RPR
REVIEW OF POLICY RESEARCH

Achieving Adaptive Governance of Forest Wildfire Risk Using Competitive Grants: Insights From the Colorado Wildfire Risk Reduction Grant Program

Antony S. Cheng
Colorado State University

Lisa Dale
Columbia University

Abstract

Competitive grants are increasingly used to induce proactive collaborative action by a range of actors to reduce forest wildfire risks. Given the rigidity of past wildfire risk governance, it is important to assess the adaptability of competitive grants as a new governance approach. Adaptive governance theory is used as a lens to assess the adaptability of the Colorado Wildfire Risk Reduction Grant (WRRG) program, which awards funds to successful applicants to reduce fuel on non-federal lands at a community scale. Four best practices from the theory were applied: participation of and collaboration among diverse actors; co-production of knowledge and learning toward adaptive management; cross-scale interactions and fit between the scale of governance and the scale of the ecological problem; and the capacity for innovation and re-organization. Using data and information about the WRRG structure and processes, awarded grantees from the first five granting cycles from 2013 to 2016, our direct participation-observation as part of the Advisory Committee, and results from the WRRG effectiveness monitoring report, we examine the extent to which the WRRG program exhibited adaptive governance attributes. For each adaptive governance attribute, we found evidence of factors facilitating and frustrating adaptiveness of the WRRG program. We situate our findings within the broader context of using competitive grants as a forest wildfire risk governance approach and address additional directions for adaptive governance research.

KEY WORDS: adaptive governance, forest wildfire risk, competitive grants

摘要： 竞争性基金越来越多的被用作一种手段来促进参与者之间的合作以达到降低森林火灾风险的目的。相比过去林火风险管理中的僵化，作为一种新的治理方法，竞争性基金可能具有更强的适应性。我们运用适应性治理理论来评估科罗拉多林火风险补助金（*WRRG*）的适应性。该计划向成功的申请者提供资金以促进社区内非联邦土地森林可燃物的清理。该理论的四种最佳实践模式包括：不同参与者的协作；基于适应性理论的共同学习和探索；治理范围与生态规模之间的契合和跨范围合作；创新和重组。作为咨询委员会一部分，我们收集利用了*WRRG*的结构和流程的相关数据进行研究。从*2013*年至*2016*年，我们直接参与调查了前五个授予周期内的被资助者。根据*WRRG*有效性监测报告，我们研究*WRRG*程序显示的这些被资助人自我适应和自我管理的属性和程度。对于每个属性，我们揭示了它们有利于和不利于*WRRG*计划适应性的证据。最后，我们将使用竞争性基金促进林火风险治理的方法放在更广泛的背景下进行评价并提出有关适应性治理的其他研究方向。

关键词: 适应性治理, 林火风险, 竞争性基金

Introduction

Globally, climate-related natural disasters such as drought, wildfires, insect and disease outbreaks, and flooding have increased in frequency, size, duration, and severity over the past 30 years, resulting in losses of human life, damage to built infrastructure, and irreversible alteration of native ecosystems (Hoeppe, 2016). The pace and scope of these changes challenge the adaptability of governance arrangements to mitigate

Review of Policy Research, (2020) 10.1111/ropr.12379

the risks and impacts associated with these events (Ahrens & Rudolph, 2006; Djalante, Holley, & Thomalla, 2011; Folke, Hahn, Olsson, & Norberg, 2005). The governance of forest wildfire risk in the United States is emblematic of this challenge.

Since the early 1900s, forest wildfire risk governance has been largely comprised of federal land management agencies and state forestry agencies cooperating to suppress unwanted wildfires (Southard, 2011; Stephens, Collins, Biber, & Fule, 2016). This approach has had some successes, but a century of fire suppression has allowed wildland vegetation to accumulate over large geographic areas, thereby making subsequent fires potentially larger and more intense (Hessburg et al., 2019; North et al., 2015; Stephens et al., 2016). Concurrently, human population and land development has expanded into fire-prone forested areas, termed the "wildland-urban interface" or WUI (Radeloff et al., 2005), magnifying the need for fire managers to suppress fires to avoid losses of human life and infrastructure, and further contributing to the build-up of wildland vegetation ready to burn in future fires (Calkin, Cohen, Finney, & Thompson, 2014; Calkin, Thompson, & Finney, 2015). Predicted increases in drought conditions and warming average annual temperatures for western North America are likely to compound the risks and consequences of forest wildfires and overwhelm the ability of fire managers to safely respond (Abatzoglou & Williams, 2016; Schoennagel et al., 2017).

In sum, wildfire managers have institutionalized a rigid feedback loop that will continue to exacerbate undesirable social and ecological impacts unless governance approaches can shift to more forcefully disrupt the pattern by becoming more adaptive (Busenberg, 2004; Fischer et al., 2016; North et al., 2015; Schultz, Thompson, & McCaffrey, 2019a). In recent years, legislative and administrative policy changes have been enacted with the explicit acknowledgment that the scope and scale of forest wildfire risk in the United States exceeds the federal government's authority and capacity, and, instead, is a shared burden to be collectively undertaken by government agencies at all levels, Tribal entities, non-governmental organizations, and community residents (Abrams, 2019; Jakes et al., 2011; Steelman, Kunkel, & Bell, 2004; USDA & USDI, 2002; USDA Forest Service, 2018; Wildland Fire Leadership Council, 2014). Common across these policies is the proposition that when landowners and managers collaboratively plan and coordinate actions to reduce flammable vegetation—termed "fuels reduction" (Stephens et al., 2012)—around community assets and infrastructure, the potential for severe wildfires spreading through communities can be reduced. As this risk of catastrophic wildfire is reduced, firefighters will have an expanded set of management options available to them that can move beyond full suppression.

However, inducing proactive, collaborative risk reduction actions, especially between public and private landowners and managers, remains a governance challenge in itself (Bergemann, Schultz, & Cheng, 2019; Busby & Albers, 2010; Fischer & Charnley, 2012; McDowell, 2003). Social science research indicates that many private landowners living in fire-prone areas understand that they bear responsibility for undertaking wildfire risk mitigation on their own lands (McCaffrey & Olsen, 2012); however, the financial costs associated with reducing flammable fuel is a pervasive barrier to taking action (Abscher, Vaske, & Shelby, 2009). Further, landowners realize that if their neighbors do not conduct and maintain fuel reduction activities, their own efforts may not be effective at reducing wildfire risk exposure (Ager, Kline, & Fischer, 2015; Ferranto et al., 2013; Stein et al., 2015). Even if adjacent landowners recognize the need to take collective actions, collaborative wildfire risk management

requires sufficient financial resources to be effective (Cheng & Sturtevant, 2012; Sturtevant, Moote, Jakes, & Cheng, 2005).

Federally funded competitive grants have long been employed as a governance strategy to overcome financial barriers to wildfire risk management for local governments, communities, and property owners. The U.S. Department of Agriculture's Forest Service (USFS), in cooperation with state forestry agencies, administers the largest source of funds, the State Fire Assistance program established by the Cooperative Forestry Assistance Act of 1978 (Southard, 2011). For example, based on publicly available budget data, between 2005 and 2017, over $756 million was allocated to state, local, and community-based entities to undertake preventative actions, such as reducing flammable vegetation around susceptible structures and supporting state and local governments' firefighting capacity and preparedness (https://www.fs.fed.us/about-agency/budget-performance).

The Collaborative Forest Restoration Program was the first federal competitive funding programs directed at forest vegetation management projects across land ownership boundaries, specifically targeting projects spanning federal, Tribal, state, and county jurisdictions in the State of New Mexico (Prante, Thacher, McCollum, & Berrens, 2007; Steelman et al., 2004). Established in 2000 and administered by the USFS, the program has been allocating approximately $5 million per year through a competitive grant process and is governed by a multi-stakeholder federal advisory committee. This New Mexico-specific program was a model for the national Collaborative Forest Landscape Restoration Program (CFLRP) established in 2010, with the exception that the CFLRP targeted preventative forest restoration projects solely on national forest lands (Schultz, Jedd, & Beam, 2012). As of this writing, the CFLRP has funded 23 projects across the United States with annual appropriations between $40-60 million, with projects selected through a competitive review process governed by a multi-stakeholder advisory committee (Butler & Schultz, 2019).

The most recent federal competitive grant program to address wildfire risk is the Joint Chiefs Landscape Restoration Partnership established in 2014 between the chiefs of the Natural Resource Conservation Service and the USFS (Cyphers & Schultz, 2019). The Joints Chiefs program focuses funding on jointly planned and implemented federal-private land fuel reduction and forest restoration projects. Between 2014 and 2017, the program directed over $150 million to 55 projects nationwide (Cyphers & Schultz, 2019). Recognizing that state governments play a role in wildfire risk governance and management, legislatures in California, Colorado, Oregon, Utah, and Washington have enacted funding programs from their respective state general funds to support greater participation in coordinated, cross-boundary fuel reduction activities by local governments, community organizations, and property owners in fire-prone areas (Schultz & Moseley, 2019).

Despite the growth in competitive grant programs as a forest wildfire risk governance approach, little is known about their functioning, performance, and adaptability. Indeed, in the expansive body of scholarship on adaptive governance of social-ecological systems (Chaffin, Gosnell, & Cosens, 2014; Fischer et al., 2016; Karpouzoglou, Dewulf, & Clark, 2016; Smith et al., 2016; Steelman, 2016), research on competitive funding programs is largely absent. Our aim in this paper is to begin filling this knowledge gap by applying the adaptive governance lens to a case study of the structure, functioning, and adaptability of the Colorado Wildfire Risk Reduction

Grant (WRRG) Program enacted by the Colorado General Assembly in 2013. The WRRG is a governance strategy designed to induce pro-active, collaborative fuel reduction actions on non-federal lands in and around fire-prone communities in Colorado. Specifically, we examine the extent to which the WRRG program has embodied key tenets of adaptive governance, including: participation of and collaboration among diverse actors; co-production of knowledge and learning toward adaptive management; cross-scale interactions and fit between the scale of governance and the scale of the ecological problem; and the capacity for innovation and re-organization (Chaffin et al., 2014; Djalante et al., 2011; Folke et al., 2005; Karpouzoglou et al., 2016; Rijke et al., 2012; Sharma-Wallace, Velarde, & Wreford, 2018).

We first review the scholarship on adaptive governance to identify key tenets, and then identify prior research and knowledge gaps relevant to our case study. This is followed by a description of the Wildfire Risk Reduction Grant Program's background, a description of assessment methods and data sources, and a presentation of assessment results. We end with an interpretation and discussion of results, implications for better utilizing competitive grant funding programs as a governance strategy for addressing forest wildfire risk in fire-prone areas, and contributions to adaptive governance scholarship by from an under-researched arena of social-ecological systems governance.

Adaptive Governance: Key Tenets, Attributes, and Prior Research Relevant to Forest Wildfire Risk Management

In the context of reducing risks to, and enhancing the resilience of, complex social-ecological systems such as fire-prone landscapes, governance refers to the collection of formal and informal rules, economic incentives, social norms, and decision-making processes involved in steering how actors access, allocate, use, and protect natural resources (Lebel et al., 2006). Adaptive governance, then, refers to the attributes, processes, and behaviors through which governance participants anticipate and adjust to the inherent uncertainty and complexity associated with complex social-ecological systems (Folke et al., 2005; Garmestani & Benson, 2013). Early theoretical works and more recent systematic reviews of the adaptive governance literature elucidate four broad categories of best practices (Chaffin et al., 2014; Folke et al., 2005; Karpouzoglou et al., 2016; Plummer et al., 2012; Sharma-Wallace et al., 2018; Wyborn, 2015a): inclusive participation of and collaboration among a diverse range of stakeholders, co-production of knowledge and learning, cross-scale interactions and matching the scale of governance with the scale of the ecological problem, and the capacity for innovation and re-organization.

Inclusive Participation and Collaboration

Collaboration is both a process and a behavioral orientation through which two or more actors combine their skills, knowledge, and assets to achieve beneficial outcomes they could not achieve alone (Cheng & Sturtevant, 2012; Gray, 1989; Wondolleck & Yaffee, 2000). Collaboration is theorized to contribute to adaptive capacity and governance by engaging the participation of actors with different knowledge, experiences, appreciations, and resources in a joint problem-solving process (Armitage, Berkes, & Doubleday, 2007; Folke et al., 2005; May & Plummer, 2011; Olsson, Folke, & Berkes, 2004). As broader and more inclusive participation takes place by a diversity of individuals, opportunities

to harvest knowledge, assets, and support, and have a wider societal impact increase. Central to achieving collaborative progress are so-called boundary-spanning and bridging entities—individuals or organizations that operate in the interspace between agencies and organizations, scientific disciplines, research and management, and other boundaries, and enact processes and actions to foster the co-production of knowledge and social learning (Berkes, 2009; Crona & Parker, 2012; Wyborn, 2015a).

Co-production of Knowledge and Learning

Governance arrangements that explicitly access, include, and integrate diverse forms of knowledge and ways of knowing may provide stakeholders a richer understanding about the complexity and uncertainties of the social-ecological systems in which they operate (Berkes, 2009; Bouwen & Taillieu, 2004; Fazey et al., 2007). In turn, actors with a systems view of the complex linkages and feedback loops are more likely able to devise innovative strategies for reducing risks and enhancing resilience of the social-ecological system (Checkland, 1981; Daniels & Walker, 2001). Given the complexities and uncertainties associated with complex social-ecological systems, structures and processes that emphasize social learning can facilitate continuous evolution of governance actors' co-production and utilization of knowledge regarding trends, interactions, and effects of multiple actions occurring at different spatial and temporal scales (Davidson-Hunt, 2006; Keen, Brown, & Dyball, 2005; Pahl-Wostl & Hare, 2004; Reed et al., 2010).

Cross-Scale Interactions and Scale Matching

Two types of scaling issues are associated with governance of complex social-ecological systems. The first is the range of spatial scales at which different biogeophysical processes occur and how those scales interact to produce ecological changes (Caraher, Zack, & Stage, 1999; Haufler, Crow, & Wilcove, 1999; Schultz, Timberlake, et al., 2019b). The second is the different levels at which governance actors and institutions operate and exert influence, such as levels of government (e.g., federal, state, municipal), levels of hierarchy within an organization, or levels of extent and influence of informal actor networks including neighboring landowners (Adger, Brown, & Tompkins, 2006; Cash et al., 2006; Ostrom, 1998; Schultz, Timberlake, et al., 2019b).

These two scaling issues interact in ways that can produce scale "mismatches" or "misfits" (Cumming, Cumming, & Redman, 2006; Gomez-Baggethun, Kelemen, Martin-Lopez, Palomo, & Montes, 2013; Schultz, Timberlake, et al., 2019b; Young, 2002). This occurs when the scale of social processes, such as governance decisions or societal demand for goods and services derived from natural resources, are decoupled from the scale of ecological change processes or ecosystem service provisioning (Cumming et al., 2006). Scale mismatches have long been implicated as one of the primary contributors to ecological exploitation, conflicts, and degradation (Cortner & Moote, 1999; Gomez-Baggethun et al., 2013; Holling & Meffe, 1996; Schultz, Timberlake, et al., 2019b). Cross-scale communication, learning, and coordination networks through boundary-spanning objects, processes, and organizations are mechanisms for overcoming scale mismatches (Cash et al., 2006); however, power structures and dynamics often work against this kind of adaptation and serve to reinforce existing arrangements (Adger et al., 2006).

Capacity to Innovate and Re-organize

The capacity to innovate and re-organize is an outgrowth of institutions, interactional processes, and individuals that enhance the flexibility of governance arrangements to anticipate the trends in and impacts of compounding perturbations, quickly devise and allocate resources to experiment with new actions, and rapidly re-organize new governance strategies (Armitage, 2005; Fazey et al., 2007; Folke et al., 2002; Gupta et al., 2010). Institutional dimensions include flexible rules and structures defining who participates in resource allocation and use decisions, which values receive priority when making these decisions, what and whose knowledge receive priority, who bears burdens and who receives benefits resulting from the decisions (Berman, Quinn, & Paavola, 2012; Young, 2010). Interactional processes include venues and networks through which individuals from diverse sectors and across scales of social-organization can communicate, learn, and coordinate collective actions (Folke et al., 2005; Gupta et al., 2010; Pelling & High, 2005; Plummer & FitzGibbon, 2007). Individual-level attributes include leadership (Armitage, 2005; Folke et al., 2005; Gupta et al., 2010) and positive attitudes and perceptions of feasibility and efficacy of actions (Grothmann, Greksch, Winges, & Siebenhüner, 2013; Lockwood, Raymond, Oczkowski, & Morrison, 2015).

Prior Adaptive Governance Research and Knowledge Gaps Relevant to Forest Wildfire Risk

Empirical research explicitly focused on the adaptive governance of forest wildfire risk has historically been scarce compared to other natural resource management contexts. As this field of inquiry grows, the adaptive governance lens has been applied to assess the adaptability of wildfire policy and management at national and subnational levels (e.g., states, provinces), and at the local community level. Adaptive governance-themed research into wildfire management planning and response spans the globe, including the State of Victoria, Australia (O'Neill & Handmer, 2012); the boreal forests of Saskatchewan, Canada (Almstedt & Reed, 2013); Greece (Morehouse, 2011); and northwestern South Africa (van Niekerk, 2014). In the United States, the well-documented negative consequences of the fire suppression feedback loop is used as evidence in critiques pointing to the overall lack of adaptive governance of forest wildfire risk (Busenberg, 2004; Fischer et al., 2016; North et al., 2015; Schultz, Timberlake, et al., 2019b; Steelman, 2016; Steelman & Burke, 2007; Stephens et al., 2016).

Adaptive governance-focused research at the local community level suggests a similar range of variation in adaptability as national and subnational governance approaches due to the influence of, and interactions between, local social-ecological contexts and institutional-organizational forces. Abrams et al. (2015) demonstrate how adaptive governance differences between communities are mediated by available human capital, the presence and capacity of community-based civic organizations, community development histories, and ecological settings. The influence of patterns of social interaction among actors within and between different segments within a local community, coupled with the rich diversity of people-place histories and values, has resulted in communities being differentially adaptive in their strategic and tactical approaches to addressing wildfire risk, as uncovered in numerous community case studies conducted by Paveglio and colleagues (Carroll & Paveglio, 2016; Paveglio, Carroll, Stasiewicz, & Edgeley, 2019; Paveglio & Edgeley, 2017; Paveglio et al., 2015), and others (Abrams, Davies, & Wollstein, 2017; Canadas, Novais, & Marques, 2016).

While the adaptive governance lens has been a fruitful area of applied research in the forest wildfire risk domain, competitive grant programs to induce participation and collaboration in wildfire risk reduction activities is an unknown governance context. Despite the widespread use of this governance tool, competitive grant programs themselves have not been the subject of focused research, leaving a gap in understanding the adaptive governance of forest wildfire risk. A more rigorous assessment of the performance of competitive grant programs can expand theoretical and practical knowledge about factors that facilitate or frustrate the adaptability of this governance strategy intended to induce collaborative wildfire risk management across land ownership jurisdictions. This is especially critical in light of the aforementioned critiques about the lack of adaptiveness in wildfire risk governance.

Colorado's Wildfire Risk Reduction Grant Program

With 6.6 million acres of private land in the WUI adjacent to federal land (Colorado State Forest Service, 2009), a rapidly growing population, increasingly frequent drought cycles, and rising average annual temperatures, Colorado is in many ways an ideal case study of the adaptive governance of forest wildfire risk. Between 1996 and 2012, wildfires burned over 350,000 acres, with the majority of the area burned occurring in dry forest types in Colorado's Front Range—an area bounded by Interstate 25 on the east and the Front Range of the Rocky Mountains to the west, and from Pikes Peak in the south to the Colorado-Wyoming border to the north—and in southwestern Colorado. Dry forests are dominated by Ponderosa pine and Douglas fir in the Front Range and Ponderosa pine and white fir in southwestern Colorado. These areas contain a mix of landownerships, with private, county-administered, and state lands adjacent to or intermixed with national forest lands administered by the U.S. Forest Service. Two fires in 2012 were especially consequential, the High Park Fire west of Fort Collins and the Waldo Canyon Fire in Colorado Springs. These two fires were ignited during a severe drought, spread across public and private landownerships, and burned nearly 600 homes.

While Colorado's higher-elevation subalpine forests—those dominated by lodgepole pine, spruce, subalpine fir, and aspen—historically had fire return intervals between 200 and 600 years, outbreaks of the mountain pine beetle and spruce bark beetle between 2002 and 2012 caused forest mortality in over 4.5 million acres (Colorado State Forest Service, 2013). With the large volume of dead, dry trees and warming average annual temperatures, policy makers and agency officials perceived heightened wildfire danger to mountain communities; outdoor recreation and tourism economies; and water delivery systems, electrical power lines, and natural gas pipelines that traverse the forest.

With the prospect of increased wildfire risk due to climatic changes and the awareness that collaborative community engagement in preventative actions were necessary, state elected officials and administrators set about crafting legislative proposals to increase the pace and scale of wildfire risk mitigation actions on non-federal lands, which include lands owned and controlled by state, county, and municipal governments, and lands owned by private organizations and individuals. The Colorado General Assembly had already established a competitive grant program in 2009 administered by the Colorado State Forest Service to cost-share fuel reduction projects on non-federal lands in the state (House Bill 09-1199; https://leg.colorado.gov/sites/

default/files/images/olls/2009a_sl_411.pdf). However, the 2012 fire season created a sense of urgency to expand the state's investment and involvement in proactive fuel reduction.

In 2013, the Colorado Department of Natural Resources (DNR), one of 20 cabinet-level agencies in the executive branch of state government, proposed and ultimately gained sufficient legislative support to pass the Wildfire Risk Reduction Grant Program (WRRG; Senate Bill 13-269; https://leg.colorado.gov/sites/default/files/digest2013.pdf). The WRRG received an initial appropriation of $10 million from the state's general fund derived from Colorado taxpayer revenues. Since that inaugural year, the program was reauthorized the subsequent three years at $1 million per year. Between 2013 and 2017, the program was administered out of the DNR's Assistant Director for Parks, Wildlife, and Lands office. In 2017, the Colorado General Assembly enacted a statute to transfer WRRG program from the DNR to the Colorado State Forest Service and switched the funding source from the taxpayers' general fund to the state's oil and gas Severance Tax Fund (Morici et al., 2019).

Assessment Methods

Like many competitive grant programs, the WRRG program is comprised of three interacting processes that, taken together, create a governance arrangement:

- The rules, structures, and processes governing grant decision-making, such as: eligibility rules; proposal parameters and application rules; proposal evaluation and selection criteria; and rules authorizing certain people to make granting decisions.
- The grant applicants and eventual grant awardees, such as: who they are; where are they situated physically, economically, and socially; their proposed actions that will achieve program goals; and their capacity to fully deliver on proposed actions.
- The effectiveness monitoring strategy and outcomes, including: pre- and post-project observation or measurements to gauge the degree to which grantees' accomplishments and performance met program goals and expectations, and the mechanisms through which subsequent program and project adjustments were made.

For our assessment of the WRRG, we compiled data and information from the first five granting cycles that occurred between 2013 and 2016 into three units of analysis corresponding to these aspects of competitive grants. Due to low amounts in the Severance Tax Fund, no grants were awarded in 2017 and 2018. Our compilation strategy was sensitized (Boeije, 2002; Denzin & Lincoln, 1998) by the four categories of adaptive governance attributes in order to focus the types of data and information relevant to assessing the adaptability of the WRRG program.

Data for the first unit of analysis were derived from the design parameters of the program as expressed in the statute and attributes of the administrative process of awarding grants as embodied in the activities of the Advisory Committee. Additionally, a review of Advisory Committee scoring matrices and meeting notes served as sources

of evidence for the administrative process, and evidence of the extent to which committee proceedings involved all members, questions and concerns were vetted, and learning was occurring from effectiveness monitoring results. We also drew on our participation and subsequent observations to reflect on the performance of the WRRG program.

On this last point, a disclosure about our "positionality" relative to the WRRG is warranted with respect to our participant-observation methodology (Cheng & Randall-Parker, 2017). Lisa Dale was Assistant Director of Parks, Wildlife, and Lands for the Colorado DNR at the inception of the WRRG; in that role, she was a primary author of the WRRG and chaired the WRRG Advisory Committee between 2013 and 2015. Tony (Antony) Cheng is director of the Colorado Forest Restoration Institute and a member of the Advisory Committee. Our "insider" position vis-à-vis the WRRG program's creation, governance, and administration has two methodological implications. First, we have ready access to information on the WRRG program; while this information is publicly available, individuals external to the process are unlikely to be aware of its existence. Second, our understanding of the internal assumptions and intent that drove the creation of the WRRG affords us unique insight on assessing the extent to which the WRRG performed as a policy tool to induce collaborative collective action.

For the second unit of analysis, we compiled and sorted the distribution of awards by funding amount and by grantees' organizational types. WRRG data were publicly available by the DNR program administrator. Each grant cycle dataset lists the name of the applying organization, names of awarded and unawarded grants, and grant amounts. For the third unit of analysis, we draw on effectiveness monitoring summaries from each funding round and on the final WRRG effectiveness report produced by CFRI (Morici et al., 2019). This report is a summary of the results of pre- versus post-fuel reduction fire behavior metrics for 21 out of the 102 fuel reduction projects.

In the analysis and interpretation phase of the assessment, we did not utilize a formalized qualitative research approach, whereby documents are coded using qualitative research software for themes and patterns (Strauss & Corbin, 2008; Thomas, 2006). Our process drew on theories of academic-practitioner knowledge creation (Amabile et al., 2001; Nonaka, 1994; Rynes, Bartunek, & Daft, 2001), whereby we employed an interactive argumentation-based approach in which data and information about each aspect of the WRRG program and from our recollections of WRRG Advisory Committee deliberations were iteratively evaluated against each of the four categories of adaptive governance tenets and attributes (Barry, Britten, Barber, Bradley, & Stevenson, 1999; Mauthner & Doucet, 2003). This argumentation process entailed face-to-face and written claims and counter-claims between us, emulating the knowledge creation framework of Nonaka (1994) of moving between tacit practice-based knowledge acquired from operating within the WRRG program and explicit theory-based knowledge derived from the adaptive governance literature. This interactive argumentation-based process of analyzing and interpreting assessment data and information explicitly accounted for our respective positionalities and corresponding frames of references relative to the WRRG policy and program (Dryzek, 1993; Valovirta, 2002), and has been applied in other forest policy and program assessments (Cheng et al., 2016; Cheng & Randall-Parker, 2017).

Assessment Results

Rules, Structures, and Processes Governing WRRG Decision-Making

Five provisions comprise the statute establishing the WRRG program: eligibility requirements, advisory committee makeup, matching funds, capacity building, and monitoring. First, eligibility guidelines for the WRRG program were explicitly crafted by legislators to induce collaborative participation among property owners in fire-prone landscapes. In this way, the program was designed to coordinate risk reduction actions across multiple landownerships in a sufficiently large geographic area so as to modify wildfire behavior and impacts. Individual homeowners were not eligible to apply. Instead, home or property owners associations, local fire protection districts (special taxing districts in unincorporated, often rural areas, charged with providing fire protection and response), local or regional non-governmental organizations, and local governments were encouraged to develop projects that included multiple adjacent property owners for maximum effect. The grant application asked for information about the number of homeowners and other community partners committed to participating and requested signed letters to confirm their intent. Not only were these eligibility requirements intended to be consistent with scientific understanding about wildfire, they were also intended to create new opportunities for neighboring property owners to develop relationships, build trust, and share knowledge about wildfire risk reduction practices.

Second, anticipating a competitive process, the developers of the WRRG program worked to ensure broad review by diverse stakeholders. According to the authorizing law, the Advisory Committee must contain representatives from: a local research university, the Department of Natural Resources, the Department of Public Safety, Colorado State Forest Service, a local municipality with jurisdiction in a fire-prone community, a federal land management agency, the forest products industry, the biomass energy industry, a nonprofit collaborative group involved in the mitigation of wildfire, and an organization with expertise in water. The Advisory Committee was charged with reviewing and ranking applications, debating the merits of conflicting policy priorities relative to the applications, and selecting awardees. The representatives from federal and state agencies were also experienced in administering other grant programs addressing forest health, natural hazard planning, and water conservation. In this way, the authorizing law implicitly regarded the Advisory Committee to be the central governing body for the grant program; the Committee was also responsible for obtaining monitoring results and considering potential programmatic changes as appropriate. An underlying vision for the WRRG Advisory Committee was that each committee member represented a particular stakeholder group, thereby integrating the perspective of that group into the allocation of awards, and also implicitly assuming a level of stakeholder ownership in addressing the wildfire risk co-management challenges facing communities.

Third, the WRRG requires each application to demonstrate a one-to-one financial match, thereby doubling the impact of WRRG funds. Beyond stretching limited public dollars, matching funds has long been a staple of state government grants. Indeed, the 1:1 matching funds requirement was a powerful political tool for building legislative support when the program was initially up for a vote. In-kind contributions

counted toward the match. Several state legislators were persuaded to vote in favor of the new program, knowing that participants would have financial incentives to follow through on their intended fuel reduction activities.

Fourth, the WRRG included explicit attention to longer term risk reduction strategies. While some communities in the WUI need support to reduce fuels in and around homes and common spaces (e.g., property association common areas, county open space and parks), others may be better served over the long term through building their physical infrastructure capacity to better maintain landscape health. For example, if a poorly resourced county were able to purchase the equipment to cut trees or process residual woody material, it is possible that hundreds of homeowners in that area would have access to the machinery over many years. In this way, a single grant award could potentially create lasting improvements to landscape-scale fire risk conditions and build long-term community engagement. With this in mind, up to 25% of total grant dollars were specifically allocated to "capacity building" grants. Communities used those funds to invest in equipment and equipment utilization programs that outlived the grant period, and potentially enhanced their ability to reduce risk over a longer time frame.

Fifth, the WRRG directs up to 5% of annual program funding to assess the program's effectiveness on reducing fuel hazard and risk exposure. The emphasis on measuring effectiveness derived from concern among state legislators that taxpayer funds be applied to achieve a positive return on public investments. The Colorado DNR entered into a cooperative agreement with the Colorado Forest Restoration Institute (CFRI) at Colorado State University to develop and implement an effectiveness monitoring strategy for the WRRG. The CFRI's effectiveness monitoring strategy applied field measurements of vegetation immediately prior to and 1 year after fuel reduction activities, quantified changes in fuel quantity and arrangement, and predicted changes in fire behavior metrics using available computer fire behavior modeling (Reinhardt, Keane, Calkin, & Cohen, 2008). Model outputs include metrics for surface fireline intensity (measured as the energy output of a predicted fire given the fuel quantity and arrangement), rate of fire spread, and crown fire potential (Scott & Burgan, 2005; Scott & Reinhardt, 2001). Effectiveness monitoring results were intended to be used by the Advisory Committee to determine if adjustments to the grant program would be necessary over time.

Between 2013 and 2017, the WRRG program's administration and decision making was overseen by the office of the DNR's Assistant Director for Parks, Wildlife, and Lands. In 2017, the Colorado General Assembly authorized the Colorado State Forest Service (CSFS) to take over WRRG administration and transferred the program's funding source away from the state's general taxpayer fund to the more volatile Severance Tax fund derived from oil and gas development. The Severance Tax lacked sufficient funds in 2017 and 2018 and, therefore, no WRRG grants were awarded during this timeframe.

The grant-making process typically began in late May or early June, when the state's budget was approved and funding levels were known with certainty. The office of the DNR's Assistant Director for Parks, Wildlife, and Lands would initiate proceedings by convening the Advisory Committee via email and in face-to-face meetings to discuss available funding and develop, modify, and finalize the request for proposals. After the first year of implementation, the Advisory Committee would also receive

presentations of effectiveness monitoring results from CFRI and discuss whether, and to what extent, the request for proposals should be modified.

Once finalized by the committee, the request for proposals and WRRG informational materials would be sent electronically to an exhaustive list composed of grant submitters for other federal and state fire assistance grant programs administered by the Colorado State Forest Service, state liaisons from county and municipal governments, fire protection districts, and coordinators for community-based collaborative forestry and wildfire risk reduction groups. Proposal submitters would have 4 weeks to submit a proposal according to grant application instructions. Once that deadline had passed, the Advisory Committee had 4 weeks to review and rate proposals, with awards to be allocated in another 3 to 4 weeks. Proposals were scored on five criteria: budget justification (10 points); project description, objectives, and strategic value (50 points); scientific foundations and linkage to project practices (10 points); biomass utilization plan (10 points); and partners and supporters, including "hard match" of funds beyond in-kind contributions (10 points). A separate scoring system was used for applications for purchasing equipment using similar criteria. After DNR staff compiled committee members' scores and rank-ordered proposals from highest to lowest average score, the Advisory Committee met face-to-face to understand one anothers' rationale for scoring, consider changes to the initial rank-order, define the cut-off for proposals to be funded, and decide on funding amounts for proposals making the cut.

Awardees typically received their notice by late August and were given up to 2 years to complete the project. Once awarded, grantees would be required to submit invoices quarterly, submit annual project progress and budget reports, and agree to site visits and field data collection by CFRI prior to and after fuel reduction actions. Final performance and financial reports would be due to the DNR to receive final grant disbursements. CFRI would produce and disseminate pre- vs. post-fuel reduction final results for surface fireline intensity, rate of fire spread, and crown fire potential.

WRRG Applications and Awards by Organization Types

A total of 201 applications were received across all five grant cycles. Of these, 133 grants totaling $13,183,575 were awarded to 126 distinct organizations across all five grant cycles between 2013 and 2016. Grant award sizes ranged from $2,400 to $1,754,298, with 23 organizations receiving multiple grants over the five grant cycles. Over half of the projects received less than $50,000 (see Figure 1). Given a conservative estimate of $1,000 per acre to thin forest vegetation, these projects may treat up to about 50 acres. On the other end of the distribution, 10% of awards exceeded $200,000.

The distribution of WRRG program applications and funding by organizational type is shown in Table 1. Of the 133 awards, over half of the total funding went to two categories of actors: (1) local governments, including both municipal and county level units; and (2) non-governmental organizations. Fire protection districts, home/property owner associations, state governments, and other entities not classifiable into these categories comprised the remainder of awardees. The overall application success rate was 66% across grant cycles. Despite being awarded a lower overall amount, non-governmental organizations had the highest success rate at 78%; local

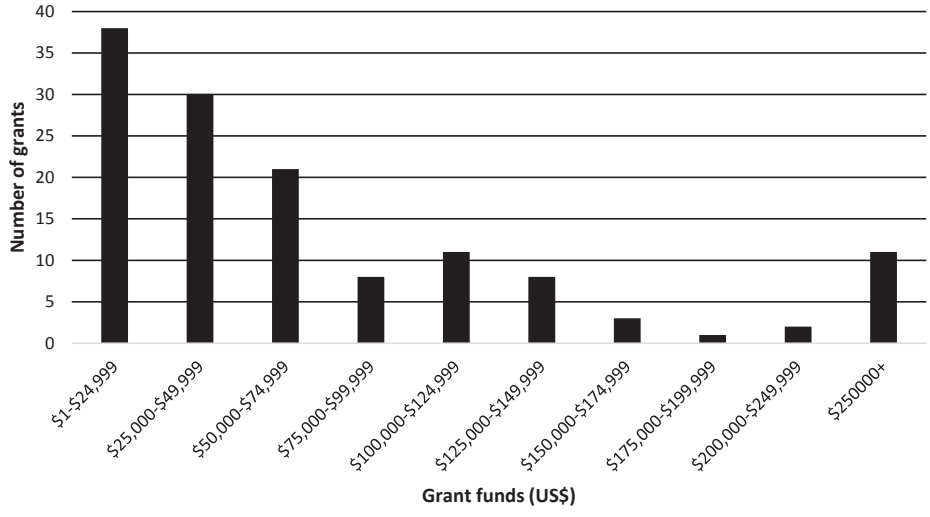

Figure 1. Frequency Distribution of Total Allocated Funds, Cycles 1–5

governments and home/property owners associations experienced success rates of 69 and 67%, respectively.

The breakdown of total award amounts reveals additional patterns. Over half (55%) of awards and 72% of the funds went to non-governmental organizations and local governments. These two organizational types also had the highest average award sizes. Four grantees accounted for 9% of awards (12 out of 133 awards) and 43% of awarded funds: one county received over 20% of awarded funds ($2.8 million), while three local non-governmental organizations accounted for 23% of awarded funds ($3 million). During the WRRG Advisory Committee deliberations, committee members with grant administration experience identified these grantees as being high capacity in terms of available human and financial resources compared to other applicants, and have been successful in procuring other grants for forest health, natural hazards planning, and water conservation. Fire protection districts, home/property owners associations, state government agencies, and other organizations received smaller percentages of total awards, with none exceeding 10%. Table 2 illustrates the ways in which awards varied across the five grant cycles. Applications from home/property owners associations steadily decreased over time, while applications from fire protection districts, local governments, state government agencies, and other organizations varied from cycle to cycle. Applications from non-governmental organizations rose slightly and then remained constant.

Effectiveness Monitoring Strategy and Outcomes—For this unit of analysis, we drew on results presented in periodic effectiveness monitoring summary reports by CFRI to the Advisory Committee between 2014 and 2016, and in the final report in 2019 (Morici et al., 2019). The final report provided a comprehensive summary and detailed analysis of the extent to which the grantees' accomplishments and performance reduced fire hazards. Technical details regarding sampling, measurements, and fire

Table 1. Wildfire Risk Reduction Grant Program Application and Funding Allocation Information by Organization Type, Cycles 1–5

Organization Type	Total Applications	Success Rate	Percent of Funded Organizations (%)	Allocated Funds	Percent of Allocated Funds (%)	Average Allocation by Cycle
Fire protection district	19	0.51	14	$1,241,659	9	$248,332
Homeowner/property association	32	0.67	24	$1,212,111	9	$242,422
Municipal/county government	35	0.69	26	$6,219,884	47	$1,243,977
Non-governmental organization	39	0.78	29	$3,258,781	25	$651,756
State government	3	0.60	2	$471,860	4	$94,372
Other	5	0.50	4	$779,280	6	$155,856
Total	133	0.66	100	$13,183,575	100	$2,636,715

Table 2. Number of WRRG Grant Applications by Organization Type and Grant Cycle

Organization Type	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Total
Fire protection district	12	5	6	5	9	37
Homeowner/property association	14	12	11	6	5	48
Municipal/county government	14	8	14	8	7	51
Non-governmental organization	9	9	9	11	12	50
State government	1	2	1	0	1	5
Other	5	3	0	1	1	10
Total	55	39	41	31	35	201

Table 3. Summary of WRRG Grantees' Self-Reported Accomplishments for Award Amount, Actual Acres Treated versus Proposed Acres to be Treated, Cost Per Acre Treated, Biomass Removed, Revenue Generated, and Jobs Provided, FY13-17 Reporting Periods

Accomplishment	No. of Grantees Reporting	Total Amount	Average	Std. Deviation	Range
Amount awarded	133	$13,183,575	$89,137	$141,309	$2,400–$1.75 million
Proposed acres to be treated	89	23,769 acres	423 acres	413 acres	5–2,830 acres
Actual acres treated	89	16,806 acres	191 acres	414 acres	6–2,551 acres
Cost per acre	94	n/a	$1,486	$1,907	$10–$7,500
Biomass removed (in cubic yards)	42	255,602 yds	6,086 yds	16,091 yds	3–80,000 yds
Biomass removed (in tons)	32	35,798 tons	1,119 tons	2,145 tons	14–10,575 tons
Revenue generated	20	$497,734	$26,197	$40,638	$200–$150,000
Jobs provided	61	666.75	11 persons	9.5 persons	0.25–29 persons

behavior computer simulation modeling were used to develop report conclusions. Pre- and post-treatment monitoring field data collection and analysis were performed for 21 out of the WRRG's 102 fuel reduction projects. All 21 monitored projects were from the first two rounds of the program, in 2013 and 2014, when a total of 48 fuel reduction projects were selected. Additionally, grantees' self-reported accomplishment data submitted to the DNR was compiled by CFRI for all projects from 2014 to 2017 reporting periods, including information about actual acres treated, costs per acre, woody biomass removed, and jobs provided (Table 3).

Three primary findings emerge from this analysis. First, across all monitored projects, the potential for crown fire measurably decreased. Crown fires are those that spread from the surface into and across tree canopies during forest fires. Under severe weather and fuel moisture conditions, crown fires can spread rapidly; create extreme fire behavior that resists control by firefighters; and send ember showers ahead of the flaming front, thereby igniting spot fires that can expand fire size and suppression difficulty. Prior to WRRG-funded treatments, 80% of projects were susceptible to crown fire under severe fire weather and fuel conditions; the remaining projects had lower susceptibility. After treatments, 36% of project areas were susceptible to crown fire.

Second, surface fuels (the live and dead vegetation materials on the ground surface) and modeled surface fire behavior metrics for many monitored projects either

did not change or actually increased as a result of fuel reduction treatments. In large part, this pattern is attributable to the lack of economic value for the woody materials from these projects. As such, the most economically efficient strategy is to leave woody materials on the ground after the trees have been cut. The consequences of this strategy are that, for a majority of projects, flammable materials were redistributed from tree crowns to the surface; in this way, both the volume and spatial coverage of this surface material were increased. Unless this material will eventually be removed either through prescribed burning (fires intentionally ignited and managed by fire managers) or mechanical means, potentially negative ecological and social effects are likely to increase (Hoffman, Collins, & Battaglia, 2018; Kalies & Yocum Kent, 2016; Kreye et al., 2014; Martinson & Omi, 2013). Due to the close proximity of all WRRG projects to human populations and housing developments, prescribed burning is rarely utilized because of societal concerns about the potential for escape, lack of sufficient human and technical resources, and air quality regulatory constraints (Schultz et al., 2018).

Third, from the grantees' self-reported accomplishments, the average number of acres treated across WRRG grantees was 191 acres (approximately 77 hectares) at an average cost across projects of $1,486/acre (71% and 67% of grantees reported these data, respectively). A smaller proportion of grantees, about 32%, self-reported data on woody biomass removed, indicating that most projects left woody biomass onsite. The standard deviations were very large for all reporting categories, indicating wide variation across projects.

Interpretation and Discussion

When examining the data and information compiled from the WRRG program against the four categories of adaptive governance, we uncovered both the presence and absence of adaptive governance best practices. Table 4 summarizes the relationship between WRRG program features and adaptive governance attributes.

Inclusive Participation and Collaboration

Analysis of data and information about the Advisory Committee, the grant applicants, and the grant awardees suggests that there is a moderate level of inclusivity in participation and collaboration in the WRRG program. As the facilitator and an active participant on the WRRG Advisory Committee, we experienced how the diversity of perspectives about expected WRRG program outcomes allowed for ongoing review and reflection among Committee members of what worked well and what needed adjustment. In particular, we observed and participated in Committee discussions about competing program priorities during the application scoring process allowed for the consideration of ecological, social, economic, and political factors. We also participated in Committee deliberations concerning the results from the effectiveness monitoring program and grantee progress reports. Committee members reported feedback from their professional networks about the benefits and challenges of the WRRG program. The integration of multiple sources of information with committee members' experiential knowledge and expertise created conditions for meaningful

Table 4. WRRG Program Features and Their Relationship to Adaptive Governance Attributes

WRRG Program Feature	Description	Connection to Adaptive Governance Attributes
Eligibility requirements	Proposals only accepted from neighborhood associations, fire protection districts, community-based non-governmental organizations, and local government entities	Incentivizes inclusive participation and collaboration across landownerships and jurisdictions Fostered cross-scale interactions between individual property owners via intermediary organizations, and between intermediary organizations and state government
Advisory committee	Composed of representatives from ten different stakeholder groups and vested with authority to review and recommend applications for funding, and to adapt the WRRG program requirements	Induced participation and collaboration among diverse interests Created a venue and process for co-producing knowledge and learning from monitoring results and program participant feedback Fostered cross-scale interactions through professional networks at local level Demonstrated capacity to be flexible and innovate in response to monitoring results and program participant feedback
Matching funds	1:1 match requirement (in-kind match permitted)	Incentivized broader participation and collaboration within communities served Limited the scale of risk reduction impact by lower capacity applicants compared to higher capacity applicants; enhanced the capacity of applicants already possessing substantial human and financial resources
Capacity building	Allocated up to 25% total grant funds to equipment procurement that would contribute to longer-term risk reduction	May have increased the scale of risk reduction impact by having applicants operate their own fuel reduction equipment, rather than hiring a contractor Did not alter the economic barriers to utilizing woody by-products or create additional markets
Monitoring	Third-party fuel treatment effectiveness monitoring and annual project accomplishment reporting	Produced results and information useful to the Advisory Committee to adapt program requirements Produced results and information useful to grantees to define measurable objectives and develop deeper understanding about wildfire hazard and risk management strategies

feedback loops and programmatic learning (Berkes, 2009; Pahl-Wostl, 2009; Pahl-Wostl & Hare, 2004).

Regarding the diversity and inclusivity of grant applicants and awardees, our assessment elucidates several trends that mirror those of the Advisory Committee. Foremost, when considering organizational types, geographic areas, and community sizes, the assessment data suggest that the WRRG has supported a broad diversity of organizations working across landownerships and at different spatial scales. The requirement that all proposals include support letters from government and non-governmental entities also ensured a degree of communication and coordination within the community that would benefit from WRRG funding. During the WRRG Advisory Committee's review of the proposals, we found that the preponderance of letters of support was not drafted from a template, but was original, specific, and descriptive. It is possible that many support letters were merely perfunctory to meet a proposal's

minimum requirement; additional research is needed to investigate the extent to which support letter contributors actually met their intended commitments to support project implementation and completion.

However, even though participation across smaller community-based organizations and larger entities was fairly similar as a percentage of total applications, the distribution of awards was skewed toward the latter organizational types. A primary reason for this is that applicants with known financial and human resources were generally from higher resource organizations, higher population communities, and economically developed areas of the state. Knowledge of these applicants came from WRRG Committee members with prior experience and interaction with these applicants in other competitive granting programs. Those applications featured complex, scientifically based, and often spatially plotted proposals, and included detailed budgets and specific timelines for action. Applications from lower income communities and areas of the state were often incomplete, offered unrealistic plans of action, and failed to integrate data that would support their proposed treatments.

The Committee struggled to distribute award funds state-wide, and became concerned that award allocation would serve to validate existing capacity discrepancies and institutionalize an inherent bias against low-resource applicants and communities. Efforts were made to deploy grant-writing assistance for communities in need, but outreach was difficult and the problem remained troubling. This may, in part, explain the decline in applications from, and subsequent awards to, smaller community-based entities. The disproportionate distribution of WRRG awards to high-capacity organizations mirrors findings from competitive grant program assessments from other public management sectors, such as community economic development (Collins & Gerber, 2008), community food production (Tanaka, Indiano, Soley, & Mooney, 2015), and public education (Manna & Ryan, 2011). This structural bias limits participation and collaboration, and affects the contribution of competitive grant programs in the adaptive governance of forest wildfire risk in particular, and of broader domains of social-ecological systems in general. A potential strategy to address this mitigation is to establish and sustain a capacity-building program parallel to the grant program that can support lower-resource organizations and communities as they participate more fully and effectively.

Co-producing Knowledge and Learning

The statutory provision requiring an effectiveness monitoring strategy had observable effects on the adaptability of the WRRG program. For example, when results from the effectiveness monitoring of the early WRRG projects showed that grantees had sufficiently reduced crown fire potential but were increasing surface fuel, the Advisory Committee adjusted subsequent proposal guidelines and scoring criteria to require future applicants to identify their plan to reduce or remove surface fuel. The effectiveness monitoring strategy also fostered learning by WRRG beneficiaries, especially private forest landowners. During pre- and post-treatment monitoring site visits, the CFRI field crew had opportunities to communicate face-to-face with landowners and other community-based partners about what results of monitoring data analysis might mean in terms of their own dynamic wildfire risk.

In this regard, the monitoring strategy effectively served as the WRRG's outreach and social learning strategy, with CFRI serving as a boundary-spanning bridging organization–a critical attribute for adaptive governance (Berkes, 2009; Crona & Parker, 2012; Mollinga, 2010). Indeed, the role of university-based programs serving as boundary-spanning bridging organizations in natural resource and wildfire risk management education is well documented (Cash, 2001; Kocher et al., 2012). However, the expansion of university-based entities to perform third-party effectiveness monitoring of resource management actions is a fairly recent development in the governance of social-ecological systems, especially in forest restoration and wildfire risk reduction contexts (Cheng, Gerlak, Dale, & Mattor, 2015; Davis, Belote, Williamson, Larson, & Esch, 2015; Schultz, Coehlo, & Beam, 2014). In the face of well-documented institutional barriers and disincentives to supporting effectiveness monitoring (Biber, 2011; Schultz & Nie, 2012; Susskind, Comacho, & Schenk, 2012), the WRRG marks an important policy innovation to support knowledge, learning, and adaptive governance.

While the structure and functioning of the WRRG program enabled learning, the focus was primarily on "single-loop" learning, in contrast to "double-loop" learning (Argyris, 1976; Argyris & Schon, 1978; Pahl-Wostl, 2009). Single-loop learning answers the question, "Did the intervention work?" In the context of the WRRG, the WRRG's effectiveness monitoring program clearly fostered single-loop learning. Double-loop learning answers the question, "Are the goals, cause-and-effect mental models, and assumptions upon which the interventions are based correct?" In the context of forest wildfire risk reduction, double-loop learning seeks to question whether wildfire risk reduction is a desirable and feasible goal in the first place. We did not observe active double-loop learning in the WRRG program. The goals and cause-and-effect assumptions about the general effectiveness of fuel reduction actions were generally taken for granted, especially given the heavy focus of high-profile programs, such as Firewise Communities/USA, on reducing fuel in close geographic proximity to built infrastructure (Abatzoglou & Williams, 2016).

However, a mismatch between the spatial scale of fuel treatment and the spatial and temporal scales at which wildfires can occur has been suggested by some wildland fire researchers (Barnett, Parks, Miller, & Naughton, 2016). Many landscape and biogeographic ecologists have long contended that climatic forcings are the primary drivers of increased wildfire risk across large spatial and long temporal scales, not forest vegetation accumulation (Baker, Veblen, & Sherriff, 2007; Hessburg et al., 2019; Schoennagel, Veblen, & Romme, 2004; Stevens-Rumann et al., 2018). Furthermore, in the face of fires that spread under severe weather and fuel conditions (hot, windy, and dry), small treatments may have limited effect on slowing spread rates or reducing intensity (Finney, 2001; Graham, 2003; Kennedy & Johnson, 2014). Hence, the window of fire weather and fuel conditions under which smaller WUI-adjacent fuel treatments may be effective are likely limited to more moderate conditions. While social learning is well postulated as a critical attribute of adaptive governance of social-ecological systems (Berkes, 2009; Fazey et al., 2007; Pahl-Wostl, 2009), questioning cause-and-effect assumptions and reframing expectations of effectiveness can surface resistance and conflict, the effects of which can be mitigated through strong leadership and well-facilitated learning (Daniels & Walker, 2001).

Cross-Scale Interactions and Scale Matching

Our assessment results reveal three scaling themes that have implications for the WRRG program's capacity for adaptive governance. The first is the large variation in the scale of fuel reduction actions across grantees, both in terms of size of treatments and the amount of biomass removed. While scientific understanding about the effects of fuel treatment size on reducing wildfire risk is still evolving (Kalies & Yocum Kent, 2016), the existing status of knowledge suggests that smaller treatments sizes have limited effects on reducing wildfire risk because the probability of a fire encountering a treatment decreases as treatment size decreases (Barnett et al., 2016).

The variations in treatment size and effectiveness are directly connected to a second scaling theme: the variation in the level of grantees' capacity. Governmental and non-governmental organizations with the existing capacity to successfully procure and manage large grants and, therefore, to complete larger-scale projects, were able to achieve a higher impact on reducing wildfire risk to the communities they serve compared to those with limited organizational capacity. Indeed, when we examine the distribution of funds across awards by organizational type, we see that a large percentage of total funding (72%, Table 1) went to two organizational types: local government agencies and non-government organizations; four individual organizations received fully 43% of the awarded funds. Hence, only a very small number of organizations within the state had sufficient capacity to develop detailed, data-rich applications that contained sufficient information to be scored highly by the Committee. Even fewer had the capacity to implement projects at a spatial scale sufficient to effect fire behavior, administer large amounts of funding, and come up with the 1:1 match requirement.

In this way, the WRRG in particular, and possibly competitive grant programs in general, institutionalize scale mismatches in wildfire risk reduction. From a policy design standpoint, the WRRG program's 1:1 match requirement can be implicated. On the one hand, the requirement was a tangible expression of the underlying intent of the WRRG program: grant recipients must invest their own financial, technical, and human resources to receive state funding as an expression of partnership in co-managing wildfire risk. On the other hand, for many small communities and organizations without large funding streams (e.g., fire protection districts and home/property owners associations), the match requirement was a defining—and limiting—factor affecting the frequency and size of grants for which they applied. This may also explain in part the decreasing number of applications from home/property owner associations and the relatively low number of applications from fire protection districts; these organizations operate with few financial resources that could serve as a match.

This situation has created a governance quandary for the WRRG program and has been uncovered in competitive grant programs from other public management sectors, such as community development (Collins & Gerber, 2008), community food security (Tanaka et al., 2015), and public education (Manna & Ryan, 2011; Nicholson-Crotty & Staley, 2012). The quandary can be summarized in this way: the capacity of successful applicants begets more capacity through large funding awards, thereby creating a positive cycle for enhancing the capacity of these already-high capacity-organizations, but potentially leaving low-capacity organizations and communities with fewer resources to engage in wildfire risk co-management over time. While the

1:1 match is a logical requirement to ensure communities have "skin in the game," it may create a "pay to play" dynamic that has not received sufficient attention in the social-ecological systems governance literature.

Given that the WRRG's explicit intent is to immediately reduce exposure of highly valued resources and assets to wildfire, then funding a large number of small-scale projects may have little to no effect on fire behavior should the fire escape initial containment (Calkin et al., 2014). In this view, participation in wildfire risk governance and management through the WRRG program is fairly exclusive to higher-capacity organizations and communities. However, for many of the applicants, the WRRG funds were proposed to be used as a starting point for engaging property owners who may have been aware of the need to co-manage wildfire risk on their property and across properties in their community, but had yet to take action. In this way, the WRRG program was as much about building the social capacities for community-level collective action in order to increase participation over time and across the state. Moreover, the Committee had to bear in mind that, in order for the WRRG to receive continued political and, therefore, financial support, legislators had to be made aware of the benefits the program was delivering to their districts. The Committee, therefore, had an incentive to distribute awards broadly, touching as many counties as possible.

The third scaling theme from our assessment was that the inherent nature of WRRG as a competitive grant program structured a set of multi-level interactions between: (1) actors that governed policy and funding decision-making, (2) intermediary organizations that secured funding and administered projects, and (3) actors that carried out the work and were affected by wildfire risk. The grant application process and the effectiveness monitoring strategy were primary pathways for communication and learning across these levels of social organization. Additionally, the DNR's WRRG program administrative team and the Advisory Committee communicated results and needs, and were accountable to the state legislature.

That the WRRG program fostered interactions among multiple levels of authority and scales of activity across 133 projects is evidence of strong adaptive governance potential, and signals opportunities for further research into, and development of, competitive grant programs in general as a social-ecological systems risk reduction governance strategy. In the area of wildfire risk reduction across landownerships, competitive grant programs are growing in number and have the potential to induce large numbers of actors to engage in cooperative, collective action to reduce their vulnerability. The explicit multi-level structures and interactions of such programs can clearly link local-level cooperative, collective actions and outcomes to higher-level institutions and policy structures. Such linkages have been widely espoused as essential features of adaptive governance of social-ecological systems, but are often difficult to empirically investigate due to the opacity of higher-level institutions and policy structures (Adger et al., 2006; Ahrens & Rudolph, 2006; Djalante et al., 2011; Pahl-Wostl, 2009). Our WRRG case study sheds insight on these multi-scalar dynamics and how they affect the adaptiveness of an important form of governance.

Capacity for Innovation and Re-organization

The law establishing the WRRG program provided the DNR administrators and the Advisory Committee with discretion over defining grant proposal parameters and the

criteria for proposal evaluation and selection. Within this discretionary space, the Advisory Committee was able to make quick decisions to change proposal parameters regarding biomass removal and disposal, based on the program's first year of effectiveness monitoring results. Additionally, the Advisory Committee had the flexibility to select projects that may not have ranked as high as others in terms of their potential short-term risk reduction impacts, but were recognized as contributing to long-term social capacity building within a low-resource community. In this way, the WRRG's governance accounted for both ecological and social factors, and was able to act nimbly to change approaches.

Despite these features, two economic factors and one political factor affected the WRRG program's capacity to innovate and re-organize. The first economic factor is the low value of woody materials from fuel reduction coupled with the high cost of removing these materials (Becker et al., 2011); the average WRRG project cost of $1,486 per acre corresponded to national averages for forest fuel reduction projects (Evans & Finkral, 2009), but without a market for woody material those costs were not sufficiently offset through revenue-generating timber sales. Given limited budgets for fuel reduction, especially on non-federal and private lands, the scale and scope of future WRRG projects are unlikely to significantly change, unless there are structural changes that open new commercial opportunities for using woody materials. Federal and state policies and programs attempting to increase these commercial opportunities have had limited effect.

The second economic factor is that, by moving the state funding source for the WRRG from the taxpayer-supported general fund to the oil and gas Severance Tax fund, the WRRG's available budgets were vulnerable to more volatile market forces. This is evidenced by the lack of available funds in 2017 and 2018 due to a downturn in oil and gas development in Colorado. This vulnerability can be reduced only through actions by the state legislature to change the state funding source back to the general fund—a prospect that, as of this writing, is remote. While it is obvious that economic factors can either facilitate or frustrate adaptive governance (Folke, 2007; Olsson et al., 2004), the challenge facing adaptive governance scholarship and practice is to more explicitly account for ways in which local-scale, cooperative governance arrangements interact with complex multi-scalar economic systems as potential change agents.

The political factor affecting the adaptive governance of the WRRG in particular, and wildfire risk in general, emerged in 2017, when the Colorado General Assembly enacted a statute to move the WRRG program administration out of the DNR, which is housed within the executive branch of state government and physically proximate to the state capitol, and into the Colorado State Forest Service (CSFS), which is housed at Colorado State University and physically distant from the state capitol. The statute also combined the WRRG with another state-funded competitive grant program to fund fuel reduction and forest improvement projects on non-federal lands. While the CSFS has abundant experience in administering State Fire Assistance and other competitive grants, it has limited capacity to inform and influence state and federal policy compared to the DNR, given its position and standing within the broader governance domain of state government.

The adaptive governance literature refers to the concept of "polycentricity" to describe multiple centers of semi-autonomous decision-making, power, and authority

over a public policy domain that can both promote or hinder the adaptiveness of a governance arrangement (Folke et al., 2005; Ostrom, 1998). On this latter point, the relative position and power of entities within a polycentric governance system can have profound effects on governance adaptiveness and intended effectiveness (Carlisle & Gruby, 2018; Wyborn, 2015b). The transfer and consolidation of the WRRG from one decision-making center to another may limit the political visibility of the program in both the executive and legislative branches of state government, and may lead to the loss of policy champions who could advocate on behalf of the program during state budget appropriations negotiations. Given the central importance of funding allocation decision-making in a governance system, longitudinal research is needed on the changing positioning and power of different entities as governance arrangements shift.

Conclusion

Competitive grant programs have emerged as one policy tool in the governance toolbox to induce pro-active, collaborative management of climate-induced risks to social-ecological systems, such as forest wildfire risk. At a basic level, increasing financial resources is necessary to overcome barriers to participation and collaborative engagement and action. In this regard, the WRRG made strides toward achieving this policy goal. The WRRG also provides a model for how to deeply integrate effectiveness monitoring into governance. However, simply throwing money at the problem may not equate to reduced wildfire risk exposure or improvements in intended social and environmental outcomes. Inequities in community capacity, governance quandaries, scale mismatches, and changes in institutional positioning and power may conspire to limit governance adaptiveness and effectiveness.

The prospect of increased frequency, size, and severity of wildfires is challenging the adaptiveness of long-standing governance approaches and is spurring new governance arrangements that emphasize pro-active, collaborative actions involving government, non-government, and community-based organizations. Ensuring that these new arrangements are sufficiently adaptive to anticipate and respond to uncertain future wildfire risks requires critical assessment and reflection. While questioning long-held assumptions about the effectiveness of approaches to risk reduction can be challenging and face resistance, it is also necessary in order to set realistic societal expectations about the benefits and limitations of such actions, policies, and programs.

About the Authors

Antony S. Cheng is Director of the Colorado Forest Restoration Institute and Professor in the Department of Forest & Rangeland Stewardship at Colorado State University. His primary research interest is in forest governance, policy and administration, with a focus on multi-stakeholder collaborative approaches to promote resilient social-ecological systems linked to forest landscapes. In his capacity as Director of CFRI, Dr. Cheng oversees programs to develop, compile, and apply locally relevant scientific information to achieve forest restoration and wildfire hazard reduction goals. He has a PhD in Forestry from Oregon State University (2000), a MS in Forestry from the University of Minnesota (1993), and a BA in Political Science from Whitman College (1990) in Walla Walla, WA.

Lisa Dale is Lecturer in Sustainable Development in The Earth Institute at Columbia University. Her research focuses on climate change adaptation policies and she serves on the leadership group for the United Nations Climate Resilience Initiative: Anticipate, Absorb, Reshape (A2R). After completing a PhD in Political Science at Colorado State University (2003), Dr. Dale conducted research on the National Fire Plan as a postdoctoral scholar with The Wilderness Society. After serving on the faculty at the University of Denver, she went on to work for the State of Colorado as an Assistant Director for the Department of Natural Resources with policy analysis responsibilities relating to endangered species, public lands, forestry, and wildfire. Prior to joining The Earth Institute, Dr. Dale serve as the Associate Director for the Yale Center for Environmental Law & Policy.

References

Abatzoglou, J. T., & Williams, A. P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences, 113*, 11770–11775. https://doi.org/10.1073/pnas.1607171113

Abrams, J. (2019). The emergence of network governance in U.S. National Forest administration: Causal factors and propositions for future research. *Forest Policy and Economics, 106*, 101977. https://doi.org/10.1016/j.forpol.2019.101977

Abrams, J., Davis, E. J., & Wollstein, K. (2017). Rangeland fire protection associations in Great Basin rangelands: A model for adaptive community relationships with wildfire? *Human Ecology, 45*, 773–785. https://doi.org/10.1007/s10745-017-9945-y

Abrams, J. B., Knapp, M., Paveglio, T. B., Ellison, A., Moseley, C., Nielsen-Pincus, M., & Carroll, M. S. (2015). Re-envisioning community-wildfire relations in the U.S. West as adaptive governance. *Ecology and Society, 20*(3), 34. https://doi.org/10.5751/ES-07848-200334

Abscher, J. D., Vaske, J. J., & Shelby, L. B. (2009). *Residents' responses to wildland fire programs: A review of cognitive and behavioral studies. General Technical Report PSW-223*. Albany, CA: US Department of Agriculture, Forest Service, Pacific Southwest Research Station. Retrieved from https://www.fs.usda.gov/treesearch/pubs/33552

Adger, W. N., Brown, K., & Tompkins, E. L. (2006). The political economy of cross-scale networks in resource co-management. *Ecology and Society, 10*(2). Retrieved from http://www.ecologyandsociety.org/vol10/iss2/art9/

Ager, A. A., Kline, J. D., & Fischer, A. P. (2015). Coupling the biophysical and social dimensions of wildfire risk to improve wildfire mitigation planning. *Risk Analysis, 35*(8), 1393–1406. https://doi.org/10.1111/risa.12373

Ahrens, J., & Rudolph, P. M. (2006). The importance of governance in risk reduction and disaster management. *Journal of Contingencies and Disaster Management, 14*(4), 207–220. https://doi.org/10.1111/j.1468-5973.2006.00497.x

Almstedt, A., & Reed, M. G. (2013). Introducing a framework for good and adaptive governance: An application to fire management planning in canada's boreal forest. *The Forestry Chronicle, 89*(5), 664–674. https://doi.org/10.5558/tfc2013-119

Amabile, T. M., Patterson, C., Mueller, J., Wojcik, T., Odomirok, P. W., Marsh, M., & Kramer, S. J. (2001). Academic-practitioner collaboration in management research: A case of cross-profession collaboration. *Academy of Management Journal, 44*(2), 418–431. Retrieved from http://www.jstor.org/stable/3069464

Argyris, C. (1976). Single-loop and double-loop models in research on decision-making. *Administrative Science Quarterly, 21*(3), 363–375.

Argyris, C., & Schon, D. A. (1978). *Organizational learning: A theory of action perspective*. Reading, MA: Addison Wesley.

Armitage, D. (2005). Adaptive capacity and community-based natural resource management. *Environmental Management, 35*(6), 703–715.

Armitage, D., Berkes, F., & Doubleday, N. (Eds.). (2007). *Adaptive co-management: Collaboration, learning, and multi-level governance*. Vancouver, BC: University of British Columbia Press.

Baker, W. L., Veblen, T. T., & Sherriff, R. L. (2007). Fire, fuels, and restoration of ponderosa pine-Douglas fir forests in the Rocky Mountains, USA. *Journal of Biogeography, 34*, 251–269.

Barnett, K., Parks, S. A., Miller, C., & Naughton, H. T. (2016). Beyond fuel treatment effectiveness: Characterizing interactions between fire and treatments in the US. *Forests, 7*, 237. https://doi.org/10.3390/f7100237

Barry, C. A., Britten, N., Barber, N., Bradley, C., & Stevenson, F. (1999). Using reflexivity to optimize teamwork in qualitative research. *Qualitative Health Research, 9*(1), 26–44.

Becker, D. R., McCaffrey, S. M., Abbas, D., Halvorsen, K. E., Jakes, P., & Moseley, C. (2011). Conventional wisdoms of woody biomass utilization on federal public lands. *Journal of Forestry, 109*(4), 208–218.

Bergemann, H. A., Schultz, C. A., & Cheng, A. S. (2019). Participating in collaborative implementation: The role of collaborative history and context. In W. H. Butler & C. A. Schultz (Eds.), *A new era for collaborative forest management: Policy and practice insights from the Collaborative Forest Landscape Restoration Program* (pp. 178–194). London, UK: Routledge.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*, *90*(5), 1692–1702.

Berman, R., Quinn, C., & Paavola, J. (2012). The role of institutions in the transformation of coping capacity to sustainable adaptive capacity. *Environmental Development*, *2*, 86–100. https://doi.org/10.1016/j.envdev.2012.03.017

Biber, E. (2011). The problem of environmental monitoring. *University of Colorado Law Review*, *83*, 1–82.

Boeije, H. (2002). A purposeful approach to the constant comparative method in the analysis of qualitative interviews. *Quality & Quantity*, *36*(4), 391–409.

Bouwen, R., & Taillieu, T. (2004). Multi-party collaboration as social learning for interdependence: Developing relational knowing for sustainable natural resource management. *Journal of Community and Applied Social Psychology*, *14*(3), 137–153.

Busby, G., & Albers, H. J. (2010). Wildfire risk management on a landscape with public and private ownership: Who pays for protection? *Environmental Management*, *45*, 296–310. https://doi.org/10.1007/s00267-009-9381-x

Busenberg, G. (2004). Wildfire management in the United States: The evolution of a policy failure. *Review of Policy Research*, *21*(2), 145–156.

Butler, W. H., & Schultz, C. A. (Eds.). (2019). *A new era for collaborative forest management: Policy and practice insights from the Collaborative Forest Landscape Restoration Program*. London, UK: Routledge.

Calkin, D. E., Cohen, J. D., Finney, M. A., & Thompson, M. P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proceedings of the National Academy of Sciences*, *111*(2), 746–751. https://doi.org/10.1073/pnas.1315088111

Calkin, D. E., Thompson, M. P., & Finney, M. A. (2015). Negative consequences of positive feedbacks in US wildfire management. *Forest Ecosystems*, *2*, 9. https://doi.org/10.1186/s40663-015-0033-8

Canadas, M. J., Novais, A., & Marques, M. (2016). Wildfires, forest management and landowners' collective action: A comparative approach at the local level. *Land Use Policy*, *56*, 179–188. https://doi.org/10.1016/j.landusepol.2016.04.035

Caraher, D. L., Zack, A. C., & Stage, A. R. (1999). Scales and ecosystem analysis. In R. C. Szaro, N. C. Johnson, W. T. Sexton, & A. J. Malk (Eds.), *Ecological stewardship: A common reference for ecosystem management* (pp. 343–352). Oxford, England: Elsevier Science Ltd.

Carlisle, K. M., & Gruby, R. L. (2018). Why the path to polycentricity matters: Evidence from fisheries governance in Palau. *Environmental Policy and Governance*, *28*(4), 223–235. https://doi.org/10.1002/eet.1811

Carroll, M., & Paveglio, T. (2016). Using community archetypes to better understand differential community adaptation to wildfire risk. *Philosophical Transactions of the Royal Society B*, *371*, 20150344. https://doi.org/10.1098/rstb.2015.0344

Cash, D. W. (2001). "In order to aid in diffusing useful and practical information": Agricultural extension and boundary organizations. *Science, Technology, & Human Values*, *26*(4), 431–453.

Cash, D. W., Adger, W. N., Berkes, F., Garden, P., Lebel, L., Olssen, P., … Young, O. (2006). Scale and cross-scale dynamics: Governance and information in a multilevel world. *Ecology and Society*, *11*(2), 8. Retrieved from http://www.ecologyandsociety.org/vol11/iss2/art8

Chaffin, B. C., Gosnell, H., & Cosens, B. A. (2014). A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society*, *19*(3), 56. https://doi.org/10.5751/ES-06824-190356

Checkland, P. (1981). *Systems thinking, systems practice*. New York, NY: John Wiley & Sons.

Cheng, A. S., Gerlak, A. K., Dale, L., & Mattor, K. M. (2015). Examining adaptability of collaborative governance in public ecosystem management: Insights from the Front Range Roundtable, Colorado, USA. *Ecology and Society*, *20*(1), 35. https://doi.org/10.5751/ES-07187-200135

Cheng, A. S., Gutierrez, R. J., Cashen, S., Becker, D. R., Gunn, J., Merrill, A., … Price, W. (2016). Is there a place for legislating place-based collaborative forestry proposals?: Examining the Herger-Feinstein Quincy Library Group Forest Recovery Act Pilot Project. *Journal of Forestry*, *114*(4), 494–504. https://doi.org/10.5849/jof.15-074

Cheng, A. S., & Randall-Parker, T. (2017). Examining the influence of positionality in evaluating collaborative progress in natural resource management: Reflections of an academic and a practitioner. *Society and Natural Resources*, *30*(9), 1168–1178. https://doi.org/10.1080/08941920.2017.1295493

Cheng, A. S., & Sturtevant, V. E. (2012). A framework for assessing collaborative capacity in community-based public forest management. *Environmental Management*, *49*(3), 675–689.

Collins, B. K., & Gerber, B. J. (2008). Taken for granted? Managing for social equity in grant programs. *Public Administration Review*, *68*(6), 1128–1141. https://doi.org/10.1111/j.1540-6210.2008.00960.x.

Colorado State Forest Service. (2009). *Colorado statewide forest resource assessment: A foundation for strategic discussion and implementation of forest management in Colorado*. Fort Collins, CO: Author. Retrieved from https://static.colostate.edu/client-files/csfs/pdfs/SFRA09_csfs-forestassess-web-bkmrks.pdf

Colorado State Forest Service. (2013). *2012 report on the health of Colorado's forests: Forest stewardship through active management*. Fort Collins, CO: Author.

Cortner, H. J., & Moote, M. A. (1999). *The politics of ecosystem management*. Washington, DC: Island Press.

Crona, B. I., & Parker, J. N. (2012). Learning in support of governance: Theories, methods, and a framework to assess how bridging organizations contribute to adaptive governance. *Ecology and Society*, *17*(1), 32. https://doi.org/10.5751/ES-04534-170132

Cumming, G. S., Cumming, D. H. M., & Redman, C. L. (2006). Scale mismatches in social-ecological systems: Causes, consequences, and solutions. *Ecology and Society*, *11*(1), 14. Retrieved from http://www.ecologyandsociety.org/vol11/iss1/art14/

Cyphers, L. A., & Schultz, C. A. (2019). Policy design to support cross-boundary land management: The example of the Joint Chiefs Landscape Restoration Partnership. *Land Use Policy*, *80*, 362–369. https://doi.org/10.1016/j.landusepol.2018.09.021

Daniels, S. E., & Walker, G. B. (2001). *Working through environmental conflict: The collaborative learning approach*. Westport, CT: Praeger.

Davidson-Hunt, I. J. (2006). Adaptive learning networks: Developing resource management knowledge through social learning forums. *Human Ecology: An Interdisciplinary Journal*, *34*(4), 593–614.

Davis, C. R., Belote, R. T., Williamson, M. A., Larson, A. J., & Esch, B. E. (2015). A rapid forest assessment method for multiparty monitoring across landscapes. *Journal of Forestry*, *114*(2), 125–133. https://doi.org/10.5849/jof.14-118

Denzin, N. K., & Lincoln, Y. S. (Eds.). (1998). *Collecting and interpreting qualitative materials*. Thousand Oaks, CA: Sage Publications.

Djalante, R., Holley, C., & Thomalla, F. (2011). Adaptive governance and managing resilience to natural hazards. *International Journal of Disaster Risk Science*, *2*(4), 1–14. https://doi.org/10.1007/s13753-011-0015-6.

Dryzek, J. S. (1993). Policy analysis and planning: From science to argument. In F. Fischer & J. Forester (Eds.), *The argumentative turn in policy analysis and planning* (pp. 213–232). Durham, NC: Duke University Press.

Evans, A. M., & Finkral, A. J. (2009). From renewable energy to fire risk reduction: A synthesis of biomass harvesting and utilization case studies in US forests. *GCB Bioenergy*, *1*, 211–219.

Fazey, I., Fazey, J. A., Fischer, J., Sherren, K., Warren, J., Noss, R. F., & Dovers, S. R. (2007). Adaptive capacity and learning to learn as leverage for social-ecological resilience. *Frontiers in Ecology and the Environment*, *5*(7), 375–380.

Ferranto, S., Huntsinger, L., Getz, C., Lahiff, M., Stewart, W., Nakamura, G., & Kelly, M. (2013). A survey of landowner practices and attitudes towards cross-boundary cooperation. *Society and Natural Resources*, *26*(9), 1082–1110. https://doi.org/10.1080/08941920.2013.779343

Finney, M. A. (2001). Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *Forest Science*, *47*(2), 212–228.

Fischer, A. P., & Charnley, S. (2012). Risk and cooperation: Managing hazardous fuel in mixed ownership landscapes. *Environmental Management*, *49*, 1192–1207. https://doi.org/10.1007/s00267-012-9848-z

Fischer, A. P., Spies, T. A., Steelman, T. A., Moseley, C., Johnson, B. R., Bailey, J. D., … Bowman, D. M. (2016). Wildfire risk as a socioecological pathology. *Frontiers in Ecology and the Environment*, *14*(5), 276–284. https://doi.org/10.1002/fee.1283

Folke, C. (2007). Sociol-ecological systems and adaptive governance of the commons. *Ecological Research*, *22*, 14–15.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *AMBIO*, *31*(5), 437–440.

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of socio-ecological systems. *Annual Review of Environment and Resources*, *30*, 441–473.

Garmestani, A. S., & Benson, M. H. (2013). A framework for resilience-based governance of social-ecological systems. *Ecology and Society*, *18*(1), 9. https://doi.org/10.5751/ES-05180-180109

Gomez-Baggethun, E., Kelemen, E., Martin-Lopez, B., Palomo, I., & Montes, C. (2013). Scale misfit in ecosystem service governance as a source of environmental conflict. *Society and Natural Resources*, *26*, 1202–1216.

Graham, R. T. ed. 2003. *Hayman Fire case study*. General Technical Report RMRS-GTR-114. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved from https://www.fs.fed.us/rm/pubs/rmrs_gtr114.pdf

Gray, B. (1989). *Collaborating: Finding common ground for multiparty problems*. San Francisco, CA: Jossey-Bass Inc.

Grothmann, T., Greksch, K., Winges, M., & Siebenhüner, B. (2013). Assessing institutional capacities to adapt to climate change: Integrating psychological dimensions in the Adaptive Capacity Wheel. *Natural Hazards and Earth System Sciences*, *13*, 3369–3384. Retrieved from www.nat-hazards-earth-syst-sci.net/13/3369/2013/

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., … Bergsma, E. (2010). The Adaptive Capacity Wheel: A method for assessing the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy, 13*, 459–471.

Haufler, J. B., Crow, T., & Wilcove, D. (1999). Scale considerations for ecosystem management. In R. C. Szaro, N. C. Johnson, W. T. Sexton, & A. J. Malk (Eds.), *Ecological stewardship: A common reference for ecosystem management* (pp. 331–342). Oxford, England: Elsevier Science Ltd.

Hessburg, P. F., Miller, C. L., Parks, S. A., Povak, N. A., Taylor, A. H., Higuera, P. E., … Salter, R. B. (2019). Climate, environment, and disturbance history govern resilience of western North American forests. *Frontiers in Ecology and Evolution, 7*. Article 239. https://doi.org/10.3389/fevo.2019.00239

Hoeppe, P. (2016). Trends in weather-related disasters: Consequences for insurers and society. *Weather and Climate Extremes, 11*, 70–79. https://doi.org/10.1016/j.wace.2015.10.002

Hoffman, C. M., Collins, B., & Battaglia, M. A. (2018). Wildland fuel treatments. In S. L. Manzello (Ed.), *Encyclopedia of wildfires and wildland-urban interface (WUI) fires*. Basel, Switzerland: Springer Nature. https://doi.org/10.1007/978-3-319-51727-8_83-1

Holling, C. S., & Meffe, G. K. (1996). Command and control and the pathology of natural resource management. *Conservation Biology, 10*(2), 328–337.

Jakes, P., Nelson, K. C., Enzler, S. A., Burns, S., Cheng, A. S., Sturtevant, V., … Staychock, E. (2011). Community wildfire protection planning: Is the Healthy Forest Restoration Act's vagueness genius? *International Journal of Wildland Fire, 20*, 350–363. https://doi.org/10.1071/WF10038

Kalies, E. L., & Yocum Kent, L. L. (2016). Tamm review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. *Forest Ecology and Management, 375*, 84–95. https://doi.org/10.1016/j.foreco.2016.05.021

Karpouzoglou, T., Dewulf, A., & Clark, J. (2016). Advancing adaptive governance of social-ecological systems through theoretical multiplicity. *Environmental Science & Policy, 57*, 1–9. https://doi.org/10.1016/j.envsci.2015.11.011

Keen, M., Brown, V. A., & Dyball, R. (2005). Social learning: a new approach to environmental management. In M. Keen, V. A. Brown, & R. Dyball (Eds.), *Social learning in environmental management: Towards a sustainable future* (pp. 13–21). London, UK: Earthscan.

Kennedy, M. C., & Johnson, M. C. (2014). Fuel treatment prescriptions alter spatial patterns of fire severity around the wildland–urban interface during the Wallow Fire, Arizona, USA. *Forest Ecology and Management, 318*, 122–132. https://doi.org/10.1016/j.foreco.2014.01.014

Kocher, S. D., Toman, E., Trainor, S. F., Wright, V., Briggs, J. S., Goebel, C. P., … Waldrop, T. A. (2012). How can we span the boundaries between wildland fire science and management in the United States. *Journal of Forestry, 110*(8), 421–428.

Kreye, J. K., Brewer, N. W., Morgan, P., Varner, J. M., Smith, A. M. S., Hoffman, C. M., & Ottmar, R. D. (2014). Fire behavior in masticated fuels: A review. *Forest Ecology and Management, 314*, 193–207. https://doi.org/10.1016/j.foreco.2013.11.035

Lebel, L., Anderies, J. M., Campbell, B., Folke, C., Hatfield-Dodds, S., Hughes, T. P., & Wilson, J. (2006). Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society, 11*(1), 9. Retrieved from http://www.ecologyandsociety.org/vol11/iss1/art19/

Lockwood, M., Raymond, C. M., Oczkowski, E., & Morrison, M. (2015). Measuring the dimensions of adaptive capacity: A psychometric approach. *Ecology and Society, 20*(1), 37. https://doi.org/10.5751/ES-07203-200137

Manna, P., & Ryan, L. L. (2011). Competitive grants and educational federalism: President Obama's Race to the Top Program in theory and practice. *Journal of Federalism, 41*(3), 522–546. https://doi.org/10.1093/publius/pjr021

Martinson, E. J., & Omi, P. N. (2013). *Fuel treatments and fire severity: A meta-analysis. Research Paper RMRS-RP-103WWW*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved from https://www.fs.usda.gov/treesearch/pubs/43632

Mauthner, N. S., & Doucet, A. (2003). Reflexive accounts and accounts of reflexivity in qualitative data analysis. *Sociology, 37*, 413–431.

May, B., & Plummer, R. (2011). Accommodating the challenges of climate change adaptation and governance in conventional risk management: Adaptive Collaborative Risk Management (ACRM). *Ecology and Society, 16*(1): Article 47. Retrieved from http://www.ecologyandsociety.org/vol16/iss1/art47

McCaffrey, S. M., & Olsen, C. S. (2012). *Research perspectives on the public and fire management: A synthesis of current social science on eight essential questions. General Technical Report NRS-104*. Evanston, IL: US Department of Agriculture, Forest Service, Northern Research Station. Retrieved from https://www.fs.usda.gov/treesearch/pubs/41832

McDowell, B. D. (2003). Wildfires create new intergovernmental challenges. *Publius: The Journal of Federalism, 33*(3), 45–61.

Mollinga, P. P. (2010). Boundary work and the complexity of natural resource management. *Crop Science, 50*(2), S1–S9.

Morehouse, B. J. (2011). Wildland fire governance: perspectives from Greece. *Journal of Environmental Policy and Planning*, *13*(4), 349–371. https://doi.org/10.1080/1523908X.2011.611678

Morici, K., Wolk, B. H., Cheng, A. S., Cannon, J. B., Williams, E. C., Caggiano, M. D., … Hoffman, C. M. (2019). *Colorado Wildfire Risk Reduction Grant Program monitoring final report*. Fort Collins, CO: Colorado State University, Colorado Forest Restoration Institute. Retrieved from https://cfri.colostate.edu/wp-content/uploads/sites/22/2019/04/CFRI_1903_Colorado-Wildfire-Risk-Reduction-Grant-Program-Final-Report_Print.pdf

Nicholson-Crotty, S., & Staley, T. (2012). Competitive federalism and race to the top application decisions in the American States. *Educational Policy*, *26*(1), 160–184. https://doi.org/10.1177/0895904811428974

Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science*, *5*(1), 14–37. https://doi.org/10.1287/orsc.5.1.14

North, M. P., Stephens, S. L., Collins, B. M., Agee, J. K., Aplet, G., Franklin, J. F., & Fule, P. Z. (2015). Reform forest fire management. *Science*, *349*, 1280–1281. https://doi.org/10.1126/science.aab2356

O'Neill, S. J., & Handmer, J. (2012). Responding to bushfire risk: The need for transformative adaptation. *Environmental Research Letters*, *7*, 014018. https://doi.org/10.1088/1748-9326/7/1/014018/pdf

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management*, *34*(1), 75–90.

Ostrom, E. (1998). Scales, polycentricity, and incentives: Designing complexity to govern complexity. In L. D. Guruswamy & J. A. McNeely (Eds.), *Protection of global biodiversity: Converging strategies* (pp. 149–167). Durham, NC: Duke University Press.

Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, *19*(3), 354–365.

Pahl-Wostl, C., & Hare, M. (2004). Processes of social learning in integrated resources management. *Journal of Community and Applied Social Psychology*, *14*(3), 193–206.

Paveglio, T. B., Carroll, M. S., Stasiewicz, A. M., & Edgeley, C. M. (2019). Social fragmentation and wildfire management: Exploring the scale of adaptive action. *International Journal of Disaster Risk Reduction*, *33*, 131–141. https://doi.org/10.1016/j.ijdrr.2018.09.016

Paveglio, T., & Edgeley, C. (2017). Community diversity and hazard events: Understanding the evolution of local approaches to wildfire. *Natural Hazards*, *87*, 1083–1108. https://doi.org/10.1007/s11069-017-2810-x

Paveglio, T. B., Moseley, C., Carroll, M. S., Williams, D. R., Davis, E. J., & Fischer, A. P. (2015). Categorizing the social context of the wildland urban interface: Adaptive capacity for wildfire and community "archetypes." *Forest Science*, *61*(2), 298–310. https://doi.org/10.5849/forsci.14-036

Pelling, M., & High, C. (2005). Understanding adaptation: What can social capital offer assessments of adaptive capacity. *Global Environmental Change*, *15*(4), 308–319.

Plummer, R., Crona, B., Armitage, D. R., Olssen, P., Tengo, M., & Yudina, O. (2012). Adaptive comanagement: A systematic review and analysis. *Ecology and Society*, *17*(3), 1. https://doi.org/10.5751/ES-04952-170311

Plummer, R., FitzGibbon, J. (2007). Connecting adaptive co-management, social learning, and social capital through theory and practice. In D. Armitage (Ed.), *Adaptive co-management: collaboration, learning, and multi-level governance* (pp. 38–61). Vancouver, Canada: UBC Press.

Prante, T., Thacher, J. A., McCollum, D. W., & Berrens, R. P. (2007). Building social capital in forest communities: Analysis of new Mexico's collaborative forest restoration program. *Natural Resource Journal*, *47*(4), 867–915. Retrieved from http://www.jstor.org/stable/24889539

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & McKeefry, J. F. (2005). The wildland-urban interface in the United States. *Ecological Applications*, *15*(3), 799–805. Retrieved from http://www.jstor.org/stable/4543395

Reed, M. S., Everly, A. C., Cundill, G., Fazey, I., Glass, J., Laing, A., … Stringer, L. C. (2010). What is social learning? *Ecology and Society*, *15*(4), r1. Retrieved from http://www.ecologyandsociety.org/vol15/iss4/resp1/

Reinhardt, E. D., Keane, R. E., Calkin, D. E., & Cohen, J. D. (2008). Objectives and considerations for wildland fuel treatment in forested ecosystems in the interior western United States. *Forest Ecology and Management*, *256*, 1997–2006. https://doi.org/10.1016/j.foreco.2008.09.016

Rijke, J., Brown, R., Zevenbergen, C., Ashley, R., Farrelly, M., Morison, P., & van Herk, S. (2012). Fit-for-purpose governance: A framework to make adaptive governance operational. *Environmental Science & Policy*, *22*, 73–84. https://doi.org/10.1016/j.envsci.2012.06.010

Rynes, S. L., Bartunek, J. M., & Daft, R. L. (2001). Across the great divide: Knowledge creation and transfer between practitioners and academics. *Academy of Management Journal*, *44*(2), 340–355. Retrieved from http://www.jstor.org/stable/3069460

Schoennagel, T., Balch, J. K., Brenkert-Smith, H., Dennison, P. E., Harvey, B. J., Krawchuk, M. A., … Whitlock, C. (2017). Adapt to more wildfire in western North American forests as climate changes. *Proceedings of the National Academy of Sciences*, *114*(18), 4582–4590. Retrieved from www.pnas.org/cgi/doi/10.1073/pnas.1617464114

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2004). The interaction of fire, fuels, and climate across Rocky Mountain forests. *BioScience*, *54*(7), 661–676.

Schultz, C. A., Coehlo, D. L., & Beam, R. D. (2014). Design and governance of multiparty monitoring under the USDA forest service's collaborative forest landscape restoration program. *Journal of Forestry*, *112*(2), 198–206. https://doi.org/10.5849/jof.13-070

Schultz, C., Huber-Stearns, H., McCaffrey, S., Quirke, D., Ricco, G., & Moseley, C. (2018). *Prescribed fire policy barriers and opportunities*. Eugene, OR: University of Oregon, Ecosystem Workforce Program. Retrieved from http://hdl.handle.net/1794/23861

Schultz, C. A., Jedd, T., & Beam, R. D. (2012). The collaborative forest landscape restoration program: A history and overview of the first projects. *Journal of Forestry*, *110*(7), 381–391.

Schultz, C. A., & Moseley, C. (2019). Collaborations and capacities to transform fire management. *Science*, *366*, 38–40. https://doi.org/10.1126/science.aay3727

Schultz, C. A., & Nie, M. (2012). Decision-making triggers, adaptive management, and natural resources law and planning. *Natural Resource Journal*, *52*, 443–521.

Schultz, C. A., Thompson, M. P., & McCaffrey, S. M. (2019a). Forest service fire management and the elusiveness of change. *Fire Ecology*, *15*, 13. https://doi.org/10.1186/s42408-019-0028-x

Schultz, C. A., Timberlake, T. J., Wurtzebach, Z., McIntyre, K. B., Moseley, C., & Huber-Stearns, H. R. (2019b). Policy tools to address scale mismatches: Insights from U.S. forest governance. *Ecology and Society*, *24*(1), 21. https://doi.org/10.5751/ES-10703-240121

Scott, J. H., & Burgan, R. E. (2005). *Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model. RMRS-GTR-153*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved from https://www.fs.usda.gov/treesearch/pubs/9521

Scott, J. H., & Reinhardt, E. D. (2001). *Assessing crown fire potential by linking models of surface and crown fire behavior. RMRS-RP-29*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved from https://www.fs.usda.gov/treesearch/pubs/4623

Sharma-Wallace, L., Velarde, S. J., & Wreford, A. (2018). Adaptive governance good practice: Show me the evidence! *Journal of Environmental Management*, *222*, 174–184. https://doi.org/10.1016/j.jenvman.2018.05.067

Smith, A. M. S., Kolden, C. A., Paveglio, T. B., Cochrane, M. A., Bowman, D. M. J. S., Moritz, M. A., … Abatzoglou, J. T. (2016). The science of firescapes: Achieving fire-resilient communities. *BioScience*, *66*(2), 130–146. https://doi.org/10.1093/biosci/biv182

Southard, L. F. (2011). The history of cooperative forest fire control and the Weeks Act. *Forest History Today, Spring/Fall*, 17–20. Retrieved from http://foresthistory.org/Publications/FHT/FHTSpringFall2011/Cooperative_Fire_Control.pdf

Steelman, T. A. (2016). U.S. wildfire governance as social-ecological problem. *Ecology and Society*, *21*(4), 3. https://doi.org/10.5751/ES-08681-210403

Steelman, T. A., & Burke, C. A. (2007). Is wildfire policy in the United States sustainable? *Journal of Forestry*, *105*(3), 67–72.

Steelman, T. A., Kunkel, G., & Bell, D. (2004). Federal and state influence on community responses to wildfire threats: Arizona, Colorado, and New Mexico. *Journal of Forestry*, *102*(6), 21–27. https://doi.org/10.1093/jof/102.6.21

Stein, S. M., Menakis, J., Carr, M. A., Comas, S. J., Stewart, S. I., Cleveland, H., … Radeloff, V. C. (2015). *Wildfire, wildlands, and people: Understanding and preparing for wildfire in the wildland-urban interface. General Technical Report RMRS-299*. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved from https://www.nrs.fs.fed.us/pubs/43016

Stephens, S. L., Collins, B. M., Biber, E., & Fule, P. Z. (2016). U.S. federal fire and forest policy: Emphasizing resilience in dry forests. *Ecosphere*, *7*(11), 1–19. https://doi.org/10.1002/ecs2.1584

Stephens, S. L., McIver, J. D., Boerner, R. E. J., Fettig, C. J., Fontaine, J. B., Hartsough, B. R., … Schwilk, D. W. (2012). The effects of forest fuel-reduction treatments in the United States. *BioScience*, *62*(6), 549–560.

Stevens-Rumann, C. S., Kemp, K. B., Higuera, P. E., Harvey, B. J., Rother, M. T., Donato, D. C., … Veblen, T. T. (2018). Evidence for declining forest resilience to wildfires under climate change. *Ecology Letters*, *21*, 243–252. https://doi.org/10.1111/ele.12889

Strauss, A., & Corbin, J. (2008). *Basics of qualitative research: Grounded theory procedures and techniques* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Sturtevant, V., Moote, M. A., Jakes, P., & Cheng, A. S. (2005). *Social science to improve fuels management: A synthesis of research on collaboration*. St. Paul, MN: US Department of Agriculture, Forest Service, North Central Research Station.

Susskind, L., Comacho, A. E., & Schenk, T. (2012). A critical assessment of collaborative adaptive management in practice. *Journal of Applied Ecology*, *49*, 47–51. https://doi.org/10.1111/j.1365-2664.2011.02070.x

Tanaka, K., Indiano, E., Soley, G., & Mooney, P. H. (2015). Building the capacity for community food work: The geographic distribution of USDA Community Food Projects Competitive Grant Program grantees.

Journal of Agriculture, Food Systems, and Community Development, *5*(3), 97–111. https://doi.org/10.5304/jafscd.2015.053.006

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2), 237–246.

USDA and USDI. (2002). *A collaborative approach to reducing wildland fire risks to communities and the environment: 10-year comprehensive strategy implementation plan, May 2002*. Washington, DC: U.S. Department of Agriculture and U.S. Department of the Interior. Retrieved from https://www.forestsandrangelands.gov/documents/resources/plan/11-23-en.pdf

USDA Forest Service. (2018). *Toward shared stewardship across landscapes: An outcome-based investment strategy. Report FS-118*. Washington, DC: US Department of Agriculture, Forest Service, Washington Office. Retrieved from https://www.fs.fed.us/managing-land/shared-stewardship

Valovirta, V. (2002). Evaluation utilization as argumentation. *Evaluation*, *8*(1), 60–80.

van Niekerk, D. (2014). From burning to learning: Adaptive governance to wildfires in the North-West Province of South Africa. *Journal of Human Ecology*, *48*(2), 329–339. https://doi.org/10.1080/09709274.2014.11906802

Wildland Fire Leadership Council. (2014). *A national cohesive wildland fire management strategy*. Washington, DC: Author. Retrieved from https://www.forestsandrangelands.gov/strategy/documents/strategy/CSPhaseIIINationalStrategyApr2014.pdf

Wondolleck, J. M., & Yaffee, S. L. (2000). *Making collaboration work: Lessons from innovation in natural resource management*. Covelo, CA: Island Press.

Wyborn, C. (2015a). Connecting knowledge with action through coproductive capacities: Adaptive governance and connectivity conservation. *Ecology and Society*, *20*(1), 11. https://doi.org/10.5751/ES-06510-200111

Wyborn, C. (2015b). Cross-scale linkages in connectivity conservation: Adaptive governance challenges in spatially distributed networks. *Environmental Policy and Governance*, *25*(1), 1–15. https://doi.org/10.1002/eet.1657

Young, O. (2002). *The institutional dimensions of environmental change: Fit, interplay, and scale*. Cambridge, MA: MIT Press.

Young, O. R. (2010). Institutional dynamics: Resilience, vulnerability, and adaptation in environmental and resource regimes. *Global Environmental Change*, *20*(3), 378–385.