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Transcending Parallel Play: Boundary Spanning for Collective Action in Wildfire Management

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Abstract: A key challenge in the United States is how to manage wildfire risk across boundaries and scales, as roles, responsibilities, and ability to act are distributed among actors in ways that do not always incentivize collective action. In this review paper, we provide several conceptual contributions to the understanding of wildfire management through the application of boundary spanning frameworks. This includes: (1) a characterization of four major types of boundaries in managing wildfire risk; (2) a review of major boundary spanning features and frameworks that integrate them; and (3) consideration of current and potential applications of the boundary spanning construct to the domain of wildfire management. Our goal is to advance knowledge of how actors in this arena may overcome "parallel play" to more collectively address wildfire risk. We generate new thinking about wildfire management, and offer potential implications and questions for future research, policy, and management.

Keywords: wildfire management; boundary spanning; risk; collective action

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1. Introduction

Wildfires globally are increasing in occurrence, size, and severity; affecting human lives and livelihoods; and causing disruptions, damage, or loss to community, economic, and ecological resources and assets [1–3]. Wildfire in the United States is both a natural ecological process and a risk to community safety and natural resource values. Wildfire risk is objectively defined as the product of the likelihood of wildfire occurring multiplied by the consequences of the occurrence to socially important resources and values [4,5]. Wildfire risk management focuses on mobilizing the human, social, financial, and technological assets of various actors and organizations to achieve three general objectives [6]: (1) reduce the likelihood of wildfire occurrence through mitigation [7]; (2) lessen the intensity and spatial extent of wildfire events through suppression; and (3) minimize the exposure of socially important resources and assets to wildfire (e.g., human populations, built infrastructure, water supplies, ecological niches not adapted to severe wildfire) [8–10].

Despite the simplicity of its mathematical representation, managing wildfire risk has been termed a "socioecological pathology" and a "wicked problem", given the dynamic interplay of human and environmental variables and sociopolitical complexity of managing landscapes that are vulnerable and prone to wildfire [11–13]. Scholars, practitioners, and policy makers in the U.S. have increasingly recognized that wildfire risks can span multiple landownerships and jurisdictions [14]. Managing these risks is complex because "spatial and temporal landscape processes [interact] with socioeconomic processes at diverse scales and across ownerships and administrative boundaries" [15]. In addition to the challenges of ownership boundaries and spatial scales, managing wildfire risk

involves entities at levels from local to national, large hierarchical organizations (i.e., federal government agencies) with internal divisions at each of these organizational levels [16], and numerous individuals who work within these entities. Adding to this complexity, a single jurisdiction can encompass many ownerships (e.g., a fire protection district), and many organizations may operate in a single jurisdiction (e.g., government agencies or nongovernmental organizations may perform various wildfire risk mitigation work within a single fire protection district).

Carrying out the objectives of wildfire management engages a variety of actors, rules, and resources. These actors, rules and resources are guided by multiple, even competing policies, incentives, and practices; as well as human values and psychological factors that can shape individual behaviors [17–19]. Further, actors' ability to work together across those differences can be impeded as their roles, responsibilities, and ability to act in managing wildfire risk are distributed in ways that may not readily incentivize collective action [19]. In particular, although federal land management agencies increasingly recognize the need for wildfire's ecological role, most state and local entities typically have missions focused on suppression [12]. Wildfire management therefore appears to often be a continued state of "parallel play", wherein different actors strive to better coordinate their respective actions yet remain disconnected by limitations to sharing resources and responsibilities in ways that would allow them to act in a more collective manner.

Recognizing these challenges, scholars suggest increased "coordination across sectors (such as air quality and land management), diverse actors, and multiple levels and jurisdictions" [18]; and "the ability to co-manage [wildfire response] across scales" [20]. To facilitate this coordination and co-management, an integrated framework for action built on mutually reinforcing policies at local, state, and national levels will be necessary. This framework would also need to address how policies and institutions interact and affect each other, include a diversity of management approaches that match the complexity of the issues at hand, and foster learning among actors across levels [12]. Pursuit of such a framework in the U.S. has largely occurred through national level initiatives that emphasize more proactive cross-boundary wildfire management across landownerships and jurisdictions. Most prominent is the National Cohesive Wildland Fire Management Strategy, which directs more collaborative approaches in three arenas: resilient landscapes, fire-adapted communities, and suppression response strategies. In each arena, the Cohesive Strategy has encouraged increasing opportunities for communication and learning among actors across scales and levels, especially through "learning by doing" and adaptation [20,21]. Policies and programs to foster coordination of mitigation activities across spatial scales and ownership boundaries have also emerged. Leading examples are the Collaborative Forest Landscape Restoration Program and USDA Joint Chiefs' Landscape Restoration Program, which respectively support the implementation of large landscape risk reduction projects and the coordination of wildfire mitigation across public and private ownerships [22,23]. In addition to these efforts, there has also been a growing focus on spatial-analytical tools (i.e., quantitative wildfire risk assessment, mapping of suppression difficulty, and atlases of potential control locations) [24]. These tools are intended to reduce uncertainty for managers who must weigh risks and strategically allocate resources for suppression response by providing more accurate and detailed information for decision support [25].

Despite these efforts, scholarship finds continued evidence of complexity and disconnection across ownerships, scales, and levels. For example, landscape fuels management and structural mitigation or defensible space treatments can complement but will not replace each other. Applying fuels management outside of the home ignition zone may be more necessary where complex topography and the potential for extreme wildfire behavior can vary recommendations for how far defensible space should extend from the home [26]. In the context of wildfire response, there are studies that testify to various instances of disconnects. For example, managers who mitigate wildfire risk may not functionally interact with those responsible for suppression, even within the same agency [11]. In addition,

the knowledge and values of local stakeholders may not be consistently incorporated into suppression decisions [27]. Disconnects between local units and national incident management teams continue to be evident [20], as well as differing missions among suppression organizations [28]. In the context of landscape scale fuels reduction, recent work examining cross-ownership mitigation projects has identified issues in spanning not only land ownership boundaries, but also the boundaries between organizations themselves. For instance, one study found issues such as a "mismatch of processes" in which "staff did not understand the other's processes in terms of jargon, expertise, funding streams, staff structure, or timelines" [22]. Even as multiple organizations sought to coordinate implementation activities within the same project areas, they faced policy or regulatory limits in how they could apply or share their resources and authorities. These limitations included restrictions on which funding types could be used on which ownerships, and an inability to transfer funds from one agency to another [29].

Given evidence of the enduring challenges to collective action in wildfire risk management, we suggest a need for new understandings in response to the question: What approaches may more effectively catalyze coordination among actors involved in managing wildfire risk to transcend their state of parallel play? As recent reflective scholarship notes, there are numerous social science concepts related to this question, yet a lack of bridging among them to help answer it [30]. To address this question, we propose, first, that more nuanced conceptions of boundaries in wildfire management are needed, particularly to better recognize other types of boundaries beyond landownership. Second, we suggest that a lens of "boundary spanning" can offer additional insight and explanatory power into the challenges of collective action in wildfire management. This is because boundary spanning research focuses not just on "working together", but on the methods and mechanisms that may generate, legitimate, and institutionalize new ideas of risk management that can induce the kinds of durable changes in systems [31–33] that scholars of wildfire management have argued are needed [12]. As boundaries are junctures that distinguish people, objects, activities, and so on from each other, boundary spanning encompasses processes of: (1) translating across differences, or facilitating cross-field understanding; (2) aligning among differences, or recognizing differences and then seeking complementarities between them; and (3) decentering differences, or identifying shared space/common ground where two or more conflicting or disparate entities can act together [33]. The first scholarly attention to boundary spanning was in 1989, when Star [34] and then Star and Griesmer introduced "boundary object", described by Star and Griesmer as "those scientific objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them" [35]. Since that time, a broad body of research from multiple disciplines has further explored boundary spanning with a focus on boundaries between "different social worlds that are inhabited by specific communities of actors" [36]. Beginning in the mid-2000s, this literature has posited that spanning these boundaries is key to fostering resilience and adaptive governance within social-ecological systems [33,37]. Importantly, boundary spanning does not demand consensus, but allows these different social worlds to intersect while maintaining their own functionalities [36].

Although boundary spanning research appears to offer relevant insights for wildfire management, the literature on this topic has been diffuse across multiple disciplines, and is not well synthesized for application to management, policy, and practice. Our purpose in this review paper is therefore to offer review and synthesis of scholarship concerning boundary spanning in natural resource management that can facilitate more robust applications of the boundary spanning construct to the domain of wildfire management. Relevant literature on boundary spanning is directly used to inform our proposed framework for articulating specific boundary spanning features that may overcome the boundaries present in wildfire management. We draw on both this literature and our situated experiences working within Cooperative Extension and related boundary spanning organizations to suggest hypotheses about what it may take to overcome "parallel play" and more collectively address wildfire risks. In doing so, we seek to generate new thinking about wildfire

management, and offer potential implications and questions for future research, policy, and management.

2. The Context of Boundaries in Managing Wildfire

To provide context, we briefly elaborate on four types of boundaries found between activities and actors present in wildfire management in the U.S. As noted, this wildfire management has three primary objectives of reducing likelihood of wildfire occurrence, lessening extent and intensity of wildfire events, and minimizing the exposure of socially important resources and assets to wildfire [6]. Achieving these objectives requires cooperative, coordinated collective action among multiple governmental jurisdictions and entities, nongovernmental organizations, and owners of private resources and assets in wildfire-prone and vulnerable areas. Since the mid−1990s, myriad national and state policies have been enacted to initiate and expand activities to reduce wildfire risk through intergovernmental, interagency, and government-community cooperation and coordination [12,38,39]. However, as one study notes, "The current wildfire governance system is highly fragmented. The governance system is an amalgamation of a variety of formal and informal policy directives, programs, budgets, and practices at the national, state, and local levels [12]".

Another means of describing this fragmentation is that boundaries separate individuals and organizations engaged in wildfire management, and challenge collective action to manage wildfire risk. It is important to more clearly identify and describe these boundaries in order to develop potential paths for spanning them. From the existing literature on wildfire management, it appears that at least four primary types of boundaries are present (Table 1).

Table 1. Summary of major types of boundaries in wildfire management.

Boundary Type	Boundaries Exist between
Landowner-ship	• Parcels of land • Policies, laws, regulations, and liabilities governing different ownerships
Functional	• Wildfire risk management functions of prevention, mitigation, and suppression
Organiza-tional	• The missions, incentives, accountabilities, cultures, and scales of different organizations involved in managing wildfire risk; and their ability to share resources and work jointly on tasks
Conceptual	• Different individuals' and organizations' conceptions of and knowledge about wildfire risk

First, the most obvious and commonly recognized are landownership boundaries. Various landownership types are governed by different policies, laws, and regulations; yet wildfires can start and spread quickly across multiple ownerships [40]. As such, cooperative and coordinated risk management actions are needed to alter this cross-ownership risk transmission [41–43]. Although a primary focus of cross-ownership wildfire management is found in the United States, this challenge is also experienced in many areas of the world, including Canada and Australia [44,45], England [46], and the Mediterranean [47,48] and Black Sea regions [49].

The second is functional boundaries. Even within entities of the same jurisdiction, boundaries exist between wildfire risk management functions, specifically between fire suppression on the one hand, and fire prevention and risk mitigation on the other [39,44,50–52]. The term "silo" is often used to connote the separation between these functions as well as the scalar nature of such separation: "The siloization of suppression activities from prevention and preparation activities further reinforces this disconnect. Response activities, especially for large wildfire events, are increasingly occurring at the national level, while preparation and prevention activities are encouraged at the local level" [12]. This siloiza-

tion is a cumulative effect of budgetary and accounting policy changes over time [39,50], and of the long history of the organizational culture of fire suppression with a distinct occupational practice and identity [8,43,53,54].

The third set of boundaries in wildfire management is organizational boundaries. A variety of federal, state, and local government jurisdictions have authority and accountability over wildfire risk management [55]. As noted by numerous observers, the diversity of missions, incentives, accountabilities, and cultures across jurisdictions and geographic scales of authority has stymied cooperative, coordinated collective action [12,16,46,53,56,57]. In addition, many of the engaged organizations contain multiple scales of authority and activity within their own structures. In particular, USDA Forest Service wildfire risk assessment, planning and management decision-making processes are consistently implicated as being barriers to cooperation [16,21,58], as noted in a review of US wildfire management by the National Association for Public Administration: "It was clear upon inspection that the interagency, intergovernmental, and interdisciplinary policies that had been adopted to guide the federal land management agencies in implementing their wildland fire programs had been substantially thwarted by the *impenetrable boundaries* separating the many parties whose contributions are needed to achieve success" [57] (emphasis added). Even in instances where the USFS communicated consistently with local government officials and community members about wildfire risk management goals and activities, the absence of formal agreements, specifically to allow entities to share resources and work jointly on tasks, can lead to unmet expectations, confusion, and frustration [58].

Finally, there is a set of conceptual boundaries related to terminology and knowledge differences. Confusion over terminology denoting wildfire risk, and differences in knowledge and understanding about wildfire, can also act as boundaries between individuals and organizations. "Wildfire risk" itself is a problematic phrase, meaning different things to different people and organizations [4]; and "the language we use to characterize resource management and, particularly, fire management appears to have become less concise over time" [5]. Relatedly, differential experience with and knowledge about wildfire can also inhibit effective wildfire management [59]. One type of conceptual boundary, or knowledge-as-boundary, occurs between researchers and practitioners operating in separate spheres [60], resulting in the lack of adoption of scientific risk analysis tools and technologies that could advance cross-boundary governance. When researchers and managers work together to co-produce and apply shared knowledge, both entities can realize gains in outcomes and in new learning [60,61]. This boundary between science and other forms of knowledge is well recognized in the literature [62] and expands beyond the traditional science-policy interface [63,64]. A second type of conceptual boundary occurs between wildland fire professionals (i.e., managers, researchers, educators) and the lay public–a boundary mediated by the public's trust in wildfire professionals [51]. As one study observed, "Despite a broad social contract between citizens and their government, public expectations of complete protection from [wild]fire are simply unrealistic and can result in deterioration of public trust if a damaging fire does occur [50]". This gap in expectation is due in part to lack of knowledge or misunderstandings about the roles and effectiveness of wildfire risk management actions.

3. Methods: Identifying Boundary Spanning Literature

3.1. Boundary Spanning Literature

This review paper is focused on synthesizing literature that provides key components of boundary theory as proposed and developed by scholars of natural resources, and little of this research is specific to wildfire. The broader literature on boundary spanning ranges widely across multiple literature domains and disciplines. In order to synthesize its key components, we employed a combination of two approaches: (1) a purposeful selection of key articles and citation searches stemming from these articles; and (2) keyword searches and reviews. Although this approach is not an entirely formal systematic review, it proved the most appropriate way to capture boundary spanning literature from a range

of disciplines that was most relevant to natural resource management, as proposed and developed mainly by scholars from this field [65].

3.2. Selection of Literature

We conducted literature searches during the time period of June 2020 and January 2021, using Web of Science and Google Scholar, to aggregate peer-reviewed academic literature on this topic. We included literature for review if it addressed boundary theory in reference to a natural resources, wildfire, or adaptive governance-related topic and had been published in the English language. First, we used key foundational and review articles to begin our literature review as they provided context and background. Foundational, in this case, was determined as authors who had established key boundary spanning terminology, and highly cited review pieces summarizing key theoretical contributions to the field (as explained in the remainder of this section). For example, we traced citations from Sternlieb et al. [63] and only chose articles where some component of boundary theory was mentioned in the abstract, such as boundary spanning, boundary object, or boundary concept (yielding [66–71]). We also searched for articles that cited Mollinga [72] and used "boundary concept" and "boundary setting". We also recognized that other boundary theory components not referenced in Mollinga [72] have also propelled this literature forward in recent years. Therefore, we added a wider search for "boundary activity", "boundary action", and "boundary work" and "adaptive governance" and "adaptive management".

We then employed other keyword searches using the following terms:

- "Boundary concept" "natural resource$" citing key article Mollinga [72].
- "Boundary object" AND "Natural resource$"; only articles citing Star and Griesemer [35].
- "Boundary object" AND "wildfire risk".
- "Boundary activity" OR "boundary action*" OR "boundary work" AND "adaptive governance" OR "adaptive systems" OR "adaptive management".
- "Wildfire risk" AND "boundary concept" OR "boundary object" (yielded zero results).

Of these collected articles, for search terms that yielded high numbers of articles, we conducted a second read of abstracts and eliminated articles that only used components of boundary theory as units of analysis but did not utilize boundary theory as a central theoretical lens. In both purposeful selection of key articles and keyword searching, references within articles were checked for relevance. For example, we initially found that using "boundary object" and "natural resources" as search terms yielded many articles employing "boundary object" loosely and in a way that overlapped with Mollinga's [72] foundational definition of "boundary concept". To rectify this, we used the search terms "boundary object" and "natural resources", filtering only for articles citing Star and Griesemer's introduction of "boundary object" [33] or Star [73], which called for a narrower definition of "boundary objects". We also found that much of the most relevant literature on boundary settings and actions was covered in initial key article citation tracing, for example, searching for "boundary", "settings", "actions", and "concepts" only yielded new articles on boundary concepts (e.g., [74]).

Our literature search resulted in a total of 56 articles that were used for this review. Our first stage of systematic searching resulted in 44 initial key articles published between 2009 and 2020. Twelve further articles were identified through the secondary supplemental keyword searching for foundational work, and these spanned from 1978 to 2009 in publication date. Most collected articles focused on contexts across the United States, although some examined contexts in other countries. There was diverse representation of scales of boundary work, including community, city, regional, and national scales.

4. Reviewing Prominent Boundary Spanning Features

In this section, we review relevant literature on boundary spanning for insights to inform our proposed framework for developing boundary spanning attributes and

functions to advance wildfire management. There is a robust body of literature that has explored the role of boundary spanning, or boundary work, in diverse organizational, institutional, and socio-political settings. Boundaries are broadly recognized in geography and other disciplines as both fiat or human-demarcation-induced (e.g., cultural and social practices and organization; places and languages) and bona fide or physical (e.g., geologic formations, ecosystems, and climatic regions) [63]. Given recognition that the boundaries within social-ecological systems are multi-faceted and complex [63], there is a need for more concrete and actionable definitions of features found in the boundary spanning literature for applicability to settings like wildfire management. The following review considers existing literature that helps clarify the meanings of four types of features: boundary people/organizations, objects, concepts, and settings (Table 2).

Table 2. Summary of commonly recognized boundary spanning features.

Boundary SpanningFeature (BSF)	Number of Articles Directly Concerning this Feature	Characteristics	Studied Examples
Boundary people/organizations	26	• Engage actors on both sides of a boundary • Create and use other boundary spanning features (e.g., objects) in doing boundary work • Create interactive settings, identify common interests	• Cooperative Extension [75,76] • Collaborative groups or organizations [62,63,77] • Multi-party land trusts [67] • Research and development organizations [78,79] • Science exchanges or networks [60]
Boundary objects	24	• Joint reference points (e.g., classifications, standards) for communication and sharing across boundaries • Broad enough to allow shared meaning and flexible interpretation among actors from both sides of a boundary • May be broad, ill-defined, and open; or more specifically definedMay be used similarly to "boundary concept"	• Concrete objects such as maps, models, or datasets [60,80,81] • Instruments such as agreements, MOUs, or organizational charters [82,83] • Concepts such as multi-use forestry [84,85]
Boundary concepts	8	• Concepts that allow communications across a boundary by creating common vocabulary • Broad enough to allow shared meaning • Often used similarly to "boundary object"	• Ecosystem services [72,86,87] • Notion of resilience [74,85]
Boundary settings	16	• Conducive settings for boundary work to occur • May be internal to an organization (e.g., its structure or culture), or external (e.g., policy)	• Broader institutions, governance arrangements, funding sources, and policies [36,72,78] • Physical, localized sites of convening (e.g., meeting venues, committees, working tables, and joint projects) [36,72]

4.1. Boundary People/Organizations

Early boundary spanning literature focused primarily on how individuals or individual roles within organizations spanned boundaries between policy and science, science and practice, or generally between different realms or entities [82,88,89]. Recognized characteristics of effective boundary spanning individuals have included knowledge about both sides of the boundary [88]; and being entrepreneurial, innovative, and collaborative [89]. Often, these spanners in information processing and external representation were "bench-level" employees rather than upper-level management [88].

Many have also examined "boundary organizations", a term first defined by Guston [82] as those who (1) provide opportunity and incentives for use of boundary objects, (2) engage actors on both sides of the boundary, (3) are accountable to each side of the boundary, and (4) support creation of boundary objects which in turn create new scientific and social order. Boundary organizations can foster social learning and social capacity through interactive settings [77,90] and in establishing new roles and relationships that reinforce boundaries while identifying common interests [91]. Environmental governance research has often focused on how boundary organizations drive knowledge co-production and integration of diverse knowledges into policy and practice [62,92], including the coordination of regional scale collective action to enact climate policy [79,92] and mitigate wildfire risk [60].

Diverse types of organizations have been identified as boundary organizations, including cooperative extension offices [75–77], governmental offices [83,93], research and development organizations [69,78], and community-based organizations and collaborative

groups that facilitate multi-stakeholder dialogue and action [21,94]. Studies have also examined organizations that specifically emerged to act as boundary spanners, such as agri-environmental collaboratives [61,66] and multi-party land trusts [67]. More recently, understandings of the evolution of boundary organizations suggest that their purpose and relation to the broader institutional context can shift, given new conditions that they themselves may have helped foster [95,96]. Some have identified the need to expand the scope of what is considered a "boundary organization" to move beyond boundaries of science and policy, or policy and practice, such as how organizations bridge levels of government [76] or negotiate diverse boundaries within the nexus of science, practice, and policy [63]. Following a more expansive definition of roles than boundary organizations, "bridging organizations" engage in broader and more flexible work to facilitate collaboration across the entire network, often bridging knowledge and skill sets [62,63]. Bridging organizations also can provide new forums for learning and conflict resolution [97], support collaborative efforts more broadly [98] and crucially, facilitate information flow across networks [93,99,100].

4.2. Boundary Objects

Boundary objects have been the subject of a large body of literature in diverse fields, including media and technology studies, sociology of sciences, and organization theory [101]. A boundary object was suggested by Star and Griesemer to be best used at the organizational level of analysis as "something people act toward and with. Its materiality derives from action, not from a sense of prefabricated stuff or 'thing'-ness"; with the recommendation that boundary object theory may be most useful at the organizational level of analysis [73]. Others have emphasized the importance of examining how boundary objects "materialize and transport an invisible infrastructure made up of standards, categories, classifications, and conventions that are specific to one or more social worlds" [101], offering both examples of both broad, "ill-defined" and more specific boundary objects [36]. Some have taken a wide interpretation of "boundary object" as a concept of shared meaning, terminology, and lexicon, that is then interpreted or translated by each party on different sides of the boundary. For example, in the realm of natural resources, boundary objects may include concepts of multi-use forestry [84] or stewardship [102]. Conversely, other scholars have focused on more concrete or actionable forms of boundary objects, such as maps that integrate and collect diverse knowledge systems [80,81], or hydrological models based on co-produced and usable science that span the interests of policymakers, scientists, and stakeholders [69,76,103,104]. Some processes are also recognized as boundary objects, including "fuzzy cognitive mapping" of perceptions of wildfire within a common region [105] and a livestock management scenario game engaging stakeholders in social learning [106]. Other studies have examined boundary objects in the form of written documents such as cooperative agreements and Memoranda of Understanding (MOUs), which maintain clear pathways between actors [78,82,83]; organizational charters, which delineate roles and responsibilities; and other written materials in the form of reports, records, and shared data [36,67,107–109].

Collaborative, inclusive, and participatory processes can lend boundary objects salience, legitimacy, and credibility as information sources or decision-support tools [110,111]. Recent work has demonstrated the need to not just identify and describe boundary objects, but understand the conditions of their emergence and the dynamics of their use over time [112]. Studies that have explored the co-generation of boundary objects by Indigenous and non-Indigenous actors highlight the importance of deliberate process to address power inequities, clearly prioritize local communities' needs, and ensure that Indigenous partners have ownership of the object and the process of knowledge generation [113,114]. Other scholars have also echoed the need to consider who "owns" the boundary object [106].

4.3. Boundary Concepts

There is a lack of uniformity in how the term "boundary concept" is used in the literature. Some scholars use it similarly to "boundary object" to denote a vague set of terminology and shared language that is negotiated across boundaries and used differently by different actors; while others use it to denote a clearly defined concept or shared language to allow different actors to communicate about the same issue [85]. Additionally, some studies may reference similar ideas without using either of these terms. For example, in describing the temporal progression of boundary work, Brand and Jax [85] highlight the importance of "coherence around problem definition or framing", which could be described as agreeing on shared boundary concepts.

Mollinga defined a "boundary concept" as "conceptual communication that allows thinking about the multi-dimensionality of natural resource management issues", and compared a "boundary concept" to a "boundary object", which are "devices that allow for acting in situations of incomplete knowledge" [72]. The co-generation of boundary concepts can also be a foundation for boundary spanning research, through which sustained interaction is key to creating concepts that resonate with individuals from diverse disciplinary backgrounds [115]. Several specific notions in environmental governance have been identified as boundary concepts, such as "ecosystem services", due to its vagueness, ambiguity, and use by multiple fields [72,86,87,116]. Similarly, "ecosystem restoration" may also serve as a boundary concept, as it brings actors from different arenas into a shared realm and set of definitions [77]. A multi-disciplinary literature review found that "resilience" acts both as a "descriptive concept", with clear definitions in both ecological and social sciences, as well as a "boundary object" that has vague, ambiguous, and negotiated meanings across the boundaries of disciplines or fields [85]. Another study found that "resilience" was well defined when used as a "boundary object" within a field, but loosely defined across fields, which held diverse meanings for it [74].

4.4. Boundary Settings

A leading definition of "boundary setting" is "settings conducive to these [boundary] concepts, devices, and methods being fruitfully developed and put into work" [72]. This includes both internal settings, such as organizational structure or research activity dynamics, and external settings, of policy initiatives on a global, national, regional, or local level, as well as broad institutional arrangements. Studies drawing from this definition have discussed boundary settings such as institutions, governance arrangements, funding sources, and policies; others have suggested that they are physical, localized sites of boundary work, such as meeting venues, committees, working tables, and joint projects [36,115,117]. Importantly, boundary settings are not constantly operating, but specifically function when and where actors from across boundaries come together [36].

Some past research has also discussed the interplay between institutional context and boundary spanning work. For example, early boundary scholars [88] described how organizational structure and problem context affected the type and extent of boundary work that occurred, or how intra- and inter-organizational design influenced the success of that work [118]. More recent studies have emphasized how institutional and governance contexts create or constrain conditions for boundary work to occur [32,96,119,120]; sought to understand the cultural dynamics that produce and span boundaries between politics, institutions, and science [121]; and applied boundary spanning ideas to policy studies, specifically by suggesting that focusing events can act as boundary objects that create opportunities for policy changes [111]. Some studies of boundary organizations have discussed how policy can facilitate boundary work, such as federal funding for collaborative restoration work [94], international climate policy [122], and water policy [69,80], national fire planning [83], and legislation specifically creating a boundary organization [78]. These studies do not explicitly refer to these policies as "boundary settings", but may contribute to understanding of how political context creates conditions for boundary work.

4.5. Integrative Frameworks for Boundary Spanning

Some recent studies have proposed theoretical frameworks for integrating boundary spanning features. For example, one study characterized boundary settings as socio-political contexts that provided the conditions for boundary organizations or spanners to mobilize shared boundary concepts and engage actors in the creation of boundary objects [72]. Another study of a boundary organization found it consisted of multiple other boundary spanning features: (1) inputs, such as funding, contracts, and scientific information, (2) outputs, such as educational resources and workshops, and (3) outcomes, all of which fostered knowledge co-production and collaboration between scientists and managers [61]. Relative to collective action around local renewable energy, researchers have described how unique combinations of objects, organizations, and settings, or "boundary bridging arrangements", emerged differently in different local contexts, given variability in local settings (e.g., landscapes, values, rules) and how those shaped both boundaries themselves and how they may be spanned [36]. For example, a boundary spanning organization may form in one locality but not another, due to differences in funding and cultures. This integrative approach to observing the entire system of boundary work in a place may provide better explanations for systems changes, as well as the integration and spanning of multiple social worlds beyond those of science and policy.

Other framings articulate boundary spanning as social-interactional processes or sets of activities that engage actors or entities on both sides of a boundary [63]. These constitute trajectories of boundary work over time, from defining of boundaries and initiation of work, to establishing ownership, interpretation, and use of generated boundary objects [114]. Studied examples of boundary spanning activities include information sharing, workshops, and trainings [11,83,93,108,123], joint policy advocacy [94], joint setting of ecosystem restoration priorities [77], and collective water quality monitoring to inform better management [76]. Other researchers have emphasized that boundary spanning should be considered a "distinct practice organizationally" and that there is a need for more concrete measures of success for boundary spanning activities [123]. These insights may imply a need for expansive definitions of "boundary activities" that can incorporate activities that foster more collaborative, or boundary spanning, processes, as well as those that directly result in more substantive outcomes.

Additionally, scholars have increasingly called for methods to evaluate the impacts and outcomes of boundary work. Measuring the outcomes and impacts of boundary work is challenging due to the messiness of policy processes and social-ecological systems embedded in context, but clearer evaluative criteria could help justify investing time and resources, and help foster outcomes such as improved knowledge exchange, stronger networks, trust, and policy improvements as potential results of successful boundary work [124]. Evaluation guidance for fire science exchange networks offers another example by distinguishing outcomes over time and by actor: short term outcomes of a participant's change in knowledge, medium-term outcomes of their change in behavior as a result of that knowledge, and longer-term, broader outcomes of improved societal condition resulting from their informed action [125].

4.6. Existing Applications of Boundary Spanning Theory to Wildfire

A limited body of literature has applied a boundary work lens to wildfire management settings. These studies have focused on boundaries between science-management [60], science-management-policy [61,126], emergency response agencies [83,127], and different entities' perceptions of fire [105]. As in the broader literature, many of the visible examples of boundary spanning are at the science-management boundary. Most notably, the Joint Fire Science Program has been examined as a regional scale boundary spanning approach [60] that has been successful at facilitating increased use of fire science by managers through its support of regional fire science knowledge exchanges/networks [126]. A study of one of these entities, the Alaska Fire Science Consortium, found that it had effectively transitioned over time from solely disseminating information to more fully operating

as a boundary organization that facilitated knowledge co-production, as it was able to deliberately marshal key capacities and processes for doing so [61]. This small body of literature reveals many unanswered and ongoing questions within wildfire management about the characteristics of effective boundary spanners [60], the challenges of spanning boundaries of multiple kinds and at multiple scales [60,126], and the temporal conditions in which effective boundary spanning emerges and transforms [61]. These questions imply that boundary theory may provide valuable concepts to inform wildfire management scholarship, and also that wildfire management may be a valuable context to advance boundary theory and provide lessons for other contexts.

5. Discussion and Propositions for Future Research

We now consider how the literature we have synthesized about boundary spanning may offer insights toward bridging the boundaries in wildfire management for more collective action by posing four provisional hypotheses. These are intended as starting points for new research directions to build knowledge of how boundary spanning features (BSFs) may manifest, interact, and encourage collective action in a wildfire risk context. They also serve to connect key aspects of boundary and wildfire management literatures. In offering these hypotheses, we draw on the synthesis of boundary spanning literature, which provides a concrete typology of four BSFs; as well as our situated experiences as applied researchers, extension service providers, and facilitators who work directly with wildfire practitioners and managers. Therefore, these interpretations, ideas, and questions reflect both the potential advantage of "insider" perspectives on the workings of wildfire management [38] as well as potential biases, assumptions, and limitations relative to our positionalities and specific to our experiences.

5.1. Hypothesis 1: Wildfire Risk Policy, Management, and Practice Have Generated Several Prominent BSFs That Vary in the Types of Boundaries That They Seek to Span

As we reflect on our experiences as well as existing research about wildfire management, we identify numerous potential examples of specific BSFs within the domain of wildfire management. Boundary spanning scholarship already recognizes boundary organizations such as fire science exchange networks, which connect scientists with managers of wildfire risk for multi-way co-production of knowledge across conceptual boundaries. Another example of a boundary organization is the U.S. Fire Learning Network, which convenes managers, practitioners, and scientists to foster a transition to more ecologically based fire management through collaborative learning and the creation of regional restoration plans [128]. In recent years, there are also examples of collaborative, multi-stakeholder groups that host dialogue across organizational boundaries to seek agreement and strategies for managing wildfire risk within defined local areas, such as the Santa Fe Fireshed Coalition, Northern Colorado Fireshed Collaborative, or Harney County Wildfire Collaborative [129,130].

Beyond boundary organizations, there appear to be other types of BSFs in wildfire management. For example, boundary settings to overcome landownership boundaries are found in general dialogues or agency direction that encourage "all-hands, all-lands" and "shared stewardship", and specific programs such as the Joint Chiefs' Landscape Restoration Partnership, which offer funding and resources for the coordinated implementation of fuels reduction treatments across public (USDA Forest Service lands) and private forestlands [22]. Similarly, the National Cohesive Wildland Fire Management Strategy broadly serves as a boundary setting by establishing broad goals and an action plan for organizations in wildfire management to coordinate more closely addressing them at multiple scales [28,43].

Examples of boundary objects and concepts also appear in wildfire management, such as Potential Operational Delineations (sometimes known as PODs) processes that engage wildfire managers with other stakeholders to identify values at risk and potential safe and effective control locations to be used during fire suppression, resulting in maps and other geospatial objects that help codify and share this information in ways that encourage

shared prioritization and action [130,131]. Documents guiding collaborative processes, such as charters, serve as a different type of boundary object creating structures in which multiple organizations can interact. All of these boundary objects are concrete, specific features that seem to have emerged to span the differences between actors working in a different functional areas of wildfire management (i.e., mitigation and suppression), as well as the variance between organizations. Boundary concepts, on the other hand, may be those that have animated major cross-sectoral interest and urgency in addressing wildfire risks, such as the notion of risk transmission from one location or ownership to another; or the goals of supporting more "fire-adapted communities" that are able to safely coexist with wildfire as articulated in the Cohesive Strategy and supported by the Fire-Adapted Communities Network [12].

It is clear that more work could expand on this preliminary identification of BSFs in a wildfire context. Further research could systematically inventory and classify BSFs by type, actors, funding sources, and decision-making levels (i.e., national, regional, state, administrative unit, project) and phases (i.e., formulation, planning, analysis, implementation, monitoring and evaluation), as this would provide an informative foundation for additional study of the outcomes and effectiveness of BSFs in wildfire risk management.

5.2. Hypothesis 2: BSFs in Wildfire Management Vary in the Types of Boundaries That They Seek to Span

Given that there are numerous BSFs in wildfire management, it then is necessary to ask which types of boundaries they may seek to span, and how effective they are at doing so. Considering the potential BSFs that we have identified vis-a-vis the four types of boundaries in wildfire, we hypothesize that most prominent BSFs appear to target issues of organizational boundaries, although some emphasize multiple boundaries, particularly both organizational and landownership boundaries (Table 3). To explore this hypothesis, research may seek to uncover if these apparent emphases are borne out with more empirical evidence. In other words, what are the theories of change behind these BSFs, and do they indeed target primarily organizational boundaries? Is there a lack of discursive clarity or terminology in problem identification relative to types of boundaries? If future research found that organizational boundaries are in fact the most common barriers that BSFs seek to overcome, this could in turn necessitate more examination. For example, are organizational boundaries the key factor that drives parallel play, and does spanning them in fact encourage more collective action as an outcome? Are BSFs needed to also span the other types of boundaries, or is targeting organizational boundaries sufficient?

In asking these questions, we also note the challenges of disentangling cause and effect; for example, do organizational differences produce and reinforce conceptual boundaries, or are structures built and evolve as a result of those differences in terminology and knowledge of wildfire risk? In exploring this, researchers will need to use empirical evidence to identify where and how truly "hard" boundaries—the lines that outline and reinforce the distribution of risk and responsibilities among actors—manifest in practice. It will also be essential to develop new theories of how multiple types of boundaries may be spanned through arrangements of boundary spanning features, attending to how those features interrelate and interact over space and time in places and across scales. This is necessary given the complex interrelatedness of both the boundaries themselves and the features that may help cross them. A further direction for research is that boundary spanning scholarship could offer substantial value in explaining not just the co-production of knowledge (i.e., across science-policy boundaries) but also the co-production of practice across many other types of boundaries as actors work together to manage wildfire risk.

Table 3. Potential examples of boundary spanning features and the boundaries that they emphasize in wildfire management

		Wildfire Risk Boundary Types Emphasized by Each BSF			
Boundary Spanning Feature (BSF)	**Prominent Example of BSF in Wildfire Management**	**Organizational**	**Landownership**	**Conceptual**	**Functional**
Boundary organization	Fire science exchange networks				
	Fire Learning Network				
	Fireshed or wildfire collaboratives				
Boundary object	Potential Operational Delineations (PODs)				
	Risk model outputs and maps				
	Collaborative charters				
Boundary concepts	Fire-adapted communities				
	Risk transmission				
	Landscape scale				
Boundary settings	Joint Chiefs' Landscape Restoration Partnership				
	Cohesive Strategy				
	Spaces wherein collaboratives convene				

5.3. Hypothesis 3: Unique Arrangements of BSFs Will Emerge, Exist, and Evolve in Different Settings Given the Variability in Their Local Settings and in How Boundaries in Wildfire Risk Management Manifest

Akin to existing theory of how boundary bridging occurs in local contexts [36], we recognize that there can be local variability in institutional, ecological, and management settings. Some landscapes have a high degree of landownership interface, which poses a fragmented landscape yet may also motivate increased interorganizational coordination. In this context, a boundary concept of ownership interface may encourage such coordination, and produce boundary objects such as agreements or contracts for delineating management responsibilities and partnerships [132]. Depending on the social complexity at hand, boundary organizations may also emerge or take on roles in helping sustain these partnerships and community engagement. Actors in landscapes experiencing frequent wildfire affecting human values may be particularly driven to address the functional boundaries of mitigation and suppression in order to better align management decisions during and before wildfire events to protect those values, resulting in boundary objects such as risk maps and potential operational delineations products [131].

Further, these boundary arrangements could dynamically evolve over time through a developmental interplay of different BSFs. In particular, prior research already suggests that this evolution may be most evident in local areas that have experienced focusing events, especially those that have multiple impacts to human values such as wildfires followed by floods and downstream impacts to drinking water [133]. We suggest that such events are significant enough in scope, scale, and breadth of effects that they are capable of stimulating a trajectory of collective boundary work, as different organizations are sufficiently compelled to reduce their parallel play and instead interact in reworked or novel ways. This trajectory could involve multiple types of BSFs in a sequence in which certain features may lay the foundation for others, given how the boundary spanning literature has suggested they operate. For example, after a focusing event, actors may use boundary concepts to create common language, establish boundary settings such as convening tables, and institutionalize commitment and resources through boundary objects. Depending on local context, boundary organizations may already exist and help initiate and organize this trajectory, and/or emerge as the need for intermediaries becomes apparent. As these multiple features accrete and interact over time, the ability of actors to utilize broader boundary settings—such as competitiveness for programs provided through state or federal policy—will grow, and acquiring additional resources or designations may force further evolution and scaling up and out of the collective work. Importantly, however, this trajectory is not linear, and may be subject to the shocks and instabilities of further natural hazard

focusing events or social changes. These might include the departure of key individuals such as policy entrepreneurs, an increase in social conflict in the larger community, or a change in landownership (e.g., sale of working timberlands to development interests). These changes could force rethinking, reworking, or even discarding of BSFs. Research approaches such as in-depth case studies employing methods such as process tracing that can more precisely characterize BSFs and their complex interactions will be necessary to illuminate these trajectories and examine these hypotheses.

5.4. Hypothesis 4: Trajectories of Collective Boundary Work Contribute to an Uneven Landscape of Investment, Capacity, and Outcomes

Neither the boundary spanning literature nor much of the wildfire management literature have delved into how boundary work could foster equity or exacerbate inequity, and for whom; although there is some recognition of how lack of human and social capital for sustained leadership, technical resources and expertise to develop and utilize boundary objects, and financial resources to match funding sources, can limit the competitiveness of some communities or areas in accessing wildfire risk reduction grant programs [38]. Some prior research suggests that communities that have experienced wildfire events and have high socioeconomic status may receive more investments in wildfire risk reduction projects [134], and that socially vulnerable communities may be less likely to receive federal mitigation funding [135]. One recent study found that consideration of environmental justice in decisions about where and how to conduct wildfire hazard reduction projects was inconsistent across a sample of national forests, and dependent on local context and agency decisions at local scales [136]. Therefore, we hypothesize that BSFs may be a key component of this local context in that they may help produce and organize necessary capital and resources.

Particularly in areas where a density and connectivity of BSFs thickens over time, momentum may grow as actors move away from parallel play and towards more visible coordinated collective action. Areas with well-organized, visible boundary spanning arrangements may be able to demonstrate criteria such as a history of collaboration and a strategic plan of prioritized actions, and increasingly able to acquire resources that then further build their capacity. Broader-scale actors external to these areas, such as agency leadership or nonprofit intermediaries, can further foster this momentum through sense-making in stories, communications products, or peer learning that further legitimizes and elevates the visibility of certain efforts. Research may further compound this unevenness if it focuses on prominent case studies of communities or projects that appear successful. At the same time, other places with less visible or formalized trajectories may struggle to gain this momentum or be challenged to even initiate trajectories in a policy environment that typically demands a track record and evidence of BSFs to warrant investment. Yet, the work of building and using these features itself typically requires resources, particularly to sustain the operations of boundary organizations or to produce technically or scientifically intensive boundary objects. To explore this hypothesis, future research could characterize not just the socioeconomic status of communities relative to levels of investment but also their socio-organizational structures, including the presence or absence of various arrangements of BSFs and their ability to engage external boundary settings such as policies and programs to draw resources.

6. Conclusions

This paper has provided several conceptual contributions to understanding of wildfire risk management and the challenges of spanning boundaries in that domain. We offered a characterization of four major types of boundaries in governing wildfire risk, suggesting that in addition to landownership, there are organizational, functional, and conceptual boundaries that challenge collective action. We also provided a review of major BSFs—organizations/people, objects, concepts, and settings—and frameworks that integrate them. This review allowed us to then articulate several hypotheses for application of boundary spanning theory to wildfire management. We identified numerous examples

of BSFs present in wildfire management, and questions for future research about how those may act to span the different types of boundaries, their outcomes, and their potential interrelationships. Our intent was to generate new thinking about what challenges collective action in wildfire management. We also suggest a few potential implications for policy and management.

One implication is the need to make policies and manage wildfire risk with more understanding of the multiple boundaries in wildfire management. Landownership and functional boundaries in wildfire are more visible, and therefore have been addressed more directly in policy and received more attention in research. Characterizing and working to overcome the more abstract organizational and conceptual boundaries is a more challenging task. Moreover, each type of boundary is interrelated with others, compounding the complexity of wildfire management. For instance, landownership boundaries are inherently difficult to manage across because they involve actors divided by functional, organizational, and conceptual boundaries.

Another implication is that policy and management approaches have largely provided more singular tools that target one boundary type at a time, and require competition for limited resources. The result appears to be trajectories of collective boundary work that (1) emphasize some boundary spanning features more than others, (2) may be inadequate to address all boundaries in wildfire management simultaneously, and (3) may be more achievable in areas with histories of coordination and resources. As the costs and impacts of major wildfire events continue to affect a broad array of communities and landscapes, it seems infeasible that every area will be able to afford and sustain a full suite of boundary spanning features. Agency leadership and political decisionmakers may need to more explicitly consider equity in program and policy design, and how to support communities that face substantial risk yet struggle to organize to address it. Results from the kind of research we call for could more precisely identify conditions under which certain boundary spanning features are key, and inform strategic interventions.

Given the multiple and powerful boundaries at hand in managing wildfire risk, the pull of the default state of "parallel play" will undoubtedly remain in many communities and at the national level. However, new insights into what drives collective action by overcoming these boundaries may help transcend that state. As wildfire continues to increase in frequency, severity, and impact, the pursuit of such insights will be critical.

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