al., 2021 for exception). Redundancy and modularity support durability and flexibility in ecological systems (Anderies & Hegmon, 2011; Folke, 2006) and social networks (Bodin et al., 2006; Burt, 2001). They may perform a similar function in team cognitive structures (Uitdewilligen et al., 2010). Redundant team cognitions feature numerous pathways connecting between sets of understandings (Figure 4.3). This redundant network may support greater error mitigation (Burke et al., 2005), detection of anomalies (Flach et al., 2017), and adaptive capacity (Pahl-Wostl & Hare, 2004; Walker et al., 2006). For example, Soto et al. (2021) found that over a three-year knowledge co-production project focused on regenerative agriculture in Spain, project partners strengthened and enlarged their social network. Partners increased the number of information fluxes facilitating information exchange and dissemination. However, the denser network also reinforced a shared set of perceptions where actors, and after three years, actors received less information from outside the group (Soto et al., 2021).

Modularity in team cognition features limited cohesion between sets or clusters of understandings. Literature associates modularity with greater creativity, innovation, flexibility, better monitoring, and the exchange of non-redundant, novel, and critical information (Burt, 2001; Gargiulo & Benassi, 2000; Reiter-Palmon et al., 2012; Weick, 1969). Modularity reflects a

structure whereby diverse but complementary understandings are bridged to form a collective cognition (DeChurch and Mesmer-Magnus, 2010). Establishing multi-teams, sub-teams, or 'teams of teams' may support cognitive modularity (Mathieu et al., 2008; Salas et al., 2012). Multi-teams support greater cohesion within the cluster and lower cohesion between clusters of shared understandings. This organizational structure may provide a greater capacity to adapt or challenge the assumptions of the larger group (O'Reilly III & Tushman, 2018; Gargiulo & Benassi, 2000). Over the past two decades, The Nature Conservancy has partnered with the USDA Forest Service and the four agencies of the U.S. Department of Interior to develop learning networks that advance shared learning about wildfire adaptation strategies among diverse partners (Goldstein & Butler, 2010; Huffman, 2013). For example, the Fire Adapted Learning Networks facilitate knowledge sharing whereby communities can connect with other communities and across multiple scales, greatly expanding the set of ideas taken into consideration (Fischer et al., 2016; Goldstein et al., 2010; Paveglio, 2021).

Tradeoffs between modularity and redundancy represent an important team research frontier (Kharrazi et al., 2020). Too much redundancy may result in suboptimal use of team resources (Mohammed et al., 2010; Smith & Hou, 2015). Too little cohesion may result in a lack of trust and coordination (Gargiulo & Benassi, 2000). A balance is needed (Bodin et al., 2006). However, the redundancy and modularity of the group also change over time as members interact and socialize. Teams tend to exhibit relational inertia, becoming overly redundant, connected, and closed the longer they work together (Baumeister et al., 2016; Gargiulo & Benassi, 2000; Gibson, 2001; Weick, 1969).

4.3.2 Factors that support resilient team cognitions

In our literature synthesis, we looked for factors that help support a dynamic structural change between a more shared mental model and a more distributed team model, i.e., a resilient team cognitive model. We identified four factors: awareness, facilitation, incentive structures, and cognitive perturbation.

4.3.2.1 Awareness.

It is said that "you do not fight for what you do not know" (Lugo, 2020, pg. 94). Our review of over 100 knowledge co-production evaluation publications suggests that while team learning is broadly being evaluated, integrative and iterative learning are not explicitly recognized (see Appendix G). Currently, it is unclear to what extent KCP practices are trying to support interactive and integrative team learning or how those terms are being interpreted. Scholarship in knowledge co-production emphasizes the importance of integrative and iterative learning. However, these discussions are missing from practice. Foremost, supporting resilient team cognition requires an explicit awareness by team members that this is a shared goal. Teams must recognize both the importance and difficulty of supporting both integrative and iterative team learning. Teams further need greater conceptual clarity about what integrative and iterative team learning means. Greater awareness indirectly influences changes in facilitation and incentive structures.

4.3.2.2 Facilitation

Facilitation refers to the mediation and structuring of discussions, the balancing of contributions, and the creation of opportunities for equal participation (Palm and Thoresson 2014, Ernst et al. 2017). Skilled and neutral facilitators are consistently identified by research and practice as necessary to keep KCP processes inclusive and reflexive (Ansell & Gash, 2008;

Colavito et al., 2019; Collins & Ison, 2009; Ernst, 2019b; Fazey et al., 2013; Leach et al., 2013; Miller et al., 2014; Reed et al., 2014; Rodrigues, 2020; Soto et al., 2021).

Facilitation by a third neutral party is likely essential to support resilient team cognitions. While KCP practices generally share flat and consensus-seeking decision processes (Fazey et al., 2013; Scolobig & Lilliestam, 2016; Tippett & How, 2020), power imbalances remain a major constraint and criticism (Muñoz-Erickson, 2014; Tippett & How, 2020; Wolff et al., 2019; Zurba et al., 2022). The significant informational complexity and conflict resolution skills needed to address complex environmental challenges have necessitated group facilitation (King, 2000). Facilitation can be instrumental in supporting an awareness of the intention to engage in team learning and what that might look like. Facilitation requires both time and money. Incentive structures need to be in place to support investments in facilitation.

Facilitation has been recognized as necessary to support reflexivity and overcome the inherently dynamic nature of adaptive or social learning (Argyris & Schön, 1980; Groot et al., 2002; West, 1996). However, we know little about facilitating reflexive capacities at a group level (Groot et al., 2002) or about the tradeoffs and synergies between strong and stable shared mental models and dynamic transactive team memory systems (Santos et al., 2016; Uitdewilligen et al., 2010). Environmental dispute resolution facilitators have historically focused on managing productive discussion, overcoming conflict, and reaching agreement (Ozawa & Susskind, 1984; Susskind, 2008). Little of their attention has gone to establishing adaptive collective cognitions (Groot et al., 2002; King & Jiggins, 2002). Among the numerous facilitators we spoke with as background research for this paper, most had an intuitive sense of how to help members shift between constructing shared understandings and challenging assumptions. Still, none could point to a socio-cognitive model they based it on.

Recognition of interdependence

Facilitation should emphasize recognition of interdependence among team members. Changes in team cognitive structure are socio-cognitively expensive (Burke et al., 2006). To invest that energy, team members need to recognize their interdependence with other team members (Hagemann & Kluge, 2017; Mannix & Neale, 2005). They necessitate a commitment to the team and the process. To support RTC, members must recognize the interdependency of their roles and actions. When they do, teams exhibit greater social coherence and identification (Millward et al., 2010; Van den Bossche et al., 2006), a greater sense of shared responsibility (Ansari et al., 2013), openness to the arguments and interests of other members (Wagemans, 2002), and greater inclination to search for mutually agreeable solutions (Laws et al., 2014).

Recognition of legitimacy

Facilitation should also emphasize a recognition of legitimacy. RTCs emerge from the recognition of the legitimacy of all members. For RTCs to emerge, group members must negotiate and accept a plurality of understandings (Agrawal & Lemos, 2015; Bar-Tal, 2004; Daly, 2016), which requires them to recognize the legitimacy of other members' understandings, i.e., cognitive legitimacy (Norström et al., 2020). Recognition of legitimacy necessitates flexibility (Lemos & Morehouse, 2005), humility (Ghodsee & Orenstein, 2021; Rodrigues, 2020), and reflexivity (Bixler et al., 2022; Polk, 2015). Knowledge co-production processes frequently contend with knowledge that challenges members' expectations surrounding timing, power, scale, certainty, and source credibility (Röling & Wagemakers, 1998). Members typically engage in boundary work, demarcating or drawing boundaries around what constitutes legitimate, credible, and salient knowledge) (Brugnach et al., 2008; Cash et al., 2003; Gieryn, 1995; Jasanoff, 1987; Kim, 2014). Boundary spanners, as a specific type of facilitator, may be

necessary to explicitly recognize differences in members' boundaries and to facilitate knowledge sharing, blurring, or bridging across those boundaries (Jerneck & Olsson, 2011).

Psychological safety

Of critical importance is for facilitators to establish a safe space for knowledge exchange. Psychological safety is the shared belief held by team members that the team is safe for interpersonal risk-taking (Edmondson, 1999). Psychological safety is both borne of and leads to the development of mutual respect and trust (Edmondson, 1999). Psychological safety supports integrative learning by supporting open information exchange and effective conflict management (Edmondson 1999). It supports iterative learning through a positive emotional climate that prevents premature cognitive closure (Salazar et al., 2012). Research links higher levels of psychological safety to members seeking feedback, exploring and sharing information, experimenting, and taking risks (Edmondson, 1999; Gunderson & Light, 2006; Spraggon & Bodolica, 2017). Teams who support psychological safety are more willing to discuss errors and unexpected information (Burke et al. 2005) and shift directions as situations change (Edmondson 1999). Alternatively, without psychological safety, group members are unlikely to build trust and support collaboration (Read et al., 2016) and instead display a defensive orientation, minimizing creativity and innovative behaviors at work (West, 2008).

4.3.2.3 Incentive structures

Knowledge co-production practices are designed to bring together an incredible diversity of knowledge; however, too often, the process is oriented around the slim overlap of shared understanding among the team. The incentive structure to promote agreement far outweighs any cognitive benefits that come from challenging assumptions and destabilizing agreements (Uitdewilligen et al. 2010, Santos et al. 2016). The pressure to reach an agreement and stay there

is cognitive, social, and institutional. A focus on tangible agreements, usable knowledge, and operational plans is likely to miss that most of the co-produced knowledge, i.e., the emergent knowledge held by the team, is not captured in the plan. If practitioners are serious about supporting integrative and iterative team learning, more explicit attention to incentive structures, tradeoffs, and risk may be required (Armitage et al., 2008). Greater investments are necessary to support the initial stages of project design, including team formation.

Relational learning

There is a growing focus on the importance of incentivizing relational learning. While resilient team cognitions are shaped by cognitive learning, they are bolstered by relational learning, i.e., building relationships and learning about other actors' interests, experiences, and roles. Resilient team cognitions emerge from building the capacity to learn (i.e., learning to learn) (Bremer & Meisch, 2017; Fazey et al., 2007; McDougall, 2001) Capacity building for transdisciplinary teams to learn together in productive ways should be valued as a productive project benefit (Berkley & Beratan, 2021). Guidelines for process design and implementation should detail "safe-to-fail" spaces that encourage experimentation and reflexive open dialogue to share multiple understandings (Armitage et al., 2011; Curtin, 2014).

Increasingly studies are focusing on "getting the people part right" to sustain collaborative efforts (Berkley & Beratan, 2021). Relationships can profoundly influence different social actors' ability to support cognitive learning (Armitage 2008). Creating opportunities for team members to spend significant time and resources at the very start of a project has been shown to have substantial performance benefits in support of cognitive learning (Ernst, 2019b; Read et al., 2016). There is significant path dependency in knowledge co-production practices. Therefore early investments in building relationships and establishing psychological safety

reduce barriers when opportunities arise to connect or disconnect respective knowledge. Relational learning, in terms of positive shared experience, can also result in psychological safety (Edmondson 1999, Kozlowski and Ilgen 2006). Personal connections can create a "third space" that bridges between actors and reduces the barriers to integrative learning (Thornton & Scheer, 2012, p11). Relationships also reinforce the recognition of interdependence and legitimacy, as team members see each as multi-dimensional actors (Salas et al., 2018).

4.3.2.4 Cognitive perturbation

Iterative learning, whereby existing conceptions are replaced by new ones, often involves cognitive perturbations (Steger et al., 2021). Perturbations are conditions that fall outside the system's normal variability and create radical alterations of structure. While perturbations can be damaging, exposure to volatility is also vital for the group to thrive and grow (Taleb, 2012). Team cognitive resiliency depends on cognitive perturbation - critical, surprising, or non-conforming evidence or ideas representing a marked departure from the group's shared understanding. Knowledge interruptions, conflicts, crises, surprises, and changes can function as an opportunity for critical reflection (Jasanoff, 2004; West, 1996), institutional change (Chapin et al., 2010), focus (Birkland, 1997), transformation (Gallopín, 2006) or "creative destruction" (Schumpeter 1950). Cognitive perturbation may ignite or foster learning by changing what is known (Heikkila and Gerlak 2011), expanding the temporal frame of reference (Argyris 1993), resolving social uncertainties (Röling and Wagemakers 1998), and articulating shared beliefs (Folke et al. 2003). Cognitive perturbation can 'unfreeze' shared understandings (Lewin, 1947) and catalyze new idea formation (Gunderson et al., 2015) or the adoption of knowledge claims that already existed as an idea but had not yet made it into the decision-making process (Newig et al., 2019; Pennington, 2011).

How a group responds to a cognitive perturbation is necessary to reveal its resiliency. However, a history of perturbations or exposures may also be essential in catalyzing resiliency (Holling, 1973). Traditional management, which suppresses or buffers teams from stressors, inhibits active processing (Gersick and Hackman, 1990) and is associated with habituation and dysfunction in novel situations (Folke et al., 2003; Gorman et al., 2010). An extended period in which no errors occur will degrade any future response to errors (Derbyshire & Wright, 2014). Alternatively, teams who have had positive experiences with critical incidents exhibit greater flexibility and innovation (Cooke et al. 2013), are better able to leverage latent diversity (Nelson et al., 2007), and support greater psychological safety (West 1996, Edmondson 1999).

4.4 Summary on the significance of resilient team cognitions for knowledge co-production practices

The role of transdisciplinary teams in co-producing knowledge to address sustainability challenges is proliferating (Brandt et al., 2013; Harris & Lyon, 2014; Lang et al., 2012). Increasingly, actors outside of academic spheres are seen to hold forms of knowledge and expertise that are indispensable for creating knowledge that can contribute to societal problem-solving (Nowotny et al., 2001). Societal expectations of what these teams can accomplish are daunting, especially given the difficulty of the task at hand (Jagannathan et al., 2020). Balancing the convergence and divergence of multiple understandings remains one of the main challenges of transdisciplinary knowledge co-production (Boon et al., 2014). However, it is also critically important to get it right. Despite these challenges, transdisciplinary knowledge co-production may be our best chance to mediate conflicts and improve socio-ecological conditions. The key insight of this paper is that for knowledge co-production practices to facilitate integrative and

iterative team learning, teams need to accommodate diverse and novel knowledge with corresponding changes in cognitive structure.

Constructing shared understandings and challenging assumptions don't have to be at odds with one another. However, without an appreciation of cognitive structure's role in reinforcing team learning functions, practices may result in premature cognitive closures or endless dialogue. Knowledge co-production literature has few connections to team cognition. This chapter contributes to understanding the relationship between team cognitive structure and team learning in transdisciplinary teams engaged in KCP.

While this paper brought in constructs from team cognition to help clarify the role of cognitive structure in knowledge co-production practices, there may be an equal benefit of bringing constructs from knowledge co-production into team cognition. A growing interest within team cognition literature on transdisciplinary teams and decision-making for complex and uncertain challenges (Mohammed et al., 2021) makes knowledge co-production practices a synergistic research frontier. While language around integrative and iterative team learning is prominent in most KCP literature, there is significant ambiguity about how this translates to practice. Integrative and iterative team learning represents a high bar for practice. Before we can start to measure the performance of team learning, we need to reconcile the divergent views about what integrative and iterative team learning ought to and realistically could entail. We see this insight paper as a first step in a much larger conversation about evaluating and facilitating team learning in KCP practices.

Chapter 5 Conclusions

To address society's most pressing sustainability challenges, collaborative environmental governance practices are increasingly turning to transdisciplinary knowledge co-production (Brandt et al., 2013; Harris & Lyon, 2014; Lang et al., 2012). A core principle of knowledge co-production is recognizing and legitimizing multiple understandings (Meppem & Bourke, 1999; Norström et al., 2020; Wyborn et al., 2019). By bringing together researchers and practitioners with multiple understandings of the challenge, co-production practices are expected to support processes, knowledge, and decisions that are more just, salient, credible, actionable, durable, and adaptive; team processes that support learning, relationship building, capacity building, and empowerment, and more sustainable outcomes. Critiques of practices suggest that these aspirations are not being met (Jagannathan et al., 2020; Lemos et al., 2018; Mach et al., 2020). One limiting factor may be the way practice attends to multiple understandings.

My dissertation research aimed to improve how knowledge co-production practices attend to, i.e., recognize, include, respect, and sustain multiple understandings to address complex sustainability challenges. To support this aim, I asked:

(1) How can knowledge co-production practices identify and characterize multiple understandings of western wildfire challenges?

(2) How can knowledge co-production practices quantify the distribution of and explore the relationship between multiple understandings of western wildfire challenges?

(3) What model of team learning could help transdisciplinary teams continue to take advantage of their multiple understandings?

The findings of this research answer these questions to provide three key contributions. First, the mixed method investigation combines stories and numbers to provide detailed characterizations of the multiple understandings currently shaping western wildfire challenges. Second, this research contributes to scholarship in collaborative environmental governance by providing insight into approaches to improve the recognition and legitimization of multiple understandings within knowledge co-production practices. Empirical findings from Chapters 2 and 3 emphasize the importance of maintaining the language and power as well as the complexity and connectivity among actors' understandings. Third, I present a novel conceptual model that connects team cognitive structure to team learning within the context of knowledge co-production practices (Chapter 4). This model advances scholarship in transdisciplinary research by synthesizing the literature on the role that cognitive structure plays in how teams can continue to take advantage of their multiple understandings.

5.1 Influential actors' understandings of western wildfire challenges

Western wildfires represent one of numerous complex and rapidly changing sustainability challenges society faces. Differences in actors' understandings could help inform our collective understandings of these challenges. They can also hinder decision-making and make these challenges more intractable. Our research provides empirical data about the spectrum of ways influential actors understand these challenges. These findings could help practitioners engaged in sustainability practices attend to these multiple understandings more effectively.

Chapter 2 describes a qualitative narrative analysis of influential actors' social narratives of western wildfire challenges. While numerous prior characterizations of wildfire narratives have depicted understandings in terms of their dichotomy, conflict, or cohesion, our conversations with influential actors revealed a multitude of overlapping ways actors are engaging with these challenges. I identified nine social narratives that distinguish actors' conceptualization across four core storyline elements – strategies, scales, frames, and language. While these elements were identified inductively, they broadly resonate with previous findings. I found that differences in strategies and scales largely align with disciplinary backgrounds and agency capacity. I also identified defensive posturing and negative characterizations of other groups, signaling to identify challenges. These challenges may reflect lingering resentments from historical conflicts, like the 'Timber Wars,' criminalization of traditional fire practices, and discriminatory housing practices.

Constructing the social narratives revealed simplifications and minimizations participants use to characterize other actors' understandings. However, these simplifications did not line up with the complexity of understandings I saw among our participants. While participants recognized western wildfire challenges as being complex and therefore requiring complex understanding, their assumptions about other actors' understandings fail to capture this complexity. Social narratives of wildfire reflect simplified storylines. However, I found that participants aligned with perspectives corresponding to multiple social narratives. This aligns with previous studies suggesting that understandings are being overly simplified (Friberg, 2019; Paveglio, 2021).

In Chapter 3, I describe a quantitative survey that builds directly on the social narrative analysis study to quantify the distribution of and explore the relationship between actors'

perspectives and understandings of western wildfire challenges. I discuss survey findings in support of greater inclusivity. First, to mirror the distribution of understandings across the population, the survey suggests that 'Manage,' 'Adapt,' and 'Revitalize' reflect more commonly held or dominant narratives while 'Control' was less common. I found that two factors explain about half of the variation among the respondents. First, a view about the role of fire in terms of a desire to control and minimize fire vs. a desire to utilize more fire. This aligns with the 'war on fine' and 'living with fire' storylines (Tedim et al., 2021). Second, respondents varied in where they think interventions should occur, in the forest vs. in communities. This implies distinctions in actors' sector and scale. Team composition should include representation of both sides of both views.

Second, for process design to incorporate important distinctions and conflicts between understandings, I characterized the relationships between participants' perspectives and their understandings. Our survey results suggest three types of differences in perspectives – conflicting, divergent, and nuanced. I found negative associations between the 'Revitalize,' 'Justice,' and 'Conserve' narratives and the 'Control,' 'Work,' and 'Market' narratives. In contrast to these distinctions, I found nine nuanced differences in perspectives that are not mutually exclusive. These differences might represent productive "early wins" to support achievable objectives, create safe spaces, and establish a commitment to the group process (Leith et al., 2016).

Lastly, our findings suggest that actors' understandings overlap and do not align with interest groups. On average, each pair of respondents agreed on about two-thirds of the perspectives. Further, while I found that two factors account for nearly half of the variation

among respondents' understandings, the distribution of views along those two factors is largely moderate.

5.2 Implications for collaborative environmental governance practices

Our findings about wildfire understandings have implications for the broader field of collaborative environmental governance. In this dissertation, I was motivated by a need to improve how knowledge co-production practices attend to multiple understandings. Two cross-cutting criticisms of practices emphasized this need, a failure to reflect the full spectrum of understandings (Mach et al., 2020; Meadow et al., 2015; Page et al., 2016; Reed & Abernethy, 2018) and a failure to adequately address power inequities that stem from the different understandings of the challenge, i.e., discursive power (Chakraborty et al., 2022; Guerrero et al., 2018; Tengö et al., 2014; Wyborn, 2015). This dissertation emphasizes approaches for addressing these limitations.

5.2.1 An approach to identify and characterize multiple understandings (research question 1)

To effectively bring together multiple understandings of sustainability challenges, knowledge co-production practices require an initial exploratory process for identifying and characterizing those multiple understandings (Chakraborty et al., 2022; Tengö et al., 2014). Practice currently lacks a sufficient approach to support this exploratory process. Chapter 2 describes a research study in which I employed a narrative analysis to identify and characterize the multiple understandings of influential actors engaged with western wildfire challenges. Narrative analysis is often used in public policy to better understand how actors make sense of

conflicts, uncover nuances and details of people's experiences and understandings, and identify multiple understandings rather than finding one generalizable understanding (Feldman et al., 2004; Hunter, 2010). The analysis of social narratives specifically examines those narratives that are shared by and representative of social groups (Shenhav 2015). I constructed multiple social narratives by inductively looking for similarities and dissimilarities among the core elements of the individual narratives of interviewees. I found social narrative analysis to be a pragmatic and explicit approach to identifying and characterizing multiple understandings. I further found social narrative analysis to be an effective mechanism to reveal the boundaries actors use to justify their understandings' legitimacy, credibility, and salience. Revealing these boundaries could help practitioners better address discursive power.

5.2.2 An approach to inform an inclusive selection of project team members (research question 2)

Including multiple views is expected to support decisions that are more comprehensive, robust, innovative (Berkes & Armitage, 2010; Jagannathan et al., 2020), responsive (Bousquet et al., 2017; Lemos, 2015), and just (Mach et al., 2020; Miller & Wyborn, 2018). However, there needs to be more guidance on how practitioners should identify actors who can represent sufficiently diverse views of the challenge (Horcea-Milcu et al., 2022; Reed et al., 2014; Steger et al., 2021). Chapter 3 provides an approach for systematically exploring the spectrum of understandings to support more inclusive collaborative practices. I design a survey that quantifies the distribution of and explores the relationship between actors' perspectives (represented by a series of statement pairs) and broader understandings (represented by social narratives) of western wildfire challenges. Quantifying the distribution of perspectives and

understandings, e.g., which perspectives are more commonly accepted or what are areas of conflict, can help ensure that project teams mirror the distribution of understandings among the broader population. The survey design provided a useful way to represent the complexity and meaning associated with actors' views by exploring the relationship between actors and their perspectives and understandings. This complexity helps inform a more inclusive selection of project team partners by showing how traditional approaches that simplify actors' views and interests may be insufficient or even counterproductive. Furthermore, I depicted actors' views in terms of their affiliation with the nine social narratives and shared these results with respondents in real-time. I found that depicting their understandings through a combination of multiple social narratives resonated with people. It also seemed to prompt reflexivity – a critical examination of their understandings (West, 1996). This aligns with other narrative studies that suggest that, when seen side by side, contesting narratives, each positing claims of reality, get actors to openly question their assumptions (Meppem & Bourke, 1999). Reflexivity is necessary to support inclusivity. Approaches should not just be about bringing actors with multiple understandings to the table but also about addressing discursive power in discussion and project outcomes. Reflexivity may help actors become more aware of their own partial and positioned view facilitating the recognition and legitimization of multiple understandings.

5.3 Implications for transdisciplinary research

Knowledge co-production practices emphasize team learning among transdisciplinary teams as a critical factor in achieving project outcome goals. To effectively support co-production, team learning should incorporate both integrative learning – a convergent movement from multiple understandings to a shared understanding and iterative learning – a divergent

movement from shared understanding to multiple understandings. This constitutes a very high bar for practice. However, little research has evaluated the extent to which teams are meeting this high bar or what factors help facilitate meeting this high bar. To inform the evaluation and facilitation of team learning, practice needs a conceptual framework, or approach, for what team learning looks like (research question 3). In Chapter 4, I draw on literature in team science that suggests that team learning shapes and is shaped by team cognitive structure. Team cognition refers to the way knowledge is shared or connected among team members. I introduce the construct of resilient team cognitions as a particular structure of team cognition that can support team learning among transdisciplinary teams addressing complex sustainability challenges. The key insight of this paper is that for knowledge co-production practices to facilitate integrative and iterative team learning, teams need to accommodate diverse and novel knowledge with corresponding changes in cognitive structure. I see this insight paper as a first step in a much larger conversation about what it means to sustain multiple understandings in knowledge co-production practices.

5.4 Broader lessons and implications for practice

5.4.1 Persistent tensions and gaps

The three chapters provide insight into how knowledge co-production practices can better attend to multiple understandings to address complex sustainability challenges. However, my research further highlights persistent tensions and gaps that prevent practice from effectively meeting scholarship's great expectations. I identified three persistent tensions that may be particularly problematic.

5.4.1.1 Rigor and legitimacy

> *"In many parts of the broader dialogue, solid science details across a range of disciplines are conflated with feelings and partial truths that render them less than useful to further discourse"* Input from a research participant.

Actors who share a constructivism-interpretivism epistemology see co-production as a "more accurate representation of the ways in which knowledge is constructed and influenced by society" (Meadows et al. 2015, pg.181). These actors emphasize a collaborative rationality whereby knowledge is perceived as more legitimate, credible, and salient if researchers and affected actors are a part of the knowledge production process. Alternatively, actors who share the epistemology that knowledge can be objectively and deductively investigated prefer a more technically accurate instrumental rationale. They may see knowledge co-production as compromising the rigor, quality, objectivity, and independence of evidence, a "tainting" of science (Meadows et al. 2015, pg. 181). For these actors, attending to multiple understandings may reflect a necessary obstacle and a potential to educate others to do the 'correct' thing (see Caniglia et al., 2021; Paveglio, 2021; Reed & Abernethy, 2018). Challenges occur when project partners or team members have different or conflicting epistemologies. While it may not be possible to resolve these differences, explicit recognition of plural epistemologies and rules of engagement may help facilitate more effective and transparent knowledge co-production practices.

5.4.1.2 Urgency and capacity building

> *"We know what to do; we just need to get those partnerships on the ground to get it done,"* A public official discussing fuels management at a professional workshop.

Significant tensions exist between the high-stake urgency of sustainability challenges (Funtowicz & Ravetz, 1993) and a belief that practice needs to 'go slow to go fast.' There is no question that complex sustainability challenges require immediate action. The rapidly escalating impacts of wildfire challenges, for example, require a timely response, not only because of a closing climate window (McNeeley & Shulski, 2011) but also because of the implications on communities (e.g., smoke, power outages, loss of ecosystem services) (National Academies of Sciences Engineering and Medicine, 2020). However, it is not clear how to balance between the upfront process-based investments to attend to multiple understandings (e.g., building relationships, trust, and capacity among actors) and the more goal-based tangible benefits of attending to multiple understandings to produce more actionable knowledge (Chambers et al., 2021). "Too-soft a tone and a focus on learning can decrease the sense of urgency needed for timely goal attainment" (Brouwers et al., 2022, pg. 36). This tension generally divides between managers who feel they already know what needs to happen and are trying to get the funding and social sanction to get things done and mediators and community leaders who stress that failing to get participation right may destabilize decisions making the process more inefficient and lengthier. The tension between opening up and closing down represents an efficiency paradox (Chambers et al., 2022; Stirling, 2008). Closing down is necessary to do the work and have the ability to act, but the timing of closing may cause rigidity (Boon et al., 2014; Cundill & Fabricius, 2009; Muñoz-Erickson et al., 2017).

5.4.1.3 Convergence and Divergence

> *"We strive to be emergent. It's interesting to think about how to be freshly emergent for 20 years. I had a leader come up to me after a workshop and say, 'I agree with everything, but it occurs to me that we're a little bit of an echo chamber, and there's an*

assumption that fire is good and we need more fire but does that leave us in a place where we don't hear people who don't agree with that?' Interview subject

On the one hand, practice aims to construct shared understandings – converging towards a subset of ideas everyone can agree on, improving communication and efficiency. On the other hand, there is a focus on recognizing multiple understandings and sustaining that divergence of views to remain flexible and comprehensive and to respect the autonomy of diverse views. Both ideas are about attending to multiple understandings, but they work in opposite ways. One attending by converging, the other attending by diverging. Scholarship and empirical evidence suggest it is challenging to sustain both functions. The incentive structure to support and make progress reduces the capacity of teams engaged in knowledge co-production to challenge assumptions (Boon et al., 2014). The initially sought-after cognitive complexity and diversity of individual and community knowledge systems are often minimized to align with the "coherent set of assumptions about what the problem is and how it ought to be addressed" (Goldstein and Butler 2009, p1014). As practice generally lacks approaches to evaluate and reflect on how it attends to multiple understandings, these opposing functions are not explicitly discussed.

5.4.2 Recommendations for moving forward

Across the studies, I came across three recurring concepts central to improving how practice attends to multiple understandings: reveal power, prompt reflexivity, and support relational learning.

5.4.2.1 Reveal power

Despite normative aspirations of addressing power inequities, evidence suggests that sustainability practices, including knowledge co-production, often perpetuate power inequities

(Ansell & Gash, 2008; Chapman & Schott, 2020; Tengö et al., 2014). On par with power over territories and resources, discursive power shapes whose perspectives are reinforced and what evidence is considered (Goldstein & Butler, 2010; Purdy & Jones, 2012; Rawluk et al., 2020; Shenhav, 2015). Discussion about how to address discursive power has sparked an interest in going beyond identifying understandings to surfacing thicker, contextualized, and power-sensitive understandings (Cleaver & Whaley, 2018; Gray et al., 2022). However, these scholarly conversations have not materialized as explicit boundary demarcations in practice. In Chapter 2, I examine how the qualitative analysis of social narrative analysis can effectively reveal differences in the boundaries actors use to demarcate the knowledge they perceive as legitimate, credible, and salient. In Chapter 3, I characterize the perspectives and social narratives that are more dominant or common among influential actors, constituting discursive power.

5.4.2.2 Prompt reflexivity

Attending to multiple understandings must go beyond identifying and characterizing what or how actors conceptualize challenges to reflecting on one's own understanding of the challenge. Reflexivity represents a process of critically examining one's understanding. Reflexive practice is essential for any social change, revealing how theoretical, cultural, institutional, and political contexts affect learning processes, actions, and values (Nowotny et al., 2001). Reflexivity allows actors to step outside their heads to exhibit critical awareness and the contingency of their understandings and assumptions. Reflexivity has been shown to support the capacity for perspective-taking and mutual understanding (Polk, 2015). Reflexivity can also represent a team process (Bixler et al., 2022; West, 1996). Reflexive groups are more inclusive and adaptive and less defensive and reactive (West, 1996). When addressing science-based challenges, experts are often challenged to recognize their own understandings as partial and

positioned, promoting a view from nowhere Field (Williams, 2017) instead. “Dominant narratives are not called stories. They are called reality” (McKinnon, 1996, pg.235). Reflexivity involves ‘opening up’ knowledge production processes for review and critique and, as such, is an essential predecessor to effective knowledge co-production (Godemann et al., 2011; Innes & Booher, 2010; Polk, 2015).

5.4.2.3 Invest in relational learning

Attending to multiple understandings requires providing opportunities that support relational learning and relationship building (Fernández-Giménez et al., 2019). Relational learning is a non-cognitive form of learning centered on the appreciation of the understandings and perspectives of others, that in turn, can lead to increases in trust and cooperation between actors (Baird et al., 2014; Ensor & de Bruin, 2022). Co-production, i.e., bringing together different ways of understanding the issue, is not just an intellectual task but also a socio-emotional process (Dewulf et al., 2009). Evaluative studies of collaboration and co-management often cite that the best learning occurs outside the meeting rooms and in the field or pub Field (Butler & Schultz, 2019; Colavito, 2017) as actors get to know each other. Relational learning emphasizes learning about other actors (Huitema et al. 2010). Research suggests a relationship between developing a better awareness and understanding of how other actors think and the ability to work effectively together (de Vries, 2019; Plummer & FitzGibbon, 2007). When we come to know people as multi-dimensional beings, we recognize we are not that different, and it becomes harder to ignore their views (Voelkel et al., forthcoming). In this way, relational learning builds collaborative capacity (Baird et al. 2014). Learning about and acknowledging each other’s contributions may also enhance the ‘interpretative flexibility’ (Pinch & Bijker, 1984) of a knowledge co-production process. Storytelling through narratives can provide a

memorable pathway for actors to learn about other actors' understandings. Social narratives may facilitate relational learning by functioning as a boundary object, a flexible interpretive object that enables collaboration among actors with multiple or diverse understandings (Star & Griesemer, 1989). Furthermore, when combined with reflexivity, storytelling can support relational learning toward more shared mental models (Tesler et al., 2018).

5.5 Final thoughts

Complex sustainability challenges are not going anywhere. Evidence has long shown that trends are accelerating (Stefen et al., 2007). While society cannot solve these challenges (Levin et al., 2012; Rittel & Webber, 1973), it can collaborate in an attempt to address them to mediate impacts. Decades of scholarship in collaborative environmental governance have suggested that ''successful collaboration depends on including a broad enough spectrum of stakeholders to mirror the problem'' (Gray, 1989, pg.155). A growing emphasis on knowledge co-production suggests that scholars and practitioners increasingly recognize the need to bring together actors with diverse understandings to work together and produce knowledge. However, there seems to be a significant mismatch between the normative aspirations of scholarship and how co-production practice looks on the ground (Djenontin & Meadow, 2018; Jagannathan et al., 2020; Mach et al., 2020). In this dissertation, I laid the groundwork to help create a stronger connection between practice and scholarship by examining how practices can better attend to multiple understandings.

This dissertation combines over a decade of my scattered conversations, crazy thoughts, research investigations, and a few tears. Ultimately, I hope it helps facilitate conversations among practitioners and scholars about how to more authentically and effectively bring together

actors with diverse understandings to support meaningful collective action and mediate the seeming intractability of our contemporary sustainability challenges.

Appendices

Appendix A: Glossary of Key Terms

Attending: Giving attention to, applying care, managing. In this dissertation, I refer to attending in terms of recognizing, including, respecting, and sustaining multiple understandings of complex sustainability challenges.

Boundary work. The process of demarcating or drawing boundaries around what counts as knowledge, or what views are perceived as legitimate, credible, and salient (Brugnach et al., 2008; Cash et al., 2003; Gieryn, 1995). Boundary management refers to the process of facilitating knowledge sharing and integration among actors with multiple understandings by blurring or recognizing boundaries (Jerneck & Olsson, 2011). Competitive boundary work refers to the process of maintaining, reaffirming, and defending boundaries around shared understandings (Langley et al., 2019). Collaborative boundary work refers to the process of blurring, bridging, or dissolving boundaries between multiple understandings (Langley et al., 2019).

Cognitive perturbation. Perturbations are conditions that fall outside the system's normal variability and create radical alterations of structure. Cognitive perturbations refer to critical, surprising, or non-conforming evidence or ideas that represent a marked departure from the group's shared understanding.

Collaborative environmental governance. Environmental governance refers to the set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes to result in environmentally and socially sustainable

outcomes (Bennett & Satterfield, 2018; Lemos & Agrawal, 2006). The collaborative approach to governance can encompasses any method, model, or process that is deliberative and consensual, and engages participants collectively and constructively to leverage the unique attributes and resources of each for the greatest impact (Booher, 2004; Emerson et al., 2012).

Complexity science. Complexity science focuses on understanding how change occurs in complex adaptive systems (i.e., systems that are made up of many interdependent, heterogeneous parts that interact in a nonlinear fashion) (Levin, 1999). Complexity science is the foundation for resilience thinking and the management of social ecological systems (Holing, 2001).

Conceptualizations are implicit or explicit articulations of what epistemic agents know or understand (Pritchard, 2009). Knowledge structures (e.g., mental models or cognitive maps) are ordered relationships between ideas that shape individuals' interpretation and reasoning (Axelrod, 2012). Fuzzy cognitive maps and narratives are two forms of conceptualizations of understandings used in sustainability science (Gray et al., 2014; Meppem & Bourke, 1999).

Constructivism-interpretivism. A philosophical paradigm that informs research. Constructivism suggests that individuals actively construct their knowledge and understanding of the world through personal experiences, social interactions, and mental processes (Van Der Walt, 2020). Interpretivism suggests that understandings are a product of people's interpretations of events and evidence and consequentially partial and positioned (Fazey et al., 2014; McCarthy, 2006; Van Der Walt, 2020).

Discursive power. Control over what (and whose) understandings are valued and used to inform decisions (Purdy & Jones, 2012).

Epistemology. Peoples' theory of knowledge, including what counts as knowledge, the degree to which different kinds of knowledge are certain, and the presumed relation between the knower and the object that is known (Nisbett et al., 2001).

Evidence. Factual information, empirical data, or observations that demonstrate the validity of a claim or proposition (Kosso, 2011).

Frames. Frames shape understandings by emphasizing certain knowledge while minimizing other knowledge. Frames are constructed by implicit and explicit boundaries actors formulate about what knowledge is credible, legitimate, and relevant knowledge (Bremer & Meisch, 2017; Cornelissen & Werner, 2014; Nisbett & Wilson, 1977).

Influential actors. Recognized experts from multiple disciplines and actors with informed understandings outside of academia who are shaping public discourse and thinking around sustainability challenges.

Integrative learning. A team learning function whereby multiple understandings are brought together to construct shared understandings, common ground, or an agreement among actors.

Intractable problems. Long-standing disputes that are highly resistant to resolution (Davis & Lewicki, 2003).

Iterative learning. A team learning function whereby understandings are differentiated to respond to diverse and new knowledge or understandings of the challenge. Double and triple learning loops are common examples of iterative learning (Pahl-Wostl & Hare, 2004).

Knowledge. Evidence positioned relative to an actor's or institute's perspective. Knowledge is distinguished from reality, fact, or truth and is what is perceived to be viable or justifiable by actors (Fleck, 1928; Lugo, 2020; Williamson, 2000).

Knowledge co-production, (KCP) refers to a collaborative and interactive strategy to construct knowledge that is more place-based and action-oriented by intentionally bringing together actors with a plurality of understandings (Armitage et al., 2011; Jagannathan et al., 2020; Norström et al., 2020).

Knowledge systems, or ways of knowing. Frameworks, principles, or methods that inform how actors acquire and interpret knowledge about a particular phenomenon. Knowledge systems include epistemologies, or ways of knowing, that connect knowledge to communities of practice (Brugnach & Ingram, 2012; Tengö et al., 2014). Science, traditional ecological knowledge (TEK), and indigenous knowledge (IK) represent three types of knowledge systems (Berkes, 2009; Cash et al., 2003; Meppem & Bourke, 1999; Rathwell et al., 2015).

Mixed methods. A research design that draws upon the strengths of both quantitative and qualitative approaches to provide an innovative strategy for addressing complex challenges (Creswell & Plano-Clark, 2011). In an exploratory sequential design, the researcher first collects and analyzes qualitative data, and these findings inform subsequent quantitative data collection (Fetters et al., 2013)

Narratives. Narratives are explicit and coherent stories about what is happening and what should be done (Fischer, 2003). Narratives represent a scheme of how actors give meaning to or interpret their experiences and knowledge. Social narratives refer to common stories that capture shared experiences, disciplines, cultures, and beliefs (Polkinghorne, 1995; Shenhav, 2015).

Perspectives. An actor's point of view, i.e., the vantage point from which a piece of evidence or an event is seen (Holmes, 2020).

Philosophy of science. Philosophy of science is a branch of philosophy concerned with the foundations, methods, and implications of science. The central questions of this study

concern what qualifies as science, the reliability of scientific theories, and the ultimate purpose of science. Science, Technology, and Society (STS) is an interdisciplinary field that focuses on the ways in which scientific, technological, and social factors interact to shape modern life (Beck & Wehling, 2012; Nowotny et al., 2001; Rathwell et al., 2015).

Psychological safety is the shared belief held by team members that the team is safe for interpersonal risk-taking (Edmondson, 1999).

Reflexivity a process for critically examining one's understanding and their influence. A team or organization can be reflexive about their understanding (Bixler et al., 2022; West, 1996).

Relational learning is a non-cognitive form of learning, centered on the appreciation of the understandings and perspectives of others, that in turn can lead to increases in trust and cooperation between actors (Baird et al., 2019; Ensor & de Bruin, 2022).

Resilient team cognition, (RTC) a particular structure of team cognition that can support team learning among transdisciplinary teams addressing complex sustainability challenges. Teams with resilient team cognitions have the capacity to accommodate structural change to sustain integrative and iterative team learning.

Socio-ecological systems are integrated systems in which people interact with natural components (SES) (Liu et al., 2007). Sometimes referred to as coupled human natural systems (CHNS).

Sustainability science. A study of the practices that aim to meet the needs of present and future generations through environmental governance practices that improve the interactions between natural and social systems (Bennett & Satterfield, 2018; Glaser, 2004; Horcea-Milcu et al., 2020). Sustainability challenges reference social and ecological conditions and processes that deviate from what is considered healthy or desirable (Fischer et al., 2016). A complex

sustainability challenge refers to challenges associated with addressing complex adaptive systems. The unique features of complex adaptive systems make challenges especially complicated, or wicked (Walker et al., 2010; Weber & Khademian, 2008). Examples of common complex sustainability challenges include climate change, biodiversity loss, water shortages, and wildfires.

Team cognition. The knowledge-building processes or the emergent mental representations characterizing the degree of convergence of team-relevant knowledge, content, and structure. The structure of team cognition, i.e. the pattern by which knowledge is organized, represented, and distributed within the team and has been shown to have an important relationship to team learning (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2021).

Team learning is an emergent phenomenon that goes beyond psychological changes in individuals, in which team members intersect, amplify, and compile team-level manifestation of collective knowledge (Kozlowski & Bell, 2008).

Team mental models. Mental models are representations of actor's understandings in terms of the way they structure knowledge. Team mental models characterize team members understandings in terms of how it is shared or connected. Team mental model explain the performance of teams in terms of their ability to work together (Mohammed et al. 2017; Cannon-Bowers & Salas, 2001).

Team science. A relatively nascent field that has emerged out of industrial psychology (Salas et al., 2018) and organizational studies (Salazar et al., 2012; Stokols et al., 2008). It examines the relationship between the composition and interactions of team members and team performance outcomes (DeChurch & Mesmer-Magnus, 2010; Ilgen et al., 2005; Kozlowski, 2018; Mohammed et al., 2017; Wildman et al., 2012). There is potential confusion with team

science referring to the study of science teams or expert teams. While sustainability practices often involve scientists working in transdisciplinary teams, we refer to the broader study of teams.

Team transactive memory. Transactive memory systems are a form of cognitive architecture that encompasses the knowledge uniquely held by group members and a collective awareness of who knows what on the team (DeChurch & Mesmer-Magnus, 2010). The core logic of a transactive memory system is that team members can be sources of external knowledge and rely on each other to be responsible for different but complementary areas of learning and expertise (DeChurch & Mesmer-Magnus, 2010; Wegner, 1987).

Transdisciplinary teams include members from multiple academic fields as well as non-academic members, i.e., practitioners, local community members, decision makers (Brandt et al., 2013; Harris & Lyon, 2014; Lang et al., 2012; Nowotny et al., 2001; Plummer et al., 2022). Transdisciplinary research emphasizes understandings that emerge from when researchers from different disciplines not only work together to address a common problem but also integrate their diverse expertise and methods to create a new framework or understanding that transcends the boundaries of their individual disciplines (Stokols et al., 2008).

Understandings refers to how actors construct meaning, interpret, or make sense of knowledge, drawing from their diverse perspectives, experiences, cultures, and ways of knowing (Pritchard, 2009). Shared understandings refer to the understandings that are shared, or common, among actors (Daly, 2016; Davenport, 2018; Norström et al., 2020). Multiple understandings refer to the plurality of interpretation. Mutual understanding refers to members' ability to recognize and respect the understandings of other members, even if they do not agree with (or share) those understandings (Emerson et al., 2012).

Views. An actors' perspectives, knowledge, ways of knowing, understandings, and epistemology in relation to a sustainability challenge.

Appendix B: Interview Guide

A. Basic Info:

Appendix Table B.1 Interview guide - basic information about interviewee

Interviewee, title and org	
Interviewee Role	
Method of id	
Interviewer	
Date	

A. Background research

Interviewee

- bios, links to papers/reports, links to YouTube videos

Org

- Mission, vision, work, etc.. links to reports, web pages, videos

B. Interview Questions and notes

1. Introduction

- About me at SEAS and background with fire and at PNW

2. Recap goal of convo (0h:0m)

- Intro to WFFI
- Get your perspective on the western wildfire problem.

- Learn more about what you are doing as (title) at (organization) to address wildfire risk beyond what I could find through background research (to prepare, I've looked at X,Y, Z, read this and that)
- Thoughts about the big questions that need answers, problems that need solutions;
- Recommendations for other individuals and organizations working in this space
- Although we are interviewing you as a representative of an organization, we want you to be candid about your views so we plan to treat what you say confidentially. We won't attribute anything that you say to you or your org when we use this information.

3. About WFFI (0h:05m)

- We are an interdisciplinary working group of faculty, students, and postdoctoral fellows who work on wildfire, forest, and community issues in one way or another. Our goal is contribute to the wide field of research on wildfire management by focusing in on wildfire risk as a SES; that is, a product of complex and often problematic relationships between forests and how they are managed; human communities and how we live in forested areas; and climate change and the way it affects forest conditions;
- In our first year, we are communicating with people who we consider thought leaders or really knowledgeable about wildfire risk to (a) better understand why it has become so intractable and (b) identify areas where we need more problem-oriented research. In our second year, we plan to undertake approximately 5 focused problem analysis to help develop solutions to specific aspects of the wildfire risk problem (economic, technical, behavioral, ecological). In the third year, we hope to develop ideas for policy and programmatic initiatives and management strategies based on our findings.

- Do you have any questions about the WFFI before I move on to my questions about your views and work on wildfire risk?

4. Views on wildfire risk (0h:10m)

- I want to start big picture and ask you to help me better understand this phenomenon of wildfire risk in the West, including what you think are the major causes, why people are concerned, and what some of your ideas are for solutions.

CAUSES:

- Starting with cause, from my understanding, it's well recognized that although fire historically played an important and beneficial role for both ecosystems and human systems, more recent history of forest management and fire suppression practices have created flammable conditions in forests. With climate change, conditions are becoming even more flammable. And with expansion of human communities into the wildlands, we have more ignitions. What else am I missing, in terms of what has led to this problem?

CONSEQUENCES/CONCERNS:

- So we've talked about what led to this current wildfire risk situation; now I want to hear about why you think we should be so concerned? What's on the news is that wildfires are now causing unacceptable levels of damage to human communities. They are threatening our homes and infrastructure; we are also becoming increasingly aware of smoke risks to our health. Wildfires are also threatening our forest ecosystems, including many of the things we value from those ecosystems: water, scenery, habitat, carbon storage. Tell me more about your views on the big impacts, from your perspective, of these uncharacteristically large fires?

SOLUTIONS:

- As for solutions, it seems that although there is widespread agreement that wildfire is a major problem, and there are many people and organizations working on this issue, the problem just seems to be getting worse. Wildfire risk seems to have defied our capabilities for fire suppression; community fire protection; and forest management and restoration. It has defied our efforts to develop policies and programs and new technologies. What do we need to know more about so we can address this problem? What problems do we still need to solve? What nuts do we need to crack?

5. Work (0h:30m)

- Relating to solutions, you/your org is making big efforts in some of these areas. Fill me in on how you see yourself contributing, as well as some of the challenges you're facing.

6. Research questions (0h:40m)

- Now that you've helped me better lay out the problem of wildfire risk, and what you and your organization are doing to address it, let me see if I can recap on what I think I heard in terms of big questions that need more attention from researchers like us at WFFI.

7. Other thought leaders and resource people? (0h:45m)

- Again, the reason we chose you as a person to talk to is because you're recognized for being a thought leader on this topic, and knowledgeable about many aspects of the wildfire problem. Which other people seem to be leading the thinking on this topic of wildfire risk? Who else is really knowledgeable who we should talk to get a better understanding of this complex issue? Especially people working in different domains of the problem. Who should we talk to to folllw up on the research questions we just discussed?

8. Intersection orgs? (if there's time)

- We're particularly interested in learning more about organizations that are doing substantive work in all four domains of the problem--fire, forests, communities, and climate--i.e., are grappling with and aware of the complexity of the issue as opposed to focusing on any one aspect

Appendix C: Correspondence Between Perspective Statements and Social Narratives

Appendix Table C.1 Correspondence between perspective statements and social narratives

	Statements	Manage	Work	Market	Control	Regulate	Conserve	Revitalize	Justice	Adapt
	Counts	14	15	13	14	11	15	14	14	12
Q1A	We should use unplanned ignitions under good conditions as an opportunity to restore ecological function.	**1**					**1**	**1**		**1**
Q1B	We should not use unplanned ignitions to burn for resource purposes as it is a dangerous and costly means to manage our forests.		**1**		**1**					
Q2B	To manage the long-term health impacts of wildfire smoke, we need to increase the amount of prescribed burning on the landscape now.	**1**						**1**		
Q2A	The short-term health impacts from smoke may outweigh any long-term potential benefits of using prescribed burning to reduce future wildfire risk.		**1**		**1**				**1**	
Q3B	Liability reform is needed to incentivize prescribed burning practices	**1**						**1**		
Q3A	Escaped fires from prescribed burning are too high of a liability		**1**		**1**	**1**				
Q4A	To reduce impacts to communities from wildfires we must educate the public about the importance of fire.	**1**								**1**
Q4B	To reduce impacts to communities from wildfires, we must learn to listen to what the public is saying.		**1**						**1**	
Q5B	There is no future in which we do not see dramatically more smoke, in more areas, for longer periods of time									**2**
Q5A	There are viable management options that allow us to dramatically reduce smoke and emissions due to wildfires.		**1**							
Q6B	We need to increase the pace and scale of fuels treatments by identifying practices that can work in many places	**1**								
Q6A	We need to increase place-based solutions by identifying practices that are tailored for specific communities.							**1**	**1**	
Q7A	There are a lot of opinions out there. Our forest and fire management plans must be grounded in science	**1**								**1**
Q7B	Science is important, but we must incorporate multiple types of knowledge							**1**		

	Statements	Manage	Work	Market	Control	Regulate	Conserve	Revitalize	Justice	Adapt
Q8A	The more we suppress fires, the more expensive and risky the conditions	**1**						**1**		**1**
2	Foremost, we need to focus our efforts on hardening the wildland urban interface					**2**	**1**			
Q9B	Foremost, we need to focus our efforts on managing our wildland forests	**1**								
Q10B	Climate mitigation, in the form of emissions reductions, is our best tool against wildfires									**2**
Q10A	Fuels reduction, in the form of thinning and prescribed burning, is our best tool against wildfires	**1**								
Q11B	The Western wildfire crisis is predominantly a WUI problem. If we change how and where we build, we won't have a fire problem.					**2**	**1**			
Q11A	The Western wildfire crisis is predominantly a forest and climate problem. Some of these fires burn so hot and fast, that no amount of WUI mitigation will stop them.	**1**								**2**
Q12B	Fire in wildlands is not a disaster. Fire in homes and communities is absolutely a disaster					**2**	**1**		**2**	
Q12A	Western wildfires pose an existential crisis to our forests. We cannot separate the health of our forests from the impact on communities.	**1**								**2**
Q13B	To the extent it is safe, we should try to stop all fires in the wildlands as soon as possible				**1**					
Q13A	To the extent it is safe, we should try to let fires burn in the wildland.	**1**					**1**			
Q14B	Our wildfire problems are tied to overly restrictive environmental and economic policy.		**2**	**2**						
Q14A	Our wildfire problems are tied to persistent socio-economic inequities.							**1**	**2**	
Q15B	The insurance industry has the financial incentive to develop and deploy the best, most accurate models so they can properly manage their risks			**2**						
Q15A	Insurance premiums need to be regulated to protect homeowners								**1**	
Q16B	Putting a ceiling on insurance premiums, or a moratorium on non-renewals, causes a market distortion and covers up the true price signal of risk.			**2**						
Q16A	Insurance reform helps stabilize the market and reduces risk to homeowners affected by disasters.								**1**	
Q17B	We should restrict development in high risk fire hazard zones.					**2**	**1**			
Q17A	It is unrealistic to restrict development in high risk fire hazard zones.			**2**					**1**	

	Statements	Manage	Work	Market	Control	Regulate	Conserve	Revitalize	Justice	Adapt
Q18A	Home mitigation practices such as home hardening and defensible space are the most effective means to protect communities from wildfire.			**1**		**2**	**1**			
Q19B	The communities most affected by wildfire are also least likely to recover from the long-term financial stress following a disaster								**2**	
Q19A	Communities most affected by wildfire have chosen to live in high risk fire hazard areas. The cost of their home is a reflection of that risk.			**2**						
Q20A	Justice means vulnerable populations don't disproportionality bear the burden of the Western wildfire crisis.								**2**	
Q20B	Justice means wildfire protection and recovery is the responsibility of communities living in the WUI, and not taxpayers living miles away.			**2**						
Q21B	To put fire back in balance, we need to use all the tools available to us to invite more fire to the landscape							**1**		
Q21A	To put fire back in balance, we need to control and minimize the amount of fire on the landscape.				**2**					
Q22B	We need more people managing fire. Therefore, we need to mainstream and democratize fire. Fire management doesn't just belong to government agency professionals.							**1**		
Q22A	We need more fire professionals managing fire. Therefore, we need to invest more into our hot shot crews. They are specialized, trained, and certified.				**1**					
Q23B	We need to decolonize fire management. We need to de-fund the Forest Service. We need to tear down the system and build another one.							**2**		
Q23A	We need to restore the function and mission of the Forest Service. We need to provide the agency with the resources and freedom to manage our national forestlands.				**1**					
Q24B	Fire managers need to participate in Indigenous-led trainings and learn from communities who have successfully managed fire in the West for millennia.							**2**		
Q24A	Our fire managers are expertly trained to fight fires and conduct burns. To suggest that historic practices are appropriate for today's fire landscape is out of touch given conditions on the ground.				**1**					
Q25B	Salvage logging should be prohibited, it is unilaterally damaging to ecosystems. Large dead trees still retain nearly all of their carbon.						**1**			
Q25A	Salvage logging is necessary to capture carbon into sustainable products. A burned forest is a major net contributor of carbon emissions.		**1**							
Q26B	Fuels reduction measures need to ‘pay for themselves’ or they will not be a long term viable solution.		**1**							

	Statements	Manage	Work	Market	Control	Regulate	Conserve	Revitalize	Justice	Adapt
Q27A	Forest roads are a source of ignitions and thereby increase wildfire risk						**1**			
Q27B	Forest roads are necessary access points and thereby reduce wildfire risk		**1**							
Q28B	Coupling fuels reduction treatments with profit-driven forest practices usually ends up increasing fire risk						**1**			
Q28A	Economically viable forest treatments are needed to remove hazardous fuels and create a healthier forest environment		**1**		**1**					
Q29B	Environmental regulations and standards are more important than ever		**2**							
Q29A	Environmental regulations are preventing necessary work from happening on the landscape						**1**			
Q30A	Fire as a means of fuels management is the most effective way to protect our forests.	**1**					**2**			
Q30B	Fire as a means of fuels management is a waste of forest resources.		**2**		**1**					
Q31A	The objective of fire management should be to control wildfire spread.				**2**					
Q31B	The objective of fire management should be to support ecological objectives.						**1**			

Appendix D: Western Wildfire Perspectives Survey

Introduction

Welcome to the **Western Wildfire Perspective Survey**
This survey is designed to map the way you characterize the wildfire crisis in relation to your colleagues. We intend to use these data to better understand the distribution of perspectives among practitioners, academics, managers, and other stakeholders working on wildfire topics in forested regions of the western US.

Overview of the survey

- This survey is administered by researchers at the Western Forest and Fire Initiative at the University of Michigan.
- We anticipate the survey will take ***10 minutes*** to complete. You can save it and return to it at a later time.
- Please submit only one survey. You are welcome to share this survey with your colleagues.
- Your participation in this research is voluntary. You can stop participating at any time by closing the browser window.
- Your answers are confidential and only accessible to the research team. We will only report findings in the aggregate, not mentioning individuals by name.
- All data will be secured on a password-protected University of Michigan storage drive.
- If you have any questions about the research, please contact Michal Russo, michalr@umich.edu. If you have any questions about your rights as a volunteer in this research, contact the UM IRB at: hrppumich@umich.edu
- The survey closes on December 15, 2022

consent

Consent to participate in research

If you consent to complete this survey, please click the *"I agree to participate and am 18 years of age or older"* button to access the survey.

By completing this survey, you are consenting to participate in research.

Paired Statements

Part 1 of 2: Paired statements

The following pairs of statements correspond with distinct wildfire narratives or ways of thinking about the Western wildfire crisis. They represent the authentic language and expression of people who are leading the thinking on western wildfire issues.

- For each pair of statements, select the statement that resonates with you ***more***, when you consider wildfire across western US forests.
- If you cannot choose between the two statements, if you agree with both, select *both*.
- If you do not agree with either of the statements, or do not find it to be applicable, *skip* the pair.

Every person working on wildfire issues wears more than one 'hat' and tells more than one narrative. This survey is intended to map the way you characterize the wildfire crisis as a blend of these narratives.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

☐ We should use unplanned ignitions under good conditions as an opportunity to restore ecological function.	☐ We should not use unplanned ignitions to burn for resource purposes as it is a dangerous and costly means to manage our forests.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

☐ To manage the long-term health impacts of wildfire smoke, we need to increase the amount of prescribed burning on the landscape now.	☐ The short-term health impacts from smoke may outweigh any long-term potential benefits of using prescribed burning to reduce future wildfire risk.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

☐ Liability reform is needed to incentivize prescribed burning practices.	☐ Escaped fires from prescribed burning are too high of a liability.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ To reduce impacts to communities from wildfires we must educate the public about the importance of fire.
- ☐ To reduce impacts to communities from wildfires, we must learn to listen to what the public is saying.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ There is no future in which we do not see dramatically more smoke, in more areas, for longer periods of time
- ☐ There are viable management options that allow us to dramatically reduce smoke and emissions due to wildfires.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ We need to increase the pace and scale of fuels treatments by identifying practices that can work in many places.
- ☐ We need to increase place-based solutions by identifying practices that are tailored for specific communities.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ There are a lot of opinions out there. Our forest and fire management plans must be grounded in science.
- ☐ Science is important, but we must incorporate multiple types of knowledge.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ The more we suppress fires, the less expensive and risky the conditions.
- ☐ The more we suppress fires, the more expensive and risky the conditions.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

Foremost, we need to focus our efforts on hardening the wildland urban interface

Foremost, we need to focus our efforts on managing our wildland forests

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- [ ] Climate mitigation, in the form of emissions reductions, is our best tool against wildfires.
- [ ] Fuels reduction, in the form of thinning and prescribed burning, is our best tool against wildfires.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- [ ] The Western wildfire crisis is predominantly a WUI problem. If we change how and where we build, we won't have a fire problem.
- [ ] The Western wildfire crisis is predominantly a forest and climate problem. Some of these fires burn so hot and fast, that no amount of WUI mitigation will stop them.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- [ ] Fire in wildlands is not a disaster. Fire in homes and communities is absolutely a disaster.
- [ ] Western wildfires pose an existential crisis to our forests. We cannot separate the health of our forests from the impact on communities.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- [ ] To the extent it is safe, we should try to stop all fires in the wildlands as soon as possible.
- [ ] To the extent it is safe, we should try to let fires burn in the wildlands.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- [ ] Our wildfire problems are tied to overly restrictive environmental and economic policy.
- [ ] Our wildfire problems are tied to persistent socio-economic inequities.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ The insurance industry has the financial incentive to develop and deploy the best, most accurate models so they can properly manage their risks.
- ☐ Insurance premiums need to be regulated to protect homeowners.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Putting a ceiling on insurance premiums, or a moratorium on non-renewals, causes a market distortion and covers up the true price signal of risk.
- ☐ Insurance reform helps stabilize the market and reduces risk to homeowners affected by disasters.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ We should restrict development in high risk fire hazard zones.
- ☐ It is unrealistic to restrict development in high risk fire hazard zones.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Fuels reductions practices in the wildlands, provide firefighters a chance to stop the fire before it reaches the community, and are the most effective means to protect communities from wildfires.
- ☐ Home mitigation practices such as home hardening and defensible space are the most effective means to protect communities from wildfires.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ The communities most affected by wildfire are also least likely to recover from the long-term financial stress following a disaster.
- ☐ Communities most affected by wildfire have chosen to live in high risk fire hazard areas. The cost of their home is a reflection of that risk.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Justice means vulnerable populations don't disproportionally bear the burden of the Western wildfire crisis.
- ☐ Justice means wildfire protection and recovery is the responsibility of communities living in the WUI, and not taxpayers living miles away.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ To put fire back in balance, we need to use all the tools available to us to invite more fire to the landscape
- ☐ To put fire back in balance, we need to control and minimize the amount of fire on the landscape.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ We need more people managing fire. Therefore, we need to mainstream and democratize fire. Fire management doesn't just belong to government agency professionals.
- ☐ We need more fire professionals managing fire. Therefore, we need to invest more into our hot shot crews. They are specialized, trained, and certified.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ We need to decolonize fire management. We need to de-fund the Forest Service. We need to tear down the system and build another one.
- ☐ We need to restore the function and mission of the Forest Service. We need to provide the agency with the resources and freedom to manage our national forestlands.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Fire managers need to participate in Indigenous-led trainings and learn from communities who have successfully managed fire in the West for millennia
- ☐ Our fire managers are expertly trained to fight fires and conduct burns. To suggest that historic practices are appropriate for today's fire landscape is out of touch given conditions on the ground.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.a

- ☐ Salvage logging should be prohibited, it is unilaterally damaging to ecosystems. Large dead trees still retain nearly all of their carbon.
- ☐ Salvage logging is necessary to capture carbon into sustainable products. A burned forest is a major net contributor of carbon emissions.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Fuels reduction measures need to 'pay for themselves' or they will not be a long term viable solution.
- ☐ The co-benefits of fuels reduction measures are enormous, we need to better account for these benefits instead of trying to make fuels reduction measures pay for themselves.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Forest roads are a source of ignitions and thereby increase wildfire risk
- ☐ Forest roads are necessary access points and thereby reduce wildfire risk

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Coupling fuels reduction treatments with profit-driven forest practices usually ends up increasing fire risk
- ☐ Economically viable forest treatments are needed to remove hazardous fuels and create a healthier forest environment

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Environmental regulations are preventing necessary work from happening on the landscape
- ☐ Environmental regulations and standards are more important than ever

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ Fire as a means of fuels management is a waste of forest resources.
- ☐ Fire as a means of fuels management is the most effective way to protect our forests.

For each of the pairs of statements below, please select which statement resonates with you more.

If you are unable to select one, you can select both, or simply skip it to the next question.

- ☐ The objective of fire management should be to control wildfire spread.
- ☐ The objective of fire management should be to support ecological objectives.

work related factors

Part 2 of 2: Work-related questions

The following five questions are intended to understand more about the wildfire work you engage in. Work is broadly defined as any activity (whether voluntary or paid) in which you research, manage, or inform policy about western wildfires.

In the past 5 years, which States have you worked in (select ALL that apply)?

- ☐ Arizona
- ☐ California
- ☐ Colorado
- ☐ Idaho
- ☐ Montana
- ☐ New Mexico
- ☐ Nevada
- ☐ Oregon
- ☐ Utah
- ☐ Washington
- ☐ Wyoming
- ☐ Other

In the past 5 years, what scales have you mostly worked at (select ALL that apply)?

- ☐ Local (neighborhood, city, county)
- ☐ State
- ☐ Regional (multiple states)
- ☐ National
- ☐ International

- [ ] Other

In the past 5 years, which sectors have you mostly worked in (select ALL that apply)?

- [ ] Academia (e.g., University)
- [ ] Private industry
- [ ] Government (e.g., municipal, state, and federal)
- [ ] Non-governmental organization (non-profit)
- [ ] Tribal government
- [ ] Other

Over the last five years, what type of landscapes have you worked in (select ALL that apply)?

- [ ] forestlands
- [ ] grasslands or rangelands
- [ ] wildland urban interface (WUI)
- [ ] Other

In the past 5 years, what topics have your wildfire-related work generally included (select ALL that apply)?

- [ ] Landscape treatments (e.g., natural resource management, restoration, thinning, prescribed fire)

- [ ] Environmental protections (e.g., air quality, watershed protection, fish and wildlife, conservation)
- [ ] Traditional fire culture (e.g., Indian affairs, Indigenous-led training, traditional ecological knowledge)
- [ ] Research (e.g., predictive models, risk assessments, climate science, monitoring)
- [ ] Public health (e.g., smoke preparedness, mental health services, social services)
- [ ] Equity (e.g., environmental justice, community engagement, neighborhood ambassadors, affordable housing)
- [ ] Preparation and mitigation (e.g., public education campaigns, defensible space, home hardening, wildfire prep, ready, set, go!)
- [ ] Planning and local policy (e.g., community wildfire protection plans, Firewise USA, codes & ordinances, evacuation planning)
- [ ] Infrastructure (e.g., utilities, public safety power shutoffs, critical infrastructure protection)
- [ ] Wildfire response (e.g., workforce training, incident management teams, fire crews)
- [ ] Recovery (e.g., business continuity planning, long-term recovery planning, hazard mitigation assistance, flooding & erosion)
- [ ] Regulation & insurance (e.g., homeowner insurance, liability insurance, certification, policy reform)
- [ ] Industry (timber, innovation, partnerships, rural economy, tourism)
- [ ] Other (fill in)

Results

Results

The previous pairs of statements correspond with nine distinct wildfire narratives or ways of thinking about the Western wildfire crisis. Every person working on these issues wears more than one 'hat' and tells more than one narrative. The proportion and balance of the narratives they hold shed light on their perspectives. The figure below illustrates the degree to which your responses resonate with each of the nine narratives.

Please visit our survey summary page (website opens in a new tab) to see descriptions of the nine narratives and learn more about the project.

Feedback on wildfire perspectives survey

Thank you for taking our survey!
We have 2 open ended feedback questions we'd love to ask you!

What do you think of your results? How do your results resonate with how you see your perspective of the wildfire situation?

What might some opportunities and challenges be for using something like this in your work?

thank you - submit

Join our mailing list?
This survey was developed by researchers at the Western Forest and Fire Initiative. We believe that as we learn to reflect on our own perspectives and recognize and respect the legitimacy of other actors' views, we will be able to identify more just and sustainable solutions to address the western wildfire crisis. We hope that this survey can provide an initial opportunity for reflection and curiosity.

If you would like to receive any **publications from this research**, please include your name and email below. Your identity will not be linked to your survey responses.

name

email

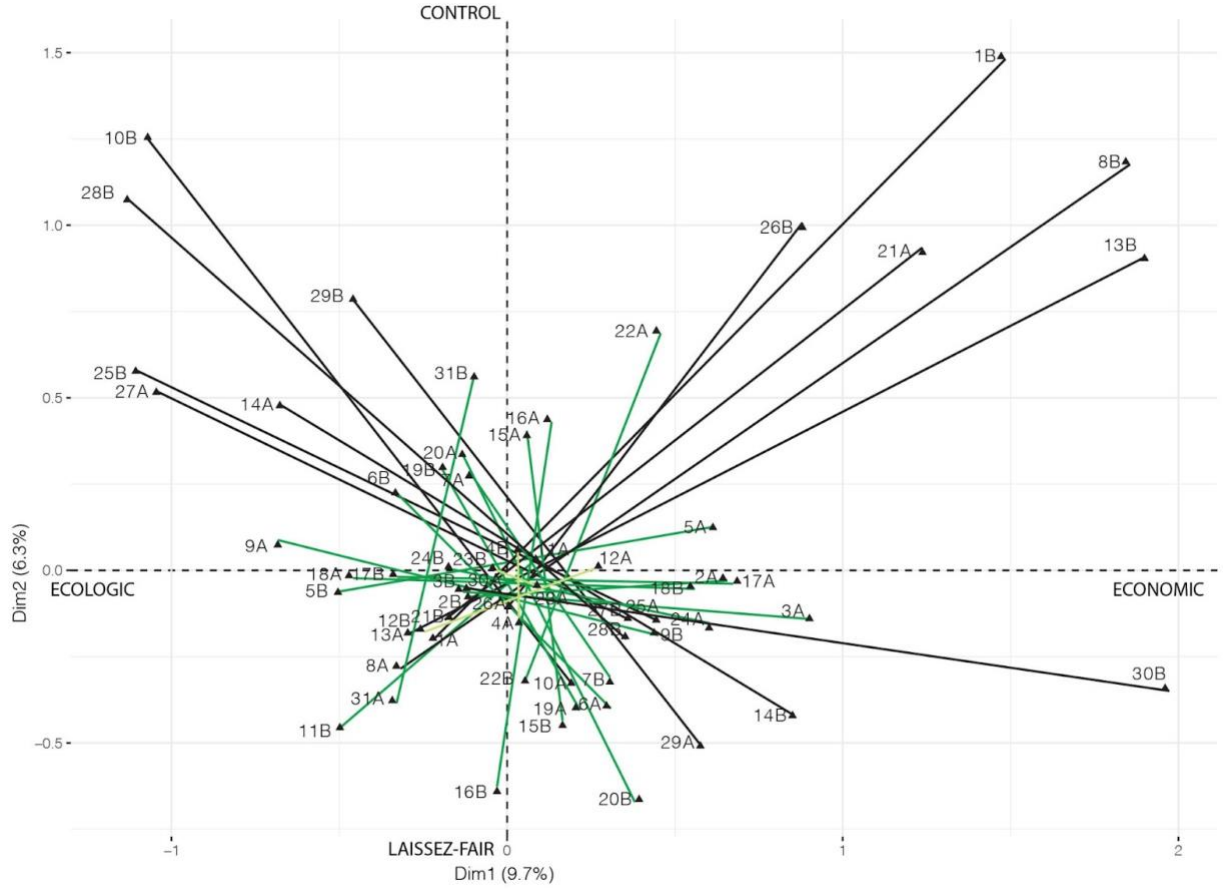
Powered by Qualtrics

Appendix E: Multiple Correspondence Analysis (MCA) Script and Results

Multiple Correspondence Analysis Script

```
[[read in libraries]]
library(readr)
library(stats)
library("FactoMineR")
library('factoextra')
[[upload file]]
MCA <- read_csv("analysis/MCAtest.csv")
[[run analysis]]
results.mca <- MCA(MCAtest.csv, ncp = 2, graph=TRUE)
[[visualize biplot]]
fviz_mca_biplot(results.mca)
[[returns the x,y coordinates for each of the 62 statements]]
get_mca(res.mca)
var <- get_mca_var(res.mca)
var$coord
```

Multiple Correspondence Analysis Results



Appendix Table E.1 MCA Biplot pairs

Statement pairs are connected by lines and colored by the degree of association. Longer lines (black) represent more differentiated or mutually exclusive statements pairs. Shorter lines (green) represent statement pairs that are less differentiated.

Appendix Figure E.1 MCA Biplot clusters

Points that closer together represent statements that are more likely to be selected together. Points that are close to the origin (0,0) are not highly differentiated by the two axes (factors). The relationship between these points is not significant. Three significant clusters are identified, A, B, and C.

Appendix F: Principal Component Analysis (PCA) Script and Results

Principal Component Analysis Script

```
[[read in libraries]]
library(readr)
library(stats)
library("FactoMineR")
library('factoextra')
[[upload file]]
PCA <- read_csv("analysis/PCAtest.csv")
[[run analysis]]
results.pca <- PCA(PCA[, 2:10], scale.unit = TRUE, ncp = 5, graph = TRUE)
[[get eigen values]]
get_pca(results.pca)
get_eig(results.pca)
[[get x,y coordinates]]
ind <- get_pca_ind(results.pca)
ind
ind$coord
```

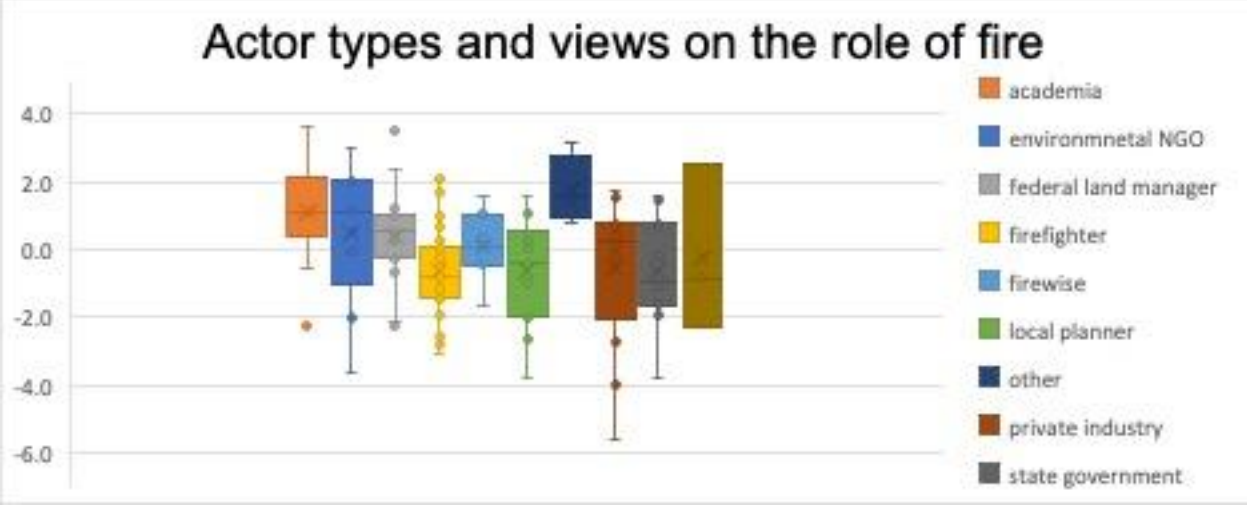
Principal Component Analysis Results

Appendix Table F.1 PCA X,Y distribution

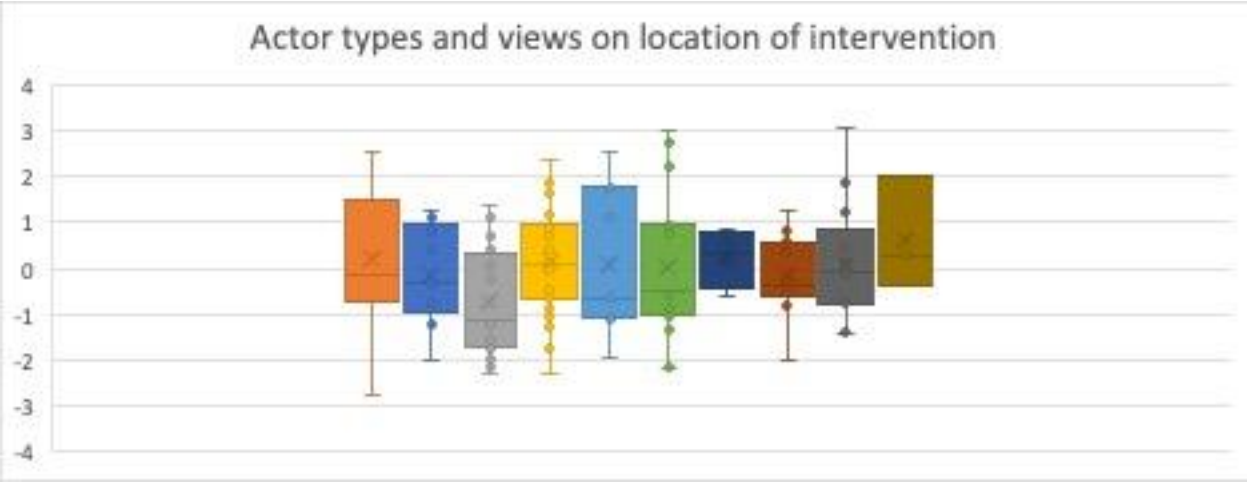
	x values	y values		
mean	0.0	0.0		
st dev	1.6	1.2		
	x freq	normal	y freq	normal
-6	0	0	0	0
-5	1	2	0	0
-4	1	5	0	0
-3	4	26	0	7
-2	11	88	10	40
-1	22	176	23	148
0	34	217	46	289
1	38	227	40	307
2	25	154	23	152
3	14	80	9	49
4	3	19	2	8
5	0	6	0	0
6	0	1	0	0

Appendix Table F.2 PCA X,Y distribution by actor type

		x values			y values		
#	Actor Type	mean	count	st dev	mean	count	st dev
1	academia	1.10	29	1.24	0.20	29	1.37
2	environmental NGO	0.46	9	2.10	-0.12	9	1.12
3	federal land manager	0.40	21	1.29	-0.72	21	1.19
4	firefighter	-0.67	40	1.25	0.16	40	1.06
5	FIREWISE	0.09	7	1.06	0.10	7	1.70
6	local planner	-0.65	15	1.57	0.04	15	1.66
7	other	1.77	4	1.00	0.24	4	0.65
8	private industry	-0.58	12	2.29	-0.14	12	0.88
9	state government	-0.64	13	1.54	0.12	13	1.31
10	tribal	-0.22	3	2.45	0.64	3	1.24



Appendix Figure F.1 Actor types and views on the role of fire



Appendix Figure F.2 Actor types and views on location of interventions

Appendix G: Review of Published Evaluations of Team Learning in Knowledge Co-Production Practices (2003-2023)

Appendix Table G.1 Published evaluations of team learning in knowledge co-production practices (2003-2023)

First author	YR	Title	systematic review	primary empirical	theoretical	conceptual model
Armitage	2012	Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic		yes		
Bark	2016	Evaluating an interdisciplinary research project: Lessons learned for organisations, researchers and funders	yes			yes
Belcher	2016	Defining and assessing research quality in a transdisciplinary context		yes		yes
Belcher	2021	Understanding and evaluating the impact of integrated problem-oriented research programmes: Concepts and considerations			yes	yes
Bezerra	2023	Stakeholder engagement and knowledge co-production for better watershed management with the Freshwater Health Index		yes		yes
Boon	2014	Balancing divergence and convergence in transdisciplinary research teams		yes		yes
Boon et al	2022	Successful climate services for adaptation: What we know, don't know and need to know		yes		
Borgstrom	2021	Retaining multi-functionality in a rapidly changing urban landscape: Insights from a participatory, resilience thinking process in Stockholm, Sweden		yes		
Bowers	2017	Team resilience as a second-order emergent state: A theoretical model and research directions			yes	yes
Brandt	2013	A review of transdisciplinary research in sustainability science	yes			
Bremer & Meisch	2017	Co-production in climate change research: reviewing different perspectives	yes			yes
Brouwers	2022	Accommodating coexisting impact rationales in knowledge co-production: The case of the Natuurpact reflexive evaluation		yes		
Cabello	2018	Unravelling narratives of water management: Reflections on epistemic uncertainty in the first cycle of implementation of the Water Framework Directive in southern Spain		yes		
Caniglia	2023	Practical wisdom and virtue ethics for knowledge co-production in sustainability science			yes	
Caniglia	2021	A pluralistic and integrated approach to action-oriented knowledge for sustainability			yes	

Chakraborty	2022	Pursuing Plurality: Exploring the Synergies and Challenges of Knowledge Co-production in Multifunctional Landscape Design		yes		
Chambers	2022	Co-productive agility and four collaborative pathways to sustainability transformations	yes			
Cornell	2013	Opening up knowledge systems for better responses to global environmental change			yes	
Cornwell & Campbell	2012	Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA		yes		
Costa	2022	Co-design of a marine protected area zoning and the lessons learned from it		yes		
Djenontin	2018	The art of co-production of knowledge in environmental sciences and management: lessons from international practice	yes			
Elbakidze	2010	Multi-Stakeholder Collaboration in Russian and Swedish Model Forest Initiatives: Adaptive Governance Toward Sustainable Forest Management?		yes		
Enengel	2012	Co-production of knowledge in transdisciplinary doctoral theses on landscape development-An analysis of actor roles and knowledge types in different research phases		yes		
Ernst	2019a	Review of factors influencing social learning within participatory environmental governance	yes			
Ernst	2019b	Research techniques and methodologies to assess social learning in participatory environmental governance	yes			
Fazey	2014	Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research	yes			
Fazey	2013	Knowledge exchange: A review and research agenda for environmental management			yes	
Fernandez-Bou	2021	Underrepresented, understudied, underserved: Gaps and opportunities for advancing justice in disadvantaged communities		yes		
Franklin	2019	Creating Broader Research Impacts through Boundary Organizations		yes		
Frantzeskaki & Kabisch	2016	Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany		yes		
Fujitani	2017	Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science		yes		
Gillard	2012	Patient and public involvement in the coproduction of knowledge: Reflection on the analysis of qualitative data in a mental health study		yes		
Guerrero et al	2018	Achieving the promise of integration in social-ecological research: A review and prospectus	yes			

Hahn	2017	Are adaptations self-organized, autonomous, and harmonious? Assessing the social–ecological resilience literature	yes		
Hakkarainen	2022	Transdisciplinary research in natural resources management: Towards an integrative and transformative use of co-concepts			yes
Harris and Lyon	2014	Transdisciplinary environmental research: a review of approaches to knowledge co-production			yes
Hinkel	2011	Indicators of vulnerability and adaptive capacity ’’: Towards a clarification of the science – policy interface			yes
Hoffman	2017	Methods and Procedures of Transdisciplinary Knowledge Integration		yes	
Huang	2021	Beyond Indicators and Success Stories: An Emerging Method to Assess Social Learning in Large-Scale Transdisciplinary Research Programs			yes
Hubeau	2018	A reflexive assessment of a regional initiative in the agri-food system to test whether and how it meets the premises of transdisciplinary research		yes	
Jagannathan et al	2020	Great expectations? Reconciling the aspiration, outcome, and possibility of co-production	yes		
Karcher	2021	Is this what success looks like? Mismatches between the aims, claims, and evidence used to demonstrate impact from knowledge exchange processes at the interface of environmental science and policy	yes		
Klenk	2017	Transdisciplinary sustainability research beyond engagement models: Toward adventures in relevance			yes
Knapp et al	2019	Placing transdisciplinarity in context: A review of approaches to connect scholars, society and action	yes		
LaMere	2020	Making the most of mental models: Advancing the methodology for mental model elicitation and documentation with expert stakeholders		yes	
Lang	2012	Transdisciplinary research in sustainability science: Practice, principles, and challenges	yes		
Leith	2018	An operation on ‘the neglected heart of science policy’: Reconciling supply and demand for climate change adaptation research		yes	
Lemos	2005	The co-production of science and policy in integrated climate assessments		yes	
Louder	2021	A synthesis of the frameworks available to guide evaluations of research impact at the interface of environmental science, policy and practice	yes		
Maag	2018	Indicators for measuring the contributions of individual knowledge brokers			yes
Mach	2020	Actionable knowledge and the art of engagement			yes

Malmbord	2022	Knowledge co-production in the Helge a catchment: a comparative analysis		yes	
Manuel-Navarrete	2021	Fostering horizontal knowledge co-production with indigenous people by leveraging researchers' transdisciplinary intentions		yes	
Mascarenhas	2021	Assessing the learning process in transdisciplinary research through a novel analytical approach		yes	
McEwen	2022	Building local capacity for managing environmental risk: a transferable framework for participatory, place-based, narrative-science knowledge exchange		yes	
Meadow	2015	Moving toward the deliberate coproduction of climate science knowledge			yes
Minga-Vallejo	2016	Methods for the evaluation of social learning (2017-2021): Systematic literature review	yes		
Molinengo	2021	Process expertise in policy advice: Designing collaboration in collaboration		yes	
Muccione	2019	Joint knowledge production in climate change adaptation networks		yes	
Nguyen	2019	Collaboration and engagement produce more actionable science: quantitatively analyzing uptake of fish tracking studies		yes	
Norstrom	2020	Principles for knowledge co-production in sustainability research			yes
Oteros-Rozas	2015	Participatory scenario planning in place-based social-ecological research: insights and experiences from 23 case studies	yes		
Page	2016	Co-designing transformation research: lessons learned from research on deliberate practices for transformation		yes	
Palmer	2016	Practices for facilitating interdisciplinary synthetic research: The National Socio-Environmental Synthesis Center (SESYNC)		yes	
Pitt	*2018*	Wrestling with the complexity of evaluation for organizations at the boundary of science, policy, and practice			yes
Plummer	2022	Transdisciplinary partnerships for sustainability: an evaluation guide			yes
Pohl	2010	Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal		yes	
Pohl	2021	Conceptualizing transdisciplinary integration as a multidimensional interactive process			yes
Polk	2015	Transdisciplinary co-production: Designing and testing a transdisciplinary research framework for societal problem solving		yes	

Posner	*2019*	Evaluating the impacts of boundary-spanning activities at the interface of environmental science and policy: A review of progress and future research needs		yes	
Price	2023	From reflection diaries to practical guidance for transdisciplinary research: learnings from a Kenyan air pollution project	yes		
Priess	2014	Integrative Scenario Development		yes	
Reed	2018	Facilitating Co-Production of Transdisciplinary Knowledge for Sustainability: Working with Canadian Biosphere Reserve Practitioners	yes		
Restrepo	2020	Assessing the quality of collaboration in transdisciplinary sustainability research: Farmers' enthusiasm to work together for the reduction of postharvest dairy losses in Kenya	yes		
Restrepo	2018	Evaluating knowledge integration and co-production in a 2-year collaborative learning process with smallholder dairy farmer groups	yes		
Reyers	2015	Navigating complexity through knowledge coproduction: Mainstreaming ecosystem services into disaster risk reduction	yes		
Robinson	2021	Using knowledge to care for country: Indigenous-led evaluations of research to adaptively co-manage Kakadu National Park, Australia	yes		
Rodela	2019	Environmental governance in an increasingly complex world: Reflections on transdisciplinary collaborations for knowledge coproduction and learning	yes		
Rölfer	2022	Resilience and coastal governance: knowledge and navigation between stability and transformation		yes	
Roux	2017	Transdisciplinary research for systemic change: who to learn with, what to learn about and how to learn	yes		
Roux	2010	Framework for participative reflection on the accomplishment of transdisciplinary research programs		yes	
Rubenstein	2016	Critical reflections on building a community of conversation about water governance in Australia	yes		
Ruiz	2020	Land use planning in the amazon basin: Challenges from resilience thinking		yes	
Schneider	2021	Co-production of knowledge and sustainability transformations: a strategic compass for global research networks		yes	
Schuttenberg	2015	Making the most of mental models: Advancing the methodology for mental model elicitation and documentation with expert stakeholders	yes		
Scolobig	2016	Comparing approaches for the integration of stakeholder perspectives in environmental decision making	yes		

Sellberg	2017	Improving participatory resilience assessment by cross-fertilizing the Resilience Alliance and Transition Movement approaches		yes	
Shrestha	2017	Interactive Knowledge Co-Production and Integration for Healthy Urban Development		yes	
Siew	2016	Transdisciplinary research in support of land and water management in China and Southeast Asia: evaluation of four research projects		yes	
Singh	2021	Measuring successful processes of knowledge co-production for managing climate change and associated environmental stressors: Adaptation policies and practices to support Indian farmers	yes		
Slater	2020	Social learning and transdisciplinary co-production: A social practice approach		yes	
Steelman	2021	Evaluating transdisciplinary research practices: insights from social network analysis		yes	
Stokols	2008	The Ecology of Team Science. Understanding Contextual Influences on Transdisciplinary Collaboration	yes		
Tabriz	2020	Logic model framework for considering the inputs, processes and outcomes of a healthcare organisation-research partnership		yes	
Tebes	2018	Team science, justice, and the co-production of knowledge		yes	
Tedim	2021	Supporting a shift in wildfire management from fighting fires to thriving with fires: The need for translational wildfire science		yes	
Trimble	2019	Participatory evaluation for adaptive co-management of social-ecological systems: a transdisciplinary research approach		yes	
Van Kerkhoff	2006	Linking knowledge and action for sustainable development	yes		
Verwoerd	2020	Negotiating space for knowledge co-production		yes	
Wagner	2023	Effectiveness factors and impacts on policymaking of science-policy interfaces in the environmental sustainability context	yes		
Wall	2017	Developing evaluation indicators to improve the process of coproducing usable climate science	yes		
West	2019	Beyond “linking knowledge and action”: towards a practice-based approach to transdisciplinary sustainability interventions			yes
Wyborn	2015	Co-productive governance: A relational framework for adaptive governance		yes	
Zierhofer	2007	Disentangling Transdisciplinarity	yes		
Zurba	2022	Learning from knowledge co-production research and practice in the twenty-first century: global lessons and what they mean for collaborative research in Nunatsiavut	yes		

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