Review

A Mixed Methods Literature Review and Framework for Decision Factors That May Influence the Utilization of Managed Wildfire on Federal Lands, USA

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Abstract: There is increasing discussion in the academic and agency literature, as well as popular media, about the need to address the existing deficit of beneficial fire on landscapes. One approach allowable under United States federal wildland fire policy that could help address this condition is by deliberately managing wildfire with a strategy other than full suppression (hereafter referred to as 'managed wildfire'). To improve the understanding of the managed fire decision-making process, we conducted a mixed methods review of the existing literature. This review spanned 1976 to 2013 and used thematic coding to identify key factors that affect the decision to manage a wildfire. A total of 110 descriptive factors categories were identified. These were classified into six key thematic groups, which addressed specific decision considerations. This nexus of factors and decision pathways formed what we describe as the 'Managed Fire Decision Framework', which contextualizes important pressures, barriers, and facilitators related to managed wildfire decision-making. The most prevalent obstacles to managing wildfire were operational concerns and risk aversion. The factor most likely to support managing a fire was the decision maker's desire to see the strategy be implemented. Ultimately, we found that the managed fire decision-making process is extremely complex, and that this complexity may itself be a barrier to its implementation.

Keywords: wildland fire use; prescribed natural fire; managed fire; wilderness fire; decision-making; suppression; framework

1. Introduction

Numerous scholars have noted that a century of fire suppression has contributed to a deficit of characteristic wildfire in many parts of the western United States [1–4] and that neither fire frequency nor fire-related effects is sufficient to maintain characteristic ecosystem function, goods, or services [3–8]. This recognition has led to increased interest, from fire managers to policy makers, in how fire can be safely and effectively reintroduced into these landscapes.

There are two main strategies for reintroducing fire. The first strategy, commonly known as prescribed fire, entails carefully and deliberately igniting fire to achieve land management objectives [9]. These burns are often conducted by professional land management agencies, private landowner cooperative groups or individuals, tribal entities, or non-profit landholders. Prescribed fire is referred to as 'planned fire' in US federal wildland fire policy as well as in other countries [10,11]. Prescribed fire as a management tool in North America has a long history, originating among the indigenous peoples who first populated North America [12,13], later used by early European settlers and private landowners [14], and eventually adopted by government land managers as early as the 1930's [15,16]. On

US federal lands, prescribed fires are subject to a formal environmental review and are implemented within strict prescriptive parameters designed to meet specified objectives. They are typically conducted outside of the characteristic season for wildfire in the local ecosystem, but within the margins of available burning conditions [4,12,14,15]. Recent research has shown prescribed burns are difficult to implement at the scale necessary to achieve landscape restoration goals [14,17].

The second strategy to reintroduce fire, used primarily on federal lands, occurs when the response strategy to new wildfires does not unilaterally focus on suppressing the fire at the smallest possible size within the shortest time frame. This strategy is currently referred to as managing the wildfire for an objective 'other than full suppression' (OTFS) in federal reporting documents such as the National Interagency Fire Center (NIFC) Incident Management Situation Report (IMSR) but has been known by other names in past policy iterations, including 'Wildland Fire Use fires' [18]. For the sake of simplicity, the OTFS term is usually shortened by wildfire professionals to 'managed fire.' This strategy often entails managing the wildfire in a manner that achieves ecologically beneficial outcomes. Under current US policy, the OTFS strategy may be implemented either on the entire fire, or on segments of the fire [11]. This is a change from pre-2009 wildfire policies that required wildfires to be managed for either suppression or resource benefit, but not both simultaneously [18]. The current policy allows for all unplanned fires to be managed for suppression objectives, or for resource benefit objectives (or both), but is ambiguous regarding when and where the appropriate usage of these strategies should be employed. An OTFS strategy often requires local pre-planning to have been completed, such as amending the Land Management Plan, to allow for its use as a management tool [19–21]. Additionally, external regulatory agencies such as air quality districts address OTFS wildfires as a planned land management action rather than an emergency response [22]. Without careful dialogue and mutual understanding, land managers may be inadvertently sending mixed messages to collaborating agencies regarding the true strategic intention during wildfires managed for OTFS [22].

Although the strategic outcome of managed fire is largely the same as that of prescribed fire, it lacks the same project-specific prescriptive and administrative requirements that accompany prescribed fire implementation. Moreover, the desired end state objective of managed fire tends to be more open-ended, as these fires frequently burn for longer periods of time and have greater heterogeneity in their fire effects [5,23]. Recent studies have shown that managed fires can provide beneficial ecological effects on the landscape, especially where it has been used over a long period of time [24,25].

The ability to manage wildfires on US federal lands became a possibility in the 1960's [10,16]. In 1968, the National Park Service (NPS) became the first federal agency to officially allow managed natural fires [26]. The US Forest Service (USFS) followed suit to a limited degree in 1972 within designated areas of the Northern Rockies [16,27] and officially transitioned from a policy of 'fire control' to 'fire management' in 1978 via an update to the National Forest Manual, which also enabled the use of managed fire strategies [28,29]. In 1995, the first formal interagency fire management policy was adopted and included support for the use of managed wildfire on federal lands [30]. National wildland fire policy updates occurred in 2001, 2003, 2007, and 2009, all of which have encouraged federal fire decision-makers to find opportunities to use wildfire for positive outcomes [11,18,31,32].

Policy changes and updates have also changed the language used to describe managed fire. Official nomenclatures tied to significant policy changes or updates include 'Prescribed Natural Fire' (PNF), from 1968 to 1994, 'Wildland Fire Use' (WFU), from 1995 to 2007, and the brief use of 'Appropriate Management Response' (AMR), in 2008 [33]. Other terms we encountered in the literature include 'let burn,' 'natural fire,' and 'wilderness fire' [34,35]. After US wildland fire policy was updated in early 2009, the terminology shifted again; all vegetation fires became classified as either 'planned' (i.e., prescribed fire) or 'unplanned' (i.e., wildfire). An unplanned fire can be managed for 'resource protection' objectives or 'resource benefit' objectives, or both if the circumstances allowed [11,36]. In this review,

we use the term 'managed fire' as an all-encompassing phrase when a policy context is not otherwise stated and nomenclature (e.g., WFU, PNF) is used when a particular policy period is being referenced.

Although both recent academic and agency literature [37–43] have advocated the need to increase opportunities to leverage the use of managed fire to achieve the desired resource-based outcomes, studies explicitly exploring how and why decisions are made to manage rather than suppress a wildfire are limited. Decision-making that occurs during wildfire events has been shown to be complex, requiring the consideration of myriad factors [44]. Previous research seeking to identify and describe the principal factors affecting wildfire suppression decision-making, their influences, and the pathways these decision processes take have covered a range of subjects including sociopolitical pressure, resource allocation, ecological ramifications, and risk reduction [27,33,45–47]. However, these research efforts have focused more on the attributes of suppression-based decisions. Fire scientists and managers have long identified managed wildfire as an important component within the larger integrated fire management system to mitigate increasing wildfire impacts in the western US [48,49]. Despite this, little work has been completed to provide tools or knowledge to managers that might help them to identify potential pathways for expanding its generally limited application.

The purpose of this review is to identify what factors decision-makers consider in the decision to manage a wildfire for an objective other than full suppression. We analyze and synthesize literature that directly addresses decision-making in the context of managed fire to identify the range and relative influence of decision factors. A simple research question guided the review process: *Within the available scientific literature, what factors have been considered in the managed fire decision-making process, and how do they affect the decision made?* We hope this systematic assessment of known decision-making factors specifically related to the managed fire decision-making process can provide insights into potential future opportunities to manage wildfire as well as illuminate areas where further research on managed wildfire decision-making is needed.

2. Materials and Methods

A systematic process was used to identify publications that specifically addressed decision-making in the context of managed wildfire. Papers were sought that included data derived directly from federal land managers in the United States who possessed wildfire decision-making authority. Although we acknowledge that such data may exist in Australia and other countries with a rich legacy of both wildland fire management and policy, the focus of this review is solely on the US, given that social, cultural, and geopolitical factors vary widely across national views regarding fires. The methods used were modeled and adapted from those used in [50–53]. The search process was designed to be detailed and iterative. It included four separate search phases (Figure 1). Papers that met the inclusion and evaluation criteria were thematically coded and synthesized.

The primary literature search was completed using bibliographic databases of academic papers (e.g., Web of Science, JSTOR) as well as a purposive sample of previously discovered titles and researchers. Search terms were designed to locate literature that specifically examined decision factors used by fire managers in the context of managed wildfires. Example queries included phrases such as 'wildland fire use', 'let-burn', 'prescribed natural fire', and 'fire for resource benefit'. We limited our search to papers published after 1968, as US wildland fire policy did not allow for managed fire before this date [54]. The research in our review appeared soon after policy changes were implemented in the 1970's, continued through the late 1990's, and peaked during the WFU policy era of the early to mid-2000's. Although several papers were published after the 2009 policy update, these included data collected from before the changes took effect. Although we had hoped to gain a sense of whether the policy update had affected the decision process, no papers were found that deliberately sourced their data after the 2009 policy update. The most recent paper

included in this review was published in 2013, which we postulate was due to the research time lag or lack of research.
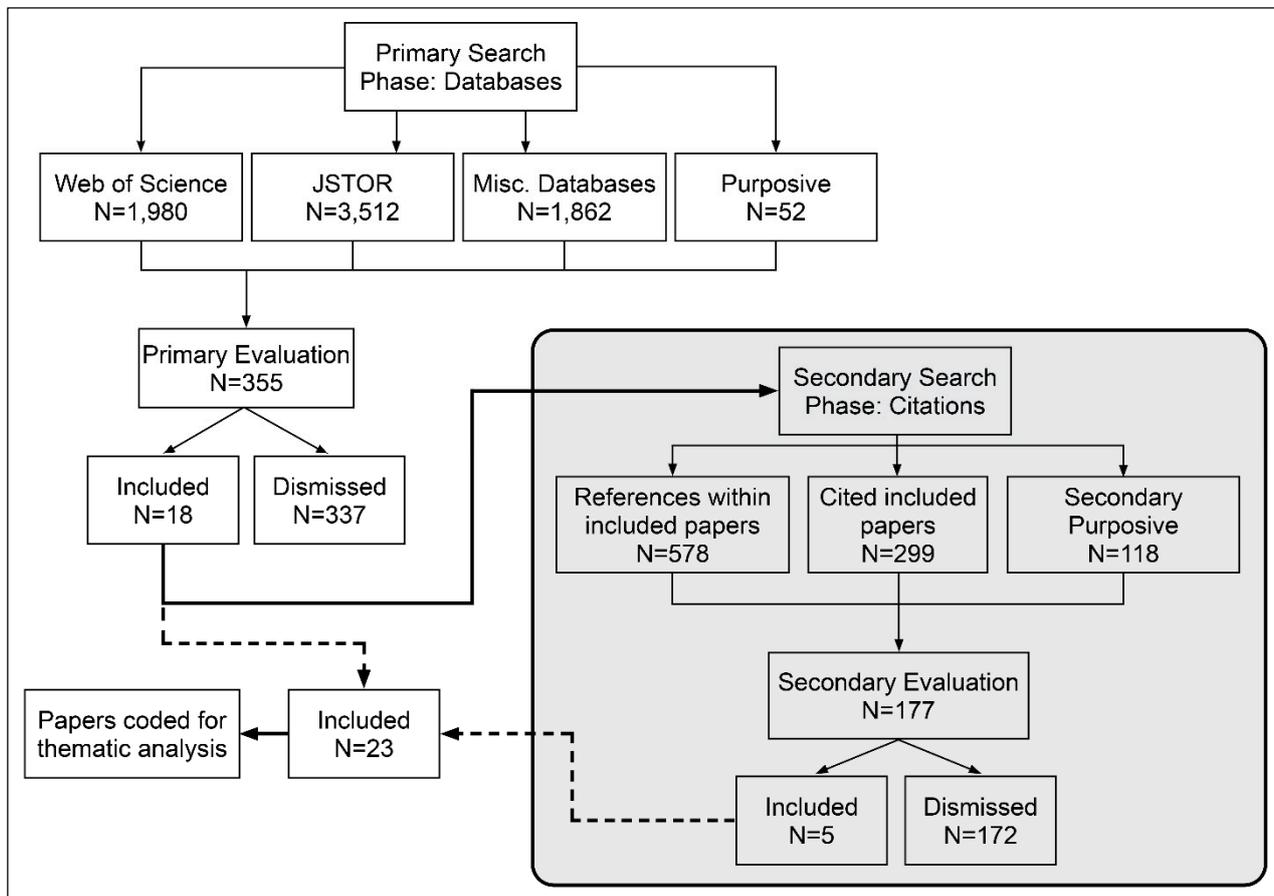
Figure 1. Visualization of the literature search and evaluation process. N refers to the number of papers evaluated at each phase. At each phase, abstracts or full paper texts were examined and compared to the inclusion criteria. Only those meeting the inclusion criteria were coded during the thematic analysis process.

Literature titles and abstracts were first assessed for consistency with the two primary inclusion criteria: (1) peer- or editor-reviewed, and (2) within the context of managed fire decision-making in the US. Papers that met these initial criteria were then examined in greater detail to ensure that papers directly addressed decision factors related to managed wildfire decision-making, with evidence derived from either original research or personal fire manager experience (Table 1). Finally, a second search, using a modified sourcing approach, was conducted. This phase assessed every citation contained within the final set of papers from the initial search, as well as every paper that cited one of them. Finally, we repeated this process for titles and researchers uncovered during the second search.

Table 1. All 110 descriptive themes organized under their respective Key Thematic Categories. The actual descriptive theme occurrence count is shown in parentheses. In total, 23 papers were coded.

Facilitators	Unaligned	Barriers
	Fire Environment	
Favorable fire behavior conditions (2)	Fire danger rating (4)	Fire conditions unfavorable (2)
Favorable climatic conditions (1)	Expected weather (3)	Fire danger too high (2)
Favorable fire weather conditions (1)	Drought index (2)	
Previous fuel reduction work (1)	Fuel type and condition (2)	

Table 1. *Cont.*

Facilitators	Unaligned	Barriers
Fire Outcomes		
Improvement to forest health (4)	Air quality concerns (6)	Uncertainty of outcome (6)
Allow natural processes in general (3)	Expected fire behavior (5)	Air quality–regulatory (5)
Expected future fire behavior (3)	Expected fire growth (5)	Air quality–public impact (4)
Reduction in fuel (3)		Lack of information (1)
Improved wildlife habitat (3)		
Reduce exposure to fire staff (2)		
Reduced suppression damage (1)		
Expected reduction in smoke impact (1)		
Sociopolitical Factors		
Collaborative relationships in place (7)	Public support (3)	Political fallout concern (8)
Public supports (5)	Impact to cooperators and neighbors (2)	Lack of public support (6)
Communication related to the event (4)	Impact to recreational users (2)	Conflict with cooperators (3)
Public has been educated (2)	Political support (2)	Economic impact (3)
Education opportunity for the public (1)	Economic impacts (1)	External input opposes (2)
Economic gain (1)	Opportunity to educate the public (1)	
Institutional Influences		
Cost savings (7)	Available funding (6)	Culture not normalized to WFU (5)
Policy supports natural role of fire (5)	Policy details (3)	Lack of resources–Financial (5)
Culture of fire use (5)	Differences of opinion (3)	Lack of agency support (4)
Agency supports (2)	Fire cause (1)	Post fire rehab–no money (2)
Planning completed (2)	Agency support (1)	Local-Regional prohibitions (2)
Technology and data support (2)		Not a priority (2)
Peer recognition (1)		Policy as a barrier (2)
		Financial cost–post fire (2)
		Policy misinterpretation (1)
		Reporting accomplishments (1)
Operational Considerations		
Previous fires make it easier (3)	Resource availability (5)	Lack of resources, Operational (10)
Understanding of local area (2)	Proximity to boundary (4)	Ownership boundaries (8)
No smoke impact (1)	Planning support (4)	Lack of resources, Planning (3)
No infrastructure at risk (1)	Coordination is in place (3)	Lack of dedicated training (2)
Better access in non-wilderness (1)	Expected duration of fire (2)	Fatigue length of time required (2)
Reduced resources need (1)	Preparedness level (2)	Existing fire load too heavy (2)
	Amount of fire allowable (2)	Insufficient ignitions (1)
	Experience with fire (1)	
	Fatigue of staff (1)	
Perceived Risk		
Personal ethic supports (9)	Risk to infrastructure (4)	Bias for suppressing wildfire (6)
Personal satisfaction (1)	Acceptable risk levels (3)	Threat to infrastructure (6)
	Risk to human life (3)	Threat to natural resources (5)
	Risk to natural resources (3)	Threat to public safety (4)
	Personal risk (2)	Stigma of failure (4)
	Risk of escaping boundary (2)	Concern for career advancement (4)
	Risk to firefighters (1)	Generalized risk aversion (3)
	Agency Administrator satisfaction with the plan (1)	Threat to private property (3)
	Confidence in staff (1)	Lack of incentive (2)
		Threat to firefighters (1)
		Lack of fire familiarity (1)
		Liability concerns (1)
		Threat to reputation (1)

Of the approximately 8400 publications that were peripherally or directly examined, only 23 met the full inclusion criteria. The 23 papers included in this review are described in Table 2. While it is possible that relevant papers were not identified through this process, after a retrospective examination, we believe that the literature included represents the primary body of literature that directly discusses decision-making factors in the context of managed wildfire in the United States.

Table 2. Literature included in the review as well as the research design, the authors' role in data derivation, and the policy context under which the data were collected.

Paper Citation	Research Design	Author's Role	Policy Context
Bonney, B.J. 1998. Use of alternative suppression strategies during 1994 on the Clearwater National Forest.	Case Study	Decision Maker	Prescribed Natural Fire
Bunnell, D.L. 1995. Prescribed natural fire planning considerations: conflicting goals.	Case Study	Researcher	Prescribed Natural Fire
Daniels, O.L. 1976. Fire management takes commitment.	Case Study	Decision Maker	Prescribed Natural Fire
Daniels, O.L. 1991. A Forest Supervisor's perspective on the prescribed natural fire program.	Case Study	Decision Maker	Prescribed Natural Fire
Desmond, J. 1995. Interagency wilderness fire management.	Case Study	Fire Manager	Prescribed Natural Fire
Devet, D.D. 1976. DESCON - Utilizing benign wildfires to achieve land management objectives.	Case Study	Fire Manager	Prescribed Natural Fire
Doane et al. 2006. Barriers to wildland fire use: a preliminary problem analysis.	Qualitative research	Researcher	Wildland Fire Use
Hunter, M. 2007. Wildland fire use in Southwestern forests: an underutilized management option?	Case Study	Researcher	Wildland Fire Use
Kolden, C.A. and T.J. Brown. 2010. Beyond wildfire: perspectives of climate, managed fire, and policy in the USA.	Qualitative research	Researcher	Wildland Fire Use
LaSalle, V.J. 1995. A vision for the future of fire in wilderness.	Case Study	Decision Maker	Prescribed Natural Fire
Miller, C. and P. Landres. 2004. Exploring information needs for wildland fire and fuels management.	Qualitative research	Researcher	Wildland Fire Use
Mutch, R. 2008. Wildland fire use: incentives and disincentives. Case Study.	Case Study	Researcher	Wildland Fire Use
Poncin, D.B. 1995. Prescribed natural fire strategies and tactics.	Case Study	Fire Manager	Prescribed Natural Fire
Steelman, T.A., and S.M. McCaffrey. 2011. What is limiting more flexible fire management–public or agency pressure?	Qualitative research	Researcher	Appropriate Management Response
Steelman, T.A., and S.M. McCaffrey. 2013. Best practices in risk and crisis communication: implications for natural hazards management.	Case Study	Researcher	Appropriate Management Response
Tomascak, W. 1991. Improving a prescribed natural fire program: the Northern Region's approach.	Case Study	Researcher	Prescribed Natural Fire
van Wagtendonk, J.W. 1995. Large fires in wilderness areas.	Case Study	Researcher	Prescribed Natural Fire

Table 2. *Cont.*

Paper Citation	Research Design	Author's Role	Policy Context
Wildland Fire Lessons Learned Center (WFLLC). 2005. Initial impressions report: wildland fire use.	Qualitative research	Researcher	Wildland Fire Use
Wildland Fire Lessons Learned Center (WFLLC). 2006. Wildland Fire Use: lessons from the past and present that impact local fire and fuels management programs.	Case Study	Researcher	Wildland Fire Use
Williamson, M.A. 2005. Influences on the decision to authorize wildland fire use.	Qualitative research	Researcher	Wildland Fire Use
Wilson, R.S., P.L. Winter, L.A. Maguire, and T. Ascher. 2011. Managing wildfire events: risk-based decision making among a group of federal fire managers.	Qualitative research	Researcher	Wildland Fire Use
Zimmerman, G.T. 1999. Appropriate management responses to wildland fire: options and costs.	Case Study	Researcher	Wildland Fire Use
Zimmerman, T., M. Frary, S. Crook, B. Fay, P. Koppenol, R. Lasko. 2006. Wildland fire use–challenges associated with program management across multiple ownerships and land use situations.	Case Study	Researcher	Wildland Fire Use

2.1. Coding and Thematic Analysis

The papers that met our inclusion criteria were loaded into the NVivo 12 Plus qualitative data analysis software [55], read line by line, and coded using an inductive 'grounded theory' strategy [56]. This approach to coding is useful for allowing factors and category themes to develop organically, without a predetermined codebook [50,52]. The code and theme description language was continually adjusted during the coding process until consistent representations of decision-making factors were derived.

2.2. Topic Codes

In the initial review of the literature we observed that decision factors could be alternatively discussed as a barrier, a facilitator, or sometimes even described without a clear indication of the effect on a final decision. To represent these observed differences, we created the overarching topic codes we called Barriers, Facilitators, and Unaligned. Barriers served to persuade the decision away from managing a wildfire; these were often obstacles that needed to be mitigated. Conversely, Facilitators made the decision to manage a wildfire easier to make for fire managers. Unaligned factors existed as a consideration, but with no clear effect on the decision on a particular fire, and are likely context dependent in their influence. In this review, we will use capitalization when referring to a specific Barrier, Facilitator, or Unaligned factor that was derived from our thematic coding.
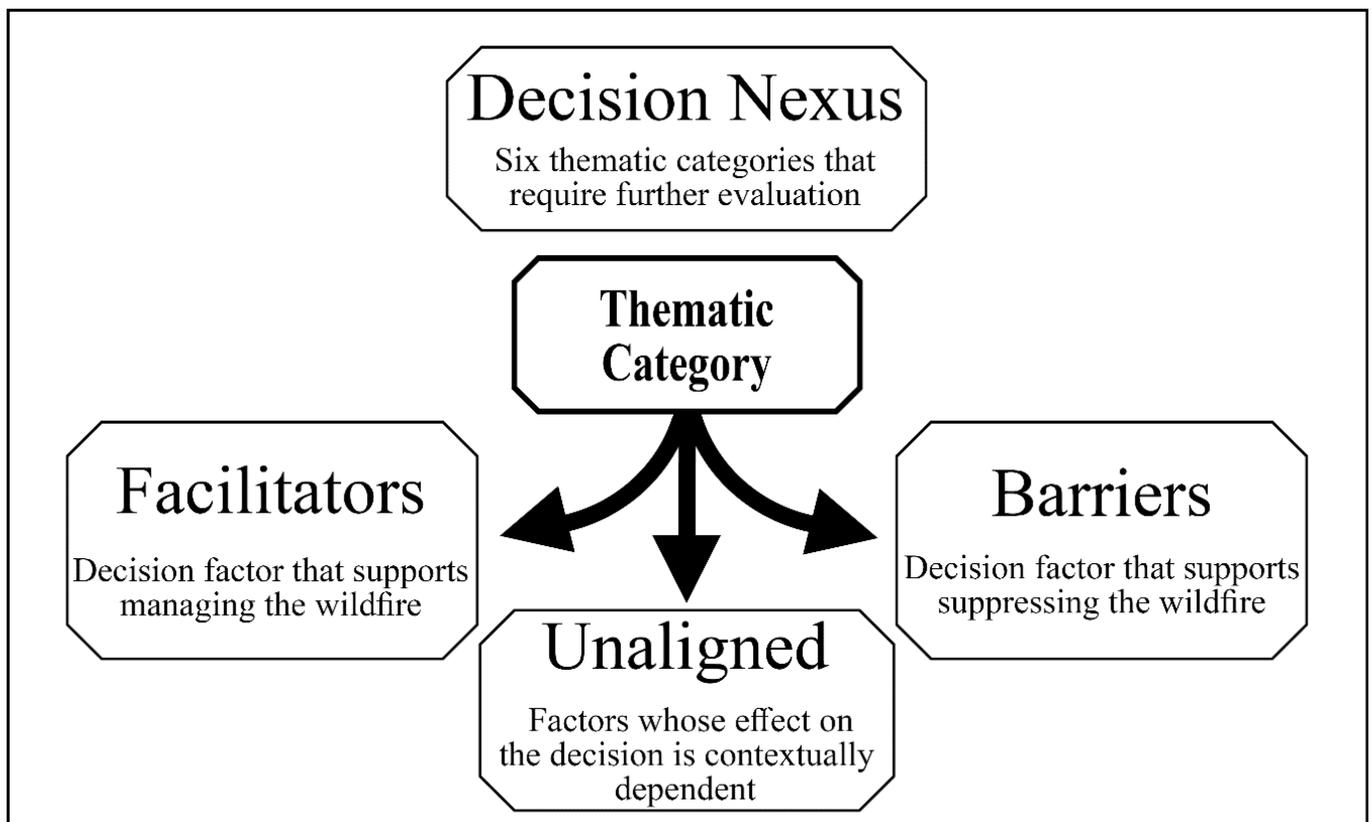
2.3. Descriptive Categories

Next, we coded to identify descriptive categories. These categories characterized specific decision factors reported within a paper to affect the decision-making process. These factors were coded to specific descriptive categories as well as one of the three topic codes. For example, if a decision maker remarked that times of high fire danger were not the best time to implement managed fire, the language was coded as 'fire conditions unfavorable,' and was also coded under 'Barriers.' This process was repeated wherever a specific decision factor was identified in a paper. Because we were coding for factor presence, descriptive themes were only coded once per paper. The clearest example of

each descriptive theme was kept if multiple examples were found. In total, 110 descriptive categories were derived from the coding process.

2.4. Key Themes

During the descriptive coding, similarities across categories began to emerge and, as a result, 110 descriptive categories were subsequently grouped into a set of six organizing principles that we describe as 'key themes.' These thematic categories operated as a nexus between topic codes and descriptive categories and provide an analytical framework for understanding decision-making. The key themes are described as the Fire Environment, Wildfire Outcomes, Sociopolitical Factors, Institutional Influences, Operational Considerations, and Risk Perception. This final organization resulted in all 110 descriptive categories being classified under both a topic code and a key theme within the final Framework (Figure 2). For example, the descriptive category 'favorable climatic conditions' is classified under the Fire Environment key theme as well as the Facilitator topic code. The final Managed Fire Decision Framework is a visualized arrangement of all the Barrier, Facilitator, and Unaligned descriptive categories organized under six key themes. We discuss the Framework in more detail in the Discussion section.

Figure 2. Thematic Category decision flow within the Managed Fire Decision Framework.

3. Results

The complexity associated with making managed wildfire decisions is immediately evident in the first descriptive coding iteration, which identified 110 specific categories. Of these, 36 were considered Unaligned, 41 as Barriers, and 33 as Facilitators. Unaligned factors were reported in 9 of the 23 included publications, whereas at least one Facilitator or Barrier was reported in 21 of 23 papers. The most frequently occurring descriptive category was the Barrier 'lack of resources: operational.' Among Facilitators 'personal ethic supports' was the most prevalent, and among Unaligned, 'available funding' and 'air

quality concerns' co-led in frequency. Table 2 lists all descriptive categories, how often they occurred, and their respective key themes.

3.1. Fire Environment

Fire Environment factors related to local physical conditions that influenced the decision-making process. Unaligned factors appeared to operate as background contextual elements; items were mostly considered prior to new wildfire ignitions with no clear indication of how they may ultimately influence the final decision. Several authors reported that, along with fire location, getting a sense of what the fire is likely to do if left to burn was among the first evaluation tasks required of fire managers [33,57]. The current fire danger rating was the most frequently reported Unaligned factor [33,57,58]. Other considerations included the state of the fuel bed [35,57] and expected near-term weather patterns [57,59,60]. These factors were often associated with discrete metrics or descriptive rating scales such as fuel moistures, fuel loading, or the Energy Release Component. As these factors are measured and recorded over long periods of time, they allow for a direct comparison of past conditions to potential future fire behavior [27,60].

Fire Environment Barriers were identified when conditions were associated with the potential for large fire growth, such as a high fire danger rating, or when excessive fuel loadings were present [20,61,62]. Facilitators were described when either the short-term weather or seasonal climatic conditions were favorable [61,63]. Previous fuel management work in the area also helped facilitate the decision, as did a belief that favorable fire behavior would be present while managing the fire [57,61,64]. Overall, findings across papers suggest a preference for managing wildfires when fuel and weather conditions were moderate, or when end-of-season events were closer at hand. One study found an interesting relationship, where 94% of the managed fires studied occurred during wetter La Niña climatic conditions [63].

3.2. Fire Outcome

Fire Outcome factors related to potential positive and negative effects if a fire were to burn. These outcomes could manifest at different time scales and were largely conjectural. Unaligned Fire Outcome descriptive categories considered what the direct and indirect effects of a managed wildfire were expected to be. Air quality was the most often identified consideration [35,60,65], with decision makers evaluating air quality acceptability [58], ambient visibility [59], and potential air quality impacts to adjacent residential valleys [57]. Managers also sought information regarding potential burn patterns and whether the fire would burn within the natural range of variability [35,57–59,65].

Fire Outcome Barriers generally focused on uncertainty regarding two distinct air quality concerns: regulatory and public impacts. Regulatory concerns generally related to the implementation of the federal Clean Air Act, the management of which is delegated to the state level [10,58,66]. Decision-makers were concerned that managed fires may be viewed by air quality regulators as planned events, thereby subject to air quality standards similar to prescribed fire [35,67,68]. When managed fires exceed air quality standards, land management agencies are potentially subject to considerable fines. Air quality standard exceedances were also described as potentially leading to interagency distrust and limitations to future managed fire events [68,69]. The complicated patchwork of air quality oversight across state agencies was also seen as a Barrier [67,68]. The second air quality Barrier related to the impact of smoke on the public, especially from managed fires close to communities. Several papers reported reluctance to manage fire due to their belief that the public views them as unnecessarily polluting the air [20,62,67]. Concern about negative community feedback also appears in the Sociopolitical Factors and Perceived Risk key themes.

A generalized lack of certainty regarding what the outcomes of a fire would be was another common Fire Outcome Barrier [59,67,70]. Although uncertainty is also related to risk aversion, several papers specifically defined uncertainty as present in the decision

process without directly tying it to measures of likelihood or consequences. The uncertainty in outcome was sometimes enough to create a disincentive to managing a fire [68].

Outcome Facilitators tended to focus on the expected beneficial outcomes from managing the fire. The most frequently reported Facilitator was an expected improvement to forest health and ecology [20,57,59,62]. Reduced fuel loads were also a potential benefit, as was hope for an improved wildlife habitat [20,57,62]. Some decision-makers saw benefits in simply letting natural processes occur on the landscape [20,62,71].

3.3. Sociopolitical Factors

Sociopolitical factors focused on external influences on managed fire decision-making: the potential impact of managed fire on external stakeholders, recreational users, adjacent landowners, and cooperating agencies, including businesses dependent on public lands such as outfitters and loggers [27,57,59]. The potential interest level of the public and political entities was also considered [20,58,60,65].

The reaction of the public, elected leaders, and cooperators was a dominant Sociopolitical Barrier. As federal lands are managed for the public, political entities can create a real or perceived leverage over decision-makers. As such, the most prevalent Barrier was the potential political fallout if a wildfire were to be managed rather than suppressed [33,60,62,72–74]. Another Barrier occurred when decision-makers felt that the public held a negative view of managed fire, especially if previously managed fires had led to negative outcomes [33,68,73]. Both [20] and [60] found that public opinion exerted considerable negative pressures on managed wildfire decisions.

Conversely, public opinion could also help facilitate managed fire decisions. The most frequently occurring Sociopolitical Facilitator related to strong collaborative relationships being in place prior to the decision to manage a fire. Relationships with neighboring landowners, wilderness users, and cooperating fire agencies were particularly important [20,23,33,35,65,72,74]. The public's influence also appeared as a Facilitator in instances where the public had shown previous support for managed fires [20,57,70,75]. Relatedly, several papers documented that the decision to manage fire was easier to make when local community members were known to understand fire's role as a natural process within forested lands or had even encouraged its wider application [57,67,75].

3.4. Institutional Influences

Institutional Influences reflected considerations internal to the land management agency. These included communication among individuals who work for the agency, bureaucratic concerns such as available funding and existing policy, and internal differences of opinion regarding the use of wildfire [20,27,57–60,65,72].

The most frequent Institutional Barrier reported was when fire cultures were not normalized to managing wildfire. Internal resistance to managed fire at both the organizational and individual level was broadly reported [20,60,71,74]. In his role as the Forest Supervisor overseeing the White Cap Wilderness Fire Study, O.L. Daniels wrote several times about his personal experience navigating the cultural shift from a suppression-biased program to one inclusive of managed fire [70,76]. Research published several decades later, after the 2001 policy update, reported the same Barrier when the implementation of WFU fires was outside the cultural norm of suppression at the local level [68,73]. Land managers with organizational values rooted in suppression as the default response were also described as more hesitant to integrate managed wildfire into their strategies and unsure whether a managed wildfire decision would be supported by their superiors [60,71].

Financial limitations also appeared frequently as an Institutional Barrier, primarily reflecting the pre-1995 policy that required local units to fund PNF's from their local budget allocations [57,58,70,72,76]. The later WFU period also created an inherent disincentive to managed fire due to the policy caveat that emergency stabilization funds were not allowed to be spent on WFU events [20,75]. Changes to policy over time and the resultant policy confusion was itself identified as a Barrier. One report described how many managers

perceived managed fire as only allowable within designated wilderness areas, despite the fact no such policy existed [68]. Within agencies, local and regional prohibitions on the practice were also identified as a Barrier [33,68,73].

Notably, Institutional Facilitators were also heavily influenced by fiscal considerations. The most frequently occurring factor was the potential to realize cost savings by managing the fire. Savings were expected to arise from implementing a strategy that used fewer resources than a traditional suppression response [20,27,33,61,62,77]. Publications from the mid-2000's described a desire to see lowered fire suppression costs, and reflected the fact that, as fire costs began to escalate in that decade, fire managers were being asked to find ways to reduce fire management costs [46,78]. One suggested way to help achieve cost reductions was to increase the scale of WFU incidents [20,62].

A local culture that supported the use of fire was another primary Facilitator, especially on land management units with a tradition of implementing managed fire [20,63,65,75]. An examination of fire practices on the Gila NF found that the acceptance of managed fire was related to a long-term commitment to foster a culture that both supported its implementation and recognized its potential ecological benefits [23]. Other papers found that the commitment and personal ethic of key organizational decision-makers served to move fire programs toward managing wildfires [58,60,70,72,76]. A national policy that explicitly supported the use of fire was also reported as a Facilitator and was even seen as causal in shifting opinions among fire managers [20,33,60,67,72]. Technological advances in pre-planning, air quality monitoring, and decision-support tools were also identified as Facilitators [20,65].

3.5. Operational Considerations

Operational Considerations primarily accounted for the amount and kinds of resources available to the decision-maker to implement a managed fire. This included personnel considerations such as the experience with managed fire, cumulative fatigue, the decision-maker's confidence in their staff, and confidence in their planning [58,60,65]. Other factors such as the regional, national, or local preparedness levels were related to availability of firefighting resources [35,57–59,65]. The fire's proximity to a management boundary was considered, especially when discussed in combination with the point in the season when a fire started [20,35,59,60,63].

The most frequently reported Barrier concerned whether insufficient operational resources would be available to staff a managed fire, especially during periods of significant resource drawdown late in the fire season [58,60–62,65,68,70,73]. Insufficient staff to help plan a managed fire was also a Barrier [58,62,73]. Papers also consistently reported a lack of desire to manage fires that had the potential to cross management boundaries [57,58,62,65,68,72,73]. One paper observed that a small fire close to the boundary was as concerning as a larger fire further away [35]. The long duration often required to manage fires was also a Barrier, particularly when there were other fires already being managed in the area, or when fatigue was seen among local staff [35,62,76].

Operational Facilitators were reported with less frequency and consistency than Operational Barriers. The most frequently identified Facilitator was the presence of previous fire burn areas that made it easier to implement the current managed fire [35,62,67]. Situations where agency staff had a long work experience were also a facilitator, as was the belief that fewer resources would be required to manage a wildfire than to suppress it [61,68].

3.6. Perceived Risk

Perceived Risk was expressed as the level of personal and professional risk decision-makers were willing to accept. The risk factors considered by decision-makers included firefighter and public safety, the risk of the fire escaping management boundaries, the risk to the infrastructure, and the risk to natural resources, as well as the potential career risk [20,35,57,60,65].

Risk Aversion as a Barrier was the most frequently reported concern in this entire review. This Barrier contained thirteen descriptive categories, which was the most within any of the six themes. Concerns driving risk aversion were often personal in nature, and included factors related to career advancement as well as a generalized sense that there was less risk in deciding to suppress fires. This risk-based bias for suppression was reflected in numerous papers [57,60,65,68,71,74]. Concern was found by managers about placing their careers at risk if a PNF left the intended management boundary [35,59,70]. Papers also reported that managers can be concerned about being stigmatized for deciding to manage a fire that later had to be declared a wildfire. Concern was also expressed about being held personally or legally liable in the event of adverse outcomes [58,60,76].

The possibility that values at risk might be threatened was another frequently reported Barrier, especially regarding possible threats to the built environment [27,59,61,62,67,77]. When noted, threats to human life addressed both an acute concern for public safety as well as the risk to firefighter lives [33,57,62,67]. Also identified in several papers was the risk to natural resources that managed fire might pose, including the potential impacts on endangered fish species or the potential to inadvertently spread invasive plants [20,59,60,62,67].

The most frequent Facilitator was where the decision maker possessed a personal ethic to manage wildfires [60]. A greater risk tolerance was observed when decision-makers personally valued the possible benefits of managing a fire [33,58,67,70,72,73,76]. The potential to reduce risk exposure was also identified, particularly when firefighters possessed an understanding of locally important terrain features and burn patterns [33,61].

4. Discussion

This review was conducted to identify the range of factors in the published literature that are considered in the managed fire decision-making process. We found an extremely broad array of factors that may be considered when deciding whether to manage a wildfire for an objective other than full suppression. While some factors were consistently identified in the literature as operating as a Barrier or Facilitator, others were simply described as something a decision-maker considered without directly indicating how it affected the decision, which we describe as Unaligned. Overall, 110 decision factors were found, which fell into six key thematic groups: Fire Environment, Wildfire Outcomes, Sociopolitical Factors, Institutional Influences, Operational Considerations, and Risk Perception.

Across the papers included in this review, barriers to managed wildfire were more consistently reported than facilitators. The fact that barriers were reported with more prevalence may indicate that decision-makers rarely begin the wildfire decision-making process from a stance of neutrality. It also may be, in part, an artifact from the research focus of most of the papers which tended to focus on identifying barriers. However, the greater overall number of barriers suggests that the decision to manage a wildfire is one that must be justified toward, instead of justified against, and that a truly neutral approach toward new ignitions is rare.

The findings from this review indicate that decision-makers have tended to view managed fire as an inherently risky endeavor. Such concerns are not unfounded, as managed fires have 'escaped' their intended boundaries and, on occasion, resulted in negative outcomes. Although these escaped fires may also result in negative ecological effects, the main concern was consistently sociopolitical in nature, such as decreased community trust, impaired air quality, and lost economic opportunity [79]. Interestingly, although papers often intimated a general fear that consequences may occur for the decision-maker, the only specific consequences described in the papers were limited to having to endure oppositional feedback and negative press. A sentiment was also seen whereby decision-makers indicated an expectation of perfect decision-making despite an imperfect decision environment. Under these circumstances, it is no surprise that decision-makers tend toward being conservative in accepting managed fire under their jurisdiction, as suppressing the fire allows them to accept less sociopolitical risk only at the expense of unknown rewards. We found no paper that described the criteria that must be met to allow a decision maker's

personal or professional fortitude to withstand negative attention in exchange for the reward of realizing positive landscape outcomes.

However, the findings did indicate that the cultural context within which decision-makers were operating can influence how risk was interpreted and acted on. As a component of wider socioecological systems, culture has been shown to influence the process of natural resource-based management decisions, including the circumstances under which risks (such as managing a wildfire) are accepted or rejected [80,81]. The literature in this review frequently reported that a key predicate for managing fire was the presence of a culture within the local fire management organization that supported its use. How this culture had been originally created was unclear but seemed to be something that built upon itself with time and experience. Statements bridging culture and policy were also common, with some papers suggesting that a policy that supports managed fire should, in and of itself, be sufficient to overcome cultural norms favoring suppression [20]. Ref. [82] similarly suggests that within federal wildland fire organizations, culture is formed by policies as well as norms. However, we saw no evidence across different policy periods of an institutional-level cultural shift away from suppression as the primary fire response strategy. Our findings indicate that the reluctance to manage fire has persisted across time and through numerous policy iterations, including the introduction of well-defined policies and procedures that otherwise supported broadening the scale of managed fire. However, our review did find evidence for cultural shifts toward managed fire at the scale of the individual and the local land management unit.

More recently, while examining how the 2009 policy update may have affected managed fire outcomes, [83] found evidence that the update provided opportunity for a greater number of managed fires to occur. However, they did not find a significant increase in the number of acres burned. In the context of this review, their results appear to suggest there may be a greater level of cultural acceptance for managed fire by decision-makers, but with a retained reluctance to allow managed fires to grow large. If this is true, the 2009 policy change may seem to allow decision-makers the ability to meet agency policy-based expectations while not also exposing themselves to the sociopolitical pressures associated with large fires.

Finally, this analysis has several limitations. First, only 23 papers ultimately met our inclusion criteria. As such, although we have suggested some potential dynamics that may be more critical than others based on the review, these should be interpreted with appropriate caution. This also limited the ability to assess the degree to which relevant factors may have changed over time. Perhaps the most important limitation is that while we classified decision factors into individual units to describe them, discussions within the papers often described a complicated network of factor interactions that were both individually and cumulatively considered. For example, if a fire environment factor such as low fuel moisture is present, fire managers may expect new fires to display extreme fire behavior. This expectation may move the response decision toward suppression. However, there may be plentiful firefighting resources available to point-protect values at risk, allowing more flexibility in the fire management approach. Or, even if there were few firefighting resources available, concern may be lower if the fire was distant from a management boundary or if it occurred late in the season. The potential network of interactions found in this review is multifarious. As such, implementing conditional or prescriptive decision-making processes for managed fire would likely be exceedingly difficult. Given the highly qualitative nature of wildfire decision-making, and the extensive latitude given to local managers to select courses of action, it should perhaps be no surprise that, within this review, the simple personal ethic of a decision-maker to want to implement managed fire was often seen as the most important facilitating factor in the decision
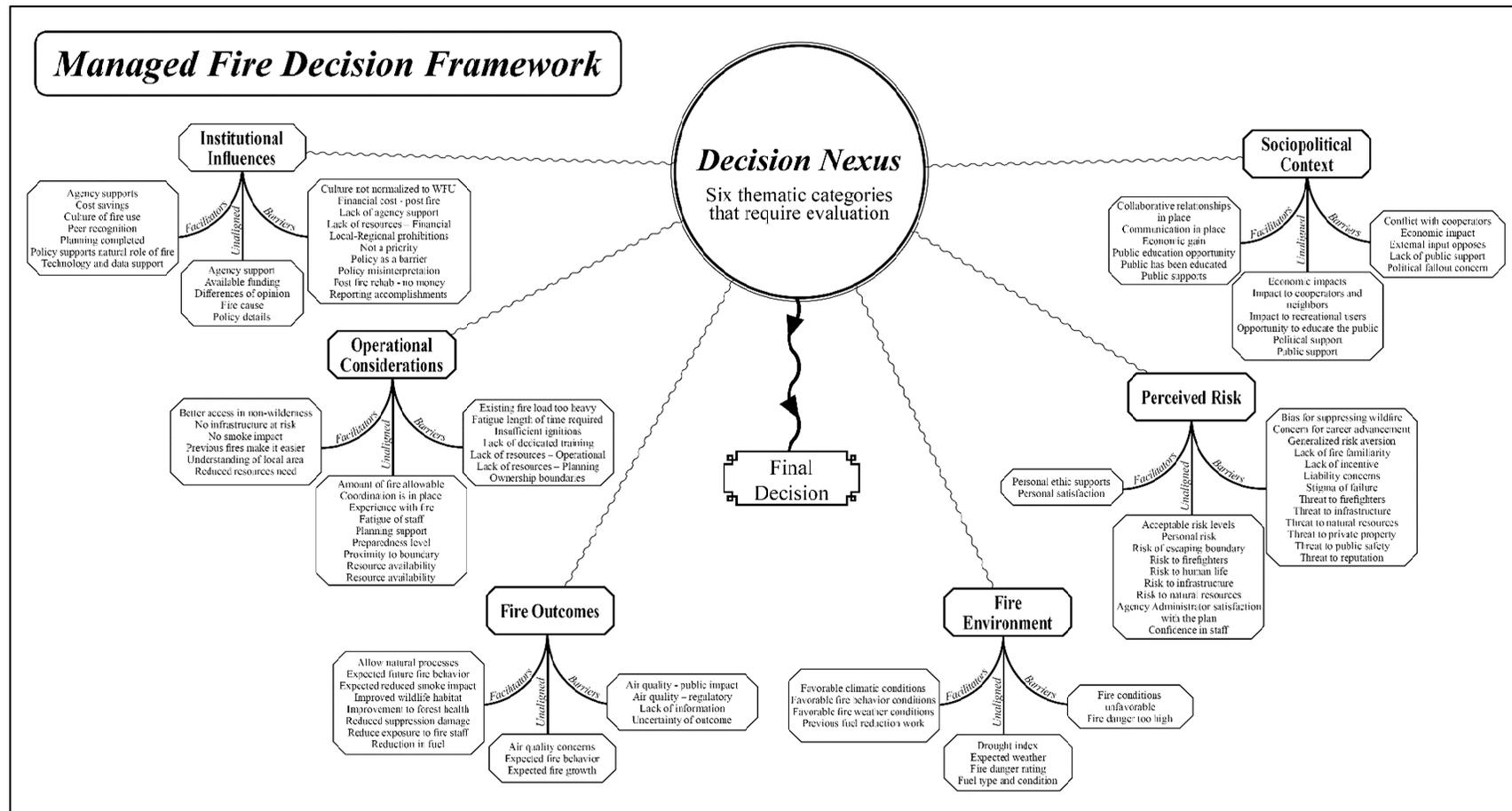
Managed Fire Decision Framework

The conceptual Managed Fire Decision Framework MFDF (Figure 3) began as a tool to help us organize the complexity associated with the managed fire decision-making we

observed during the coding process. However, the framework may have a wider potential applicability to future research efforts. For instance, future research could use the different decision factors identified in the framework to assess how different factors interact to shape decisions of whether to manage fire. The framework could also potentially be used to guide actual managed fire planning and implementation efforts at multiple levels by providing a consistent means to conceptualize and anchor conversations regarding managed fire, especially as efforts to increase the extent and scale of managed fires are explored.

The MFDF could also serve as a starting reference point for those working to address barriers and facilitators. It could be used to assess where barriers could be decreased or facilitators supported, essentially to enable a more systemic identification of potential leverage points at various levels of governance to facilitate an increase in managed fire implementation. It could also be used in the development of coursework around managed fire, which several papers in this review found to be absent from the training catalogue. The decision-making tools currently in use, such as the Wildland Fire Decision Support System [83] and Potential Wildfire Operations Delineations [84], and future decision support tools could also incorporate attributes of the framework [85].

It is important to note that the framework is not intended to provide a checklist that must be met, as not all the decision factors we identified here (or others that future research may identify) will be present in all situations. Also, as the number of Unaligned factors identified indicates, how a factor may affect the decision can depend heavily on the specific wildfire context under which it is considered. However, the literature to date suggests that all six key thematic categories at the core of the framework will be present in any wildfire decision-making process. Examining the relative influence of decision factors within those six key categories in the framework could create a useful structure to systematically identify not only critical barriers and facilitators, but also the gray areas of uncertainty that may need to be taken into greater account.

Figure 3. Managed Fire Decision Framework. Six key theme areas with their associated descriptive factors are connected to the central decision nexus. The final decision is made after incorporating elements of the key themes within the decision nexus. This is a qualitative decision, personal to the decision maker, with inherent uncertainty regarding the outcome.

5. Conclusions

There has been a consistent call to reintroduce beneficial fire in landscapes, as well as recognize the potentially important role managed fire could play in achieving this. Despite this, our literature review found surprisingly few scientific papers examining the managed fire decision-making process from the 50 year period it has been allowable under various federal wildfire policies. The key finding of this review is simply that there is a very large number of potential decision factors managers may be faced with when considering whether they wish to manage a wildfire for an objective other than full suppression. Although little can be said at this point as to how these factors interact, the number and complexity of factors alone creates an uncertain decision environment that favors personal and institutional risk aversion. This also suggests a need for more work to understand the interactions between factors and potential means of decreasing barriers and increasing the number and influence of facilitators.

Looking across these factors we see some potential reasons why, despite growing institutional support in the form of codified policy to support the goal of incorporating managed fire, the actual use of the managed fire strategy continues to be limited. Findings across papers suggest that wildfire decision-makers are under considerable internal and external pressure to make decisions that lead to favorable outcomes. The institutional default course to extinguish wildfire—thus removing both concern and uncertainty—is an attractive course of action. It is an acceptable and known practice and makes an otherwise complex decision much simpler. Although our review identifies a range of factors, including some that are more likely to act as a Barrier or Facilitator, in six key theme groups, it can only provide a general sense of how the various factors interact throughout the decision process. These factors may or may not be present on a given fire. They may operate singularly or in an interconnected manner. It is our hope that this review and the Managed Fire Decision Framework might provide a useful structure to guide future research efforts. For instance, future research could investigate whether there is a specific order to the factors that are considered, whether certain factors or thematic groups are more critical in decisions to manage fire, and, hopefully, identify potential leverage points that could be targeted to shift the balance of decisions away from default suppression.

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