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ORGANIZATIONAL INFLUENCE ON KNOWLEDGE CO-PRODUCTION

By

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Bachelor of Science, University of Washington, Seattle, Washington, 2017

Thesis

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Organizational Influence on Knowledge Co-production

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Interdisciplinary and transdisciplinary approaches are needed to effectively address the challenges facing our complex social-ecological systems. To meet this need, many approaches, including co-production, have been proposed to overcome the difficult relationship between science and governance, often termed a ‘gap’, which can continue to impede natural resource problem solving. Co-production is an iterative process that engages scientists, managers, and community members in knowledge creation and problem solving. Evidence indicates that participants are more likely to view co-produced knowledge as more salient, legitimate, and credible, and that they are more likely to use it. Evidence also indicates that this iterative and inclusive process can foster relationships between participants that enhance their ability to collaborate going forward. Despite these potential benefits, siloed and ‘static’ approaches to natural resource science and management can create organizational structures and cultures that are not conducive to collaborative research processes like co-production. This study focuses on seven co-production case studies to examine how organizational structures and cultures within the Rocky Mountain Research Station (RMRS) enable or constrain co-production processes and their subsequent outcomes. In-depth interviews with participants indicate that by adjusting performance evaluations to value the time and energy that collaborative work requires, as well as by adjusting funding to compensate for this additional time, RMRS could enhance their support of scientists’ engagement in collaborative process like co-production. However, participants also indicate that RMRS may have to invest in more scientists overall, especially those that focus on addressing management needs, to enhance their capacity as an organization to engage in co-production processes.

Keywords: Co-production, social-ecological systems, decision-making, natural resource management

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Thesis Focus and Format

This thesis will begin with an introduction to the challenges of addressing complex problems within our social-ecological systems and how co-production may be a means for engaging with those challenges effectively. I will then discuss the lack of institutional support for co-production processes and describe how this study aims to examine the way institutional structures and cultures of research organizations enable or impede co-production processes. From here, I expand in Chapter II on the case studies that are the focus of this work, the methods used to examine them, and the theoretical foundations of those methods. Chapter III is a distillation of lessons learned for the Research and Development branch of the Forest Service regarding the structures and cultures of our research stations. In Chapter IV, I transition into a draft manuscript intended to share the findings of this research with the scientific community and illuminate the benefits that co-production can have in the realm of fire science and management specifically. Chapter V enumerates various findings from this study that pertain less to the relationship between fire science and management and more to the growing literature on co-production processes, outcomes, and how these processes can be supported. In this final chapter, I conclude by indicating how further research can enrich the discussion around institutionalizing co-production.

Chapter I

Introduction

In this chapter, I describe how the complex challenges of our social-ecological systems are the impetus for efforts to co-produce knowledge, actions, and solutions. I continue to expand on how co-production processes aim to address these challenges and describe the barriers that remain to actualizing the benefits of co-production.

Global environmental change threatens ecosystems in all parts of the world, while communities confront the economic and political systems that are both shaped for, and shaped from, current modes of unsustainable natural resource management (Bosworth et al., 2008; IPCC, 2018; Jasanoff, 2004; Steffen et al., 2015). Transitioning our current practices to ones that foster and enrich the ecological process we rely on, will require momentous changes across sectors, especially in natural resource management. For decades, western scientific expertise in the United States has been cultivated largely within individual disciplines through siloed, reductionist approaches that conceptually or physically isolated systems to build understanding (Beier et al., 2017; Lemos & Morehouse, 2005). As we become more aware of the interconnections in our social-ecological systems, we are recognizing that these reductionist approaches are not sufficient for understanding complex problems in their unique contexts (Mauser et al., 2013). We require new approaches that integrate knowledge from different disciplines and knowledge beyond academia to more comprehensively understand systems and how to effectively shift toward more sustainable natural resource management (Kirchhoff et al., 2013; Mitchell et al., 2004; Patterson & Williams, 1998; Reid et al., 2009).

The effort to integrate more diverse forms of knowledge into natural resource management has highlighted what many have described as a longstanding ‘gap’ between science and governance (Nel et al., 2016; Oliver et al., 2014; Roux et al., 2006; Van Kerkhoff & Lebel, 2015; Wyborn, 2015). Scientific work is often produced and circulated in the research community, but does not always get used in decision-making for a variety of reasons, including that decision-makers may be unaware of its existence, or that the work itself may be inapplicable to the specific challenges they confront (Dilling & Lemos, 2011; McNie, Parris, & Sarewitz, 2016; Oliver et al., 2014; Roux et al., 2006). Research has proliferated on how to create scientific products that are actually used by decision-makers, often referred to as ‘actionable science’, and has identified various methods by which the tasks and challenges of decision-makers can be more efficiently and effectively supported by scientific products (Beier et al., 2017; Clark et al., 2016; Kirchhoff et al., 2013; Mauser et al., 2013; Meadow et al., 2015). Emerging from these efforts to unite science and decision-making, knowledge co-production is a process that may confer unique advantages (Cash et al., 2003; Ostrom, 1996).

Co-production is a process of knowledge creation and problem solving that incorporates diverse perspectives, including those from decision-makers who may be applying that knowledge to policy and practice (Lemos & Morehouse, 2005; Norström et al., 2020; Van Kerkhoff & Lebel, 2006; Wyborn & Leith, 2018). By enlisting the expertise of diverse actors, co-production emphasizes shared learning amongst participants through the process of integrating their diverse knowledges (Beier et al., 2017; Buizer et al., 2011; Cash et al., 2006; Mauser et al., 2013; Nel et al., 2016; Reid et al., 2009; Roux et al., 2006; Schuttenberg & Guth, 2015). Co-produced knowledge is more likely to be seen as salient, legitimate, and credible by those involved, and thus more likely to be used by those involved (Beier et al., 2016; Cash et al., 2006, 2003; Cook et

al., 2013; Dilling & Lemos, 2011; Kirchhoff et al., 2013; Lemos & Morehouse, 2005; McNie et al., 2016; Meadow et al., 2015; Nel et al., 2016; Wyborn & Leith, 2018). Lemos and Morehouse (2005) and Mauser et al. (2013) argue that these qualities emerge from co-production specifically because of its emphasis on iterative and inclusive engagement of participants throughout the knowledge creation process, which ensures end user needs can inform resultant knowledge products (Lemos & Morehouse, 2005; Mauser et al., 2013). The benefits of co-production are also not limited to a single project. Beier et al. (2017) and Nel et al. (2016) suggest that the more profound result of co-production processes is the establishment of relationships between participants that can enable the kind of collaboration required to transition toward more adaptive and dynamic modes of managing complex systems.

Research on co-production outlines myriad benefits, but one of the barriers to co-production is that a model of siloed, reductionist, and static approaches still permeate organizational structures and cultures (Wyborn et al., 2019; Wyborn & Leith, 2018). Additionally, resource management concerns are context specific, and different institutional influences, such as organizational structures and cultures, are relevant depending on the locality (Meadow et al., 2015; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018). Djenontin and Meadow (2018) argue that the structures of organizations involved in co-production, as well as their professional cultures, can impact the success of co-production and propose that institutional support and incentives for co-production processes may need to be strengthened. Wyborn et al. (2019) similarly call for further research into how to institutionalize co-production either within organizations or through enabling policies, and note the interconnections between structures and cultures, and how each can shape the other. Research organizations are institutions that can be particularly influential in co-production processes because scientists are often embedded in, and

influenced by, their structures and cultures. If we want to realize the benefits of co-production, we need research organizations that support and incentivize this type of engagement. To understand the influence of research organizations on co-production, this research examines specific case studies of co-production and the views of scientists, managers, and community members involved in those cases. The goal of this research is to understand how the structures and cultures of research organizations impact co-production processes and their subsequent outcomes.

Literature

Science and Decision-making

In the United States, scholars have long observed a ‘gap’ between science and practice (Roux et al., 2006), and an incongruence between science and governance more broadly (Wyborn & Leith, 2018). A focus on governance, as opposed to practice or management, acknowledges that each are shaped by policy and the resulting institutional structures and cultures that influence how natural resources are stewarded (Lemos & Agrawal, 2006). Concern from scholars that science is not integrated into, and adequately used in, decision-making processes has propelled further investigation into the causes of this ‘gap’ (Cash et al., 2003; Van Kerkhoff & Lebel, 2015; Van Kerkhoff & Lebel, 2006; Wyborn, 2015). Van Kerkhoff and Lebel (2006) to argue that this ‘gap’ could be more accurately characterized as an existing interface, meaning there are existing connections and interactions between scientists and decision-makers taking place. Some of the challenges present in these existing connections and interactions are cultural, epistemological, and ontological differences between scientists, decision-makers, and community members who may have different ways of understanding and prioritizing natural

resource challenges and coming to solutions (Cook et al., 2013; Jasanoff, 2004; Mauser et al., 2013; Roux et al., 2006; Schuttenberg & Guth, 2015). These differences in perspectives and goals between actors can result in ineffective collaboration. For example, managers have described scientific products as not sufficiently context-specific, difficult to understand, not at the appropriate scale, and not produced in the appropriate timeframe to be relevant to decision-making (McNie et al., 2016; Oliver et al., 2014; Roux et al., 2006). Similarly, researchers have described that managers do not seem to understand their work, the limitations of scientific processes, or prioritize their findings in decision-making (Roux et al., 2006). Scholars have proposed and analyzed several modes of joining science and decision-making with the goal of producing ‘actionable science’ that transcends the disparate worlds of research and management (Beier et al., 2017; Clark et al., 2016; Kirchhoff et al., 2013; Mauser et al., 2013; Meadow et al., 2015).

Approaches to Connecting Science and Decision-making

One method of bridging science and decision-making is the ‘loading dock model’ in which knowledge is transmitted in a linear fashion from scientists to managers. This model can involve a request from a manager for a specific scientific output, which is then delivered to the ‘loading dock’ of a decision-maker’s desk (Beier et al., 2017; Cash et al., 2006). Or it can be the production of scientific knowledge that then resides in the ‘loading dock’ of the peer-reviewed literature (Beier et al., 2017; Cash et al., 2006). In each case the research then passively awaits its potential use. The assumption of this model is that scientific products will be applicable to the specific challenges confronted by decision-makers, an assumption that is not corroborated by research on the perceptions of decision-makers who indicate that science is not always perceived as relevant to their concerns (Dilling & Lemos, 2011; McNie et al., 2016; Oliver et al., 2014;

Roux et al., 2006). A similar form of linear transmission of knowledge is when scientists test the applicability of their technology or knowledge in the settings in which they are intended to be used (Meadow et al., 2015). This process involves learning on the part of researchers because they test the effectiveness of scientific products where they will be applied and reconsider their work in terms of its applicability (Meadow et al., 2015). However, the scientific products are still delivered to stakeholders who themselves have a passive role in their creation. In contrast, the exchange of knowledge among many involved parties, sometimes facilitated by boundary organizations that work in the space between researchers and decision-makers, acknowledges that research and management can be informed by the experiences and expertise of multiple perspectives (Cash et al., 2006; Kirchhoff et al., 2013). These approaches emphasize social learning, the process by which individuals share their knowledge and learn from each other to cultivate a more comprehensive understanding of problems and potential solutions (Kirchhoff et al., 2013). Training researchers to more effectively communicate with non-scientists, or embedding scientists within management agencies, are other efforts to cultivate shared understanding between scientists and managers around natural resource challenges and enhance the usefulness of science (Cook et al., 2013).

Co-production Approach

Knowledge co-production is an approach that expands the benefits of social learning into an ongoing process of collaboration between scientists, decision-makers, and other invested parties with the aim of addressing a specific problem (Van Kerkhoff & Lebel, 2006; Wyborn, 2015). Roux et al. (2006) describe co-production as “a shift from a view of knowledge as a ‘thing’ that can be transferred to viewing knowledge as a ‘process of relating’ that involves negotiation of meaning among partners” (p. 16). This shift may better address the complex and

quickly changing challenges that climate change and other issues pose for resource management (Beier et al., 2017). Viewing knowledge as a ‘process of relating’ allows for diverse types of expertise to be integrated into a learning experience that can reframe the scope and scale of a problem and inform how to address it (Beier et al., 2017; Buizer et al., 2011; Cash et al., 2006; Mauser et al., 2013; Nel et al., 2016; Reid et al., 2009; Roux et al., 2006; Schuttenberg & Guth, 2015). This shared understanding contributes to participants’ sense of ‘ownership’ over the resultant knowledge (Dilling & Lemos, 2011), and towards the perception that this knowledge is legitimate, credible, and salient, which enhances the likelihood of it being used in decision-making (Cash et al., 2006, 2003; Clark et al., 2016; Kirchhoff et al., 2013; Lemos & Morehouse, 2005; Meadow et al., 2015; Nel et al., 2016; Polk, 2014a). Legitimacy refers to the perceived unbiased nature of the knowledge or technology, including treating different views fairly (Cash et al., 2003). Credible knowledge is viewed as “true”, including whether the scientific product actually functions as claimed (Cash et al., 2003). Saliency is judged by the relevance of the knowledge or product to those who may use it, such as decision-makers (Cash et al., 2003).

Co-production aims to create knowledge and solutions that are ‘owned’ by participants and seen as legitimate, credible, and salient through iterative and inclusive processes (Dilling & Lemos, 2011; Lemos & Morehouse, 2005; Mauser et al., 2013; Nel et al., 2016; Reid et al., 2009; Sarkki et al., 2015; Schuttenberg & Guth, 2015; Wyborn, 2015). Co-production aims to include diverse participants, especially those who may use the resultant knowledge, in an iterative process that helps address many of the challenges at the interface of science and decision-making. Decision-makers and community members can help enhance the salience of the knowledge by providing insight into the timeline and spatial scale of their decision-making processes and concerns (Beier et al., 2017; Cash et al., 2006, 2003; Cook et al., 2013). Similarly,

researchers can describe the limitations of their research processes, explain what kinds of questions their work can answer, and what these answers could be used for (Beier et al., 2017; Cash et al., 2006). Through this knowledge sharing, the research objectives, methods, and products can be negotiated and informed by multiple actors, which improves the likelihood that participants will perceive the resultant co-produced knowledge as legitimate (Cash et al., 2003; Lemos & Morehouse, 2005). Deeper understanding of research processes and scientific uncertainty can also improve participants perceptions of knowledge as credible (Beier et al., 2017; Schuttenberg & Guth, 2015).

While co-production processes can have many benefits, different worldviews can also pose tradeoffs in terms of cultivating salience, legitimacy, and credibility amongst participants who may have disparate methods for assessing each of these qualities (Cash et al., 2006, 2003; Cook et al., 2013). An example is when knowledge outside of western science is incorporated, it is possible that resultant knowledge products may be less credible to researchers (Cash et al., 2003). Similarly, indigenous people may see a process that involves scientists from government agencies, which have a long history of disenfranchising indigenous communities, as less legitimate (Armitage et al., 2011; Schuttenberg & Guth, 2015). Therefore, it is important to emphasize that participants are more likely to view knowledge as salient, credible, and legitimate when its produced through an inclusive process that allows for substantive and equitably valued contributions (Lauer et al., 2018; Schuttenberg & Guth, 2015). Research has shown that facilitators can play an important role in integrating diverse perspectives into co-production processes to ensure participants can achieve this kind of equitable engagement (Cook et al., 2013; Reid et al., 2009; Van Kerkhoff & Lebel, 2006). Additionally, the iterative nature of co-production is integral to creating the opportunity for participants to contribute to knowledge

creation throughout the process, and it also provides the space and time for participants to establish relationships with one another (Lemos & Morehouse, 2005; Mauser et al., 2013; Sarkki et al., 2015).

Interpersonal relationships often take time to develop and the on-going engagement characteristic of co-production can provide this time. The opportunities for ongoing interactions can facilitate formation of relationships between researchers, decision-makers, and community members which can have lasting benefits due to the way they can enable adaptive capacity going forward, beyond the culmination of a specific project (Littell et al., 2012; Nel et al., 2016; Van Kerkhoff & Lebel, 2015; Wyborn, 2015; Wyborn & Leith, 2018). The dynamic character of resource management challenges has prompted more researchers and managers to call for ‘adaptive management’ styles based on reflection and adjustment, with an emphasis on learning (Buizer et al., 2011; Cash et al., 2003; Littell et al., 2012; Wyborn, 2015). The establishment of relationships between those with diverse types of knowledge enhances the capacity for continuing this type of learning as projects and new challenges are assessed (Nel et al., 2016; Reid et al., 2009; Van Kerkhoff & Lebel, 2006; Wyborn & Leith, 2018). Co-production is therefore more than a means to an end. It can be integrated into the way researchers and managers adapt to increasingly complex situations and can enhance their ability to co-produce knowledge and new ways of addressing future challenges.

Operationalizing Co-production

Given the context-specific nature of decision-making processes, knowledge co-production has been done in a variety of ways. Co-production can involve the work of diverse actors who collectively define a problem and shape the research intended to solve it, with

researchers then conducting the science (Wyborn & Leith, 2018). Alternatively, diverse stakeholders may be involved throughout the process, such as in cases where local knowledge from community members is incorporated with scientific research to make tools to inform natural resource decision-making (Nel et al., 2016; Reid et al., 2009; Wyborn & Leith, 2018). The literature abounds with guidelines and recommendations for how to design co-production processes (Beier et al., 2017; Clark et al., 2016; Dilling & Lemos, 2011; Djenontin & Meadow, 2018; Wyborn & Leith, 2018). In the initial stages, Beier et al. (2016), Clark et al. (2016), and Wyborn and Leith (2018) suggest that instead of a request for scientific products by managers, or an immediate offer of a scientific product by researchers, that there should be time to discuss the needs, goals, and concerns of those involved. Beier et al. (2016) and Wyborn and Leith (2018) recommend that researchers in co-productive processes understand the contexts in which decisions will be made, as well as the potential constraints to what knowledge can be used in those contexts. This advice addresses the goal of creating knowledge that integrates diverse experiences and expertise and addresses the challenges related to creating knowledge that is compatible with decision-making processes.

As discussed above, the benefits of co-production emerge from the process through which it's undertaken. Scholars stress that co-production should focus on the iterative and inclusive process, and not only the knowledge created for a given project (Beier et al., 2016; Dilling & Lemos, 2011; Wyborn & Leith, 2018). However, power differences between participants as well as institutional predispositions toward siloed, reductionist, and static approaches to natural resource management can limit the success of these processes (Armitage et al., 2011; Clark et al., 2016; Cvitanovic et al., 2015; Littell et al., 2012; Mauser et al., 2013; Reid et al., 2009; Schuttenberg & Guth, 2015; Turnhout et al., 2019; Van Kerkhoff & Lebel, 2006;

Wyborn & Leith, 2018). As with all decisions, co-production involves value judgements regarding what knowledge is considered, and what outcomes are desirable, which can perpetuate certain kinds of power (Clark et al., 2016; Jasanoff, 2004; Turnhout et al., 2019; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018). Co-production processes should acknowledge differences in power and adjust to encourage the integration of multiple forms of knowledge (Armitage et al., 2011; Clark et al., 2016; Reid et al., 2009; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018).

Further, many organizations involved in co-production may be designed in a way that impedes co-production processes and their outcomes. For example, management agencies often privilege, and thus afford power to, 'static' approaches to resource management which emphasize maintaining current ecosystem conditions rather than managing for dynamic processes (Littell et al., 2012; Schuttenberg & Guth, 2015). Statutory mandates and regulations that emphasize static ecosystems may not be amenable to the learning and adaptive management enabled by on-going, collaborative process like co-production (Nel et al., 2016; Wyborn & Leith, 2018). Additionally, the procedures, timelines, and knowledge requirements of management decision-making processes may not align well with the on-going and inclusive processes of co-producing. Instead, these processes can perpetuate more siloed natural resource management by not supporting or incentivizing collaboration amongst agency staff or with potential partners from other agencies or organizations (Cvitanovic et al., 2016). Management agencies also afford power, through statutory mandates and regulations, to western science for informing decision-making, which has emphasized a reductionist approach that is insufficient for addressing the challenges inherent in complex social-ecological systems (Armitage et al., 2011; Mauser et al., 2013; Schuttenberg & Guth, 2015). Organizations that conduct research, such as academic

institutions and public or private research organizations, can similarly encourage siloed and reductionist approaches to knowledge creation by incentivizing scientists to pursue projects that will lead to publications, rather than incentivizing engagement with managers (Cvitanovic et al., 2016). Consequently, those seeking to co-produce knowledge to inform decision-making may find it difficult to do so within current institutional structures (Armitage et al., 2011; Cash et al., 2003; Mauser et al., 2013; Polk, 2014a; Van Kerkhoff & Lebel, 2006; Wyborn et al. 2019). The legacies of prioritizing certain types of management and knowledge generation will need to be addressed to allow institutions to transition toward more adaptive management approaches that integrate knowledge from diverse sources (Armitage et al., 2011; Plummer et al., 2013; Schuttenberg & Guth, 2015; Wyborn & Leith, 2018). Beier et al. (2017) recommend that research institutions adjust to better support co-production by providing scientists with greater flexibility in research projects and processes and recommend that management agencies and funding organizations could better support co-production processes by funding organizations and individuals to participate in co-production processes. They argue that these kinds of changes may be important means of enhancing capacity to engage in more knowledge co-production.

Influence of Context on Co-production

These recommendations and guiding principles do not prescribe a specific procedure for operationalizing co-production. The challenge of creating ‘one-size-fits-all’ directions for co-producing is that resource management exists within specific political, social, and ecological contexts (Meadow et al., 2015; Nel et al., 2016; Norström et al., 2020 Reid et al., 2009; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018). Consequently, each endeavor toward co-producing knowledge may begin with different access to time and resources, and may involve organizations or governing bodies with different capacities for co-producing, including different

constraints (Littell et al., 2012; Polk, 2014a; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018). The objective described in the literature is not to identify ‘the way’ to co-produce, but rather to understand the core aspects of the process and how they may be operationalized in different contexts (Beier et al., 2016; Meadow et al., 2015; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018). In an effort to meet this objective, scholars have called for further examination of co-production case studies to increase the knowledge base from which decision-makers, researchers, and other community members can identify co-production processes that may fit their specific needs and limitations (Meadow et al., 2015; Nel et al., 2016; Van Kerkhoff & Lebel, 2015).

Institutional structures and cultures are an important aspect of this context because of their potential to enable or constrain co-production processes and subsequent outcomes, as previously discussed (Armitage et al., 2011; Cash et al., 2003; Mauser et al., 2013; Polk, 2014a; Van Kerkhoff & Lebel, 2006; Wyborn et al., 2019). To better understand these enabling or constraining factors, and how co-production has been attempted amidst them, Djenontin and Meadows (2018) recommend further research into how organizations can support or incentivize collaborative research such as knowledge co-production. Research organizations are already engaging in collaborative projects that aim to co-produce knowledge and examination of these projects can reveal how their structures and cultures impact the processes. Public and private research organizations are institutions with a unique position at the interface of science and decision-making. They have their own procedures or regulations that can inhibit or enable co-production processes and they also finance research within academic institutions which allows them to encourage, or require, co-production through funding mechanisms (Reid et al., 2009; Schuttenberg & Guth, 2015; “USDA Forest Service,” n.d.). Because they are uniquely influential

in this way, I focus this study on how research organizations are incorporating co-production processes into their work. More specifically, I examine how the structures and cultures of research organizations impact co-production processes and their subsequent outcomes.

My research contributes to an understanding of how research organizations can enable co-production. Case studies on the different ways co-production processes are operationalized within the specific limitations and capacities of research organizations can build our knowledge of the role of research organizations in this process and what organizational changes may provide better support for co-production processes going forward.

Chapter II

Case Studies and Methods

Throughout this chapter, I expand on the cases that are the focus of this study, the methods used to examine them, and the theoretical foundations of those methods. This study of research organizations focuses on the Rocky Mountain Research Station (RMRS), one of five regional research stations that comprise Forest Service Research and Development which is an arm of the Forest Service operating within the United States Department of Agriculture (“U.S. Forest Service Risk Management Assistance Teams Communication Plan,” 2017). Because RMRS is embedded in an agency that also includes the decision-makers who will likely use its scientific work (the managers in the National Forest Systems arm of the Forest Service), RMRS plays a role similar to that of a boundary organization. Boundary organizations help facilitate and translate knowledge between groups that are positioned differently such as researchers and decision-makers and can help bridge the ‘gap’ between science and governance in natural resource management (Guston, 1999). RMRS can perform a similar function because it exists in the space between the scientific work of academia and the application of knowledge to public land management by the Forest Service (“USDA Forest Service,” n.d.). This role allows RMRS to produce knowledge in close cooperation with the decision-makers who will be using it, and also gives them influence over the production of knowledge by academia through funding mechanisms that can guide what kind of research is done (“USDA Forest Service,” n.d.). For these reasons, RMRS is an especially interesting research organization to focus on in this investigation.

The research and technological development undertaken by RMRS includes work in biological, physical, and social science fields, which are intended to help the Forest Service meet its mission “To sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations” (“USDA Forest Service,” n.d.). Many factors, including climate change, invasive species, and historic fire suppression create challenges for the Forest Service in terms of stewarding ecological systems to meet the needs of future generations (Bosworth et al., 2008; Raymond, Peterson, & Rochefort, 2013). Instead of maintaining forest resources in a somewhat static state for perpetuity, managers are confronting what it means to ‘sustain the health, diversity, and productivity’ of dynamic, ever-changing ecosystems impacted by global processes (Armitage et al., 2011; Littell et al., 2012; Schuttenberg & Guth, 2015; “USDA Forest Service,” n.d.).

To adjust to this complex management challenge, the Forest Service has already begun employing collaborative processes. For example, the North Cascadia Adaptation Partnership (NCAP), begun in 2010, brought together researchers, managers, and a broad range of community members to assess the vulnerability of various natural resources to climate change and to develop methods to reduce these vulnerabilities (Raymond et al., 2013). Co-production in this process was heralded as particularly successful by participants, and recommended to others who share the complicated task of stewarding natural resources in the age of climate change (Raymond et al., 2013). Work by Littell et al. (2012) and Mitchell et al. (2004) has similarly corroborated the benefits of co-production processes for forest management, and RMRS scientists are currently working with managers and community members to co-produce knowledge and solutions for natural resource challenges through a variety of collaborative processes.

This study focuses on seven case studies of co-production identified by RMRS, including:

1. Community Wildfire Protection Plan (CWPP), which was authorized by the 2003 Healthy Forest Restoration Act and defined as a plan describing the hazards of wildfire in a community as well as proposing mitigation strategies. While CWPPs have been created at community scales across the United States, I am studying the process of creating a CWPP for Missoula County, Montana, which falls within the Northern Region (Region 1).
<https://www.missoulacounty.us/government/public-safety/office-of-emergency-management/community-wildfire-protection-plan>
2. Community Planning Assistance for Wildfire (CPAW), which was established jointly by Headwaters Economics and Wildfire Planning International in 2015 and is funded in part by grants from the U.S Forest Service. This work has been done in 30 communities across the United States and I'm studying how the process was undertaken for Chelan County, Washington, which resides within the Pacific Northwest Region (Region 6).
<https://planningforwildfire.org/project/chelan-county-washington/>
3. Potential Wildfire Operational Delineations (PODs), which help wildfire responders and managers operationalize responses to wildfire based on the location and its associated risks and vulnerabilities. This approach has been used on numerous forests throughout the Western United States and I am studying how the PODs process was implemented on the Tonto National Forest in Arizona and on the Santa Fe and Carson National Forests in New Mexico which fall within the Southwest Region (Region 3).

<https://fireadaptednetwork.org/collaborative-spatial-fire-management-getting-ahead-fire-using-potential-operational-delineations/>

4. Risk Management Assistance Teams (RMATs), which aim to assist those actively fighting wildfire to make decisions regarding the tradeoffs of firefighter exposure, risk to highly valued assets, and the potential benefits of wildfire (“U.S. Forest Service Risk Management Assistance Teams Communication Plan,” 2017). I am studying the most highly involved members of RMATs across several fire events.

<https://wfmrda.nwcg.gov/RMAT.html>

5. WiRē (Wildfire Research) Team program, which tasks researchers and practitioners with innovatively integrating social science into wildfire education and mitigation strategies (“USDA Forest Service,” n.d.). I am studying two out of the ten sites the WiRē Team has worked. Each these sites are in Colorado and fall under the Rocky Mountain Region (Region 2).

<https://www.fs.fed.us/rmrs/groups/wire-wildfire-research>

6. National Grasslands Research Project, which is a project involving the Thunder Basin and Buffalo Gap National Grasslands and engages managers and community members in designing and conducting research into how grasslands respond to fire. This site is in South Dakota within the Rocky Mountain Region (Region 2).

<https://www.fs.fed.us/research/people/profile.php?alias=jacquelinepott>

7. Sagebrush Ecosystem Research Project, which is a collaborative project involving several public land management agencies and community members in creating a framework for how the different portions of the sagebrush biome respond to wildfire and

how this knowledge can inform management. The project is based in Nevada within the Intermountain Region (Region 4).

<https://www.fs.fed.us/rmrs/people/jchambers>

The specific sites for study were chosen in collaboration with RMRS scientists who identified cases that they perceived as especially successful. These case studies enable in-depth analysis of how initiatives such as CWPP or PODS operate in particular places with specific sets of scientists and managers. Studying a variety of processes also allows me to better understand how the institutional context of RMRS can constrain or enable co-production across different projects.

Study Population

This study examines the perspectives of individuals who participated in the case studies described above. These participants include Research Grade and Professional Grade scientists within RMRS, as well as partnering scientists from universities and other government agencies and research branches, who are referred to throughout as ‘scientists.’ Decision-makers in federal agencies and the agency staff that work to implement these decisions are referred to as ‘managers’ throughout, and all participating city and county government officials, representatives of non-governmental organizations, and community members are referred to as ‘community members.’ Given that co-production processes emphasize inclusion in knowledge creation, and simultaneously confront many of the structural and cultural barriers to the incorporation of diverse perspectives, I consider it crucial to examine how co-production processes are perceived from actors with different roles, and potentially different kinds of power.

Sampling

I conducted in-depth, semi-structured interviews with 4-7 participants in each of the case studies described above, with a total of 33 participants. For this study, I limited myself to a sample size of approximately 30-40 interviews, which is expected to provide the rich information that in-depth interviews are designed to confer, and also is the upper limit of what is often digestible for a qualitative analyses that aims to identify patterns within and across responses (Patterson & Williams, 2002). Out of the 4-7 interviews per case, I interviewed at least one RMRS scientist from the project and at least one manager from a federal natural resource management agency from the project, except for one case where the main partners in the project were representatives of non-governmental organizations. When the main partners were managers, but the project included community members as well, I expanded to interview 1-2 of them.

To select respondents, I used chain referral and purposive sampling. RMRS scientists identified the cases that they perceived as examples of knowledge co-production, as well as key contacts. I began by interviewing the key contact for each case, and from their referrals I decided who to interview next in that case. For this determination I purposively sampled to include similar numbers of scientists, managers, and involved community members (Berg 2009). Additionally, I selected interviewees who were the most involved in the projects, and where appropriate and possible I selected people who have different perspectives than other participants. I aimed to interview participants who were the most engaged in the process to better understand the influences that the structures and cultures of RMRS had on the processes and outcomes. In addition to this goal, I aimed to understand the different perspectives of participants because the constraints or enabling aspects of the organizational context may be experienced

differently by each participant based on their roles and contributions. Therefore, selection of interviewees was based on maintaining a balance of scientists, practitioners, and community members with an emphasis on those who were the most involved, and of those I aimed to select participants who had different perceptions of the process.

Data Collection

Because these cases are distributed across the western United States, interviews were conducted over the phone unless respondents were in the Missoula area and able to conduct the interview in person. Of the potential interviewees contacted, one practitioner was not able to reschedule after they could not make our initially scheduled interview call. All other contacted individuals were able to participate in an interview. Interviews were semi-structured and conducted with an interview guide to provide continuity and comparability across interviews while remaining flexible to allow for follow up questions pertaining to the uniqueness of individual's responses and experiences (Hesse-Biber & Leavy, 2006; Patterson & Williams, 1998; Rubin & Rubin, 2005). The interview guide is a set of questions constructed around what has emerged from the literature as influential in the outcomes of co-productive processes and what I knew at the outset about co-production within RMRS (See Appendix A). By conducting each interview with the same core questions, I ensured that the main themes of interest are addressed while allowing interviewees to take the conversation in additional directions (Patterson & Williams, 1998). The interviews each began with questions that help gauge the context of the case and the respondent's participation and establish rapport between the respondent and myself (Hesse-Biber & Leavy, 2006). The questions then transition towards the collaborative process and the respondent's experiences with that process. Interview questions emphasized the operationalization of co-production, in terms of how collaborations came about,

the extent to which knowledge was co-created, and how collaboration was undertaken throughout. I then transitioned toward questions regarding outcomes, such as whether the culmination of the process led to a product that respondents perceived as useful and whether respondents think these collaborative projects should be pursued going forward.

The semi-structured nature of the interviews allowed for discussion of ideas and concerns that are not explicitly addressed by the pre-determined interview questions but which the respondent may identify as relevant or important to the project (Hesse-Biber & Leavy, 2006). This was intended to allow for a more conversational tone throughout the interview to help maintain rapport and trust (Hesse-Biber & Leavy, 2006; Rubin & Rubin, 2005). This more flexible structure also allowed for follow-up questions to achieve greater detail, depth, and nuance throughout the interviews (Patterson & Williams, 1998; Rubin & Rubin, 2005). Additional questions to encourage detail, depth, and nuance are all attempts to distill meaning from what may otherwise be relatively ambiguous statements, and help ensure that I understand the significance of particular statements (Hesse-Biber & Leavy, 2006; Rubin & Rubin, 2005). The strength of in-depth interviews are these more detailed and nuanced descriptions of individuals' experiences (Hesse-Biber, 2017). While survey data can help gauge distribution of perspectives in a population, in-depth interviews can allow for respondents to provide the rich descriptions of their thoughts and experiences that are often absent with survey methods. Since I am interested in learning how RMRS culture and structure impair or enable co-production, I am interested in understanding respondents' experiences in detail to gauge what and how they experience limitations to, or support for, working on collaborative projects. By conducting interviews in a semi-structured way, I aimed to adapt to the progression of the interviewees responses to ensure that I did not ask questions that the interviewee had already answered un-

prompted, or dramatically re-direct the conversation to adhere to interview question order (Patterson & Williams, 2002). Both of these choices could cause discomfort or confusion for the interviewee, and unnecessarily curtail a conversational flow that could have progressed through the questions more smoothly, though in a slightly different order (Patterson & Williams, 1998). Because of this flexibility, interviews have lasted from around 45 minutes to an hour and a half.

Interviews were recorded and respondents were ensured that responses would be anonymous, and the identity of respondents will not be shared beyond myself and a small team of researchers at the University of Montana (all in accordance with University of Montana IRB approval). If a respondent was initially uncomfortable at the prospect of being recorded, this was discussed to ensure they fully understood how their responses would be used and their privacy safeguarded, and if necessary, I was ready to discuss possible alternatives. All participants agreed to be recorded.

Data Analysis

Recordings were transcribed by a professional transcription service. I then listened to each recording and read the corresponding transcription to ensure accuracy and that the names of the respondents were removed. I then coded each transcript using NVivo 12 software. Coding is the process of identifying concepts and themes that appear within each interview, and across the interviews (Rubin & Rubin, 2005). Using the literature on co-production processes, I identified pertinent concepts, but I also employed aspects of the grounded theory method of coding to allow for analysis of themes that the literature may not have previously addressed (Rubin & Rubin, 2005). Interviews were first analyzed individually, then comparatively, to identify broader patterns between and across participants. Analysis was an iterative process of reading

and re-reading interview transcripts to code for different concepts and themes as larger patterns emerge. This approach allowed for ongoing development of meaning as the analysis progressed (Rubin & Rubin, 2005). To begin, I adjusted and adapted my codes to reflect different themes as I coded the first eight transcripts. After coding eight interviews, I revisited my codes, grouping some things and moving text between codes that I considered a better fit. I then recoded all eight transcripts based on the revised codes. I continued to add and adapt themes and codes as necessary to capture the nuance of their experiences in the projects.

Chapter III

Forest Service Research & Development: Opportunities and Challenges for Co-production

Throughout this section, I synthesize lessons learned from this study for Forest Service Research and Development and identify specific adjustments that could be made to provide further support for scientists and research stations that wish to continue or increase their engagement in co-production processes.

Executive Summary

To better understand the opportunities and challenges associated with collaborations between USDA Forest Service Research and Development scientists, federal land managers, and community partners, we examined seven case studies of wildfire co-production in the Western U.S. The goal of this study was to understand the benefits of co-production and how Forest Service Research and Development might incentivize and institutionalize these collaborative processes. The scientists and managers who participated in these projects affirmed that they have experienced a ‘gap’ between fire science and management that has long been discussed in the literature (Roux et al., 2006). As found by Kosher et al. (2012) and Hunter (2016), participants in these projects have observed that fire science is not always perceived as relevant to the concerns of managers, that scientific products are not always well understood by managers, and that cultural differences between scientists and managers can cause difficulties in communication and mistrust. Despite these challenges to working together, participants corroborate the assertion from White et al (2019) that increased engagement between scientists and managers is necessary, citing a lack of individual capacity and knowledge to accomplish their natural resource management goals. Participants similarly affirm the benefits observed in recent co-production

literature when explaining that their co-production processes have helped them overcome some of these challenges (Wyborn & Leith, 2018). However, participants have also articulated a variety of challenges that impede their ability to engage in collaborative process such as co-production. These benefits and challenges are summarized below along with recommendations for the Rocky Mountain Research Station and other research stations to enhance the connection between fire science and management.

Benefits of these Projects

- The integration of knowledge from managers and community members has enhanced the relevance of fire science to management.
- These collaborative processes facilitate greater transparency and broader inclusion in science and decision-making, building support for the resultant knowledge products and their use.
- These processes also support on-going learning amongst participants, which has allowed them to refine and improved their knowledge products over time and improve the ability of scientists and managers to work together.

Challenges to Engaging on Co-production

- Performance metrics for Research Grade scientists value and incentivize publishing in peer-reviewed journals to the extent that these scientists experience a disincentive to collaborate through co-production processes, given the time commitments required.
- Funding tend to favor short-term projects rather than the intensive, long-term work associated with co-production.

- Professional Grade scientists who work on science application experience limited career advancement compared to Research Grade scientists, incentivizing them to leave these positions and leading to a loss of expertise in science-management translation.
- Staffing capacity within RMRS limits the extent to which the station can meet the demand from managers for this type of collaborative work.

Recommendations for Institutionalizing Co-production

- **Value collaborative work in the performance evaluations of Research Grade scientists.** Research Grade scientists are currently evaluated on metrics such as technology transfer and impact, with the section on impact specifically stating that “impact is rarely reflected in the number of scientific publications” (Forest Service, 2008, p. 72). Despite this, participants argue that in panels, scientists are still primarily evaluated by the number and quality of their peer-reviewed publications. Since the criteria for evaluation already calls for consideration of technology transfer and impact, it may be necessary for Forest Service Research and Development (R&D) to change the performance evaluation points system to more highly value those aspects. For example, only two of the twelve descriptions characterizing the highest rating for Factor 4 – Contributions, Impact, and Stature include activities such as information and technology transfer or applying research to management or policy, which are often the main aims and outcomes of collaborative processes like co-production. These two descriptions are also listed under ‘advisory activities’, indicating that they may be viewed as more peripheral to a researcher’s work than as a portion of their primary duties. R&D could make a structural adjustment to include these activities as primary duties of a researcher, not only for the highest point level, but also for the intermediate and lower levels as well. This

structural adjustment may enable researchers to dedicate time and energy toward co-production processes because their performance evaluations would codify value for the activities and outcomes co-production often entails. Additionally, more value could be assigned to research that is intended to address management concerns, regardless of how innovative or complex. For example, Factor 1 – Research Assignment generally assigns less value to applied research than basic research. This study indicates that researchers may not see it as their role to conduct the applied research required to address manager’s concerns in part because this applied research is not valued in their performance evaluations. R&D could make a structural adjustment to assign more value to the types of research that address management concerns, enabling researchers to pursue this work with the knowledge that their time and energy will be recognized in their performance evaluations. Each of these structural adjustments may have the added benefit of legitimizing a cultural shift in their research organizations towards valuing more applied work.

- **Extend the duration of funding for collaborative projects.** As a funder, RMRS can extend the duration of funding for collaborative projects such that the financial support aligns with the anticipated duration of the process.
- **Expand upward mobility for Professional Grade positions.** Enhanced career advancement opportunities for Professional Grade positions can incentivize scientists to remain in these positions and cultivate skills and institutional knowledge of science and technology transfer, building overall capacity in this area. As one participant noted, this could be done by providing a similar career trajectory for Professional Grade scientists as

what currently exists for Research Grade scientists, enabling scientifically minded people to pursue a career specifically focused on applying science to management needs.

- **Use the benefits of co-production to argue for more capacity.** Co-production can confer a suite of benefits, such as ensuring that research is relevant and usable in management, and these benefits support an argument for increasing capacity in RMRS and other stations to work collaboratively with managers and community members.

Considerations

A shift toward research that is specifically relevant to managers and community members may require a shift away from science that is perceived as more novel and highly valued within the scientific community. The tradeoffs between producing knowledge that is perceived as highly credible by the scientific community and producing knowledge that is perceived as highly relevant by managers may require careful consideration as R&D works to enhance the connection between science and management.

Chapter IV

Draft Manuscript

This chapter takes the form of a draft manuscript that collates the findings of this study with respect to the challenging relationship between fire science and management. The manuscript is written for the intended audience of the Journal of Forestry.

Abstract

In the fire world, there have been many efforts to increase the relevance and utility of science for management. However, barriers persist, such as cultural differences between scientists and managers, the perception that science is not relevant to management concerns, and the inaccessibility of science. To overcome these challenges, White et al. (2019) argue that increased engagement between scientists and managers is needed to support natural resource planning and management. Numerous studies have touted the benefits of co-production, collaborative processes that involve scientists and managers in knowledge creation and problem solving, but further research is needed to understand how to institutionalize support and incentives for co-production processes across different organizations and scales. Research organizations are institutions with unique influence because they both fund and employ scientists. To better understand the role of research organizations in enabling and constraining co-production, this study examined seven co-produced fire projects associated with the U.S Forest Service Rocky Mountain Research Station (RMRS). Analysis of these projects provides insights into how the structures and cultures of research organizations influence co-production processes and their subsequent outcomes. In-depth interviews with scientists, managers, and community members involved in these projects indicate that research organizations like RMRS may be able to

institutionalize support for co-production by adjusting the way they incentivize researchers, increasing investment in scientists that specifically focus on applying research to management, increasing the scientific personnel over-all, and supplying long-term funding to adequately support more time intensive co-production processes.

Keywords: Co-production of knowledge, social-ecological systems, decision-making, natural resource management

Introduction

Wildfires in the United States continue to become more frequent, severe, and complex, indicating a growing need to plan for and respond to these events (JFSP, 2011; (Pence & Zimmerman, 2011; Stephens, 2005). However, managers who are responsible for utilizing the best available science in wildfire planning and response may struggle to do so if this science is not accessible and applicable to management needs (JFSP, 2011). Numerous efforts have endeavored to enhance the accessibility and applicability of fire science to management, including the establishment of the Joint Fire Science Program (JFSP) in 1998 (JFSP, 2011). JFSP initially focused on funding research designed to inform management and evolved to establish a national network of regional fire science consortia to function as boundary organizations between fire scientists and managers (JFSP, 2011). While Hunter (2016) and Maletsky et al. (2018) have observed that the program has led to use of fire science in numerous management processes, Kosher et al. (2012) and Hunter (2016) argue that several barriers continue to impede the application of fire science in management, such as cultural differences between scientists and managers, a lack of trust that impedes communication, institutional and bureaucratic challenges, the inaccessibility of science, and the perception that fire science is often not relevant to

management concerns. In a review of the use of science in Forest Service resource management, White et al. (2019) conclude that natural resource planning and management in the United States will ‘likely require increased engagement between managers and scientists,’ such as through co-production processes that bring managers and scientists together to create actionable knowledge (p. 13). Co-production incorporates diverse perspectives, specifically those of end-users, in the creation of knowledge (Lemos & Morehouse, 2005; Van Kerkhoff & Lebel, 2006). Co-production addresses barriers to integrating science and management through iterative processes that can enhance the salience, credibility, and legitimacy of knowledge, as well as foster mutual understanding and working relationships that can be leveraged for future collaborative work (Wyborn & Leith, 2018). Despite these benefits, Djenontin et al. (2018) and Wyborn et al. (2019) argue that further research is required to understand how support for co-production can be institutionalized in academic institutions as well as public and private research organizations. To better understand how fire science can be more useful for, and better integrated into, management, this study examines co-production in the U.S. Forest Service Rocky Mountain Research Station (RMRS) and specifically how organizational structure and culture influence co-production process and subsequent outcomes.

Literature Review

Scholars have long observed a ‘gap’ between science and practice (Roux et al., 2006), and an incongruence between science and governance more broadly (Wyborn & Leith, 2018). A focus on governance acknowledges that both science and management are shaped by policy and the resulting institutional structures and cultures that influence how natural resources are stewarded (Lemos & Agrawal, 2006). Institutional structures and cultures are interrelated, often co-creating each other overtime, and thus the influence they can have is interconnected as well

(Wyborn et al., 2019). One institutional structure is the Joint Fire Science Program (JFSP), established in 1998, as an effort to bridge the gap between fire science to management (JFSP, 2011). Governed by management agencies within the Department of Interior and by the Forest Service, JFSP initially focused on funding research designed to inform management and on making fire science more accessible for managers. The structure of this program emphasizes research that is applicable to management needs and can generate a culture of valuing more applied knowledge, in contrast to research programs that do not focus on addressing management concerns and thus may not generate a culture of valuing that type of research. A ten year review of JFSP-funded research led to the recommendation that JFSP invest more in fostering ‘two-way’ communication between fire scientists and the intended users of fire science (JFSP, 2011). In response, the JFSP established a national network of regional fire science consortia to further facilitate communication between fire scientists and managers to enhance the applicability of science to management concerns (JFSP, 2011; Copp et al., 2018). Kosher et al. (2012) argue that despite this effort, barriers remain to the use of fire science by managers, such as cultural differences between scientists and managers that impede their communication, manager perceptions of science as often not relevant to their localities or concerns, and a lack of time on the part of scientists and managers to do the work of translating research outputs for application. While Hunter (2016) and Maletsky et al. (2018) identified several instances where the fire science consortia facilitated the use of science by managers, Hunter (2016) noted that “institutional and bureaucratic barriers, lack of trust between managers and researchers, and lack of research relevance” remained obstacles to its use (p. 4-7). In a review of the use of science in management, White et al. (2019) conclude that natural resource planning and management will

‘likely require increased engagement between managers and scientists,’ such as in co-production processes (p. 13).

Co-production involves collaboration between scientists, managers, and other invested parties in knowledge creation and problem-solving (Van Kerkhoff & Lebel, 2006; Wyborn, 2015). Roux et al. (2006) describe co-production as “a shift from a view of knowledge as a ‘thing’ that can be transferred to viewing knowledge as a ‘process of relating’ that involves negotiation of meaning among partners” (p. 16). This ‘process of relating’ allows for diverse types of expertise to be integrated into a learning experience that can both reframe the scope and scale of a problem and how to address it (Beier et al., 2017; Buizer et al., 2011; Cash et al., 2006; Mauser et al., 2013; Nel et al., 2016; Reid et al., 2009; Roux et al., 2006; Schuttenberg & Guth, 2015). When scientists and managers are able to build a shared understanding of a problem, they are more likely to see the knowledge that they co-produce as legitimate, credible, and salient, and the knowledge is more likely to be applied to management decision-making (Cash et al., 2006, 2003; Clark et al., 2016; Kirchoff et al., 2013; Lemos & Morehouse, 2005; Meadow et al., 2015; Nel et al., 2016; Polk, 2014a). Legitimacy refers to the perception that the knowledge or technology is unbiased and integrated different perspectives fairly (Cash et al., 2003). Credibility refers to the perception of the knowledge as true and that the scientific product will function as claimed (Cash et al., 2003). Saliency refers to the perceptions of the knowledge as relevant to those who may use it, such as managers (Cash et al., 2003).

Co-production aims to create knowledge that is ‘owned’ by both scientists and managers, through iterative and inclusive processes (Dilling & Lemos, 2011; Lemos & Morehouse, 2005; Mauser et al., 2013; Nel et al., 2016; Reid et al., 2009; Sarkki et al., 2015; Schuttenberg & Guth, 2015; Wyborn, 2015). Including diverse participants in the research process, from managers to

scientists to community members, especially those who may use the results, helps address many of the difficulties to connecting science and management. The salience, or relevance, of the research products can be improved by integrating the knowledge of managers and community members into the design of the research, or into existing research products, to ensure the work pertains to their concerns (Beier et al., 2017; Cash et al., 2006, 2003; Cook et al., 2013).

Similarly, researchers can describe the limitations of their research processes, explain what kinds of questions their work can answer, and what these answers could be used for (Beier et al., 2017; Cash et al., 2006). Through this knowledge sharing, the research objectives, methods, and products can be negotiated and informed by both scientists and non-scientists, which improves the likelihood that participants will perceive the results as legitimate (Cash et al., 2003; Lemos & Morehouse, 2005). Deeper understanding of research processes and scientific uncertainty can also improve participants perceptions of knowledge as credible (Beier et al., 2017; Schuttenberg & Guth, 2015).

Given the context specific nature of natural resource management, knowledge co-production can be conducted in a variety of ways. The literature abounds with guidelines and recommendations for how to design co-production processes (Beier et al., 2017; Clark et al., 2016; Dilling & Lemos, 2011; Djenontin & Meadow, 2018; Wyborn & Leith, 2018). However, these guidelines and recommendations do not prescribe a specific procedure for operationalizing co-production. Each co-production endeavor involves organizations with different capacities and constraints, discrepancies of power, and different decision-making contexts (Littell et al., 2012; Norström et al., 2020; Polk, 2014b; Turnhout et al. 2019; Van Kerkhoff & Lebel, 2015). Thus, the literature does not aim to identify ‘the way’ to co-produce, but rather describes the core aspects of the process and how they may be operationalized in diverse contexts (Beier et al.,

2017; Norström et al., 2020; Meadow et al., 2015; Van Kerkhoff & Lebel, 2015; Wyborn & Leith, 2018). The structures and cultures of the relevant organizations, which often can co-create one another, are a particularly important aspect of this context because they can enable or constrain co-production processes and subsequent outcomes. Djenontin and Meadows (2018) call for additional research into how institutions can support and incentivize co-production, with Wyborn et al. (2019) specifically calling for further research into how co-production can be institutionalized at the level of organizations. To address this, I examined how the Rocky Mountain Research Station, as a public research organization, has been working to co-produce knowledge to inform fire management. Specifically, I studied how RMRS structures and cultures impact co-production processes and subsequent outcomes through an analysis of seven case studies of co-production. Case studies on the different ways that co-production is operationalized by research organizations can help us understand what institutional changes can better support these processes going forward.

Methods

I conducted in-depth, semi-structured interviews with participants from seven collaborative projects identified as knowledge co-production by RMRS scientists. Since these collaborative projects include some, though not all, attributes of ‘co-production’ characterized in the literature, I frequently refer to them as ‘collaborative projects’ while discussing their implications for co-production. In-depth interviews provide detailed and nuanced descriptions of individuals’ experiences (Hesse-Biber, 2017; Patterson & Williams, 2002), which was critical to understanding how participants perceived limitations to, or support for, working on collaborative projects. The semi-structured nature of the interviews allowed participants to initiate discussion of ideas and concerns that are not explicitly addressed by the pre-determined interview questions

(Hesse-Biber & Leavy, 2006). Each of the seven projects involved at least one RMRS scientist working with communities or management agencies in the western United States planning for wildfire mitigation or response. Three of the projects involved RMRS Professional Grade scientists, who work more on applying research to management, and four of the projects involved RMRS Research Grade scientists who conduct research. RMRS scientists, as well as scientists from universities, government agencies, or other research branches, are referred to throughout as ‘scientists.’ Decision-makers in federal agencies and the agency staff that work to implement these decisions are referred to as ‘managers’ throughout. All participating city and county government staff, representatives of non-governmental organizations, and community members are referred to as ‘community members.’ This study examined the perspectives of 4-7 participants from each project, with a total of 33 people interviewed. I used chain referral as well as purposive sampling to include similar numbers of scientists, managers, and community members (when applicable) to understand a diversity of perspectives on the collaborative processes (Berg, 2009; Patterson & Williams, 2002). Additionally, I aimed to interview those most knowledgeable of the organizational influence of RMRS by selecting participants who were most involved in the projects. Interviews were conducted over the phone with the exception of some local participants whose interviews were conducted in person. All of the individuals I contacted participated in an interview, with the exception of one person. Interviews utilized an interview guide to provide continuity and comparability across interviews while remaining flexible to allow for follow up questions and emergent phenomena (Hesse-Biber & Leavy, 2006; Patterson & Williams, 2002; Rubin & Rubin, 2005). The interview guide was based on the co-production literature and preliminary understanding of RMRS and the seven case studies (See Appendix A). Interviews lasted from around 45 minutes to an hour and a half. Interviews were

recorded, professionally transcribed, proofed, and conducted in compliance with the University of Montana Institutional Review Board. I coded each transcript using NVivo12 software. I identified pertinent concepts using the literature on co-production processes and employed aspects of grounded theory to allow for analysis of themes not previously addressed in the literature (Patterson & Williams, 2002; Rubin & Rubin, 2005). Interviews were first analyzed individually and then comparatively to identify broader patterns between and across individuals. Analysis was an iterative process of reading and re-reading interview transcripts to code for different concepts and themes as larger patterns emerge. This approach allows for an ongoing development of meaning as the analysis of responses progresses (Rubin & Rubin, 2005).

Results

Below, I begin by discussing participants' views on the difficulties of bridging fire science and management, as well as their perception that this is necessary. I transition to note the ways that participants describe their collaborative projects as addressing and overcoming these challenges, and then note how participants have perceived RMRS structures and cultures to impede their ability to engage in collaborative projects. Finally, I outline several adjustments that participants argue could alleviate these challenges and enhance support for collaborative work such as co-production.

The Disconnect Between Science and Management and the Call for Collaboration

Throughout our interviews, scientists, managers, and community members described the challenge of working across science and management. Around half of participants (15) characterized a kind of 'gap' or separation between scientists and managers, with one scientist explaining:

The Forest Service has a huge chasm between research and management. They have a problem, a big problem. . . . We have a very hard time creating things that the field needs and even a harder time communicating how to use them. (Scientist 12)

This scientist argues that the disconnect between science and management leads to scientific products that may not be relevant to management concerns or easily understood. One manager described the disconnect as more of a lack of understanding:

I think there's this sort of sense of folks that are in the management side, "well, scientists don't get it. They don't get how hard this is" or anything like that, but then on the flip side, a lot of the researchers are saying things like, "Don't they hear us?" And so I don't quite know how to bridge that gap sometimes. But I feel like where you start with is an olive branch and a relationship. (Manager 23)

This manager argues that the difficulty and complexity of management is not understood by scientists, while scientists may not feel heard when trying to convey their findings, concluding that building understanding between scientists and managers may depend on forging relationships between the two efforts. Many participants (11) also explained that one of the challenges to effectively connecting science and management is that the two efforts often operate based on different epistemologies, with one scientist conveying this when describing different ways of knowing about fire:

The fire management community is very much an experiential community. Basically, you don't get to a decision-making role without having done the job right below you. To really have a say in something, you have to have started with a Pulaski. . . . Fire management has gotten far more complex, and it's a far bigger organization than it used

to be. We're arguing that to really get better we have to use a different approach. We have to bring in analytics. (Scientist 10)

This scientist distinguishes between the analytical knowledge they can contribute as a researcher and the experiential knowledge of fire managers, conveying that the culture of management values experiential knowledge while this scientist argues that it is inadequate to address the complexity of fire management and that their analytical knowledge is needed. Another scientist, who has also spent time working in fire management, expands on this difference between science and management:

We have all the stuff that says, "use the best available science," . . . and so we're supposed to do this, and management is supposed to embrace this stuff, but like in fire, we're like a bunch of old knuckle-draggers that don't like science. And really, we struggle with being told what to do. We struggle with science. We struggle with the researchers, because they act like they know what they're doing and they're clueless, because they don't know what the real world is like. There's this chasm again. There's a chasm.

(Scientists 12)

This scientist described, from their own experience in management, that managers can feel resistant to using science because the scientists may present their knowledge with a kind of authority that managers do not perceive scientists have. The scientist notes that managers may value their experiential knowledge over research products, again characterizing this difference in epistemologies valued by managers and scientists and the challenge it posed for their cooperation.

Despite the challenging relationship between science and management, many participants (12) noted that they depend on their collaborative partners to meet the broader objectives of their organizations. One scientist spoke about this idea when describing the motivation for their own collaborative project:

It became very obvious that none of us had all the expertise, nor all the dollars, or the manpower to do this thing on its own, and everybody going their own way, doing their own thing, oftentimes was cross purposes with one another. (Scientist 7)

In this description, the scientist conveys that collaboration enables participants to exceed what they could achieve independently with the capabilities and expertise of their own organizations, and that their collaboration also prevents their independent efforts from working against each other.

Overall, participants described a challenging relationship between science and management that can impede the use of science by managers, while also arguing that they need to cooperate on complex problems and that more effective connections between science and management may be required.

The Benefits of Co-production

To enhance the applicability of science to management, RMRS scientists are attempting to co-produce knowledge through a variety of collaborative processes. One way that scientists, managers, and community members are working to co-produce knowledge is by co-designing research projects. Many participants (17) described that discussing research together allowed them to refine research questions, methods, and analyses to better address management concerns.

One manager described this phenomenon when responding to a question about whether these projects change the usefulness of science for management:

I believe that it does because I think by directly having those conversations we can say, “if you tweak this just a little bit maybe this can help answer this question.” Or we can just have a broad question and say "This is one of our concerns that we have. Is there any way you can incorporate this into your research?" Or we'll be having a conversation and the researchers may just pop up and say, "Well we can incorporate that in." Or, "We can help address that question by doing this, or by piggy backing that on to what we're already doing." Or, "We have already collected data that maybe we can analyze differently to help address that question." And so I really feel like that it works both ways where we're enhancing the research and the research is kind of enhancing our ability to make decisions on the ground. (Manager 4)

By communicating about the research with scientists, this manager argued that they can help inform and shape the questions, methods, and analysis to enhance the research’s applicability to management decision-making. One RMRS scientist on this project similarly spoke to this benefit, explaining that through conversations with managers and community members, they had learned what form of data was easiest for them to use in management. That realization allowed them to adjust to collect data in a way that would be more easily digestible by their project partners. Many participants (22) also suggested that collaborative projects can integrate management knowledge into existing research outputs. One community member who works fighting fire described this approach:

When we first got their product, ground truthing it, I'd say it was 80% inaccurate. I'm just throwing out a number. I mean, it could've been 60, but it could've been 90. It's just, it didn't provide good planning. [A decision-maker] . . . couldn't look at their map and say, "Oh, well, that's red," or "Oh, that's green," and make a decision off of it. He would have to go out and ground truth every single one of them because it wasn't reliable enough. What we did was look at some of the parameters that they used, so to go from a yellow to a red we'll say was a 30% slope. Well, okay, 30% slope is pretty steep. In this area where people are building stuff, a 20% might be the more accurate number because we would look at it as practitioners and say, "That area is a red, not a yellow. Change your parameter from 30% down to 28%. Let's take a look at that." (Community member 28)

This community member notes how their experiential knowledge was important for enhancing the utility of the modeling tool for decision making. In this project, participants worked to apply landscape-scale modeling of wildfire behavior throughout their community and convey varying levels of wildfire risk to inform decision-making. Local managers and community members were able to bring their experiential knowledge of risk to the project and refine how the model characterized the risk of projected wildfire behavior. Through this process, participants integrated physical science of wildfire behavior with the values and experiential knowledge of managers and community members who are responsible for interpreting the threat that different wildfire behaviors pose given the values on the landscape and their ability to respond. Almost all participants (24) emphasized the importance of valuing different kinds of knowledge in collaborative processes. One scientist conveyed this in their description of the value of operational knowledge:

Everybody has a different knowledge background . . . Most of the time, people who are full-time scientists probably aren't going to have the operations background. They're going to know that we need to get fire in this area. They might know this is a tricky area, but they're not going to understand, "Okay a hot shot crew that's on full when it's 90 degrees out can build this many lines or this many miles or feet of line in an hour." That kind of thing. . . . Understanding the limitations and abilities of operations is really important for us to understand what's possible on the ground. (Scientist 18)

This scientist explained that they paired management knowledge of operational limitations, such as the capacity to reach a fire in a given area and effectively suppress it, with fire behavior models to help convey wildfire risk and inform how managers respond. This process resulted in a product that mapped Forest Service land into various zones of wildfire risk. The boundaries of these zones were determined by where managers would most likely be able to engage and suppress a wildfire, based on scientists' models of potential fire behavior and the operational opportunities and limitations of accessing and suppressing a fire given the location and terrain. The zones were then characterized as different levels of risk based on scientists' models of potential wildfire behavior likely to occur in that area, the values that managers and community members perceived as at risk on the landscape, and the risk wildfire could pose to adjoining zones. The boundaries and risk characterizations of these zones thus constitute a knowledge product that has integrated the knowledge of managers and scientists to inform decision-making. A community member similarly spoke to the importance of valuing different forms of knowledge:

Different perspectives are great, but they've got to be willing to work with people and to see value in those different perspectives. If they don't see that, it's not going to be real - let's just say collaboration is going to be difficult. So they need to be pretty open minded,

and willing to look at things, and try new things. With that approach, I think you end up then - having these various perspectives, you're going to, again in my experience, you're going to have a much more robust - even if it's not a complete solution - you're going to have a much more robust answer to your questions. (Community member 5)

This community member emphasized that the value of different perspectives must be acknowledged in the collaborative process so that those perspectives can be effectively integrated into potential solutions. They continue by noting that this knowledge integration leads to solutions that are more comprehensive. Many participants described that integrating diverse kinds of knowledge enhances the resultant products, as this manager noted:

Both of those kinds of bodies of knowledge are incredibly important. To have something that puts them together in a really thoughtful way, that's the goal, is a pretty powerful tool. . . . To have something beforehand that we can utilize to help us inform those decisions that we're making in terms of managing a wildfire is incredibly useful. That we're not only utilizing the deep, professional judgment and knowledge of the folks on the ground but also informed by really rigorous peer-reviewed science and methodology is something that will be really useful in terms of being able to describe our thought processes and how we went through looking at risk management when we're managing a wildfire. (Manager 15)

This manager described that the outputs of their collaborative project, a union of professional and scientific knowledge, will be useful for informing decision-making for fire management, as well as explaining how those decisions were made. Many participants (15) described how these collaborative projects enhanced transparency around research and the way that information was

used by managers, noting that this transparency can build support for both the research outputs and the management decisions that are informed by them. One scientist spoke to this concept when discussing their project, explaining:

We talk a lot with all those groups and try and do problem-driven research. And if you do it that way, then hopefully whatever you find out not only will be more relevant, but also will be more trusted if you've involved the community in the process. . . . I think it's just transparency, you know? Like, they sort of understand how this knowledge didn't just come out of a black box. (Scientist 2)

By incorporating a broad range of participants into the research process and informing communities about the work, this scientist argued that the projects, and their outputs, gain more credibility and legitimacy because more people understand how they came about. In addition to this transparency, many participants (14) also describe that the inclusion of more diverse participants in the process, such as researchers, managers, and community members, enhances the overall credibility of the work. One manager explained this component of collaboration by describing:

If research just showed up and said, "Hey, we got these cool things we want you guys to try," chances are they wouldn't pay much attention. If Fire leadership showed up and said, "We want you to do this," the local [decision-maker] is going to be like, "What? We're not sure." That's kind of how we grew to develop our team, so there'd be high level expertise and credibility in each of those people so that when you showed up somewhere, people were quick to accept because they'd go, "Oh yeah. I know So-and-So, and they are good at this" or whatever. (Manager 11)

This manager conveyed that when different kinds of people are engaged in a process, a broader range of people will see the types of people they trust involved and thus find the outcomes more credible.

Participants also described the importance of opportunities for learning. Many participants (18) talked about the experience of building a shared understanding throughout their projects, leading to adjustments in their questions, methods, or intervention approaches over time. One scientist conveys this when describing their process:

It's developing a more nuanced and sophisticated understanding of the problem of wildfire in general. Of how practitioners grapple with it, the complexity of the context. Not just the local context, but the state context, and the federal policy and funding mechanisms in place. But it's also developing shared understanding within the team, shared language, shared history, that is really critical. (Scientist 30)

This scientist conveyed that the collaborative project involved learning about the broader context of wildfire from different perspectives as well as learning amongst partners around how to communicate across these different perspectives to cultivate shared understanding.

Scientists, managers, and community members articulated how these collaborative projects can help address the 'gap' between science and management, both in terms of adjusting the focus of research as well as enhancing communication between collaborative partners. Participants also described that these collaborative efforts can enhance the breadth of knowledge incorporated into scientific tools for management application, as well as increase transparency around the scientific and management decision-making processes, building trust and credibility.

The Challenges of Co-production

While participants described many benefits from these collaborative projects, they also elaborated on some of the barriers and challenges of engaging in them. Many participants (21) explained that these projects are not part of their normal job duties and entail additional work that is not typically recognized in their performance evaluations. More specifically, participants (10) argued that for Research Grade scientists within RMRS, collaborative work is additional to their primary duties of conducting and publishing research, which is the focus of their evaluations. One scientist expressed this challenge when describing the tradeoffs between addressing management concerns and working on peer-reviewed publications:

You've got to understand, as a scientist my job position is not graded on how well I address those little things that they ask me. It's graded on how my publications are. My position is not designed to answer their every, little science question. My position is supposed to be publishing according to RMRS. . . . there will be times where I have to say, "No, I don't have time." Then that could hurt future relationships, not because they're angry or anything, but they'll be like, "Well they couldn't help me." . . . So I have to prioritize publications. (Scientist 1)

Later in our conversation, this same scientist reiterated:

I have to make a decision: Am I going to invest time and money and travel to go out . . . and help them with that? I decided that it's worth that. It's worth that relationship and it's worth getting to see where it goes. So I have to choose that and when I'm doing that, I'm not writing a paper back in my office. (Scientist 1)

These descriptions illustrate how scientists sometimes choose to work collaboratively at the expense of working on publications, or vice versa. The scientist quoted above also explained that publications are the focus of their position and how they are assessed in their performance evaluations. Another scientist further described how performance evaluations focus on publications rather than the more “applied” work of collaborative projects:

We can basically go and say, "Here's our body of work," every few years to a group of our peers. They can look at that and say, "Yes, you meet the standards of this next level." That panel process itself is very focused on an old model of research: What did you publish? What's your association within professional societies? How are you considered in your group of science peers? Applied research has typically not been well valued in the panel process, in my opinion. (Scientist 10)

Later in our conversation, this same scientist referenced their collaborative work again:

There isn't a lot of incentives to do it. It's pretty easy to sit around and write papers and not do all this other work, and there's not much disincentive for it. (Scientist 10)

This scientist explained that their engagement in collaborative work is additional to their job duties, and that the time and energy they put into collaborative processes is not valued in their performance evaluations. Some participants argued that scientists who are not engaging in this kind of collaborative work may be seen as outperforming their peers in performance evaluations if they are achieving higher numbers of publications even if those engaging in collaborative projects are producing more benefits for natural resource management. This was viewed as an additional disincentive to spend time and resources collaborating. When asked about the

importance of producing publications from their collaborative work, one partnering scientist similarly expressed this challenge, commenting:

Yeah, it's critical. Otherwise, I couldn't be a part of it. (Scientist 30)

This indicates that the dominant focus on publications in performance evaluations can create a disincentive for research scientists to engage in collaborative processes.

The current funding structures for scientists were also viewed as a barrier to collaboration. Out of the seven projects studied, only one received additional funding from RMRS for their collaborative work, including funding for some of their partners. Almost all of the people who felt they had financial support to engage in collaborative work were part of this particular project (this project is expected to produce several publications from their work, ensuring that scientists receive “credit” in performance evaluations). Of the other six projects, only one participant described receiving financial incentives or support for engaging in these kinds of collaborative projects:

I was given several awards. I guess that's giving a person money and kudos too, so that's a good way to reward someone and incentivize their work. (Scientist 6)

This scientist indicated that this type of recognition and reward is a good means of incentivizing collaborative work. In contrast, another scientist referenced yearly awards distributed by RMRS and argued that they don't reflect an incentive appropriate to the amount of investment by the scientists:

We talk about pay for performance, but it doesn't exist. (Scientist 10)

This scientist conveyed that the amount of financial support from RMRS through these awards is not compensatory for the performance of scientists who are investing in these collaborative efforts. Some scientists explained that they rely on external funders for money to do their research, and that can incentivize them to collaborate. One scientist explained this situation when responding to a question regarding the way RMRS incentivizes collaborative work:

I have to bring in funding if I want to do a research project, so I would say it's naturally incentivized. If I want to get a publication which helps advance my career, which I don't really care one hoot about my career, I just care about people, I need to bring in money so I can do the science. I would say it is incentivized. . . . I think it's inherently incentivized from the standpoint of without their [external funders/collaborators] support, I couldn't do what I'm doing. It's not like somebody says . . . "you're going to get more support from RMRS because you have a collaboration" no, that's not the incentivization. (Scientist 1)

This scientist explained that RMRS does not provide additional financial resources for taking on collaborative work, and that instead, the scientist's dependence on external funders works as an incentive to collaborate with them. However, many participants (10) also argued that this external funding can make collaboration challenging because it's often designed for a more short-term form of research, with one scientist speaking to this when describing their involvement in collaborative work:

A lot of these efforts, sometimes there's a budget that comes from a national office that will help promote this whole collaborative effort, but, at the same time, these collaborative efforts, they take a while. They're big efforts. So, I would say that a lot of

times, the money or funding that they are putting to these efforts upfront, aren't totally thought through in terms of what actually is needed. (Scientist 8)

While this scientist expressed that collaborative projects are being supported financially by the national office, they also point out that these funds do not account for the additional time that collaborative work requires. Another scientist, who works primarily on science application, spoke to this challenge when commenting on how research scientists in RMRS are funded:

The money is short-term. It's always like a year, there's no long-term soft money commitments; very few. So, the money that they do get, that isn't hardwired for the station, the RMRS station, it's soft money. It's usually just a year. So, it's hard . . . it's hard to develop a program and things that'll last if your money is year to year. (Scientist 12)

Later in our conversation, this scientist added:

They're not fully funded. The tenured scientists are, I think, for the most part, but if they have any technicians, specialists, then many of them aren't. So, they're always looking for money, which is hard. (Scientist 12)

This scientist illustrated that research scientists with RMRS often depend on external funding to do their research projects, and that this funding tends to be allocated for short periods and thus doesn't account for the increased investment of time and energy that is required for longer duration collaborative projects. This can mean that research scientists spend more of their time piecing together inadequate funding to continue their work.

Beyond the constraints that individual scientists experience to engaging in collaborative processes, many participants (11) also describe that as a team, or organization more broadly, they simply do not have the staff capacity to meet the demand for these kinds of projects. One scientist spoke to this challenge when discussing their collaborative work:

I feel like if we had more staff and capacity, we could do it a lot. I mean, we have to turn away work because we don't have the personnel. We don't have the permanent positions.
(Scientist 24)

This scientist argued that with more personnel they could do more collaboration, and that instead they have to turn away collaborative opportunities. Another scientist described that they have seen the need for more staff and taken initiative to grow their team:

The collaboration I've been involved with, if you get your external money, you can do things with it. And we're [RMRS] going to allow you to do more things with it once you've really established that that money is solid. But I haven't seen the station pony up its own money. We haven't gotten any additional station positions or station funding since I've been here essentially. My group's grown dramatically, and the station's contribution hasn't changed. (Scientist 10)

This scientist illuminated that even when this work is successful to the extent that they would like to grow their team to do more of this collaborative engagement, the onus is on the scientist to find funding for new positions because RMRS does not provided additional financial support. Some participants specifically emphasized the need for more Professional Grade scientists who

are not incentivized to publish but instead focus primarily on applying science to management concerns, with one scientist conveying this perspective when discussing their collaborative work:

I feel like if we had a bigger buffer, we could just get more out there. I just feel like there's so much science that could be translated and used that we're not taking advantage of, and that the scientists are busy doing their science. The people here, the tech-transfer people are like, "Hey, we want to take your science and do cool stuff with it." It's good for their PD, you know what I mean? As much science as we can get out there in their name, it benefits them, and it benefits the user, so I think it's a win/win. I just feel like this buffer of the tech-transfer zone is really important and could be grown. (Scientist 24)

Here 'tech-transfer' refers to a variety of activities such as adjusting tools to be more easily usable, training individuals on how the tools work, maintaining them over time, and providing feedback to scientists on any problems or further needs that users are experiencing. This scientist argues that Professional Grade positions can do tech-transfer work, applying research products to management, while researchers continue doing further research. One scientist expanded on this same idea when describing the need for more tech-transfer positions, explaining.

What happens is, if you [a Research Grade Scientist] create something useful, that the field needs, there's no mechanism to be able to have that thing move on and get out of development, and move into operation and maintenance . . . It's like a teenage kid in your basement that will never leave your house. You have to continue to maintain it, and maintain it, and maintain it. And once you make a couple really useful models or things, then most of your time is going to just maintaining this success or two, and could be throughout the rest of your career . . . So, instead of saying, okay here's this useful thing,

science has got it where it needs to be, let's give it to someone who can then maintain it, and take care of it, and answer the questions from the field, and teach people how to do it, the scientists still have to do all that. And so then, if you got one of those or two of those, you can't go and create new science, right? You're trying to maintain this thing that everybody wants. (Scientist 12)

This scientist explained that tech-transfer work can not only help translate and maintain research products for management use, but that they also enable researchers to continue creating new tools, instead of spending their energy maintaining their successful products. While many participants (16) spoke to the need for translation of research products for use in management, some Professional Grade scientists argue that the structure of their positions disincentivizes them to make a career out of that kind of applied work with RMRS, with one scientist describing:

The research station as a whole, I think, still holds onto the fact that if you're not a PhD research scientist bringing in research dollars, then you're not necessarily worth as much, in a manner, and then the professionals who are actually doing the science application side of things . . . there's very limited mobility for people like us, so we leave. Eventually people who have these kinds of skills that the research station needs, leave, because they're very limited. (Scientist 17)

This scientist believed that RMRS needs this kind of work and that they simultaneously undervalue it in a way that encourages Professional Grade scientists to leave their positions. This same scientist elaborated later in our conversation, explaining:

There's such a limited growth potential for the professional series within the research

station. It's like you either become [a Research Grade scientist] or you top out pretty quick. (Scientist 17)

In this case, by 'topping out' the scientist is referencing a lack of upward mobility (specifically in terms of ability to move up in federal GS scales), meaning that there is a limit on promotional opportunities that Professional Grade scientists reach fairly quickly.

Participants characterized the challenges, such as professional disincentives and inadequate funding mechanisms, as well as the tradeoffs to engaging in collaborative projects and advancing professionally. They also explained that, beyond their individual challenges to engaging in collaborative projects, they lack the personnel on their teams and in RMRS overall to meet the demand from managers and community members for collaborative work and the relevant, useful scientific support it provides.

Institutional Support and Incentives

To address the challenges to working collaboratively, some participants recommended adjustments to performance evaluations to enhance support for scientists and managers to work collaboratively. One non-RMRS scientist suggested this change when responding to a question about how their collaborative work could be better supported:

Different departments [in universities] have different formulations for how they evaluate whether or not somebody is worthy of tenure promotion, or just promotion in general. Those formulas can just look different. Maybe if you need, I don't know, 10 peer-reviewed, high impact papers, and this is totally just a made-up number, maybe you need eight of that kind and two technical papers that are for an applied audience, providing

incentive in that way to publish and to translate academic findings into useful results.
(Scientist 30)

This scientist argued that increasing the value given to outputs for applied audiences in their performance evaluations is one way to further support university scientists in engaging in this kind of collaborative work. An RMRS scientist similarly noted that their incentive structure should change to reward collaborative work:

It just seems like the station has always talked about, “we need to do more of this [collaborative work with managers], we need to do more of this.” My response is: That's all I do. I don't really know why we've been having this same conversation since I've been here, when it's not like, “here are the things that individuals have done that really work. We [RMRS] want more of it, and we're going to incentivize it.” Or “We [RMRS] are comfortable that there's a handful of people that are going to do this kind of collaborative work, and the other people are going to do more basic science or work in the scientific community in their discipline with their academic peers” . . . It's like, okay, you [RMRS] like that, but then you don't recognize it when it's happening, and you allow people to choose to opt out. Again, you can opt out if you want. Like I was saying with the firefighters, if you say you want this, and somebody can say, "No, I don't want to do it," what's going to happen to them? Nothing. You say, "Not only am I going to do it . . . I do it very, very well. What have I gotten from it?" Independence to keep doing it.

(Scientist 10)

Participants also offered solutions related to the funding structure for RMRS Research Grade scientists. Many participants (10) suggested that grants could be adjusted to more adequately

compensate for the time investment and duration of these efforts. One scientist spoke to this notion when describing how RMRS could better support collaborative work:

I think long-term funding. We've been cobbling together funding from various sources, always on a wing and a prayer that the next year we'll be able to figure it out. And there are fluctuations in the federal budget that change based on politics, and timing, and fire seasons, and all sorts of things. It means some years we're really scrambling and spending a lot of time and energy trying to cobble together resources. Just because you apply for a grant, doesn't mean you get it. So it's applying for a grant, and revising a proposal, and submitting it again, and looking for other sources of funding. Sustained funding for these kinds of efforts that you know that you're investing in procedures and practices that you will use again in three years, in five years, because you know that you'll have funding.

(Scientist 30)

This scientist emphasized that funding could be adjusted to support the large time investment and the long-term nature of these projects, to appropriately incentivize participation and save them the time and energy of piecing together smaller grants.

Many participants (11) recommended greater investment in scientist positions to build capacity for RMRS to engage in collaborative research. One manager argued for more scientist positions when talking about the challenges of collaborating with limited staff and funding:

There may be things that we really want to have some research input or involvement in and if funding is not available to look into that, it may be something that on the ground as a manager you feel is a fairly critical question to get answered, but because the funding

isn't available, or there aren't enough - I mean I know our researchers work a ton, and they take on a lot. And so sometimes even trying to find summer help is a challenge, and to be able to collect data. So I think that additional funding could help in providing people and providing the funding to maybe get more researchers on the ground answering more of those questions. (Manager 4)

This manager expressed how limited funding for researchers and limited scientists available can lead to crucial management questions not getting answered. They argued that part of the solution is not only providing funding for current scientists to be able to address management questions, but also providing funding for more scientists overall to get them on the ground to answer questions.

One Professional Grade scientist argued that RMRS could better support collaborative work by expanding the career advancement opportunities for these applied science position. When responding to a question about how RMRS could provide more support to their collaborative work, they explained:

Having a parallel path for the professionals as what the scientists [Research Grade scientists] have, to where you could progress up through different GS scales, and have a career level GS scale that's a retirement level kind of position. Without these, people - you either, like I said, you get a PhD and become a research scientist, which then you have to be bringing in grant money so you're not doing as much of the applied stuff. Or you leave, and you go to the national forest system, and you work out of the regional office at a higher-level analyst position. (Scientist 17)

By not supporting career advancement for Professional Grade positions that is on par with Research Grade positions, this scientist argued that RMRS provides a disincentive to continue with this type of work. Without adjustments, the scientist worried about the impact of high turnover in Professional Grade positions:

You've constantly got new people coming in without the skills, and without the institutional knowledge of having been there for a while, to be able to push this stuff forward. (Scientist 17)

By 'stuff' the scientist refers to the application of research for management needs that they do in their collaborative work. They argued that there are benefits to having experienced personnel in this role, which, based on their previous comment, requires more upward career mobility for people in these positions. In their preceding comment, they also conveyed that when Professional Grade scientists leave to pursue career advancement through Research Grade positions, that they have less time to do applied work because they have to bring in grant money for their research. Research Grade scientists explained that they are evaluated based on their peer-reviewed publications, that they have to bring in grant money to conduct publishable research, and that engaging in collaborative work often comes as a tradeoff to those activities. This is only exacerbated by a funding structure that does not provide adequate support for the time intensive and long-term nature of collaborative projects, which means that Research Grade scientists often have to spend more time piecing together grants when they take on collaborative projects.

Discussion

Participants in these projects affirm that they too have experienced the ‘gap’ between science and management that has long been discussed in the literature (Roux et al., 2006). As found by Kosher et al. (2012) and Hunter (2016), participants have observed that fire science specifically is not always relevant to the concerns of managers, that scientific products are not always well understood by managers, and that cultural differences between the two can cause difficulties in communication, mistrust, and can manifest as different epistemologies. Despite these challenges to working together, participants corroborate the assertion from White et al. (2019) that increased engagement between scientists and managers is necessary because neither type of professional has the organizational capacity nor the knowledge to accomplish their natural resource management goals independently. Participants similarly affirm recent co-production literature when arguing that collaborative processes have helped them overcome some of these challenges. By integrating different forms of knowledge, participants explain that they have been able to enhance the relevance of fire science for specific contexts, incorporating decision-making processes, financial resources, community values, and diverse goals and objectives into knowledge creation and problem-solving. Managers and community members can work with scientists to incorporate this context-specificity into the co-production process, and this is a critical way to generate the knowledge, actions, or approaches that can address the unique complexities of a given natural resource challenge (Mauser et al., 2013; Norström et al., 2020). This emphasis on integrating knowledge from scientists, managers, and community members is a key attribute that differentiates co-production from other collaborative endeavors. Each of the collaborative projects studied in this research aimed to co-produce in different ways,

through different processes, but they all generated knowledge or actions built from the diverse knowledge of project participants.

Participants also argue that these collaborative projects facilitate greater transparency and broader inclusion, each of which increases the extent to which managers and community members view the knowledge or solutions produced as credible and legitimate, garnering their support for its use in management. These projects have also enabled on-going learning amongst participants that has improved their work to understand, plan for, and respond to wildfire over time and improved the ability of scientists and managers to work together on that effort. Based on a synthesis of co-production research, Wyborn et al. (2019) found similar benefits in numerous co-production projects across regions and at various scales.

While previous research provides guidelines for how scientists and managers can work to effectively co-produce and recommends that scientists should be supported and incentivized to engage in collaborative processes like co-production (Beier et al., 2017; Clark et al., 2016; Dilling & Lemos, 2011; Meadow et al., 2015), institutional structures and cultures continue to limit this engagement (Djenontin & Meadow, 2018; Turnhout et al., 2020; Wyborn et al., 2019). The results presented here indicate that research organizations like the Rocky Mountain Research Station may be able to better support scientific engagement in co-production processes by embracing several institutional changes. Participants explain that the current performance evaluations for Research Grade scientists do not value or incentivize engagement in collaborative projects and instead prioritize peer-reviewed scientific publications, a challenge often noted in previous examinations of co-production processes (Beier et al., 2017; Clark et al., 2016; Cvitanovic et al., 2016; Dilling & Lemos, 2011). Peer review publications are intended to build

and refine scientific knowledge, and often stem from questions that arise in scientific literature. While co-production processes can lead to publications, these processes also aim to address the questions and concerns of a more diverse constituency and build from the knowledge of non-scientists. This iterative and inclusive process of co-production often requires more time from scientists, which can limit their ability to work on and produce publications. If scientists are primarily rewarded for peer reviewed publications, they can experience a disincentive to engage with questions and knowledge outside of the scientific community, especially if the process to do so may further limit their time to work on publications. In this study, participants also described how funding structures are not designed to compensate scientists for the intensive and long-term nature of collaborative projects. Interestingly, Professional Grade scientists who specifically work on science application, and could potentially collaborate more readily, describe feeling undervalued and limited in terms of career advancement compared to Research Grade scientists, which incentivizes them to forego their work applying science to management in RMRS for career opportunities in the private sector, in academia, or as a Research Grade scientist. Beyond the challenges experienced by individual scientists, participants also conveyed that there are not enough scientific personnel on their projects, or at RMRS as a whole, to meet the demand from managers for this type of collaborative work. This indicates that managers find collaborative projects beneficial but suggests that RMRS has limited capacity to engage in such work.

Research organizations could enhance capacity for research scientists to engage in co-production by adjusting performance evaluations to value and reward collaborative work, as well as by adjusting grantmaking so that funds more adequately compensate for the time and resources this work requires. For performance evaluations, research organizations can value research focused on societal needs, such as the questions and concerns of public land managers.

Research organizations such as RMRS, that currently have evaluation criteria that focuses on engaging with management needs, can increase the value assigned to management-relevant research and co-production activities in the evaluation process. In organizations where leadership have encouraged scientists to work more collaboratively, as is the case in RMRS, this type of structural adjustment provides incentive and recognition for that work. In addition to supporting Research Grade scientists, greater investment in the upward career mobility of tech-transfer positions, that work directly on applying research products to management concerns, may also be necessary to further expand capacity to engage with managers. As one participant noted, this could look like a parallel career trajectory to Research Grade scientists that enables scientifically minded people to pursue a career specifically focused on applying science to management needs. Participants also indicate that it may be necessary to increase the numbers of each type of scientist to meet the demand from managers for scientific support.

These changes would enhance capacity for collaborative processes in different ways since each kind of scientist has a different focus. Supporting the engagement of research scientists in collaborative processes would enable the incorporation of management knowledge, priorities, and context into the design of scientific research. Investing in tech-transfer positions, on the other hand, could enable greater capacity to collaborate with managers in refining and adjusting research products for applicability to management contexts. These tech-transfer positions could also support the maintenance of these tools as they continue to be used in management. While a ‘bigger buffer’ of tech-transfer personnel could help integrate manager knowledge and needs into existing research products, this ‘buffer’ could also further separate managers and researchers from directly engaging together. This poses an important tradeoff since many of the benefits of co-production come from iterative engagement between scientists

and managers throughout the process, such as shared learning and relationship building that can support further collaborative work (Lemos & Morehouse, 2005; Nel et al., 2016; Schuttenberg & Guth, 2015; Van Kerkhoff & Lebel, 2015; Wyborn, 2015; Norström et al. 2020). While some participants suggested that a tech-transfer buffer between management and research could free researchers to continue pursuing new questions, scholars have indicated that a greater connection between scientists and users is critical to generating science that will be useful for addressing natural resource challenges (Sarewitz & Pielke, 2007; White et al., 2019). To enhance the capacity of research organizations to create useful science for management, it may be necessary to enhance capacity for both types of positions to engage collaboratively with management. This would support researchers in investigating questions that are pertinent for managers, while also supporting tech-transfer scientist's capacity to collaborate with managers in applying research products to a variety of management contexts.

Some of the work that participants attribute to Professional Grade scientists is similar to the tasks of 'boundary spanners' or 'boundary organizations' who work to facilitate the connection between science and its application in management contexts (Cash et al. 2003). Investing in designated 'boundary spanners' within the station may be another approach to enhance the connection between fire science and management. However, investing in these kinds of mediator roles, without making the other adjustments to Research Grade and Professional Grade positions, could further distance scientists from engaging with managers and community members directly. This study also indicates that without adjustments to Research and Professional Grade positions, challenges could remain regarding whose role it is to apply research products to management contexts and whose role it is to address those management

questions that may not lead to peer-reviewed publications, but that are perceived as critical questions by managers.

Enabling researchers to focus on more applied questions that address management concerns, even if they do not fill gaps in the scientific literature, requires confronting the differences between what knowledge is valued by managers and what knowledge is valued by the scientific community. As Cash et al. (2003) noted, efforts to enhance saliency, credibility, and legitimacy of knowledge for some participants of co-production processes can often decrease perceptions of saliency, credibility, and legitimacy for others. When research organizations make this type of shift to provide outputs that are more salient for managers, they may jeopardize the credibility of their research within the scientific community, which currently assigns more value to questions and knowledge that builds from and contributes to the scientific literature. A cultural and structural shift in research organizations and the broader scientific community may be necessary to assign value and support for research into management concerns. RMRS may be particularly interested in making this shift since Forest Service research stations were initially established in 1947 specifically to provide insight into natural resource management (Williams, 2005). However, other research organizations may also be interested in making this shift since many rely predominately on public funding to conduct their work (NSF, 2019), which can be construed to necessitate accountability to public interests and needs. Addressing public interests and needs by conducting research that engages with the management challenges of our public lands may be particularly paramount at this time given the risk that climate change, invasive species, wildfire, etc., pose to the natural resources that we depend on.

This transition toward valuing science that engages with decision-making contexts and the knowledge of non-scientists may require a cultural shift in the scientific community away

from prioritizing publications since it is often the scientific community that conducts performance evaluations of scientists. This cultural shift could be aided by structural adjustments in performance evaluations to emphasize the value of engaging with managers to address their needs through collaborative processes like co-production (Clark et al., 2016). These changes have the potential to simultaneously address tensions that arise from the different epistemologies of scientists and managers. While these differences can enrich collaboration with diverse knowledge, they can also lead scientists and managers to perceive one another as lacking credibility according to their own epistemologies. Participants in this study indicated that to overcome this tension and conduct successful collaborations, it was crucial for them to demonstrate value and respect for the diverse perspectives and knowledge that participants contribute. By adjusting to assign value to more applied work, the scientific community may be able to codify value for the experiential and contextual knowledge that non-scientists can contribute to the process of co-producing knowledge and solutions that are more applicable to management.

Funding constraints can pose a challenge for making some of these adjustments. Providing funds compensatory for the time and duration of collaborative processes, as well as funding additional scientist positions and increasing the salary potential for Professional Grade scientists, may be beyond the current financial capabilities of RMRS. Congress may need to allocate more funds to RMRS and other stations so that they can actualize these adjustments and forge a more effective connection between fire science and management going forward.

Conclusion

Given the increasing severity and frequency of wildfires in the United States, it is clear that we will have to increase investment in planning for and responding to these challenges (JFSP, 2011; Stephens, 2005). What is also clear is that wildfire management is becoming increasingly complex (Pence & Zimmerman, 2011) and while managers are required to use the best available science to inform their decisions, this science cannot be used if it is not accessible and applicable to management needs (JFSP, 2011). Engagement between scientists and managers is a critical way to ensure that science adequately addresses management needs, and this study indicates how research organizations such as RMRS can enhance this engagement by providing support for collaborative processes such as co-production.

Beyond RMRS, public and private research organizations, including academia, have similar institutional structures and cultures that can support or impede the engagement of scientists in co-production. Adjustments to how scientists are evaluated and funded can be implemented to incentivize and support scientists in pursuing this type of collaborative work. Similarly, research organizations can consider investing in more personnel to enhance their overall capacity to collaborate and increase opportunities for scientists to pursue a career that is focused more specifically on applying science to management needs. By embracing these changes, all kinds of research organizations can begin to actualize a cultural shift toward valuing the more applied, contextual work of addressing management needs.

Chapter V

Additional Outcomes of Co-production and Challenges to Institutionalization

This chapter focuses on themes that emerged across these collaborative projects that, while not mentioned in the preceding manuscript which focuses on fire science and management, are relevant to the literature on co-production more broadly.

Co-production Outcomes

Many participants (16) described a shift towards a more collaborative approach to their work, both between scientists and managers as well as amongst other partners, during and after these projects. One manager spoke to this shift when asked whether their experience in this collaborative project has changed how they approach their work:

I think it does kind of change how we think about things. When we're trying to plan on the ground management, we're trying to think of 'what could research gain out of this?' Without them having to do any additional work other than maybe having a plot or something like that where they can kind of just come in and collect data. I think that we very actively are working towards trying to figure out how can we incorporate research actively into things that we're doing on the ground for management. (Manager 4)

This manager noted that since this collaborative experience, they now approach management with research in mind, and consider the synergies they could create between their practices and data collection for research. An RMRS scientist similarly characterized a shift towards greater cooperation with management when asked how this collaborative work might change the work of their organization:

I think it informs the work of RMRS. If you have collaborations, it helps build larger projects that RMRS can support. By collaborating with non-science partners, it forms a relationship. I can just only go back to the relationship . . . we'll be getting feedback on what they need, and we can be addressing those issues. In the future, I would hope that it forms a feedback loop where I do research with these people based on some concerns that they have. You finish the research cycle, you produce a publication and that will either produce new questions or it'll produce context to questions unrelated to that topic, but since they have a relationship with us, they will approach us and say, "Hey can you do this?" I don't know that it changes the underlying mission of RMRS, but it might inform what future work RMRS can do. (Scientist 1)

Like the previous manager, this scientist also articulated the synergies they anticipate between that their research and management, such as opportunities for management needs and concerns to inform their research questions. Many participants (18) also argued that their work in these collaborative projects is leading to future collaborations, with one manager explaining:

I feel like this is a great collaborative opportunity and ways to engage our research community and our partners and now we're using it for a springboard for a lot of great opportunities in other realms. (Manager 23)

This manager noted that they are leveraging this collaborative effort to facilitate the start of more collaborative opportunities on other subjects going forward.

Along with this shift toward more collaborative approaches to their work and on-going collaborative efforts beyond these projects, several participants (12) also convey that there's an

increased demand for these kinds of collaborative process from managers and community members as they learn about the projects and their outcomes.

People are seeing what's going on, and they're clamoring for those products [from the collaborative project] . . . They see that they want something, and they do feel like they need it, and they could use it. So, more and more communities will see that they want these kinds of products, but that in my mind is like, well, we're taxing our capacity here to provide them. We just got a request for some more communities to provide [project products] to them, and there's only me, really, doing it right now. Everybody else is pretty tapped, but if we had more, we could do that. (Scientist 24)

This scientist not only describes they their team is already at capacity in terms of the amount they can work collaboratively with communities but explains that these collaborative projects have the effect of increasing the demand for them from managers and community members. These two observations indicate that the demand for collaborative work may only increase as scientists continue in these projects and they would need increased capacity to meet that growing demand.

These descriptions indicate that co-production processes are inspiring scientists and non-scientists to work more cooperatively, are fostering future collaborations, and are becoming more highly demanded by managers and community members as they learn of these projects and their outcomes.

Challenges to Institutionalizing Co-production

With the growing demand for these kinds of collaborative processes, there were multiple perspectives amongst participants around how to increase scientific capacity to engage with managers and community members to co-produce. Some argued that additional scientists should be housed within research stations to ensure co-production occurs with a close connection to research, with one scientist speaking to this when describing the need to translate research outputs for managers:

That's the biggest challenge I see, is that there's just not a whole lot of ability to support and maintain these products [research outputs]. Within the station there's like, none. Then within the forest service system there's none either . . . So that either needs to be picked up within the station, and they need to create this much larger analytical support system that has growth potential, so everybody doesn't keep leaving it, or it's going to go to the national forest system, and it'll go into the regional offices, and then we'll lose that connection with research. But that's what's being touted out there right now, it's either going to go to the regions, or the research station would have to step up and really invest some longer- term support for this kind of work. And that would include hiring more people, and giving people growth potential, and I don't know if I see that happening.

(Scientist 17)

This same scientist continued to comment on the consequences if these scientific positions are established through the management arm of the Forest Service:

They [the Forest Service] are going to be the ones going out to the forest and doing all these stakeholder collaborations. And then the fact that there's even a research branch

behind what they're doing is lost. So the opportunity for the research station to even be known as somebody who's driving these kinds of things is gone. . . . We become less relevant. (Scientist 17)

This scientist indicated that if additional scientific support is not housed within the research station, the RMRS will become even less relevant to management and may lose their opportunities to engage collaboratively in these kinds of co-production projects. To maintain relevancy to management, this scientist argues that RMRS will need to enhance their support of Professional Grade positions. Alternatively, some participants argued that it may not be the role of research stations to scientifically support management in that way, with one scientist conjecturing:

I don't know if it's something that RMRS is positioned to address. I don't know if it's something that the Forest Service system needs to have more people to support those. It might be that the Forest Service system needs to provide . . . liaisons more that could help in that position. . . . I mean if RMRS had a boatload of money, I'd say let's hire some extra postdocs and scientists and . . . have them directly assigned to some of these issues that these managers are bringing up that aren't necessarily as glamorous but I know that there's many scientists or research-types or applied-types that would really care and enjoy doing those things. I don't know if that is really in the mission of RMRS. The current mission. And I don't know if it's truly feasible with the way the budget is right now.

(Scientist 1)

These descriptions indicate that there are different perspectives on the best way to enhance scientific capacity to engage with and address management needs.

In addition to these concerns around the capacity of scientists to work with managers, several managers and community members (10) describe that, like scientists, they similarly encounter challenges to participating in these kinds of collaborative projects. A higher-level manager conveyed this when explaining the strain that participating in these projects can place on the workloads of their staff and colleagues:

It's really hard because everybody has normal jobs, right, and then we ask them to do this other work on the side. It's hard . . . They want to do it. They want to do it, but the demands of their other job and home life are always challenging. (Manager 11)

This manager pointed out that despite interest in working collaboratively, these projects are additional to manager's normal job duties, meaning that their engagement can put a strain on their other professional and familial obligations. Another manager similarly conveys this challenge:

We've really struggled to get something in draft on the timeline that they wanted because people just, we did not have the capacity nor the time to work on it . . . it's time and capacity. Because we are volunteering, it's collateral. (Manager 9)

By describing this work as “volunteering” and “collateral”, this manager expressed that their engagement in this collaborative project is not a part of their formal job duties. Another manager explicitly addressed how their work in collaboration is not part of how their professional performance is evaluated, explaining:

Frankly I would be just fine in my performance review if I did none of this work. You know? If I wasn't passionate about it and really believed that we could reduce risk to our

communities and our first responders and put fire back on the landscape in the systems that I believe it belongs there - If I wasn't passionate about this stuff, why would I bother? ... As long as I produce my widgets, which is, you know, I'm going to treat a few acres and I'll give it X amount of board foot volume, and I keep the neighbors happy to a degree, I would have the same exact performance review. (Manager 23)

This manager addressed that working in these collaborative projects is not something that they're recognized for in their performance evaluations and expresses that they engage in this work because of personal motivation despite that lack of recognition.

These descriptions demonstrate that institutional support and incentives may be necessary in organizations such as management agencies, local government, and non-governmental organizations to enhance the capacity for non-scientists to participate in co-production.

Conclusion

While this study has observed several of the benefits that scholars have previously attributed to co-production (Wyborn & Leith, 2018), it also illuminates some of the particular challenges to institutionalizing co-production processes across different organizations and scales in the United States. While research organizations may be able to make adjustments to better support their scientists in collaborative projects, it is also apparent that further work may be needed to explore how other involved organizations, such as management agencies, city and county governments, and non-governmental organizations can institutionalize support for these processes. Some institutional adjustments for research organizations may be applicable to these other organizations, such as adjustments to performance evaluations to value and incentivize collaborative work. However, further research could identify additional adjustments that

organizations could adopt to address the specific challenges non-scientists experience to working collaboratively in co-production processes. Additionally, conflicting perspectives around the best way to enhance scientific capacity to engage with managers affirms work by Wyborn et al. (2019) that indicates more research is needed to understand how support for co-production can be institutionalized at broader scales such as the national network of natural resource management.

Appendix A: Interview Guide

Thank you for agreeing to participate in this interview. As I described over email, this study is looking at several collaborations where scientists worked with non-scientists on research or other knowledge creation intended to be used in management decision-making. The main focus of this research is to understand how the Rocky Mountain Research Station can support these collaborations going forward, so in addition to hearing about the project itself, I'd like to learn about how (being at RMRS/working with RMRS) impacted your ability to (work in collaboration with managers and other stakeholders/collaborate).

Did you happen to get a chance to read the Informed Consent?

(if not, describe project, the benefits of their participation, confidentiality, tape recording)

(If yes) Great, as it mentions this interview is confidential, which means that what you say will never be connected to your name and that we won't use any information that could identify you when presenting or reporting the findings of this study.

As it also mentions, I would like to tape record our interview. This helps me ensure I accurately record your views while also being able to really listen and respond to what you're saying, is that okay with you?

Okay I'm going to turn on the recorder and then I'm just going to ask you again while we're recording: Do you consent to having this interview recorded?

Do you have any questions before we get started?

Individual Context

1. I'd like to begin by learning a bit about you, could you tell me about your current position?
Probe: Who do you work for? How long have you worked where you do now?
Probe: Is this the same position you held during the [project name]? (if not) Could you tell me about that position?
2. How did you become involved in the [project name]?
Probe: What was your role in the [project name]?

Roles, Process, and Barriers

3. Who participated in the [project name]?
4. Could you walk me through the [project name] process from the start to finish?
5. What role did the different organizations play in this project?
6. Could you describe how the main objectives of the [project name] were established?
7. How do those objectives relate to the goals of [participant's organization]?
8. Do you feel like the [project name] adequately met those objectives?
 - a. If not, why?
 - b. If so, how?

9. What were some of the challenges and barriers that the project faced?
Probe: Are there things that the different organizations involved could do to alleviate those challenges or barriers?

Their Participation

So we started out talking a bit about your work, and the project itself, and now I'd like to transition more into your participation during the project

10. Was your participation in [project name] encouraged by RMRS or did you participate of your own initiative?
a. If discouraged, how/why?
b. If encouraged, how/why?
Probe: Was your involvement in the project incentivized by RMRS?
11. What are some of the barriers you faced to participating in a collaboration like this [project name]?
12. Has your experience with collaboration in the [project name] changed how you may approach your work in the future?
a. If so, how?
b. If not, why not?

Their Organization

I'd like to transition now to focus more on your organization

13. Do collaborations like this, where scientists, managers, and other stakeholders work together, change the work of [participant's organization]?
14. Do collaborations like this between scientists, managers, and other stakeholders change the usefulness of the new knowledge that's created?
15. What role do you think these kinds of collaborations should play in [participant's organization] in the future?
16. Are there ways [participant's organization] could better support these kinds of collaborations in the future?
Probe: What things might need to change about your organization to support these kinds of collaborations?
[For non-RMRS Scientists] Are there changes that RMRS could make to better support these kinds of collaborations going forward?

Wrap Up

17. That's the end of my questions, is there anything you'd like to describe about the [project name] that I haven't asked about?

I'd like to hear more about this collaboration from other scientists, managers or stakeholders who were highly involved, are there any people you may recommend I speak with?

Thank you for your time today, I appreciate the opportunity to hear from you. If you have any additional questions or comments, please let me know.

Appendix B: Data Tables

Manuscript	
The Disconnect Between Science and Management and the Call for Collaboration	
Community Member 5	I mean just from a generic standpoint, the task of translating management questions into something that can be researched is always difficult. Some more difficult than others.
Manager 9	We get research done, we publish it. The land manager knows that it's out there. They might even read the article. But what does that actually mean for them on the ground? How does that actually impact the day-to-day? It's a hard balance because a lot of times, again, it comes back down to capacity and duty. They might not even have time to read the research article. So how do we get that information to them? Are there different ways? Is it social media? Is it through training? Is it through a workshop? Do we need to follow-up . . . with something massive, do we need to then go to the field and hold trainings or workshops across the west? We've talked a lot about that kind of thing.
Scientist 8	I think the advantage of these collaborations is you learn more about the science. It's because you are working directly with the researcher, you get a lot more information than you would from just reading a paper, a published paper. I mean, reading the published paper is sort of a start, but I think a lot of the researchers sort of have an idea of, "I just do the science. The managers then interpret that science in the way that they see fit on the management on the ground, which in some cases, I would say, a lot of managers don't fully understand the science, and I would say that they probably aren't reading the papers. So having the one-on-one interactions and more of that collaboration setting provides more of that information as well as how best to use that scientific information.
Community member 5	It's also important to have a way to digest the findings into outreach material that can actually be usable for guiding management decisions . . . we don't have a lot of peer-reviewed publications for this area, so that's always important. But we also have to have material that is more accessible for our average members who may not have access to a peer review journal. Or that may not really be the best approach, from a writing standpoint, to get that usable information into their hands.
Scientist 12	The managers will look at them, be like, "ah, they're just academics, they think they know what they're . . . they're in their labs, they're in this fake world, we're in the real world with politics and with laws, and with all these other special interests weighing on us, they're just these researchers that think they know

	everything." And the researcher's like, "you freaking idiots, here's the science. Why are you doing what you're doing?"
Scientist 21	It can't be perceived as we know better than you, and we're telling you what to do. So it's a real, it's this dance of like integrating in that culture, and I see this on the fire side of things. So I'm on an incident management team in the summer, and a big reason I do that is because I feel like it's super-critical for me to understand the fire management world from the inside, and understand that culture so that I can have a better idea of how to change it. Rather than just being someone in the outside of that saying, "You guys are doing it all wrong. Let me tell you how to do it." Because that doesn't ever go over well. There are people in RMRS and in research who take that approach, and they're resented for it. So it is, yeah, it's a challenge.
Manager 23	Part of it's just because, I think, those of us who've worked with the research branch, I think there's sort of this intimidation factor, if you will, because these folks are scientists, you know, you might say the wrong thing or they may not respect you or whatever because they're scientists. So I think there's a little bit of that under current or it's something like, well, the scientists don't understand what it really means to do this kind of work on the ground so we can't have a relationship with them.
Manager 23	With this science and management realm and that opportunity to work with, for example, the Rocky Mountain Research Station and building that trust and that relationship. Again, I'm fortunate because I had that history, but I will tell you, what's interesting, it made my staff really nervous. They don't have that trust and that relationship, or at least they didn't. They do now, but it was really interesting. . . . Kind of the fear of the unknown and how this data would get used, and in their mind, abused. But they're not really in that realm anymore. Sort of trying to break down those barriers from both sides.
Scientist 21	I do see it often as the job of research to sort of push the envelope. You know, push people outside of their comfort zones, in a way. Because we have these cultures around the way that we manage forests, or the way that we manage fire. When there's a realization that maybe those cultures aren't working, and that they're not effective, I feel like what often happens is people who are working in that sort of just dig in their heels, and they're like, "This is the way we've always done it." It's kind of the job of research to be like, "No, but that doesn't have to be the way you do it." So I think a lot of Forest Service researchers find themselves often taking positions counter to the agency as a whole, because we're trying to affect change. Change is hard for people in organizations.
Community member 25	Very often we work as a liaison between elected officials and key stakeholders in a community and the larger research academics arena. A lot of us . . . are trained as academics and researchers, but we do community work. And so we help bridge that connection, either with tools or in scientific - the way scientists

	talk and the communication they use is very different from how local community leaders and elected officials talk. So we try and bridge that gap.
Community member 25	I think the biggest struggle is that scientists don't know how to talk and communicate and make their science useful for most people. I think they get caught in the weeds. I think they think that what they're doing is so important that people need to know all the details. And the reality is, the simpler it is the better. We have something very, very useful to share with people but don't get caught up in the weeds. Make it simple. Make it practical. Make it applicable.
Scientist 21	The reality is, wildfire doesn't stop at boundaries. But it can be true of so many other things too. Whether it's management of critical habitat for different plant and animal species, or air quality. You name it. So I think there is this realization that we can't just be insular and think about our own little piece of ground.
Manager 9	We cannot succeed without collaboration. No one can succeed with collaboration. We must work together. . . . It's too big. It's too big and complex for an agency to be successful by themselves. Even within their own property, we still have to have others coming in and helping us either define. . . either showing us an issue or helping us solve an issue. Almost any issue, even within our own boundaries, has implications or consequences outside of those boundaries. So we must. If we're thinking about solving an issue within our boundaries, we still should be looking outside of, well, what is that consequence? What's that trade-off? And how bad are you going to impact the landscape within which I sit. And so it needs to be done at some level collaboratively. I firmly, I strongly believe and feel that.
Community member 20	Well, we're ultimately the ones who are going to either adopt plans . . . or we're the ones who are going to be allocating funding for implementation. So it only makes sense that, even if we're not as immersed in the details of drafting language for these plans, to be involved throughout the process so that we understand the goals and objectives I think is critical.
Community member 22	I think that an enhanced collaboration, hopefully will be obvious to folks that that needs to continue. I also think that some of the work that has begun . . . will force that.
Community member 27	I don't think anyone should work in a silo. No one should be just like with their head in a hole doing what they think they need to be doing. If they are, they're working way too hard, they're not effective, and they don't have buy-in from people who have a right to be at the table.

Manager 4	You know, I think as we continue to move forward and more actively participate in land management, looking at more and more treatment possibilities and options I think that the research needs to come along and help support what we're doing. Or help change what we're doing to make it more effective. You know I feel like moving forward there's great possibilities in partnership and collaboration. And it really should go hand in hand.
The Benefits of Co-Production	
Manager 9	We cannot succeed without collaboration. No one can succeed with collaboration. We must work together. . . . It's too big. It's too big and complex for an agency to be successful by themselves. Even within their own property, we still have to have others coming in and helping us either define. . . either showing us an issue or helping us solve an issue. Almost any issue, even within our own boundaries, has implications or consequences outside of those boundaries. So we must. If we're thinking about solving an issue within our boundaries, we still should be looking outside of, well, what is that consequence? What's that trade-off? And how bad are you going to impact the landscape within which I sit. And so it needs to be done at some level collaboratively. I firmly, I strongly believe and feel that.
Scientist 21	So we hear an awful lot in fire management in general, but in RMRS these days about co-management of risk, co-management of whatever it is, cross boundary work. Even all the way up to the USDA. Like the big push right now is what they're calling shared stewardship where it's really important that we're not only thinking about what's happening on Forest Service ground, but it has to be, particularly when it comes to wildfire, cross-boundary and multi-jurisdictional. So I think by having us engage in these . . . projects that's one way that RMRS sees we're helping the Forest Service to engage in that, to be active partners in cross-boundary management of wildfire.
Community member 31	The way that the project is designed, the way that the research project is designed, having it be in a way that can be integrated into actual program work versus an ad hoc just sort of, "Well, we're doing this research thing over here on the side, and it's going to wrap up in a year and then we're done." You know what I mean? That infusion into actually the research in itself, the act of doing the research and the project itself is actually moving West Region programs forward at the same time.
Scientist 10	Through those collaborations, you hear what their problems are, and you can hopefully better frame the research work that you do. I've been lucky to have these partnerships so I can kind of, I have time that they don't have to better understand their problems and look at different ways that research can help inform it. Instead of going, "How do I take my tool set and find a problem that

	fits," it's "How do I look at a problem and then take a tool set?" I think it's been valuable.
Manager 15	A lot of that exercise and what's cool with the Research Station involvement is it's not only using; you know getting that professional judgment and experience out of our folks' heads and into something that's really useful. It's also marrying that with really good underlying data and models that are peer-reviewed methodology and stuff for working through that process. It's being able to marry those two things together is a really cool thing. Having something that is then easily to provide and communicate is something I'm really looking forward to being able to utilize.
Scientist 17	We can't go out and walk every chunk of ground, so we're doing large scale modeling across large landscapes that are way too big for us to ground truth. So when you start bringing it to local units, they can do the sniff test ground truthing for you, because they already know that landscape, they drive around it, they hike around it, they fly over it. They know that landscape.
Community member 25	They've [RMRS scientists] showed a lot of interest and they've worked with communities in a way that the communities have really been receptive to what they've done. And [they've] listened, and [they've] taken their feedback and redone [their] fire models to make it more useful for people. They've [RMRS scientists] re-gauged the scale of it, the design of it, the final output so that it's actually a user-friendly format and can be easily understood by people who don't have a PhD in fire modeling. They've done things that have made it more applicable and practical for people who need to actually use it on the ground, for wildfire management.
Scientist 18	The people on the ground get it. They know what they need, and they see things that you can't see from the 10,000 foot level, and vice versa. You've got to see at all levels.
Community member 26	You get different perspectives, especially on a topic as complex as wildfire. There's not really one person or one discipline that's going to understand all the facets of it, so you need to have multiple people engaged.
Scientist 11	I think if you involve the community, your research will be informed by the community. They have a lot of ground knowledge. They have lived in this area for a very long time and they know a lot of cool things.
Manager 3	We can understand the angst that they have in some of this stuff. The key there was just more to, maybe provide them a little bit of comfort in the fact that they knew exactly what we're trying to do.
Manager 19	The mayor and the county supervisor and city council members knew what we were thinking, so when the decision was made, it didn't make everything perfect. There were still people who had great concerns, and rightfully so. This

	was literally on their doorstep. But they understood where we had come from, and it made it a much smoother process. It was much easier for them to come out publicly and support it and say we think the forest service actually knows what they're doing here.
Scientist 7	We have these collaborative things, and I never select a biologist to be the lead on the fire group, as an example, there's always got to be a fire person. And they have instant credibility with the other fire people.
Community member 27	When you take it just one way, there's going to be a line of people waiting to point out the things you've missed and why you're wrong. But when you take the collaborative approach and you present it with, "Okay, we got the blue collars' fire suppression opinion, we got the land use planner, we got the GIS specialist." Now, it's strength in numbers, and viewpoints, and approaches, we've got a pretty solid argument for the case we're making on the ground.
Manager 11	Back to the beginning, we were really in a mode of testing what would be successful, and by midway or near the end of the first year, we had a lot better sense of the right things we ought to be providing, and then by the second year, we had really amped that up.
Scientist 30	It's really only because we have stuck with this work, and kept asking questions, and kept improving our approach, and refining our understanding, our ideas, that we've gotten to where we are. It's the longevity of the relationship, the longevity of the investment and the inquiries, I think has allowed us to build what we've built.
Manager 3	The way to get everybody on the same track and on the same boat is to collaborate so that we have the chance to share thoughts, and knowledges, those sorts of things. And then we can discuss things based on the same set of data, the same set of information.
Scientist 30	In the last years of working together, we have fostered understanding of each other, and also real synergies in shared understanding that cross some of those disciplinary differences. I can't begin to overstate how valuable that is.
The Challenges of Co-production	
Manager 23	From what I've heard, that emphasis on publications can be a real disconnect sometimes. And I get that, and we want this to be an incredible science branch but what percentage of time, what does that mean for researchers and how do we answer some of those questions that don't necessarily need to be in a research paper?
Scientist 1	I think it's a concern of progressing through RMRS just because we are evaluated - there is a research grade evaluation that happens every three years for every scientist. . . .They don't tell you how many pubs you're expected to

	<p>push out every year, but there are some unwritten rules on how many you should be pushing out every year and how many you should be first author on. If you're not meeting those expectations, your evaluation might not be very good. That can reflect in your GS pay scale. If that's not an incentive to publish, I don't know what else is.</p>
Scientist 1	<p>I have to make a decision, am I going to invest time and money and travel to go out . . . and help them with that? I decided that it's worth that. It's worth that relationship and it's worth getting to see where it goes. So I have to choose that and when I'm doing that, I'm not writing a paper back in my office.</p>
Scientist 12	<p>They want to be proficient and they want to publish, but are they really listening to the needs of the field and creating the science and the tools and modeling necessary for what we need.</p>
Scientist 12	<p>A webinar is kind of a way to get to the, "We want to watch your video. We want to be shown." They want to tell you in a paper. Why do they want the paper? Because that's how they are reviewed. That's how they get tenured. Their salaries are dependent on that kind of a venue.</p>
Community member 5	<p>Most of the questions that we're looking at are longer term questions, so the length of the studies need to be longer, also. So we need folks that are willing to be engaged for longer timeframes, even if, the grant cycles aren't quite caught up with that, yet.</p>
Scientist 30	<p>I don't know. I mean, I think that the university really likes the idea of applied work. And my institute in particular, I think is supportive and committed to that notion. But there aren't tons of really great funding mechanisms within that world. This work takes tons of time and energy. And it's much different than just swooping in and collecting some data and leaving with your results. It's so much more involved. And I think mostly the funding models for these projects are based on an old assumption about how you can do research. We just got a . . . grant . . . to work with a new community. And that's great, and we're really grateful, and it's going to pay for the data collection process. But it doesn't cover any of my time. So I have to go to another source to look for money to cover my time, to participate in the process. It means we're really cobbling together funding to make what we're doing work.</p>
Scientist 21	<p>I'm not a research grade employee, it means I'm at a particular GS pay level, a grade level, and there's no potential for advancement for me, based on my work performance. So that's sort of the difference between research grade and professional. . . . Much of the work at RMRS is supported by people like me who are in professional positions, doing analyst level work. Working right alongside research scientists, and contributing to the research, but . . . I'm not the one writing proposals for new projects and serving as a PI on grants and things like that, it's more investigative.</p>

Institutional Support and Incentives	
Manager 3	I don't want to see our research people spin their wheels and expend money on something that really provides no help to us as an agency in applying our management and our objectives and goals. We have very, distinct jobs to do. I would really like to see the agency's research arm focus on that rather than maybe something that some university has said is a good thing to know. That's not a bad thing, it's just that I want to see our own research, a lot of times which includes our money, kind of focused on our agency's strategies and where we need to go.
Manager 11	How researchers are incentivized versus how managers are incentivized are different. . . . I mean I think researchers are incentivized by publishing. I don't know that they're incentivized by the work they do in collaboration with Management. For example, and managers are incentivized to get stuff done, right? Produce. Get stuff done . . . So the incentives, right? Someone ought to think about that.
Manager 11	I don't claim to understand their incentives except that I'm pretty sure they get incentives for publishing. Like we just discussed, I'd like to see them have incentives . . . for "partnering" with management.
Scientist 7	Especially the younger scientists, they're so focused on publications, publications, publications, that the station could give them more credit for promotion for doing collaborative work.
Scientist 30	I think long-term funding. We've been cobbling together funding from various sources, always on a wing and a prayer that the next year we'll be able to figure it out. And there are fluctuations in the federal budget that change based on politics, and timing, and fire seasons, and all sorts of things. It means some years we're really scrambling and spending a lot of time and energy trying to cobble together resources. Just because you apply for a grant, doesn't mean you get it. So it's applying for a grant, and revising a proposal, and submitting it again, and looking for other sources of funding. Sustained funding for this kind of efforts that you know that you're investing in procedures and practices that you will use again in three years, in five years, because you know that have funding.
Scientist 12	We created this [their collaborative project] because there's a need, and we don't have anybody that's fulfilling that need. So, not only is there a need, but we don't have anybody who can do this. So, we went out, and we reached a few people that are doing this in their other jobs, and we put them together to try to have a focus on this deficiency, but we all still have all our other jobs. It's not like we're a team and this is our job, but that's what gets back to those analyst positions, maybe two or three in each of the different regions. All of a sudden,

	then you have people that are focusing on science and analytics, and it's their job. Then, all of a sudden you can start making change, right?
Scientist 24	I guess in my mind, of course again I'm biased, but if we had more permanent positions in these RD&A [Research, Development, and Application] tech-transfer realms, we could get science out there even more. It would be very powerful.
Scientist 1	I mean if RMRS had a boatload of money I'd say let's hire some extra postdocs and scientists and have them directly assigned to some of these issues that these managers are bringing up that aren't necessarily as glamorous but I know that there's many scientists or research-types or applied-types that would really care and enjoy doing those things. I don't know if that is really in the mission of RMRS. The current mission. And I don't know if it's truly feasible with the way the budget is right now.
Additional Outcomes of Co-production and Challenges to Institutionalizing the Process	
Co-production Outcomes	
Manager 15	I think our tradition has been to find a solution quickly, solve the problem locally, move on to the next thing because there's so many things to move onto. I see us changing. Change is slow for this agency, but certainly there has been more recognition of the need to collaborate, and not just with Rocky Mountain Research Station, but with all sorts of different groups of people.
Manager 19	I would be much more open to reaching out instead of waiting when I see that we have an interesting opportunity to solve problems in a different way . . . I'd probably be more apt to reach out early on and say "Hey, come help us with this. This is what we want to take on next. What do you think?"
Community member 20	I think we need to just continue investing time and energy in them [collaborations]. This is not a one-and-done sort of scenario where we adopt a plan that might've come out of the collaborative process and then we're done. We need to put as much energy into collaborating on implementation as we did in plan development. I think it's as simple as that.
Scientist 29	We are out to 2020, and we have a whole stack of communities that want to work with us.
Challenges to Institutionalizing Co-production	
Scientist 8	I would say that the challenge was that it just takes a long time to develop these types of products. I don't think anyone really had any idea at that. But trying to do that within your other workload, it was definitely challenging for a lot of the other people that were involved in this effort. You don't necessarily plan for

	that, but you still have to get the work done. So, I think they were times where some people just couldn't engage and we just had to wait a little bit until they could re-engage, and then we could get that information from them. So, that was probably one of the biggest challenges, was just people's time loads.
Manager 4	You know, I guess the only comment that I would have is just the fact that we're fairly short staffed. Well, we're quite short staffed. . . . So, I had a huge time restriction on being able to actively participate as much maybe as I would like to. And that's probably my biggest barrier right now is just from a workload standpoint. It isn't from lack of interest, or lack of desire, It's truly kind of just from a workload standpoint.

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