BEST AVAILABLE SCIENTIFIC INFORMATION FOR WILDFIRE IN THE US SOUTHWEST: CURRENT NEEDS, BARRIERS, AND OPPORTUNITIES

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ABSTRACT

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Best available scientific information (BASI) – science that is identified as the most accurate, reliable, and relevant to the issues being considered – is increasingly sought after in wildfire and forest management contexts. Many land management policies now require the identification and use of BASI to make decisions, but little is known about how fire professionals access and exchange BASI to progress these efforts. This research aims to understand the most prominent scientific needs of fire professionals and the barriers that prevent their use of BASI in Arizona and New Mexico. I utilized a mixed-method approach to gather insights via semi-structured interviews and an online survey of fire professionals engaged in the Southwest Fire Science Consortium. Findings included the identification of four critical research areas where BASI can be expanded in the Southwest: (1) firefighter health, safety, and well-being, (2) planning strategies for fuels treatments, (3) post-fire ecological effects, and (4) strategies or factors related to increasing diversity, equity, and inclusion in fire science. Several barriers to current access of BASI emerged among participants, including difficulty keeping up with emerging science and conflict about what constitutes BASI in specific contexts. Barriers varied depending on respondent's job position and employer, allowing the development of recommendations for reducing barriers to BASI across the Southwest fire workforce. This research improves understandings of fire professionals' interactions with BASI and provides recommendations that science-exchange partnerships, research entities, and management organizations can use to improve the use of BASI on the ground.

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PREFACE

This thesis is presented in 4 chapters. The first chapter consists of an introduction. The second chapter is a whitepaper published by the SWFSC; we pronouns are used because the research was conducted by a team and the document is published. The third chapter is written as a standalone scientific manuscript, so redundancy may exist with other chapters. The fourth chapter is management implications and recommendations of the research. References are placed at the end of each individual chapter.

CHAPTER 1

INTRODUCTION

Wildfire management is becoming more complex in the US because of increasing fire severity, size, and frequency (Dennison et al., 2014; Minas et al., 2012; Singleton et al., 2019). These shifts are compounded by past forest management decisions combined with effects from climate change, intensifying fire behavior and effects (Covington and Moore, 2020; Mueller et al., 2020; Stephens et al., 2013) Additionally, expansion into the wildland-urban interface is placing more homes in the path of fires creating further complexities for fire managers who must work to protect values at risk (Radeloff et al., 2018). This is causing rapidly increasing structure loss as a result of wildfire; from 2020-2022, an average of over 8,000 structures a year burned in the US (NIFC, 2023). This escalation of worsening conditions has placed greater pressure on fire and land management professionals to maintain successful fuels management programs in and around the wildland-urban interface as efforts to establish resilient landscapes and fire adapted communities intensify (Mercer et al., 2008; Mueller et al., 2020).

The Southwestern US states of Arizona and New Mexico are experiencing these heightened fire seasons with abundant examples of damage caused from large wildfires. In 2002, the Rodeo-Chediski Fire burned over 468,000 acres and 400 structures (NIFC, 2002). The Wallow Fire burned over 538,000 acres and 70 structures in 2011 (NIFC, 2011). Most recently, an escaped prescribed burn turned into the 2022 Hermits Peak Fire burning over 341,000 acres and 900 structures (NIFC, 2022). Wildfires in the Southwest also follow the national trend of increasing fire size and severity (Dillon et al., 2011). Between 1984 and 2015, there was a statistically significant increase in the number of fires, area burned, high severity area burned, and percent high severity in forests and woodlands across the Southwest (Singleton et al., 2019).

These large and destructive wildfires lead to policy changes that affect how fire managers do their job (Ager et al., 2017). An example of this is the Healthy Forest Restoration Act of 2003 that was created after a series of significant fire seasons and events, including the 2002 Rodeo-Chediski Fire in Arizona; this act provided $760 million of funding annually for forest and fire managers to perform fuels reduction projects (Steelman and Burke, 2007).

Socially and ecologically destructive fire has placed significant pressure on forest management to produce a standardized method for identifying and applying science to land management decisions. This need led to policy changes that require managers to use best available scientific information (BASI) to make decisions and inform planning processes (Esch et al., 2018). In 2012, the Forest Service revised its planning rule – a policy that guides all land management plans within the National Forest System (Planning Rule USDA Forest Service, 2012). This revised planning rule included new language requiring the use of BASI to make management decisions and outlines a process for documenting its use. This is not the only high-level policy that mandates the use of BASI; for example, the Endangered Species Act and the US Forest Service Handbook include similar requirements. Additionally, agency-specific programs like the Collaborative Forest Landscape Restoration Program and Resilient Landscapes Program require the use of BASI (Esch et al., 2018). Federal agencies are legally required to follow the guidelines and requirements outlined in these documents and can be held responsible if they do not use BASI and document the process (Schultz, 2008).

The policies that mandate the use of BASI do not always provide consistent definitions or criteria for determining what BASI is which can lead to confusion and disagreement across organizations (Esch et al., 2018). The Forest Service provides one of the most used definitions of BASI in its 2012 planning rule. The rule states:

"the responsible official shall determine what information is the most accurate, reliable, and relevant to the issues being considered. The responsible official shall document how the best available scientific information was used to inform the assessment, the plan decision, and the monitoring program" (Planning Rule USDA Forest Service, 219.3, 2012).

The Forest Service Planning Directives guide published in 2015 expands upon the planning rule definition and outlines potential sources of BASI along with definitions for accurate, reliable, and relevant (FSH 1909.12, 2015). Other federal agencies provide fewer criteria for identifying BASI. For example, the 2006 National Park Service management guide mandates the use of best available science in management planning and defines BASI as:

"up-to-date and rigorous in method, mindful of limitations, peer-reviewed when appropriate and required, and delivered at the appropriate time" (NPS Directors Order, 7.2, 2006).

Some agencies fail to provide any information on criteria for determining BASI. For example, the US Fish and Wildlife Service requires use of the "best scientific and commercial data available" in the Endangered Species Act but gives no specific criteria to define these terms (Esch et al., 2018). This inconsistency across definitions leaves room for managers to personally interpret the policies while requiring them to take responsibility for the consequences of these interpretations in management decisions and outcomes.

Even though definitions of BASI can be inconsistent across policies, the use of BASI plays an important role in land management actions and decisions (Hunter, 2016). Fire professionals use BASI to improve decisions about wildfire risk as science supported decision can reduce uncertainty and improve credibility for managers (Colavito, 2021, Hunter et al., 2020). BASI is also used in planning efforts to develop treatment prescriptions, prioritize fuels treatment and projects, and to evaluate the effectiveness of current practices (Colavito, 2021, Hunter, 2016). In 2016 Hunter conducted research to see if published fire science is applied to management in the Southwest: the study showed that 44 of 48 randomly selected fire research projects informed fire and fuels managers in some capacity (Hunter, 2016). Application-based science is a tool fire professionals can use to when making fire-related decisions.

Recognizing the importance of funding application-based fire science, the Joint Fire Science Program (JFSP) was created by Congress in 1998 (JFSP, 1998). The JFSP is a federally funded program that provides support for research projects with direct management applications and aims to increase the use of science in management decisions (Kocher et al., 2012). The JFSP outlines its mission as "providing funding and science delivery for scientific studies associated with managing wildland fire, fuels, and fire-impacted ecosystems to respond to emerging needs of managers, practitioners, and policymakers from local to national levels" (JFSP, 2019). In 2009 the JFSP conducted a needs assessment to better understand why fire professionals were not always using science to make management decisions. The study found that fire professionals lacked access to some types of scientific information and felt there was a communication gap with scientists (Kocher et al., 2012). This spurred the creation of regional science exchange networks to better connect professionals across boundaries (Maletsky et al., 2018).

The Southwest Fire Science Consortium (SWFSC) is one of the original science exchange networks created by the JFSP. The SWFSC covers all of Arizona and New Mexico and small pieces of southern Utah and western Texas and aims to cultivate relationships between managers, scientists, and policymakers to share science and ideas across this region (Kocher et al., 2012, SWFSC, 2023). The SWFSC's mission is to "see the best science used to make management decisions and scientists working on the questions managers need answered" (SWFSC, 2023). Open communication between scientists and managers can help scientists ask the right questions, and managers trust the science being published (Hunter, 2016). These efforts have been largely successful, and professionals who are part of science exchanges feel that scientists value their opinion, have increased access to scientific information, and use that science in their positions (Maletsky et al., 2018). To better understand the questions managers and other fire professionals need answered, the SWFSC requested a research needs assessment to understand the needs of current exchange partners.

The study presented in this thesis aimed to provide a research needs assessment for the Southwest by surveying members of the SWFSC. There is a history of similar research needs assessments being conducted by other consortia in the fire exchange network. For example, the Northwest Fire Science Consortium conducted a study in 2018 to assess research needs of managers/practitioners. The study used 20 interviews and a survey with 167 respondents to assess research needs (Ellison et al., 2022). Other exchanges, like the Alaska Fire Science Consortium use data from outside sources to assess research needs; the Alaska Wildland Fire Coordinating Group publishes a research needs list every year, and the Alaska Fire Science Consortium adopts those recommendations (Colavito et al., 2019). In the Southwest, the most recent effort to assess research needs was a JFSP funded study conducted by the United States Geological Study (USGS) published in 2022. This study surveyed all fire science exchanges with the same set of questions to assess research needs; the Southwest portion surveyed 100 SWFSC members across 16 areas of fire science (Collins et al., 2022). The USGS study found that the SWFSC was perceived as performing poorly in five areas: smoke, air quality and health, invasive plant species, wildlife, economic impacts, social science, and human dimensions (Collins et al., 2022). This research expands on the USGS study by using a larger list of research needs and tailoring the survey instrument to explore regionally specific questions and additional question sets to gather information to improve BASI access and use among members.

The research needs of SWFSC members are directly connected to their ability to access science through dissemination efforts and science sharing relationships; inability to access certain types or areas of science may result in a false perception that no research exists on some topics. This research assessed how SWFSC members engage with the products and outputs and received feedback on how to improve. Additionally, this research aimed to improve understanding of SWFSC members' interaction and sharing of BASI to provide recommendations on supporting these interactions. In the Southwest there has been little research on the relationships between professionals in boundary organizations like the SWFSC (Grimm et al., 2022). These relationships can serve as one of the primary means of access to scientific information for some professionals (Kocher et al., 2012). Additionally, organizations like the SWFSC support knowledge coproduction and interaction between managers and researchers (Grimm et al., 2022). Improving the understanding of science sharing between members can help the SWFSC support existing relationships and better understand how to cultivate future interaction.

Chapter 2 is written in the form of a whitepaper for the SWFSC. The whitepaper reviews the findings from key-informant interviews with 15 present and prior board members and principal investigators of the SWFSC, referred to as board, and 161 survey responses from SWFSC members. The interviews were used to develop the online survey to provide answers in-line with the priorities of the SWFSC board. The survey aimed to answer questions on the membership base of the SWFSC, assess research needs in the Southwest, understand respondent

BASI interactions, improve the SWFSC's outputs, and allow respondents to give input on the future of the SWFSC. The whitepaper is written in easy-to-understand language with limited statistical analysis to make the document as accessible as possible.

Chapter 3 is written as a standalone scientific manuscript, with the intent to publish it in a peer-reviewed journal. Chapter 3 uses the same methodologies and data sources as chapter 2 but expands beyond descriptive statistics into more complex data analysis. The chapter includes information on where fire management and science expertise is located within the Southwest and what organizations and areas are missing expertise. Next, the chapter analyzes fire professionals use and access to BASI along with their preferences for scientific sources. Then, the chapter reviews the science-sharing relationships between organizations and positions in the Southwest. Finally, the chapter describes the barriers that prevent fire professionals from accessing and implementing BASI in their positions, and how these barriers differ across position types.

Chapter 4 is written as a short conclusion focused on the management implications of this research. The chapter provides recommendations for improving the dissemination of BASI. The chapter outlines recommendations made to the SWFSC. Finally, the chapter provides general management recommendations based on this research. Combined the chapters of this thesis aim to improve the understanding and use of BASI in the Southwest to encourage effective management practices that aim to increase the resilience of communities and ecosystems in fire prone areas.

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CHAPTER 2

CURRENT FIRE SCIENCE RESEARCH NEEDS: SOUTHWEST FIRE SCIENCE CONSORTIUM WHITEPAPER

1. Introduction

Wildfire management is becoming increasingly complex in the western US as managers work to address heightened fire behavior and longer fire seasons (Jain et al., 2017). Research-backed management decisions may improve overall management; however, not all research produced is always applicable and useful to managers, manager will be used to represent all positions involved in fire that are not conducting research (Hunter, 2016). This disconnect can be improved by ensuring researchers communicate with managers about problems, questions, and management strategies (Kocher et al., 2012). Strengthening communication between researchers and managers allows researchers to design, implement, and communicate relevant science so that managers can make the most informed decisions possible (White, 2009).

The Joint Fire Science Program is a federally funded effort that aims to improve fire science and fund research projects with direct management applications to increase the use of science in management decisions (Kocher et al., 2012). The Joint Fire Science Program outlines its mission as "providing funding and science delivery for scientific studies associated with managing wildland fire, fuels, and fire-impacted ecosystems to respond to emerging needs of managers, practitioners, and policymakers from local to national levels" (JFSP, 2019). In the fiscal year 2021, the Joint Fire Science Program funded six million dollars of fire research (DOI). This funding supports a lot of useful science, but ensuring it is communicated, translated, and implemented through fire managers can be difficult. With these problems in mind, the Joint

Fire Science Program created a network of fire science exchange consortia to provide the most relevant and current fire science to ecologically similar geographic areas (Maletsky et al., 2018).

The Southwest Fire Science Consortium (SWFSC) is one of the 15 fire science exchanges created by the Joint Fire Science Program. The SWFSC covers all of Arizona and New Mexico and small pieces of Southern Utah and Western Texas (Kocher et al., 2012). The SWFSC was created to foster relationships between managers, scientists, and policymakers to share science and ideas (SWFSC, 2023). The SWFSC started in 2009 with a mission to: "see the best science used to make management decisions and scientists working on the questions managers need answered" (SWFSC, 2023). The SWFSC is headed by a board of representatives from agencies and organizations across both Arizona and New Mexico and has an extensive membership of more than 800 managers and scientists. The SWFSC provides various online resources, including webinars, fact sheets, whitepapers, videos, and in-person events like field trips and workshops (SWFSC, 2023). Looking ahead, the SWFSC wants to ensure it accomplishes its mission and understand member preferences and needs better. This study aims to help the SWFSC by providing research needs and future direction.

Now that the SWFSC has been growing for more than a decade, a needs assessment for fire science in the Southwest is timely and poised to inform the next decade of best available scientific information. This whitepaper reviews the findings of a survey of SWFSC members, informed by key informant interviews, to identify current research needs among scientists and managers. This study was produced in partnership with the SWFSC, aiming to provide useful information for future decisions. The study used interviews with current and past board members of the SWFSC to develop an online survey. The survey was distributed to the entire mailing list of the SWFSC, and 161 usable responses were received. First, the study aimed to collect background information on SWFSC members, including demographic data, job types, and areas of expertise. Next, the study aimed to assess research needs in the Southwest based on respondents' personal scientific needs. Then, the study worked to improve the SWFSC products and better understand which products were most useful and least useful. Finally, the study asked about the future of the SWFSC and allowed respondents to give input on the direction of the SWFSC. This study sought to achieve three research objectives:

1. Identify the most significant research needs of survey respondents in the Southwest.
2. Determine opportunities and barriers for accessing and implementing the best available scientific information.
3. Provide recommendations to improve science exchange between scientists and managers based on findings.

2. Approach

A mixed-method approach was implemented to gather information about current fire science needs in two phases: (1) semi-structured interviews with key informants, followed by (2) an online survey.

2.1 Key informant interviews

Survey design was informed by semi-structured interviews with 15 of the SWFSC's current and prior board members. The SWFSC provided a list of all past and present board members, who were then contacted via email and invited to participate in this effort. The interviewees' depth of experience in the inner workings of the SWFSC and multi-decadal tenure in varied fire science fields allowed us to ask a variety of questions about past, present, and future fire science needs, and the role the SWFSC could play in assisting these advancements.

Interviewees were also asked about SWFSC outputs and products, as well as questions on the general trajectory of the SWFSC. Finally, interviewees were asked to give input on survey topics and structure. A copy of the interview protocol is attached in the appendix . Interviews were transcribed then analyzed using social science software QSR Nvivo to develop descriptive codes.

2.2 Online survey

Findings from key informant interviews and iterative feedback from the current SWFSC board informed the development of an online survey instrument to gather input from the broader SWFSC community. The survey questions are outlined in the results section. The survey and interview aimed to broadly answer the following questions:

1. What are the key research needs for fire management in the Southwest?
2. How have research needs for fire science in the Southwest changed in the last ten years?
3. Of the products and outputs the SWFSC produces, what are most useful to researchers and managers?

The survey consisted of six core sections: (1) basic background information about the respondents' experience, job position, and relationship with fire in the Southwest; (2) areas of expertise and research needs within them. Respondents were asked to select three fire science sub-fields (from an existing list of 18 sub-fields) that they felt most knowledgeable about. Respondents were then asked to report the current need for additional research across a range of sub-topics for each sub-field they had selected; (3) Respondents' use of scientific information, including the sources they use and which information they consider most useful; (4) barriers to implementing best available scientific information; (5) Respondent interactions with the SWFSC, including what products they use and how the SWFSC can better meet the need of members; and (6) demographic information. We consulted the Northwest Fire Science Consortium's needs assessment when creating the survey (Ellison et al., 2019).

The survey was sent to 813 email addresses and received 161 responses for a 20% response rate. We distributed the online survey to the entire SWFSC mailing list, used the SWFSCs social media to promote it, and encouraged members to share the survey. A reminder email was sent weekly during February 2022 to those who had yet to complete the survey. Survey data was compiled and analyzed using statistical analysis software SPSS to create simple frequencies and descriptive statistics (IBM SPSS).

3. Findings

3.1 Characterizing survey respondents

Survey participants were asked to self-report basic background and demographic information throughout the survey. Participants were allowed to select multiple options, so percentages may not add up to 100%. Respondents worked predominantly in Arizona (60%), and New Mexico (57%). Respondents worked primarily for federal agencies (56%) and universities or other academic entities (21%). Most survey participants described themselves as managers (48%) or researchers (34%). The most common vegetation types that participants worked in were ponderosa (73%), piñon-juniper (68%), and dry mixed-conifer (65%). The average participant had worked extensively in the Southwest, with a mean of 17.4 years of experience. Respondents were generally older too; 53% were between 45-64 years old, while around 27% were 18-44 years old. 66% of participants identified as male, and 33% identified as female. Participants were well educated across fields, with 31% holding a four-year degree, 31% a master's degree, and

25% a doctoral degree. Demographic information is displayed below in Table 1 and respondent job characteristics are displayed in Table 2.

Table 2-1: *Demographic information for survey respondents*

Variable Name	Variable Definition	Frequency or Descriptive
Age	Age of respondent	• 18-44 -32% • 45-64 - 53% • 65+ - 16%
Gender	Gender of the respondent	• Male 66% • Female 33% • Non-binary/other 1.5%
Education	Highest level of education completed by the respondent	• Highschool diploma or GED 4.4% • Associate degree 2.2% • Technical or trade school 3.0% • Bachelor's degree or other four-year degree 31% • Master’s degree 31% • Professional degree (e.g., MD, DSS, DVM, JD) 3.0% • Doctoral degree (e.g., Ph.D., EdD) 25%

Table 2-2: Job characteristics of survey respondents

Variable	Variable Definition	Frequency or Descriptive
Experience	Number of years the respondent has been engaged in Southwestern fire management or science	• Mean 17.4 years • Standard Deviation 10.1 Years
Work location	The Southwestern state(s) that the respondent predominantly works in	• Arizona 60% • New Mexico 57% • Utah 14% • Texas 8.1% • No Southwest experience 3.7%
Organization	Primary organization or agency that the respondent works or volunteers for	• Federal Agency 56% • University or other academic entity 21% • Private business, contractor, or consultant 8.1% • Non-governmental or non-profit 7.5% • State agency 6.2% • Tribal entity 5.6% • City or county 4.3% • Community forestry or community-based collaborative 3.7% • Private landowners or community representative 2.5% • Retired 6.8%
Position	Identified current job title or position of the respondent	• Manager 48% • Researcher 34 % • Outreach, communication, or education specialist 13% • Private contractors or business owners 3.7% • Non-governmental or collaborative employees 3.7% • Students 3.1% • Private property owners or community representatives 1.9% • Local municipality or county employees 1.9% • Politicians or policymakers 0% • Other 3.7%
Vegetation	Vegetation type that best describes the area(s) the respondent works in	• Ponderosa 73% • Piñon-juniper 68% • Dry mixed conifer 65% • Grassland 48% • Aspen 39% • Riparian 38% • Wet mixed conifer 37% • Spruce-fir 37% • Oak shrub 37% • Desert shrub 32% • Interior chaparral 26% • Sagebrush 24% • Alpine tundra 8.7% • Other 2.5%

3.2 Current research needs in Southwestern fire science

This survey aimed to determine the fire science research areas with the greatest need within the Southwest. First, respondents were asked to select the three sub-fields they were most familiar with in their line of work across a list of 18 sub fields within fire science. Sub-fields for this survey were identified via a combination of key informant interviews and a systematic review of abstracts for recent research related to fire science. Next, respondents were asked to indicate their current perceptions of research need for sub-topics within their areas of expertise. Respondents were allowed to add additional sub-topics that needed research in a textbox, however, few respondents chose to do so. Figure 1 below shows the distribution of respondent expertise across the 18 sub-field categories provided in the survey.

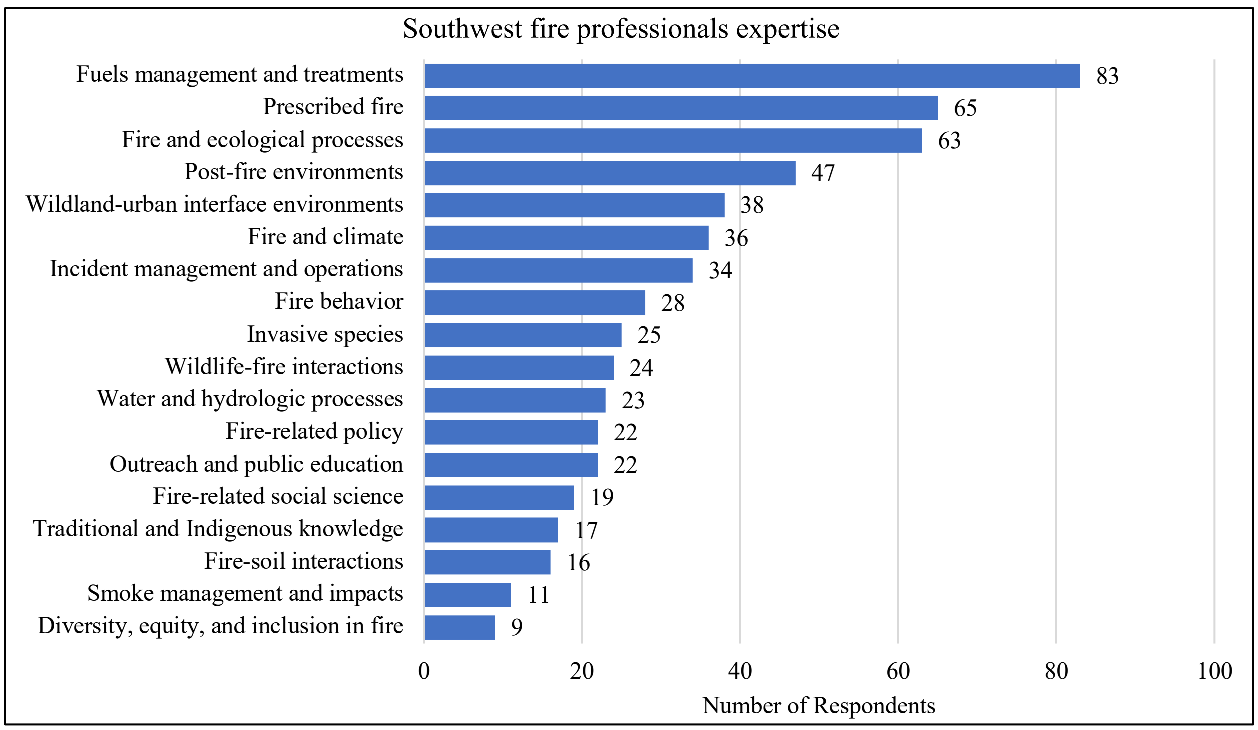

Figure 2-1: *Respondent area of expertise across the 18 research areas. Respondents were asked to select up to three topics from the list of research areas that you are the most familiar with in your line of work.*

Further information on responses related to each fire science sub-field is available in the pages below. Areas of research are ordered from respondents most selected areas to least selected. Significance of research need was calculated by averaging responses to the "significant need," "moderate need," and "slight need" categories. Sub-topics within the table are ordered from most significant need to least needed.

3.2.1 Fuels management and treatments

Fuels management and treatments was the largest area of expertise among survey respondents with 83 selecting this option (Table 3). There was high agreement that cross-boundary planning for fuel management is the most dominant research need, with 75% indicating a significant need. This was followed by the effectiveness of different fuel treatment techniques during fires, then the development and application of post-treatment monitoring programs. The least needed research in fuels management and treatments was optimizing the placement of fuels treatments.

Table 2-3: *Fuels management and treatments research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Cross-boundary planning for fuel management	75%	16%	8.0%	1.3%
The effectiveness of different fuel treatment techniques during fires	60%	23%	17%	1.3%
Development and application of post-treatment monitoring programs	54%	29%	17%	0.0%
Optimizing the placement of fuel treatments	50%	35%	13%	2.5%

3.2.2 Prescribed fire

Prescribed fire was the second largest area of expertise for survey participants, with 65 responses (Table 4). Prescribed fire use on private land represented the largest research need, with 57% of respondents selecting significant need and 32% moderate need, respectively. Federal barriers to prescribed fire was the most significant research need (59%). Planning for prescribed fires was ranked as the lowest research need, with 5.0% of respondents selecting no research needed.

Table 2-4: *Prescribed fire research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Prescribed fire use on private land	57%	32%	9.3%	1.9%
Prescribed fire effects	52%	40%	8.3%	0.0%
Federal barriers to prescribed fire	59%	25%	14%	1.8%
Non-federal barriers to prescribed fire (e.g., liability)	55%	33%	11%	1.8%
Smoke management during prescribed fires	46%	42%	11%	1.8%
Planning for prescribed fires	43%	45%	6.7%	5.0%

3.2.3 Fire and ecological processes

Approximately 63 survey respondents self-identified as experts in fire and ecological processes (Table 5). Impacts of invasive species on fire in the Southwest was the largest research need, with 58% of respondents selecting significant need and 0.0% selecting not needed. Environmental impacts of suppression was the least needed research area.

Table 2-5: *Fire and ecological processes research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Impacts of invasive species on fire in the Southwest	58%	36%	5.5%	0.0%
Range management and fire interactions	44%	35%	20%	1.8%
Grazing and fire interactions	39%	36%	23%	1.8%
Environmental impacts of suppression (e.g., dozers, retardant)	39%	32%	22%	7.4%

3.2.4 Post-fire environments

Post-fire environments was an area of expertise for 47 respondents (Table 6). Vegetation type conversions was the largest research need, with 76% of respondents selecting significant need and 20% selecting moderate need. Post-fire landscape management and risk mitigation efforts are the next highest areas of research need. The least needed research was related to Burned Area Emergency Response assessment and implementation, with only 37% of respondents selecting significant need and 22% selecting slight need.

Table 2-6: *Post-fire environments research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Vegetation type conversions	76%	20%	4.9%	0.0%
Post-fire landscape management	72%	26%	2.3%	0.0%
Post-fire risk mitigation efforts	70%	26%	4.7%	0.0%
Flooding, debris flows, mudflows, and other secondary hazards in post-fire environments	60%	33%	7.5%	0.0%
Cause and effects of reburns	46%	42%	12%	0.0%
Restoration and slope stabilization	46%	33%	21%	0.0%
Burned Area Emergency Response assessment and implementation	37%	39%	22%	2.4%

3.2.5 Wildland-urban interface environments

Wildland-urban interface environments were an area of expertise for 38 respondents (Table 7). Successful planning and zoning or development policy was the largest research need, with 74% of respondents indicating that it presented a significant need. Community recovery after wildfire was also highly ranked, with 74% of respondents selecting significant need. Firefighting strategies in the WUI and fire-resistant landscaping were the least needed areas.

Table 2-7: *Wildland-urban interface environments research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Successful planning and zoning or development policy	74%	21%	5.9%	0.0%
Community recovery after wildfire	74%	18%	8.8%	0.0%
Evacuation planning and communication	60%	29%	8.6%	2.9%
Home ignition zone management and best practices	50%	35%	15%	0.0%
Hazard mitigation in the WUI	50%	27%	21%	2.9%
Firefighting strategies in the WUI	38%	47%	5.9%	8.8%
Fire-resistant landscaping	35%	38%	24%	2.9%

3.2.6 Fire and climate

Fire and climate was an area of expertise for 36 respondents (Table 8). Managing fire regime changes posed the greatest research need, with 75% of respondents indicating there was a significant need for more science on this topic. Most of the respondents (72%) also agreed that applications of adaptation strategies had a significant research need. Experimental management (e.g., assisted migration) was the most divided subtopic, with 50% selecting significant need while simultaneously the largest number of not needed (3.8%) selected. Historic climate-fire relationships was the least needed research area, with only 41% selecting significant need and an equal number selecting moderate need

Table 2-8: *Fire and climate research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Managing fire regime changes	75%	21%	3.6%	0.0%
Applications of adaptation strategies	71%	25%	0.0%	3.6%
Climate change impacts on vegetation	50%	43%	7.1%	0.0%
Fire-monsoon-climate interactions	66%	31%	3.4%	0.0%
Climate change impacts on fire behavior and occurrence	57%	40%	3.3%	0.0%
Climate change impacts on wildlife and habitats	50%	43%	7.1%	0.0%
Experimental management (e.g., assisted migration of species)	50%	42%	3.8%	3.8%
Carbon dynamics	48%	33%	15%	3.7%
Historic climate-fire relationships	41%	41%	14%	3.4%

3.2.7 Incident management and operational firefighting

Incident management and operational firefighting was a topic of expertise for 34 respondents (Table 9). Firefighter health and wellbeing was the most significant research need (66%). Incident management and operational firefighting and several other topics presented a more even distribution of opinions on research need. Minimum impact suppression techniques/tactics (MIST) was the least needed research area, with only 24% of respondents indicating that it was a significant research need.

Table 2-9: *Incident management and operation firefighting research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Firefighter health and wellbeing	66%	28%	6.9%	0.0%
Managed or resource objective fires	55%	23%	13%	9.7%
Firefighter safety	40%	43%	13%	3.3%
Techniques and approaches to hazard and risk assessment	36%	52%	9.7%	3.2%
Use of technology to inform suppression	42%	39%	16%	3.2%
Potential Operational Delineations (PODs)	33%	48%	11%	7.4%
Effective suppression techniques	27%	50%	23%	0.0%
Decision support systems	23%	52%	26%	0.0%
After Action Reviews	33%	30%	37%	0.0%
Minimum Impact Suppression Tactics (MIST)	23%	27%	43%	6.7%

3.2.8 Fire behavior

Fire behavior was a topic of expertise for 28 respondents (Table 10). Fire-weather interactions was the largest research need (43%). While fire-weather interactions was not the highest significant need, it had a high percentage of moderate need (51%), low percentages of slight need (2.9%), and few identified it as not needed (2.9%). Fire behavior modeling and climate influence on fire behavior were the least needed research areas.

Table 2-10: *Fire behavior research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Fire-weather interactions	43%	51%	2.9%	2.9%
Changes in fire behavior over time	46%	33%	21%	0.0%
Fuel treatment impacts on fire behavior	50%	25%	25%	0.0%
Fire behavior monitoring	42%	38%	21%	0.0%
Climate influence on fire behavior	46%	29%	25%	0.0%
Fire behavior modeling	40%	36%	20%	4.0%

3.2.9 Invasive species

Invasive species was a topic of expertise for 25 respondents (Table 11). Invasive species management was the largest research need, with 77% of respondents indicating a significant need – one of the higher percentages throughout the survey. Changes in the geographic extent of invasive species was also a prominent research need, with 74% of respondents agreeing there was a significant need. Human influence on the presence of invasive species had the lowest research need of the subtopics within invasive species.

Table 2-11: *Invasive species research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Invasive species management	77%	18%	4.5%	0.0%
Changes in the geographic extent of invasive species	74%	13%	13%	0.0%
The effect of invasive species on fire behavior	61%	30%	8.7%	0.0%
The effect of invasive species on fire return intervals	57%	35%	8.7%	0.0%
Human influence on the presence of invasive species	61%	26%	8.7%	4.3%

3.2.10 Wildlife-fire interactions

Wildlife-fire interactions was a topic of expertise for 24 respondents (Table 12). Fire impacts to threatened and endangered species was the largest research need, with 65% of respondents indicating a significant need and none selecting slight need or not needed. The effects of fire on species migration was the least needed research area, with 38% of respondents selecting significant need.

Table 2-12: *Wildlife-fire interactions research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Fire impacts to threatened and endangered species	65%	35%	0.0%	0.0%
Impacts of fire severity patterns and mosaics to wildlife	68%	27%	4.5%	0.0%
Habitat fragmentation and degradation	68%	23%	9.1%	0.0%
Fire impacts to wildlife	48%	44%	8.7%	0.0%
Effects of fire on species migration	38%	43%	19%	0.0%

3.2.11 Water and hydrologic processes

Water and hydrologic processes were a topic of expertise for 23 respondents (Table 13). Secondary hazards in burned areas (e.g., debris flows, flooding) was the largest research need, with 61% of respondents selecting significant need and none selecting slight need or not needed. Watershed health and fire was the second most needed research area, with 61% of respondents selecting significant need. Fire effects on water quality was the least needed research subtopic.

Table 2-13: *Water and hydrologic processes research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Secondary hazards in burned areas (e.g., debris flows, flooding)	61%	39%	0.0%	0.0%
Watershed health and fire	61%	33%	5.6%	0.0%
Hydrologic changes in burned areas	56%	28%	17%	0.0%
Fire impacts and behavior in riparian areas	42%	42%	16%	0.0%
Fire effects on water quality	37%	47%	16%	0.0%

3.2.12 Outreach and public education

Outreach and public education was a topic of expertise for 22 respondents (Table 14). Public education was the largest research need, with 77% of respondents selecting significant need. Skill development for residents in fire-prone areas (e.g., chainsaw certification) and the formation and efficacy of collaborative groups were the least needed research areas within outreach and public education.

Table 2-14: *Outreach and public education research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Public education on fire	77%	18%	5.9%	0.0%
Public communication about fire risk and impacts	68%	21%	11%	0.0%
Fire science outreach to private landowners	61%	28%	11%	0.0%
Skill development for residents in fire-prone areas (e.g., chainsaw certification)	50%	28%	22%	0.0%
Formation and efficacy of collaborative groups	38%	50%	6.3%	6.3%

3.2.13 Fire-related policy

Fire-related policy was a topic of expertise for 22 respondents (Table 15). Barriers and opportunities for policy change was the largest research need, with 63% of respondents indicating a significant need and 31% indicating a moderate need. The next greatest research need is funding for forest health, restoration, and hazardous fuels reduction. The least needed research area is funding for fire suppression and management, with 29% of respondents perceiving it as a significant need.

Table 2-15: *Fire related policy research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Barriers and opportunities for policy change	63%	31%	6.3%	0.0%
Funding for forest health, restoration, and hazardous fuels reduction	53%	41%	5.9%	0.0%
State policies for prescribed fire	44%	50%	6.3%	0.0%
Carbon policy	59%	24%	12%	5.9%
Coordination across jurisdictions (e.g., Joint Chiefs' Partnership, CFLRP)	44%	44%	13%	0.0%
Funding for fire suppression and management	29%	59%	12%	0.0%

3.2.14 Fire-related social science

Fire-related social science was a topic of expertise for 19 respondents (Table 16). Matching communities with adaptation strategies was the largest research need, with 60% of respondents selecting it as a significant need. Social dimensions of post-fire recovery and public perceptions of wildfire risk reduction was the next greatest research need. Support or opposition for risk mitigation techniques is the lowest research need.

Table 2-16: *Fire-related social science research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Matching communities with adaptation strategies	60%	33%	6.7%	0.0%
Social dimensions of post-fire recovery	60%	27%	13%	0.0%
Public perceptions of wildfire risk reduction strategies	56%	31%	13%	0.0%
Public perceptions of fire management	63%	19%	19%	0.0%
Risk communication about wildfire	63%	19%	19%	0.0%
What extent research need for social vulnerability to fire	47%	40%	13%	0.0%
Organizational approaches to fire (e.g., collaborative groups, community organizations)	38%	56%	6.3%	0.0%
Creating fire adapted communities	56%	19%	25%	0.0%
Human behavior and decision-making about fire (e.g., evacuation behavior)	50%	25%	25%	0.0%
Economic impacts of fire	47%	27%	27%	0.0%
Impact on local fire practitioners (e.g., burnout, resource needs)	44%	31%	25%	0.0%
Relationships between fire events and insurance	36%	43%	14%	7.1%
Citizen-agency conflict	31%	38%	31%	0.0%
Engagement in mitigation programs (e.g., Firewise)	31%	15%	54%	0.0%
Media coverage and communication of fire management and mitigation	38%	25%	38%	0.0%
Support or opposition for risk mitigation techniques	40%	27%	20%	13%

3.2.15 Traditional and Indigenous knowledge

Traditional and Indigenous knowledge was a topic of expertise for 17 respondents (Table 17). Preserving cultural knowledge about fire was the most significant research need (77%). The next three subtopics – the impact of Indigenous fire use on fire regimes, application of cultural burning, and facilitating support for Indigenous fire use and management–were all identified as having equal research need, with 79% of respondents indicating a significant need. The least needed subtopic within traditional and Indigenous knowledge is effectively supporting cultural fire use via policy, although this was still prioritized by 69%.

Table 2-17: *Traditional and indigenous knowledge research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Preserving cultural knowledge about fire	77%	23%	0.0%	0.0%
Impact of Indigenous fire use on fire regimes	79%	14%	7.1%	0.0%
Application of cultural burning	79%	14%	0.0%	7.1%
Facilitating support for Indigenous fire use and management	79%	14%	0.0%	7.1%
Knowledge exchange between Indigenous and non-indigenous populations	71%	21%	0.0%	7.1%
Effectively supporting cultural fire use via policy	69%	23%	0.0%	7.7%

3.2.16 Fire-soil interactions

Fire-soil interactions was a topic of expertise for 16 respondents (Table 18). Erosion in burned areas was the largest research need, with 69% of respondents indicating a significant need. Soil hydrology followed closely behind, with 62% selecting significant need. Biocrusts was the least research need, with 18% of respondents selecting significant need.

Table 2-18: *Fire-soil interactions research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Erosion in burned areas	69%	23%	0.0%	7.7%
Soil hydrology	62%	31%	7.7%	0.0%
Burn severity	46%	46%	7.7%	0.0%
Postfire stabilization	46%	39%	7.7%	7.7%
Biocrusts	18%	64%	18%	0.0%

3.2.17 Smoke management and impacts

Smoke management and impact was a topic of expertise for 11 respondents (Table 19). Smoke impacts to firefighters was the most urgent research need, with 75% of respondents selecting significant need, 25% moderate, and no responses for slight or no need. Public communication about air quality and smoke impacts to the public followed as the second and third greatest research needs. Smoke mitigation during prescribed burns was the least needed research sub-topic within smoke management and impacts.

Table 2-19: *Smoke management and impacts research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Smoke impacts to firefighters	75%	25%	0.0%	0.0%
Public communication about air quality	63%	25%	13%	0.0%
Smoke impacts to the public	38%	63%	0.0%	0.0%
Policy and planning for air quality related to fire use and management	63%	13%	25%	0.0%
Household and community efforts to mitigate smoke impacts	38%	63%	0.0%	0.0%
Air quality research	38%	50%	13%	0.0%
Smoke mitigation during prescribed burns	25%	50%	25%	0.0%

3.2.18 Diversity, equity, and inclusion in fire

Diversity, equity, and inclusion in fire was a topic of expertise for nine respondents (Table 20). The top subtopics were inclusion of underrepresented groups in conversations and decision-making about fire and risk mitigation, gender equity and inclusion in fire-related fields, and equitable distribution of grants, funding, and resources for community risk reduction, identified by all participants as a significant research need. Equity and allocation of suppression resources was the least needed research area.

Table 2-20: *Diversity, equity, and inclusion in fire research needs*

Subtopic	Significant Need	Moderate Need	Slight Need	Not Needed
Inclusion of underrepresented groups in conversations and decision-making about fire and risk mitigation	100%	0.0%	0.0%	0.0%
Gender equity and inclusion in fire-related fields	100%	0.0%	0.0%	0.0%
Equitable distribution of grants, funding, and resources for community risk reduction	100%	0.0%	0.0%	0.0%
Access to and availability of materials in multiple languages	50%	50%	0.0%	0.0%
Environmental justice issues related to wildfire	33%	67%	0.0%	0.0%
Access to and geographic distribution of fire practitioners	20%	80%	0.0%	0.0%
Equity and allocation of suppression resources	25%	50%	25%	0.0%

3.2.19 USGS research comparison

In 2021 USGS conducted a survey of members across all 15 exchanges within the Joint Fire Science Program exchange network (see Meldrum et al. 2022). This included 810 SWFSC members, of which 100 responses were received. The USGS survey covered 16 areas of fire science and asked respondents to rate the SWFSC based on its performance in that specific area. The survey worked to understand what areas of science the SWFSC was failing to provide adequate information on. The USGS study found that the SWFSC was perceived as performing poorly in five areas: smoke, air quality and health, invasive plant species, wildlife, economic impacts, social science, and human dimensions. Our survey included very similar categories of science and the subtopics within these categories allow us to further understand where to focus efforts through the SWFSC. The following displays the five areas of research need identified through the 2021 USGS survey supplemented with additional information learned during our survey.

3.2.19.1 Smoke, air quality, and health

The survey allowed participants to select *"smoke management and impacts"* as a research area they were most familiar with in their work, and 11 survey respondents selected it. We had seven subtopics in the area of smoke management and impacts. Listed below are the seven topics, ranked from significant research need to least needed.

1. Smoke impacts to firefighters
2. Public communication about air quality
3. Household and community efforts to mitigate smoke impacts
4. Smoke impacts to the public
5. Policy and planning for air quality related to fire use and management
6. Air quality research
7. Smoke mitigation during prescribed burns

3.2.19.2 Social science and human dimensions

The survey allowed respondents to select *"fire-related social science"* as a familiar research area in their line of work. 19 respondents selected it and answered the questions. There were 16 subtopics in the area of fire-related social science. Below are the 16 subtopics listed, from the most significant research need to the least needed.

1. Matching communities with adaptation strategies
2. Social dimensions of post-fire recovery
3. Public perceptions of fire management
4. Risk communication about wildfire
5. Public perceptions of wildfire risk reduction strategies
6. Social Vulnerability to fire

7. Organizational approaches to fire (e.g., collaborative/community organizations)
8. Creating fire adapted communities
9. Human behavior and decision-making about fire (e.g., evacuation behavior)
10. Economic impacts of fire
11. Impact on local fire practitioners (e.g., burnout, resource needs)
12. Relationships between fire events and insurance
13. Citizen-agency conflict
14. Engagement in mitigation programs (e.g., Firewise)
15. Media coverage and communication of fire management and mitigations
16. Support or opposition for risk mitigation techniques

3.2.19.3 Economic impacts

Our survey did not use economic impacts of fire as a potential area of work. However, we did ask respondents to rate the level of research needed for the economic impacts of fire as a subtopic. We found that 47% selected significant need, 27% selected moderate need, 27% selected slight need, and 0.0% selected not needed. When ranked against other topics from the fire-related social science area, economic impacts of fire was in the middle of the significance of research needed. While our survey could not provide more detail on subtopics within the economic impacts of fire, our results concur with USGS that the area could use more research in the Southwest.

3.2.19.4 Wildlife

The survey allowed respondents to select *"wildlife-fire interactions"* as a familiar research area in their line of work. 24 respondents selected it and answered the questions. There were five subtopics in the area of wildlife-fire interactions. Below are the five subtopics listed, from the most significant research need to the least needed.

1. Fire impacts to threatened and endangered species
2. Impacts of fire severity patterns and mosaics to wildlife
3. Habitat fragmentation and degradation
4. Fire impacts to wildlife
5. Effects of fire on species migration

3.2.19.5 Invasive plant species

The survey allowed respondents to select *"Invasive Species"* as a familiar research area in their line of work. 25 respondents selected it and answered the questions. There were five subtopics in the area of invasive species. Below are the five subtopics listed, from the most significant research need to the least needed.

1. Invasive species management
2. Changes in the geographic extent of invasive species
3. The effect of invasive species on fire behavior
4. The effect of invasive species on fire return intervals
5. Human influence on the presence of invasive species

Our research generally agreed with the needs identified in the 2021 USGS survey. Smoke, air quality, and health, social science and human dimensions, wildlife, and invasive plant species all had areas of significant need in our research, and were identified as gaps in the USGS survey. Economic impacts was the only area that USGS identified as a gap that our survey did not provide additional information on. The five categories identified during the 2021 USGS survey can provide researchers and the SWFSC a starting point for research and our survey can provide more detail and supplemental information for these five research areas.

3.3 Use of, and access to, scientific information

Most survey respondents (n=102) answered that the use of best available scientific information is a requirement of their current job or position. This is reflected in the frequency with which respondents access best available scientific information to inform fire-related decision-making at work (Figure 2, Figure 3).

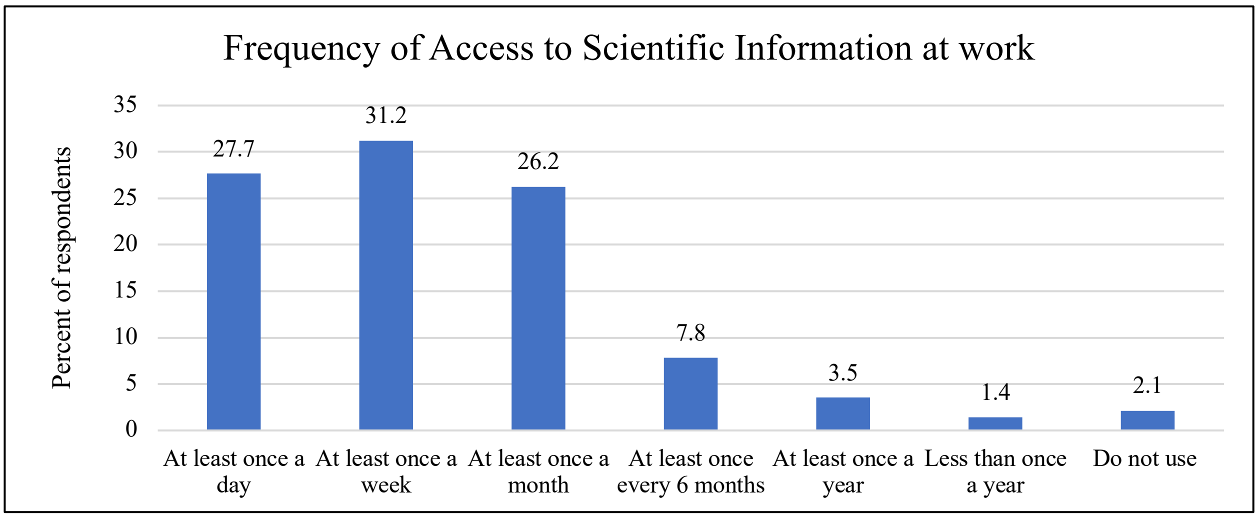

Figure 2-2: *Response to the question "how often do you use fire science research to inform the work you conduct in your current job position?"*

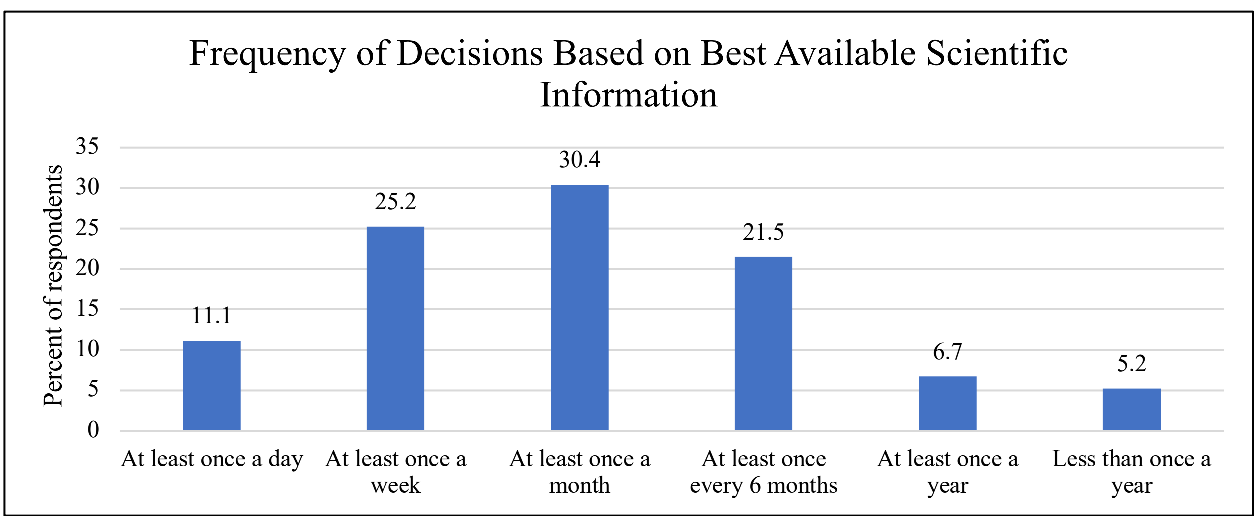

Figure 2-3: *Response to the question "how often do you actively seek best available scientific information to inform fire-related decision-making?"*

Respondents accessed best available scientific information from a variety of sources. We assessed use of different sources of information across four types of resources: academic (Table 21), specialized (Table 22), personal (Table 23), and organizational (Table 24). The sources within the tables below are ordered from most frequently accessed to least frequently used. Frequency of access was calculated and organized by mean response for each source.

Table 2-21: *Frequency with which respondents used academic resources to locate best available scientific information. The response with the highest percentage of respondents for each question is shown in bold.*

Source	**At least once a day**	**At least once a week**	**At least once a month**	**At least once every 6 months**	**At least once a year**	**Less than once a year**	**Do not use**
Scholarly search engines (e.g., Google Scholar, science.gov, Refseek, WorldWideScience, etc.)	20%	23%	**26%**	15%	5.0%	5.0%	7.1%
University library search engine or website	6.6%	17%	**23%**	17%	9.6%	11%	16%

Table 2-22: *Frequency with which respondents used <u>specialized resources</u> to locate best available scientific information. The response with the highest percentage of respondents for each question is shown in bold.*

Source	At least once a day	At least once a week	At least once a month	At least once every 6 months	At least once a year	Less than once a year	Do not use
SWFSC website or resources	0.7%	4.3%	31%	**37%**	11%	14%	2.8%
Firescience.gov (Joint Fire Science Program Website)	0.0%	2.9%	24%	**33%**	13%	18%	9.4%
US Forest Service Treesearch database	1.4%	7.1%	13%	25%	14%	14%	**26%**
Fire Effects Information System (FEIS)	0.0%	2.9%	16%	25%	12%	18%	**26%**
Fire Research and Management Exchange System (FRAMES.gov)	0.7%	1.5%	15%	22%	14%	17%	**30%**
Wildland Fire Library	0.7%	3.6%	9.5%	22%	11%	20%	**33%**

Table 2-23: *Frequency with which respondents used <u>personal resources</u> to locate best available scientific information. The response with the highest percentage of respondents for each question is shown in bold.*

Source	At least once a day	At least once a week	At least once a month	At least once every 6 months	At least once a year	Less than once a year	Do not use
Colleagues at your workplace	12%	**36%**	28%	13%	4.3%	2.9%	3.6%
Colleagues from a partner organization, agency, or institution	7.3%	21%	**37%**	20%	7.3%	7.3%	0.0%
Direct communication with SWFSC staff	0.0%	3.6%	10%	11%	16%	23%	**37%**

Table 2-24: *Frequency with which respondents used* <u>*organizational resources*</u> *to locate best available scientific information. The response with the highest percentage of respondents for each question is shown in bold.*

Source	At least once a day	At least once a week	At least once a month	At least once every 6 months	At least once a year	Less than once a year	Do not use
Internal folders or databases (e.g., google drives, share points)	9.4%	19%	**23%**	18%	9.4%	11%	11%
Local or regional collaborative groups	2.9%	13%	26%	**27%**	14%	12%	5.8%
Other regional fire science consortia or science exchanges outside the Southwest	0.0%	4.3%	21%	**25%**	16%	17%	17%

Respondents tended to agree that the more place-specific and topic closeness to their research, the better (Table 25). Local and vegetation-specific research is important in their work, highlighting the importance of regionally based science-focused organizations like the SWFSC (Figure 4).

We also found that survey respondents share best available scientific information with a diverse range of other collaborators or colleagues. Figure 5 shows the most frequent recipients of shared best available scientific information from survey participants.

Table 2-25: Considerations for accessing fire science. *The response with the highest percentage of respondents for each question is shown in bold.*

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The more place-specific a research study is, the more helpful I find it	20%	43%	31%	6.4%	0.0%
It is easy to find new research that is relevant to my line of work	13%	47%	24%	15%	1.4%
There is enough research about my local area to inform my work	4.3%	33%	36%	23%	3.6%

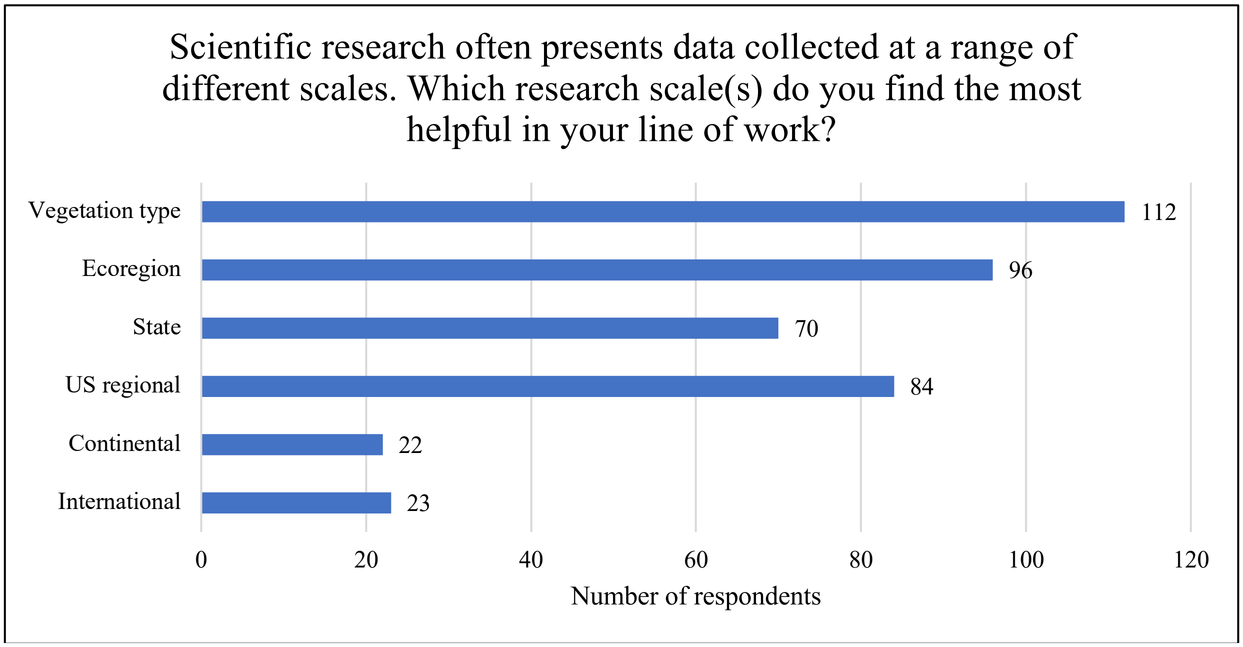

Figure 2-4*: The scales of research that are most helpful to respondents in their line of work. Respondents were allowed to select multiple scales.*

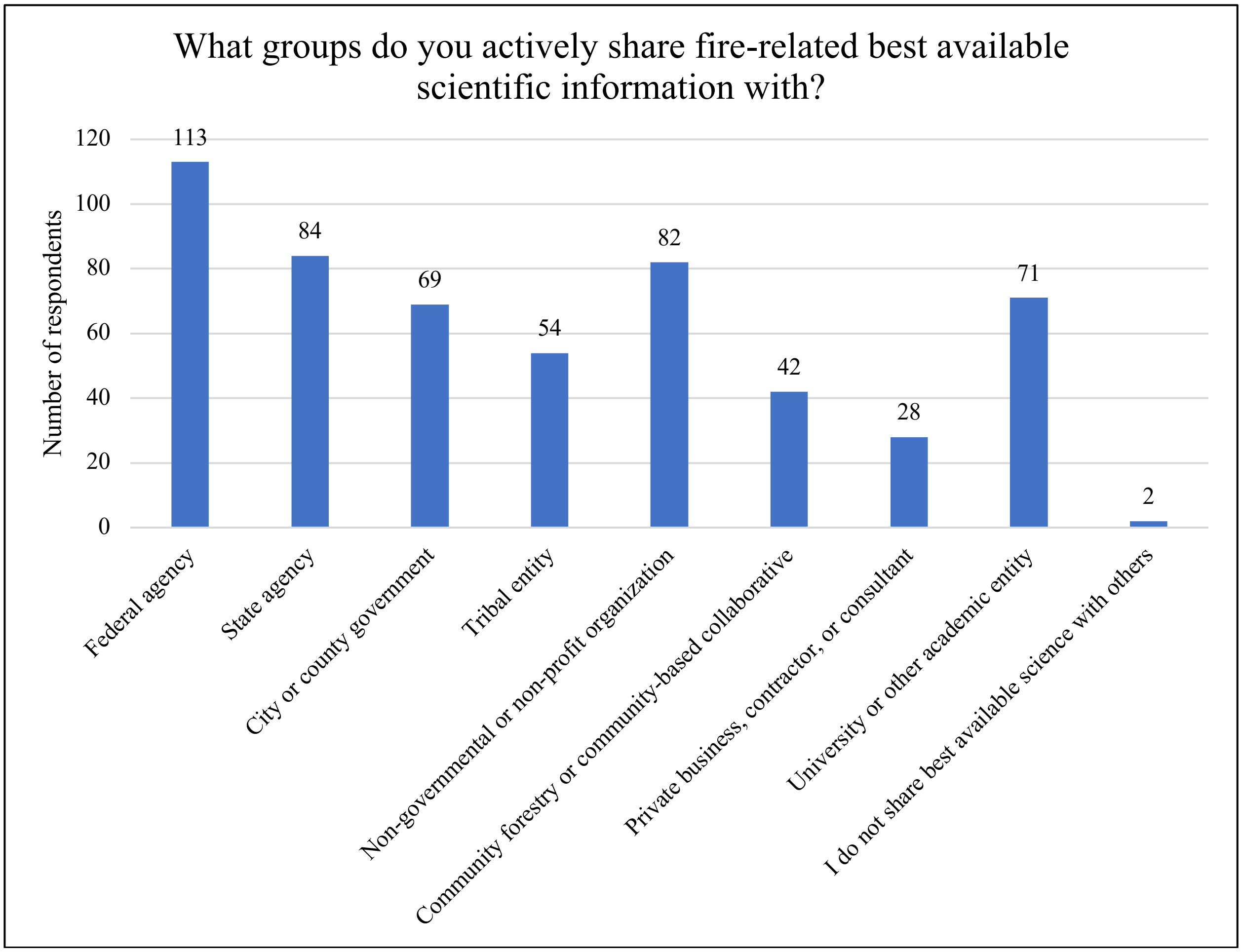

Figure 2-5: *The different groups and agencies that respondents share fire-related best available scientific information with. Respondents were allowed to select multiple groups.*

<u>3.4 Barriers to implementing best available scientific information</u>

SWFSC members are presented with various barriers to implementing best available scientific information in their positions. We aimed to understand where these barriers are present, how they correlate with job positions, and the role the SWFSC can play in encouraging the use of best available scientific information. Respondents were asked to indicate the extent to which they agreed or disagreed with a set of statements about barriers to accessing and using scientific information. Barriers are listed in Table 26 from highest to lowest agreement.

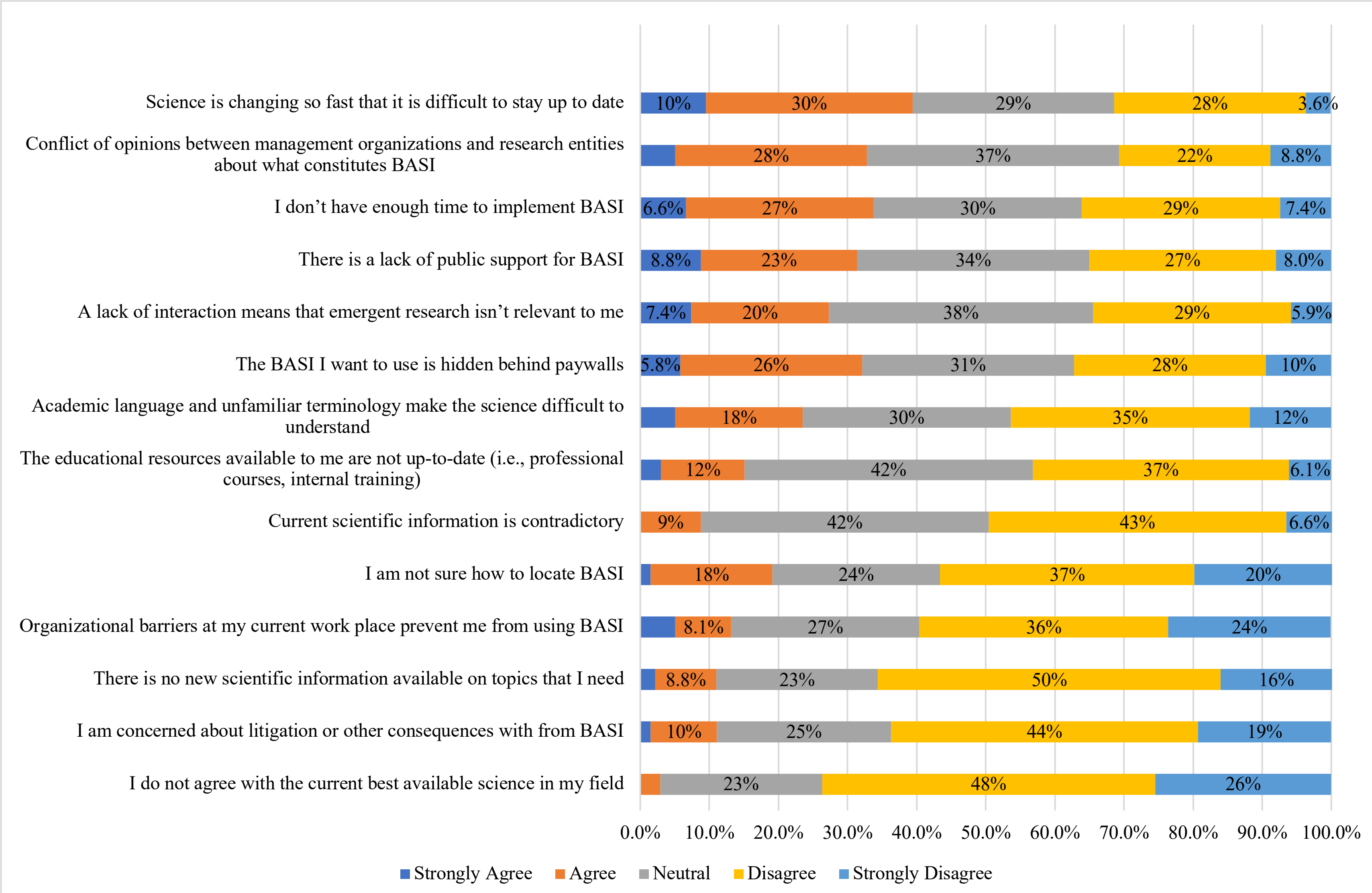

***Figure 2-6**: Barriers to using best available scientific information (BASI) across all disciplines*

To best understand how to overcome these barriers and who to communicate these solutions to, it is useful to examine the data in Table 26 by job position. Respondents' job positions were placed under one of three categories for further analysis: scientists, managers, and practitioners.

<u>3.4.1 Best available scientific information barriers for scientists</u>

Scientists were categorized as respondents who are researchers and students; 46 respondents fell under this group. The most prominent barriers to implementing or understanding best available scientific information for this group are:

1. Science is changing so fast that it is difficult to stay up to date
2. There is a lack of public support for best available scientific information
3. I don't have enough time to implement best available scientific information
4. The educational resources available to me are not up to date (i.e., professional courses, internal training)
5. The best available scientific information I want to use is hidden behind paywalls

<u>3.4.2 Best available scientific information barriers for managers</u>

Managers were categorized as respondents who are land managers, private contractors or business owners, and federal, state, county, and local municipality employees; 70 respondents are included in this group. The most prominent barriers to implementing or understanding best available scientific information for this group are:

1. Science is changing so fast that it is difficult to stay up to date
2. Conflict of opinions between management organizations and research entities about what constitutes the best available scientific information

3. A lack of interaction between researchers and managers means that emergent research isn't relevant to me
4. I don't have enough time to implement best available scientific information
5. There is a lack of public support for best available scientific information

3.4.3 Best available scientific information barriers for practitioners and outreach positions

The practitioner/outreach group were categorized as respondents who are outreach, communication, or education specialist, private property owners or community representatives, politicians or policy makers, and non-governmental or collaborative representatives or employees; 21 respondents are included in this group. The most prominent barriers to implementing or understanding best available scientific information for this group are:

1. The best available scientific information I want to use is hidden behind paywalls
2. There is a lack of public support for best available scientific information
3. Conflict of opinions between management organizations and research entities about what constitutes the best available scientific information
4. A lack of interaction between researchers and managers means that emergent research isn't relevant to me
5. I don't have enough time to implement best available scientific information

3.5 Southwest Fire Science Consortium products

The SWFSC produces a number of outputs aimed at science communication, including webinars, maintaining a website, and developing videos. Respondents indicated the outputs they most frequently interacted with, shown in Figure 6. Survey respondents also ranked which of these products are most useful. Respondents selected two in-person products, workshops, and conferences, as the most useful (Table 27). We did not count the votes of respondents who said they did not use a product in the usefulness ranking.

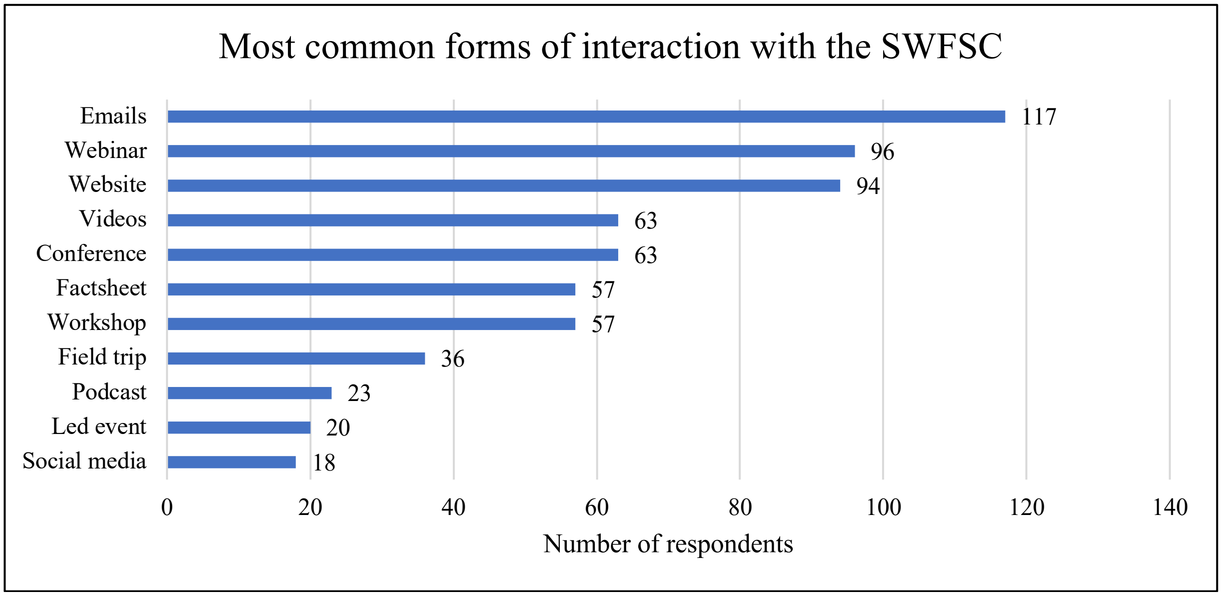

Figure 2-7: *Response to the question "What ways have you engaged with the SWFSC the past five years?" Respondents were allowed to select multiple options.*

Table 2-26: *The products of the SWFSC are listed from most useful to least useful. Response to the prompt "Please select one answer for each product."*

Product	Extremely useful (5)	Very useful (4)	Moderately useful (3)	Slightly useful (2)	Not at all useful (1)	Do Not Use	Mean
Workshops	21%	37%	6.2%	4.7%	0.0%	31%	4.08
Conferences	25%	35%	12%	4.6%	0.0%	24%	4.05
Topical synthesis papers and factsheets	20%	36%	23%	3.8%	0.0%	17%	3.87
Networking	22%	29%	19%	6.2%	0.0%	24%	3.87
Field trips	12%	32%	7.7%	3.1%	2.3%	43%	3.84
Webinars	16%	54%	13%	9.1%	0.8%	7.6%	3.81
Website	17%	39%	31%	4.5%	0.8%	8.3%	3.72
YouTube Videos	12%	30%	25%	3.8%	0.8%	29%	3.69

Field trips were a valued product of the SWFSC. Respondents were willing to travel further distances if financial support could be provided to participate in these trips. Nearly 70% of the people surveyed were willing to travel 300+ miles if the SWFSC provided a travel stipend; less than 20% would participate in the same event without financial support (Figure 7).

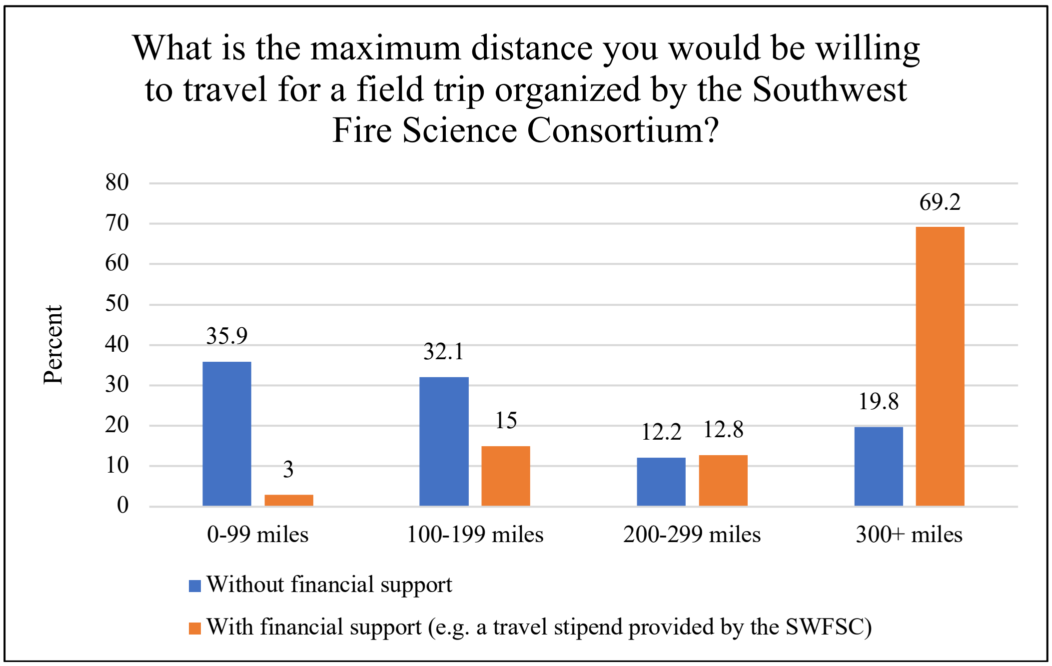

Figure 2-8: *The distance respondents were willing to travel with and without financial support. Respondents were only allowed to select one distance for financial support and one without.*

4. Recommendations and conclusion

4.1 Research priorities

This survey aimed to determine the research areas with the greatest need related to fire science within the Southwest. First, respondents were presented with 18 sub-fields within fire science and asked to select three that they were most familiar with. Then respondents were asked to indicate whether there was a significant research need for each sub-topic. The single top research need for each of the 18 areas of fire science are displayed in Table 28. We suggest that the SWFSC can play a significant role in supporting future efforts and products related to these significant research needs below.

Table 2-27: *Most significant research in fire science for the US Southwest, listed by sub-field. Sub fields are listed from most selected topics to least selected topics.*

Sub-field	Most significant research need
Fuels management and treatments	Cross-boundary planning for fuel management
Prescribed fire	Prescribed fire use on private land
Fire and ecological processes	Impacts of invasive species on fire in the Southwest
Post-fire environments	Vegetation type conversions
Wildland-urban interface environments	Successful planning and zoning or development policy
Fire and climate	Managing fire regime changes
Incident management and operational firefighting	Firefighter health and wellbeing
Fire behavior	Fire-weather interactions
Invasive species	Invasive species management
Wildlife-fire interactions	Fire impacts to threatened and endangered species
Water and hydrologic processes	Secondary hazards in burned areas (debris flows, flooding)
Outreach and public education	Public education on fire
Fire-related policy	Barriers and opportunities for policy change
Fire-related social science	Matching communities with adaptation strategies
Traditional and Indigenous knowledge	Preserving cultural knowledge about fire
Fire-soil interactions	Erosion in burned areas
Smoke management and impacts	Smoke impacts to firefighters
Diversity, equity, and inclusion in fire	Inclusion of groups in conversations and decisions

Another overarching need across these sub-fields is investigation related to fuels treatments planning, ranging from cross-boundary work to prescribed fires and the ways in which policy interacts with these efforts. Post-fire ecological effects also emerged as an important area for future research in the Southwest. Lastly, we note a growing interested in identifying strategies and approaches for more inclusive fire science in decision making and planning for wildfire and suggest that identifying factors that contribute to more inclusive efforts among Southwest-specific groups and cultures is needed across all sub-fields. This list of research needs may act as an agenda for outreach efforts, particularly topics for webinars or white papers and briefs that overview the current state of science under each subfield. These topics may also provide direction for future Joint Fire Science Program proposal calls; for example, multiple subfields prioritized the need for research related to firefighter health, safety, and wellbeing.

4.2 Barriers to best available scientific information

Most survey respondents answered that the use of best available scientific information is a requirement of their current job or position. More than 60% of respondents used best available scientific information to inform management decisions more than once a month. We found that scientists, managers, and practitioners each face different barriers to implementing best available scientific information in their positions. Providing products that help managers and scientists keep up with rapidly evolving scientific information should be a continued focus of the SWFSC moving forward. This could include monthly emails highlighting recently published science based in the Southwest, or "year in review" whitepapers that focus on emerging fire science based in the Southwest in the last year. These could be similar to the fire season reviews the SWFSC has historically published. Creating a form on the SWFSC website for researchers to self-report new publications that they feel are relevant to the Southwest may accelerate these efforts while reducing the workload of SWFSC staff.

All three groups, especially the practitioner group, struggle to access best available scientific information because of paywalls (restricted access without paying fee/subscription). The SWFSC can play an important role in alleviating this challenge by highlighting open access materials and websites where available (e.g., ResearchGate), and providing brief summaries of publications where that option is not available. These sources could be highlighted in a section of the website outlining the best areas to access free fire based best available scientific information. Other more costly options may include connecting scientists with funding opportunities that offset costs associated with open access publishing, particularly in instances where the publication may address one or more of the most significant needs identified for the Southwest.

4.3 Southwest Fire Science Consortium products

Our survey investigated which of the SWFSC's products were most useful. The three most common ways respondents interacted with the SWFSC were emails from the mailing list, attendance at a SWFSC webinar, and visiting the SWFSC website. While the three most used products were all virtual, respondents largely identified face-to-face interactions as most useful, highlighting the value of workshops and conferences. The pandemic limited the SWFSC ability to host workshops and conferences; however, they remain as the two most useful products. Engagement with in-person opportunities could be further increased with higher access to travel stipends or funding where possible. In instances where funding is not possible, focusing efforts as close to target audiences as possible will increase the likelihood of attendance. This survey indicates that there is enough interest for the SWFSC to expand its field trip, workshop, and conference offerings if the capacity for organizing these events is available.

Social media was ranked as the least used SWFSC product, and our analysis of sources for best available scientific information leads us to believe respondents look to other areas to find fire science. Continued presence on twitter may be valuable but we do not believe spreading to other platforms such as TikTok will meaningfully increase engagement.

The overall perception of the SWFSC in both key informant interviews and comments provided in the survey was positive. Respondents were generally pleased with the SWFSC products and efforts and saw a few small opportunities to improve its reach and effectiveness.

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CHAPTER 3

BEST AVAILABLE SCIENTIFIC INFORMATION FOR WILDFIRE IN THE US SOUTHWEST: CURRENT NEEDS BARRIERS AND OPPORTUNITIES

1. Introduction

Increasing complexity of forest and wildfire management under climate change necessitates the development and application of relevant science that can alleviate these challenges (Kocher et al., 2012). Fire professionals – a term I use here to include members of the diverse groups and organizations engaged in various aspects of wildfire such as public land managers, practitioners, researchers, and non-governmental organizations – are increasingly tasked with identification and implementation of this science on the ground. Policy and guidance around modern fire and land management increasingly requires the identification and use of "best available scientific information" (BASI) to inform and justify decisions that have environmental consequences and benefits (Esch et al., 2018). One such example is the U.S. Forest Service's 2012 planning rule, which states:

> *"The responsible official shall use the best available scientific information to inform the planning process required by this subpart. In doing so, **the responsible official shall determine what information is the most accurate, reliable, and relevant to the issues being considered**. The responsible official shall document how the best available scientific information was used to inform the assessment, the plan decision, and the monitoring program"* (Planning Rule USDA Forest Service, 219.3, 2012).

This definition, like many others currently in use, places the responsibility to determine what the best available science is on fire professionals. This guidance fosters a certain level of ambiguity that creates uncertainty regarding how managers navigate the process of identifying and using

BASI under many circumstances, particularly regarding hazardous fuels and fire management (Esch et al., 2018). Placing responsibility on fire professionals also likely contributes to wide variation in identification and use of BASI; not all individuals will have access to the same scientific information.

Reducing potential barriers to identifying, accessing, and implementing BASI may improve wildfire and land management professionals' ability to make informed decisions. Barriers to implementing and accessing BASI can include inability to access science because of paywalls, limited time to find and translate new science, and lack of connection to researchers who can answer questions (Colavito, 2017a, Esch et al., 2018, Hunter et al., 2020). Limited research exists on where fire professionals are accessing information, who is looking for science, and their strategies for translating science to management decisions. Science can assist in a variety of management decisions, from fuels treatment prescriptions to improving public outreach efforts can benefit from implementing tools published in scientific research (Zimmerman, 2012). Researchers in the Southwest are continually producing new scientific information, but there is a lack of understanding regarding how fire professionals interact with this science and when it is implemented (Hunter, 2016). Addressing this lack of understanding would improve the targeting of science dissemination efforts and ultimately increase the amount of applicable science available for fire professionals to make decisions.

This study aims to improve understandings of fire professionals' interactions with BASI in Arizona and New Mexico. I conducted an online survey of Southwest Fire Science Consortium (SWFSC) members to explore how they access scientific information and the barriers that prevent them from finding and implementing wildfire-related BASI in their respective organizations and positions. This information can improve the dissemination of new and existing fire science by refining the products the SWFSC creates. Understanding the barriers that prevent fire science from being implemented presents the ability to reduce these barriers and improve fire professionals' ability to make science-based decisions. Research exploring BASI use in Southwestern forest and fire management is still in its infancy, and continued research can foster more effective management and relevant science. Improved access and reduced barriers will allow managers to apply science-based solutions to the increasingly complex fire management issues in the Southwest.

2. Literature Review

2.1 Existing guidance on BASI

BASI is defined differently across disciplines and often lacks clarity regarding the exact parameters used to determine what qualifies as BASI (Esch et al., 2018). This may be because different policies mandate varying criteria for what constitutes BASI. Some policies such as the 2015 Forest Service Planning Directives include criteria for BASI, stating that information should be accurate, reliable, and relevant with explanations of the three criteria (FSH 1909.12, 2015). Other polices, like the National Cohesive Wildland Fire Management Strategy, state that a guiding principle of the policy is "Fire management decisions are based on the best available science" without providing any definition or criteria for what BASI is (NCWFMS, 2014). Policies that fire professionals are required to follow use different definitions and criteria for determining BASI. For this research and during the survey and interviews I defined BASI as "high-quality research that adheres to well-established scientific processes while articulating assumptions and uncertainties of the research" (Sullivan et al., 2006). These definitions or lack thereof, leave room for interpretation and require fire professionals to evaluate BASI on their own without sufficient guidance. This vagueness gives managers the flexibility to select management actions they feel are appropriate and justify them based on the ambiguity of many policies; however, it can lead to confusion and lack of consensus on management decisions.

The application of fire science to management actions remains understudied, particularly in the Southwest. Despite consistent research in fire science, there has been limited evaluation of its use in management (Hunter et al., 2020). A 2016 study conducted by Molly Hunter aimed to answer how often fire science is being applied to management decisions. Hunter selected a random sample of 48 fire science studies published in the Southwest, and interviewed managers to see if specific findings were being applied. Hunter (2016) found that most of the studies were being applied to management actions in some form. Much of this may be due to knowledge exchange networks like the Southwest Fire Science Consortium (SWFSC) which were formed to translate science and improve communication between managers and scientists (SWFSC, 2023). However, when research is not supported or disseminated through shared platforms like the SWFSC, it is unclear whether it is accessed or implemented into management strategies (Hunter, 2016). More research on the application of science in Southwestern fire management would assist scientists in researching applicable topics, managers in finding solutions to management problems, and knowledge exchange networks in improving connections between all groups.

2.2 BASI Interactions

Fire professionals have different preferences for interacting with and consuming scientific information, for example in-person events like fieldtrips or online resources like webinars. In 2017, Colavito surveyed managers participating in five western Community Forest Landscape Restoration Program (CFLRP) projects on their interactions with fire science (Colavito, 2017 a). When asked how scientific information is generally provided in their CRLRP projects, respondents chose informal meetings, formal presentations, and professional reports as the three most common mediums. The same respondents selected peer-reviewed articles as their preferred science delivery format (Colavito, 2017 a). By contrast, Hunter found that oral communication is a primary mean of science delivery across all types of fire professionals (Hunter, 2016). Understanding the range of mediums that professionals consume science through provide scientists and partnerships the tools to ensure science is accessed and used in the most effective ways (Davis et al., 2013).

Partnerships like the SWFSC are one way to facilitate varied types of science delivery (Malesky et al., 2018). Partnerships are effective at encouraging science sharing and delivery because they bring together a range of people with different experiences and expertise. For example, scientists use partnerships to solicit feedback and ideas for research, and managers use partnerships to learn new science and management practices (Malesky et al., 2018). Additionally, boundary spanning organizations like the SWFSC facilitate increased coproduction between members (Grimm et al., 2022). Coproduction can be defined as "the process of producing usable, or actionable, science through collaboration between scientists and those who use science to make policy and management decisions" (Meadow et al., 2015). The ability to connect scientists and the end users of that science increases the amount coproduction activities that take place through the SWFSC (Grimm et al., 2022). Partnerships can also connect organizations that lack expertise in certain topics, giving them the platform to share knowledge. For example, an organization that lacks expertise in outreach and public education may contact a partnership looking for help on a public outreach project. A partnership member with the public outreach expertise can help the organization, and vice-versa in other areas. This ability to share information and knowledge effectively expands the diversity and expertise of individual organizations to include all the cumulative knowledge held within a partnership. There is limited research on which fire professionals are searching for fire science and the areas that could benefit from improved diversity of expertise (Davis et al., 2013). Understanding who these different fire professionals are, where their expertise is, and the formats they prefer to consume science in would allow partnerships like the SWFSC to improve.

As advancements in fire science across the Southwest continue, it is important to continue to reassess if new science is being implemented into management especially with current climate changes (Kocher et al., 2012, Hunter, 2016). New fire research is sometimes lost between the researchers publishing the science and the practitioners implementing management (Adams et al., 2017). This gap can occur when researchers are publishing science in areas that managers don't have questions in or when managers are not actively seeking out new scientific information. In a 2020 study, Edgeley and colleagues found that researchers and managers working in the fire arena often have different research priorities and needs. For example, in the study respondents ranked a variety of research needs; researchers ranked invasive species as the second greatest perceived need and managers ranked invasive species as their perceived least needed research area (Edgeley et al., 2020). This disconnect in priorities may be due to a lack of regular interaction between managers and researchers. Adams et al. (2017) worked to understand how to improve interaction between managers and researchers through different theories of communication. The theories showed the importance of translating academic knowledge into easy-to-understand recommendations that use language managers are familiar with. Additionally, the more complex a topic is, the more important discourse between researchers and managers implementing the strategies is. Direct interaction between managers and researchers improves the understanding of fire research and helps researchers focus future topics (Adams et al., 2017).

These process and interactions can be encouraged through a variety of methods. Fire science consortia like the SWFSC build similar methods into their missions by aiming to connect fire professionals in geographically similar areas that share research priorities and results (Grimm et al., 2022). Universities can support the dissemination of science through dissemination techniques like working papers and workshops (Hunter, 2016). A deeper understanding of which individuals and groups inside of partnerships like the SWFSC, engage in BASI would improve understanding of how to encourage other professionals to participate in these interactions.

2.3 Barriers to using BASI

Barriers to BASI use can be categorized into two themes: barriers that prevent access and barriers that prevent implementing BASI. Barriers to BASI access prevent professionals from using science even when they are interested in finding it. Some managers lack the resources to access published scientific information because of paywalls or funding/capacity issues (Hunter et al., 2020). Other managers stated that they are personally responsible for finding and interpreting scientific information without any assistance, and they do not have the time to locate and interpret this information (Colavito, 2017 b). Personal conversations and a connection between researchers and managers reduce the time needed to access and interpret new science. Unfortunately, managers and researchers feel there is a communication gap between the fields and sometimes struggle to communicate consistently (Colavito, 2017 b). Participants of a survey on science use in the CFLRP cited science not being effectively communicated as a large obstacle to using science in their project (Colavito, 2017 a). Without access to BASI, managers, and practitioners can not implement it. Focusing on disseminating and expanding access to existing science would allow more managers to consistently apply BASI to management practices.

When fire professionals have access to BASI, other barriers can prevent them from being able to implement it. Institutional factors are often cited as a barrier to the application of fire science (Hunter et al., 2020). Examples of often cited institutional barriers include "NEPA-approved projects take priority over scientific recommendations" and "Forest management regulations prevent implementing the science" (Colavito, 2017 a). Agency policy and guidelines often lag behind science, as agencies lack the resources to update information because of lengthy amendment processes (Colavito, 2017 b). Uncertainty within scientific findings also prevents managers from applying fire science (Hunter et al., 2020). Some managers feel that the science is disconnected from the realities of implementation such as research being conducted at scales that are not useful for managers. For example, sometimes managers feel that scientific sources present findings that are too place-specific and can only apply to small parts of an ecosystem. Other times they feel that information is too broad, such as climate data that is difficult to apply at treatment scales (Colavito, 2017 b). Fire professionals also face legal risks when implementing new management strategies, which can make decisions around which science to use difficult (Borchers, 2005). Agencies can also simply lack the funding to translate and implement new scientific information. Changing management strategies can be costly, and agencies often lack the budget to make these changes (Hunter et al., 2020). Finally, conflict between external and internal views can limit the application of fire science (Hunter et al., 2020). For example, participants in CFLRPs cited "conflicting socioeconomic or political viewpoints that inhibit the use of science" as the single largest obstacle to the use of science in their project (Colavito, 2017 a). These conflicting ideas or lack of public support greatly reduce fire professionals' ability to implement BASI into new management.

Fire professionals' ability to make informed decisions can suffer from a lack of access, support, and tools to implement BASI into management practices. Little research has been published on if this contrast between the lack of access and support affects management outcomes. Examples of this contrast would show policymakers and management agencies the importance of supporting the use of BASI in fire and forest management. Without clear examples of the benefits of supporting science in management, it can be difficult for managers to articulate their needs and the positive outcomes of applying fire science to higher level decision makers. Future research on the impact of applying fire science to management practices could improve policy and agency support for fire professionals use of BASI increasing the amount of science-based management decisions made.

In summary, BASI use in fire and forest management in the Southwest is a relatively new research area with room for growth. There is no agreed-upon definition of BASI across managers or researchers, and it is unclear where fire science expertise lies within the Southwest. While some research is published on the barriers to accessing and implementing BASI, there is limited recent research on the barriers to accessing and implementing fire science in the Southwest specifically. These emerging issues led us to develop the following research questions, with a specific focus on Arizona and New Mexico:

1. Where is fire management and science expertise housed in the Southwestern U.S.?
2. Which kinds of organizations and positions frequently use and share BASI related to wildfire?
3. What barriers exist to accessing and implementing wildfire-related BASI in the Southwest?

3. Methodology

3.1 Approach

This study used a mixed-methods approach to inform the design of an online survey. SWFSC board members and principal investigators, after referred to as SWFSC board, (n = 16) engaged in a one hour-long discussion about fire science needs in the Southwest and future goals at the 2021 annual board meeting, held over Zoom. Board members participated using Google Jamboard to facilitate shared note taking and idea organization. Participants were placed in four break out groups to brainstorm research needs, then everyone regrouped to discuss these needs and organize them into categories. I also took notes during other discussions in the meeting to develop questions about the SWFSC itself. Discussions centered around SWFSC growth and purpose like where it should be expanding efforts, and what responsibilities it has. This data was used to develop the questions posed in the interview protocol that was used to interview board members of the SWFSC.

Virtual group discussions created a need for more focused and direct questions with present and prior SWFSC board members via semi-structured interviews. The data from the board discussion lacked enough detail on the specific questions the board would like to see answered in a survey. I developed an interview protocol in consultation with researchers who had conducted fire science needs assessments for other JFSP consortia (e.g., Ellison et al., 2019). The interview protocol is in the appendix. The semi structured interview protocol focused on four lines of questioning: (1) background and experience with the SWFSC, (2) observations regarding regional changes in fire science, (3) access to fire science in the Southwest, and (4) thoughts on the SWFSC and its efforts to disseminate BASI. I received contact information for 19 current board members, and 9 of the 19 previous board members, for a total of 28 potential participants. I emailed all current and previous board members for whom contact information was available. Follow up emails were sent several times in instances where no response was received, up to three times. I was able to interview 15 board members: 13 current and 2 previous members. With the permission of study participants, I recorded each interview. Interviews lasted an average of 45 minutes. Interviews focused on asking question that would develop the online survey. For example, probing questions explored where interviewees found scientific information, which was then used to create a list of potential sources for survey respondents to rank.

To develop the survey, I used a combination of our focus group session, key informant interviews, and other consortia needs assessments as a reference (Ellison et al., 2019). The survey instrument first requested background information on respondents including geographic work areas and vegetation types, employer, position, and years of experience. Next, the survey requested that respondents select the top three sub-fields of fire science they were most familiar with from a list of eighteen areas. The 18 sub-fields were developed in consultation with the SWFSC PI and program coordinator and reviewed by the current SWFSC board, with the intent to cover all broad areas of fire science in the Southwest. The survey used display logic to further question respondents on specific research needs within their most familiar areas; respondents rated research need on specific topics from not needed to significant need. Respondents were allowed to add additional notes or research needs in open ended text boxes. The next section questioned respondents on their experience using scientific information. Questions included how often respondents used science to inform their work, frequency of access to various sources of scientific information, and preferences for the most useful scale research. Next, I questioned respondents on their interaction with BASI in their positions. I asked respondents how frequently they used BASI to inform fire-related decisions, if BASI is a requirement in their position, and what groups or organizations they share BASI with. The BASI section concluded by asking respondents to select the extent to which they agreed or disagreed on various barriers that prevent their use of BASI, presenting potential barriers across the groups identified in the literature review above. Finally, the survey ended with simple demographic questions including gender, age, and level of education.

The survey was created and distributed online using web-based survey platform Qualtrics. This allowed us to track completion rates and send follow-ups with the survey link multiple times. During the first week of February 2022 the survey was sent to the SWFSC's mailing list (n = 813). Reminder emails were sent to anyone who did not complete the survey three more times, each one week apart. The SWFSC also posted the survey link on Twitter once in mid-February, and I encouraged board members to share the link with contacts too. In total I received 161 usable responses for a 20% response rate. Only seven survey respondents accessed the survey who were not on the SWFSC mailing list.

3.2 Analysis

Survey responses were downloaded then cleaned and analyzed through SPSS 28.0 (IBM SPSS). Basic questions on respondent background, expertise, use and access to BASI, and demographics were analyzed using basic descriptive statistics generation in SPSS. The top sources of scientific information were calculated using mean Likert scores, respondents selected on a scale of 1- "at least once a day" to 7- "do not use" where the lowest mean Likert score represented the most used scientific sources. To analyze BASI sharing relationships I calculated significance using a chi-squared test for each possible sharing relationship. Results were considered significant with a 2-sided exact significance P-value less than 0.05. P-Values were adjusted using the Bonferroni method to reduce chances of a Type-1 error for chi-squared tests (Weisstein, 2004).

Barriers to the use of BASI across all positions was calculated based on mean Likert score. Respondents selected an answer from 1-"strongly agree" to 5-"strongly disagree" the mean score for each barrier was calculated, then barriers were ordered. Next, I chose to divide position types into three main categories: scientists, managers, and practitioner/outreach. Dividing respondents into three broad categories allowed us to further analyze the barriers to BASI use across different position types; this allowed us to provide actionable recommendations without being too specific. Scientists were categorized as respondents who are researchers and students; 46 respondents fell under this group. Managers were categorized as respondents who are land managers, private contractors, or business owners, and federal, state, county, and local municipality employees; 70 respondents are included in this group. The practitioner/outreach group were categorized as outreach, communication, or education specialists, private property owners or community representatives, politicians, or policymakers, and non-governmental or collaborative representatives or employees; 21 respondents were included in this group. Barriers to the use of BASI for each position group was ranked based on mean Likert score; respondents selected an answer from 1-"strongly agree" to 5-"strongly disagree" the mean score for each barrier was calculated, then barriers were ranked from most agreed with to least agreed with for each position group. Finally, I calculated significant differences between the barriers that different position groups face using a chi-squared test. Results were considered significant with a 2-sided exact significance P-value less than 0.05.

4. Results

4.1 Background and Demographics

Survey respondents were asked to self-report basic background and demographic information throughout the survey. Respondents were allowed to select multiple options, so percentages may not add up to 100%. Respondents worked predominantly in Arizona (60%), and New Mexico (57%). Respondents worked primarily for federal agencies (56%) and universities or other academic entities (21%). Most survey participants identified as managers (48%) or researchers (34%). The most common vegetation types that participants worked in were ponderosa (73%), piñon-juniper (68%), and dry mixed-conifer (65%). The average participant had worked extensively in the Southwest, with a mean of 17.4 years of experience. Respondents were generally older, too; 53% were between 45-64 years old, while around 27% were 18-44 years old. 66% of participants identified as male, and 33% identified as female. Participants were well educated across fields, with 32% holding a four-year degree, 32% a master's degree, and 25% a doctoral degree.

4.2 Areas of Expertise

To understand where fire science expertise is housed in the Southwest, I asked participants to self-identify sub-fields of fire science that they were most familiar with in their line of work. I asked respondents to select their top three areas out of a list of 18 displayed in Table 1. Fuels management and treatments, fire and ecological processes, and prescribed fire were the top three selected areas of expertise. The least selected areas were traditional and indigenous knowledge and diversity equity, and inclusion in fire. Organizations and agencies appeared to have differing amounts of expertise. State and federal agencies were the only organizations to have respondents select all 18 expertise areas. In contrast, city and county government only selected expertise in 7 of the 18 areas making 11 areas without any expertise. Non-governmental or non-profit organizations displayed a more uniform spread, with expertise across 15 of the 18 different areas.

***Table 3-1**: Expertise areas of survey respondents. Expertise areas are listed from greatest to least number of respondents from the top to bottom and organizations are listed from greatest to least number of respondents from left to right. Percentages are calculated by the percentage of agency or organization.*

Expertise area	Federal agency (n=90)	University or other academic entity (n=33)	State agency (n=10)	Private business, contractor, or consultant (n=13)	Non-governmental or non-profit organization (n=12)	Tribal entity (n=9)	Community forestry or collaborative entity (n=6)	City or county government (n=7)	Private landowner or community representative (n=4)	Total
Fuels management and treatments	14%	11%	12%	12%	20%	19%	15%	22%	17%	92
Fire and ecological Processes	11%	16%	5.8%	17%	12%	3.7%	5.0%	0.0%	17%	75
Prescribed fire	13%	7.3%	9.6%	7.1%	9.8%	11%	10%	17%	0.0%	71
Post-fire environments	6.8%	16%	7.7%	4.8%	9.8%	19%	0.0%	0.0%	0.0%	55
Wildland-urban interface environments	6.2%	2.7%	12%	9.5%	4.9%	3.7%	5.0%	28%	8.3%	44
Fire and climate	5.9%	10%	1.9%	7.1%	2.4%	0.0%	5.0%	0.0%	0.0%	37
Incident management and operational firefighting	7.6%	0.9%	7.7%	2.4%	0.0%	0.0%	0.0%	11%	8.3%	35
Outreach and public education	2.6%	3.6%	9.6%	2.4%	7.3%	3.7%	25%	11%	17%	32
Invasive species	4.1%	3.6%	1.9%	7.1%	7.3%	0.0%	5.0%	5.6%	17%	29
Fire behavior	5.9%	3.6%	5.8%	2.4%	2.4%	11%	5.0%	0.0%	0.0%	33
Wildlife-fire interactions	4.4%	2.7%	3.8%	2.4%	7.3%	0.0%	10%	0.0%	8.3%	27
Water and hydrologic processes	4.1%	1.8%	1.9%	9.5%	7.3%	3.7%	0.0%	5.6%	0.0%	26
Fire related policy	3.5%	4.5%	7.7%	2.4%	2.4%	0.0%	10%	0.0%	8.3%	26
Fire-related social science	2.1%	7.3%	1.9%	4.8%	0.0%	0.0%	5.0%	0.0%	0.0%	19
Fire-soil interactions	3.8%	0.9%	1.9%	0.0%	2.4%	15%	0.0%	0.0%	0.0%	20
Smoke management and impacts	2.6%	0.0%	3.8%	2.4%	2.4%	7.4%	0.0%	0.0%	0.0%	15
Diversity, equity, and inclusion in fire	1.2%	3.6%	1.9%	4.8%	2.4%	3.7%	0.0%	0.0%	0.0%	13
Traditional and indigenous knowledge	1.5%	4.5%	3.8%	2.4%	0.0%	0.0%	0.0%	0.0%	0.0%	13

4.3 Best Available Scientific Information use and sharing

Respondents were asked how they interacted with BASI in their current position and what role it played in their decision making. Respondents frequently accessed BASI, with over 85% of respondents stating that they used BASI to inform their work once a month or more (Figure 1). Over two-thirds of respondents made decisions based on BASI once a month or more in their positions (Figure 2). There were some differences in BASI interactions based on position type. Researcher accessed scientific information the most at work, with 47% accessing scientific information at least once a day and 27% at least once a week. Outreach, communication and or education specialists also accessed scientific information frequently: 39% at least once a day, 28% at least once a week, and 28% at least once a month. In contrast, managers accessed scientific information less with 17% using scientific information at work once a day, 32% at least once a week, and 35% at least once a month.

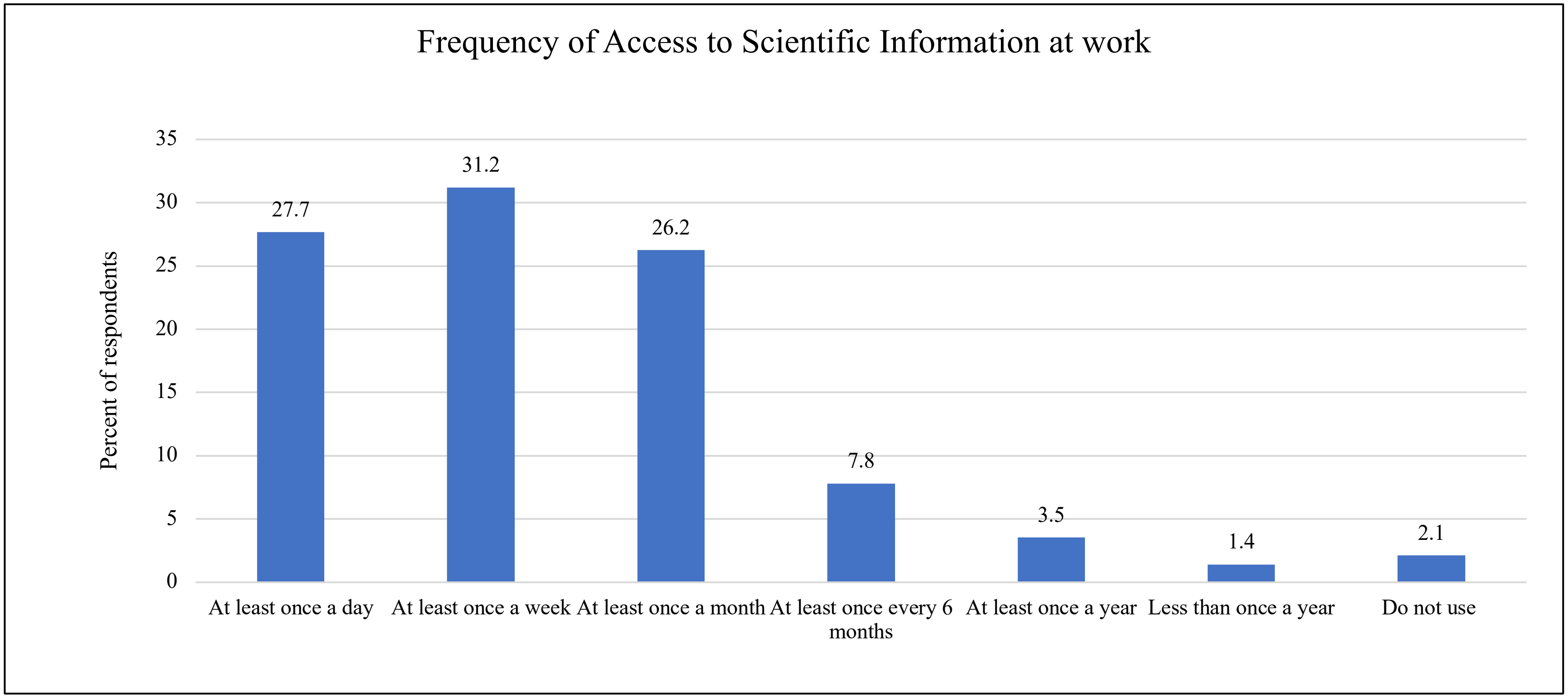

Figure 3-1: *Response to the question, "how often do you use fire science research to inform the work you conduct in your current job position?" n=141. Data labels show the percent of respondents.*

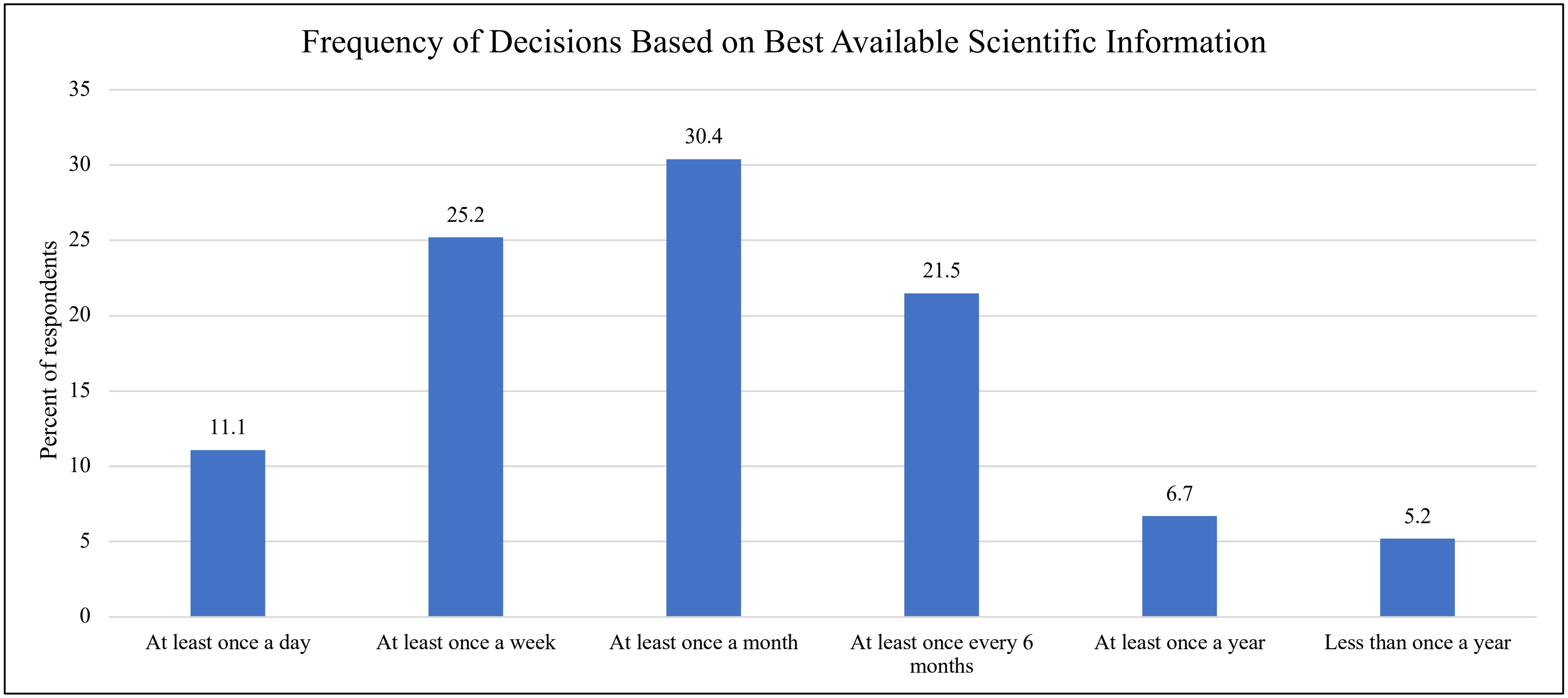

Figure 3-2: *Response to the question, "how often do you actively seek best available scientific information to inform fire-related decision-making?" n=135. Data labels show the percent of respondents.*

Respondents were also asked how often they used different science sources in their job and selected on a scale from daily to do not use. The top five sources of scientific information for survey respondents were: (1) colleagues at your workplace, (2) scholarly search engines (e.g., google scholar, science.gov, refseek., worldwidescience, etc.), (3) colleagues from a partner organization, agency or institution, (4) internal folders or databases (e.g., google drives, sharepoints), and (5) local or regional collaborative groups (SWFSC). The least used sources of scientific information were: (1) direct communication with SWFSC staff, (2) wildland fire library, and (3) fire research and management exchange system (FRAMES.gov).

I used survey questions to understand the science sharing relationships between organizations. Table 2 presents all the agencies and organizations sharing relationships. A positive sharing relationship means the sharing organization is more likely to share with that receiving organization than the other organizations in the same row. Table 2's caption explains an example of these relationships. A negative sharing relationship means the sharing organization is less likely to share with that receiving organization than the other organizations in the same row. The results show a large amount of sharing internally with like-kind organization or agency type. Some examples of this are federal agencies sharing with federal agencies and tribal entities sharing with tribal entities. Private businesses, contractors or consultants and universities or other academic entities also shared significantly more with themselves or organizations of the same type than others. City or county governments did not share a significant amount of BASI with any other organizations, and they shared significantly less with tribal entities and universities or academic entities.

Table 3-2: *Sharing of best available scientific information across agencies and organizations. Values within the table represent the p-value. Bolded values represent a significant (P<0.05) difference in the amount of BASI shared. A plus symbol represents a significantly higher amount of BASI shared and a minus represents a significantly lower amount of science exchange. For example: the first row, federal agency, shares more science with federal agencies than the rest of organizations and shares less science with (1) universities or other academic entity's or (2) retirees.*

BASI Shared To

BASI Shared From	Federal agency	State Agency	City or county government	Tribal entity	Non-governmental or non-profit organization	Community forestry or collaborative	Private business, contractor, or consultant	University or other academic entity	Private landowner or community representative	I am retired
Federal agency	**0.017 +**	0.684	0.327	0.182	0.444	0.086	0.277	**0.018 -**	0.168	**<.001 -**
State agency	0.226	0.086	1	0.266	1	0.217	0.375	0.064	0.302	0.116
City or county government	0.737	0.322	0.113	**0.006 -**	0.126	0.438	0.778	**0.014 -**	1	1
Tribal entity	0.728	0.088	0.406	**0.005 +**	1	1	**0.017 -**	**0.013 -**	1	0.530
Non-governmental or non-profit organization	0.087	0.081	0.401	0.066	**0.026 +**	**0.042 +**	0.558	0.412	0.642	0.525
Community forestry or collaborative	**0.027 -**	0.452	**0.009 +**	0.435	**0.017 +**	0.066	0.530	0.660	1	0.305
Private business, contractor, or consultant	0.088	**0.002 +**	0.345	1	0.230	0.094	**0.024 +**	0.130	1	1
University or other academic entity	**0.018 -**	0.322	0.438	**0.003 -**	0.532	0.438	0.396	**<.001 +**	0.362	0.126
Other	0.730	1	1	1	1	0.302	1	0.375	1	0.121

Specific positions are prone to sharing BASI significantly more frequently with various organizations or agencies in fire management. Private contractors or business owners are more likely to share science with other private businesses, contractors, or consultants (P=.001), community forestry or community-based collaborative entities (P=.009), and non-governmental or non-profit organizations (P=.042). Researchers are more likely to share BASI with universities and other academic entities (P<.001). Managers are less likely to share BASI with universities and other academic entities (P<.001) and community forestry or community-based collaborative entities (P=.044). Non-governmental or collaborative representatives or employees are more likely to share BASI with community forestry or community-based collaborative entities (P=.028). Finally, private property owners or community representatives are less likely to share BASI as compared to all other groups (P=.043).

4.4 Barriers to best available scientific information

I asked survey respondents to state how strongly they agreed or disagreed with statements relating to barriers that may potentially prevent them from using BASI. The top three barriers to using BASI for respondents were: (1) science is changing so fast that it is difficult to stay up to date, (2) conflict of opinions between management organizations and research entities about what constitutes BASI, and (3) there is a lack of public support for BASI. The full list of barriers is displayed in Figure 3.

Figure 3-3: *Barriers to using best available scientific information across all disciplines listed top-down from most agreed with to least agreed with. The barriers are organized using mean Likert response from 5-strongly agree to 1-strongly disagree, the mean is displayed on the right side of the figure.*

After the analysis of the data, it was apparent that respondents face different barriers across various position types. I split respondents into three main job categories, scientists, managers, and practitioner/outreach positions based on the job position they selected. Scientists and managers both indicated “science is changing so fast that it is difficult to stay up to date” is their most common barrier. Managers indicated “conflict of opinions between management organizations and research entities about what constitutes BASI” is their second most common barrier and practitioner/outreach positions it’s third largest barrier. By contrast scientists identified this as their seventh most common barrier. Scientists felt that “the educational resources available to me are not up to date (i.e., professional courses, internal training)” was the fourth most common barrier, and the other two groups indicated it is not common barrier at ninth or above. Managers and practitioner/outreach positions felt that “a lack of interaction between researchers and managers means that emergent research isn’t relevant to me” was a greater problem than scientists indicating it is their third and fourth most common barriers, with it falling as the seventh barrier for scientists. Paywalls were a significant issue for the practitioner/outreach positions indicating “the best available scientific information I want to use is hidden behind paywalls” as their most common barrier; it fell to fifth for scientists and managers. Many of the barriers were also consistently present across position types. All three position types indicated “there is a lack of public support for the best available scientific information” in their top five barriers to using BASI at work. Additionally, all three position groups felt that “I do not have enough time to implement BASI” is a top five barrier to BASI use.

Barriers to BASI use were also evaluated for statistically significant differences across the three position types. There were five barriers that were significantly different across the position groups: (1) I am not sure how to locate best available scientific information, (2) There is no new scientific information available on topics that I need, (3) The best available scientific information I want to use is hidden behind paywalls, (4) I do not agree with the current best available science in my field, (5) I am concerned about litigation or other negative consequences associated with using best available scientific information. Table 4 shows the full list of barriers and the mean responses for each group.

Table 3-3. Significant barrier differences between position groups. Numbers under position group represent mean response. Respondents selected on a scale of 1 (Strongly disagree) to 5 (Strongly agree). A lower mean represents less agreement with the statement. The standard error shows the variation between the three groups. Significant P-values ($p < 0.05$) are bolded.

Barrier	Mean	Scientists	Managers	Practitioners and outreach positions	P-Value	Standard Error
I am not sure how to locate best available scientific information	2.44	2.02	2.69	2.52	**0.008**	**0.054**
There is no new scientific information available on topics that I need	2.31	2.00	2.57	2.14	**0.013**	**0.055**
The best available scientific information I want to use is hidden behind paywalls	2.91	2.74	2.90	3.33	**0.015**	**0.039**
I do not agree with the current best available science in my field	2.04	1.76	2.20	2.10	**0.020**	**0.062**
I am concerned about litigation or other negative consequences associated with using best available scientific information	2.30	1.98	2.41	2.62	**0.032**	**0.056**
Organizational barriers at my current workplace prevent me from using best available scientific information	2.35	1.98	2.60	2.33	0.057	0.054
A lack of interaction between researchers and managers means that emergent research isn't relevant to me	2.94	2.63	3.14	2.95	0.107	0.040
Conflict of opinions between management organizations and research entities about what constitutes the best available scientific information	2.99	2.70	3.16	3.05	0.160	0.039
Current scientific information is contradictory	2.53	2.33	2.61	2.67	0.177	0.047
There is a lack of public support for best available scientific information	2.97	2.93	2.90	3.29	0.262	0.036
The educational resources available to me are not up-to-date (i.e., professional courses, internal training)	2.69	2.76	2.72	2.42	0.473	0.044
Science is changing so fast that it is difficult to stay up to date	3.14	3.22	3.16	2.90	0.506	0.035
Academic language and unfamiliar terminology make the science difficult to understand	2.71	2.54	2.78	2.81	0.627	0.044
I don't have enough time to implement best available scientific information	2.97	2.87	3.04	2.95	0.830	0.039

5. Discussion

Using fire science to make management decisions can be an effective way to increase management success (Zimmerman, 2012). This research aimed to understand where there were gaps in fire science expertise, fire professionals' experience using BASI, and the barriers that prevent fire professionals from accessing and implementing fire science. I found multiple areas of wildfire expertise that are underrepresented in the Southwest, therefore likely limiting available knowledge within and between various management organizations. This study shows that fire professionals are using BASI at different frequencies and use a wide variety of sources to find science based on factors like position, preferences, and abilities. Additionally, there is a network of science-sharing across fire organizations in the Southwest that serve as a source of science for many professionals; unfortunately, many of these may be unavailable to professionals or organizations without existing social networks. While this study shows that fire managers and researchers are generally highly engaged and interested in implementing fire science into management in the Southwest, they sometimes struggle because of barriers like paywalls and lack of public support. This research provides a foundation for advancing science communication to better support fire professionals implement BASI into land and fire management decisions.

Survey respondents' areas of expertise in fire science and management highlighted multiple gaps where agencies and organizations need to focus resources and attention on to become more holistic in their approaches to fire management and mitigation. These lesser-studied and supported areas are critical for responsive fire management, as agencies and organizations may struggle to implement related management practices without expert knowledge in these areas. For example, an organization lacking expertise in smoke management and impacts might reduce its ability to implement prescribed burns with proper smoke considerations. Without these considerations, unnecessary amounts of smoke could affect nearby populations; prolonged smoke exposure can reduce public support for prescribed burning (Olsen et al., 2014). Lack of public support is a large barrier for land managers as they implement new management practices (Hunter et al., 2020). Lacking expertise and knowledge in these areas is problematic, as organizations may make management decisions in disagreement with knowledge in these fields (Turnbull, 1997). Increased diversity of knowledge across sub-fields of fire science may improve organization's ability to implement BASI and more efficiently achieve management goals. The understanding of organizations areas of expertise could be improved with dedicated research working to understand expertise across the Southwest. Future efforts to increase the diversity of fire professionals in the Southwest by prioritizing hiring and retention efforts on these under-represented sub-fields is the foundation for this change.

Fire professionals are accessing and making decisions based on BASI at different frequencies because of different job requirements, preferences, and abilities. Improving the understanding of these different factors can help us understand where BASI expansion efforts should be focused. Many positions, like researchers, are frequently accessing BASI at work. Other positions, like private contractors or business owners, access BASI less frequently. These positions may not have access to science because of barriers like inability to access science through paywalls or other limitations (Hunter et al., 2020). Other positions like community representatives for example, may also simply not be required to access fire science as all positions have different needs (Davis et al., 2013). Understanding which of the less-frequent BASI users want access to BASI and which of them are not looking for science, will help improve the dissemination of information. Increased research on supporting non-frequent BASI users to use more BASI may help increase science supported decision making.

Southwest fire professionals access BASI through a variety of sources such as informal approaches like conversations with colleagues or formal sources like academic search engines. These sources of information can be hard to access for a person or organization without good social connectivity or institutional wealth that can support accessibility, for example by subscribing to journals in order to lift paywalls. Partnerships like the SWFSC can acknowledge these potential problems when disseminating fire science and work to include all groups by keeping access science information free wherever possible (Davis et al., 2013). Posting open-access whitepapers, factsheets, and any other science on their website allows access to relevant science, which can help organizations who struggle to access through academic paywalls. Continued research on how partnerships like the SWFSC can best disseminate science will improve equitable and easy access to BASI on the ground.

There is a large, established network of science sharing across fire organizations in the Southwest. Organizational science synergies, or knowledge exchange between organizations, are important to understand because they are the primary access to science for many professionals (Klenk et al., 2022). Many organizations shared a significant amount of science with themselves or the same type of organization. Recognizing the amount of inter-organizational sharing that takes place highlights the importance of diverse expertise within a workplace. The organizations that have expertise gaps as previously outlined lack the ability to use inter-organizational sharing in these topics and can miss important information. This necessitates diverse workplace knowledge, and directly impacts an organization’s ability to access and implement BASI. Positive benefits of workplace diversity is well supported across literature and future research on how to support increased diversity in fire management in the Southwest could benefit organizations that are aiming to increase science-based management decisions (Chrobat-Mason et al., 2013).

Specific positions tend to share more BASI with others, researchers, private contractors or business owners, and non-governmental or collaborative representatives or employees all share significantly more BASI with other positions. Supporting existing positions and creating new positions that are designed to share BASI within organizations is critical to continuing the dissemination of science – that could include the incorporation of science dissemination into position descriptions where relevant. Certain processes within agencies and organizations may be created to share BASI; examples include internal folders and databases, or workshops. However, these processes are still entirely dependent on the individual positions to share and update the information. Specific research on the relationships and individuals that drive BASI sharing in Southwest fire management would increase the capacity to support these positions. In-depth research to explore the "nodes" who facilitate critical science exchange, such as a social network analysis study, could determine individual positions that are disseminating the most science and therefore critical to support (Ager et al., 2015). This would be a great first step to strengthening science sharing relationships in the Southwest and better supporting positions who share science.

Understanding common barriers to accessing and implementing BASI will support the future use of BASI in fire management. This study showed the different barriers that various position types face when working to access and implement BASI. Partnerships like the SWFSC should seek to identify and support the reduction of these barriers: since the scientific information communicated through JFSP consortia is free and open access, increasing the amount of information published may reduce the impacts of paywalls on fire professionals.

Additionally, review and summary products that aim to synthesize scientific information into rapidly digestible text can help researchers and managers keep up to date on fire science without making large time contributions that would otherwise limit their willingness and ability to incorporate relevant findings and recommendations. Consortia are limited by their own barriers to increasing capacity including funding and resources (Kocher et al., 2012). The specific barriers to professionals implementing BASI outlined in this research and other literature allows consortia to target specific areas to improve effectiveness with the same amount of resources. For example, adding executive summaries and short reviews of existing products can allow consortia to increase the amount of science consumed without needing new research. This list of barriers should serve as a reminder as new products and ideas for science dissemination is created. Acknowledging that various positions face different barriers, with continued research on how to best support them through these barriers will allow organizations who want to, increase their BASI based decisions.

6. Conclusion

Understanding where expertise is housed in Southwest fire management, how professionals use and interact with fire science, and the barriers that prevent them from implementing and accessing science is critical to improving the use of BASI in fire management. This research uncovered areas of fire science in the Southwest that lack expertise including (1) traditional and indigenous knowledge, (2) diversity, equity, and inclusion in fire and (3) smoke management and impacts. This study showed that most fire professionals are frequently accessing and using BASI in their positions, and many of them are sharing this information with others. Further investigation into the relationships of science sharing showed lots of information is shared within the same organization or agency types. This shows that lacking expertise or diversity of knowledge within an organization can limit the ability to make fully informed management decisions. Finally, this research aimed to understand the barriers that limit fire professionals from accessing and implementing BASI into their work. I found that fast changing science made it difficult for respondents to stay up to date, and paywalls blocked access for some positions when searching for BASI. Moving forward, the use of BASI in fire management will continue to increase in importance, any measures organizations can take to encourage the use of science in management decisions will improve the chances of successfully managing increasingly complex wildfires.

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CHAPTER 4

CONCLUSION AND RECCOMENDATIONS

Fire professionals are dealing with increasingly complex fire management issues as wildfires increase in severity in the Southwest. The use of BASI supports fire professionals as they make complex management decisions, and respondents in this research were using BASI often. Respondents frequently accessed and made decisions using knowledge gleaned from the BASI they identified. This scientific information came from a variety of sources, many of which were informal channels like conversations with colleagues or partner organizations. This research shows there is a network of relationships across fire management organizations where professionals are sharing BASI. However, these relationships were not enough to support all BASI use and overcome persistent barriers to BASI in the Southwest. The fire professionals that participated in this research faced a variety of barriers to accessing and implementing BASI in their positions, ranging from institutional to personal.

Some areas of fire science may be a research need because there are not enough professionals in the Southwest that have the knowledge to share science in these topics. This research uncovered areas of fire science in the Southwest that lack expertise including (1) traditional and indigenous knowledge, (2) diversity, equity, and inclusion in fire and (3) smoke management and impacts. Many of the areas with the greatest research needs correlated with these areas that lack expertise. Both diversity, equity and inclusion in fire and traditional and indigenous knowledge were identified as areas that have significant research needs. In addition to supporting future research in these areas, it may be necessary to hire positions with this expertise that can help share this science across organizations.

Many organizations are lacking the proper tools and support to encourage fire professionals to use and share BASI. To start, there is no clear consensus on a definition of BASI across management organizations and research entities; this creates a barrier for fire professionals as it can be difficult to unify management practices across organizations. Additionally, organizations do not incentivize interaction and science exchange across positions, instead relying on the motivation of individuals to seek and share BASI. Research entities could improve this by incentivizing researchers to interact more with managers; this could be by funding research projects that incorportate co-production with managers, rewarding management connections with promotions, or by integrating managers into classroom interactions. Management agencies could also improve BASI exchange by requiring and facilitating more researcher interaction in management decisions. Using these methods to build space for more interaction between managers and researchers may help improve BASI sharing across organizations. Research entities and management organizations are not recognizing all the barriers that prevent fire professionals from implementing and accessing BASI.

This thesis has culminated in an array of recommendations that can provide guidance for individuals and organizations struggling to access and use BASI in the Southwest. These suggestions are organized below to provide directed insights for science exchange organizations, followed by individual positions. Together, the recommendations below seek to address the inequitable nature of BASI application across Arizona and New Mexico.

1. Recommendations to science exchange organizations

- Promote significant research needs identified in this survey as future topics for proposal calls, including:

    - Firefighter health, safety, and wellbeing
    - Planning for fuels treatments
    - Post-fire ecological effects
    - Strategies or factors related to increasing inclusivity in fire science
- Provide summaries of emerging research that help fire professionals keep up with emergent research. This could include:
    - Newsletter coverage of publications
    - Separate monthly emails highlighting recently published science based in the Southwest
    - "Year in review" whitepapers or briefs that focus on emerging fire science based in the Southwest in the last year.
- Create an online location for scientists to self-report their own published research related to the Southwest to support both efforts above.
- Share opportunities to access peer-reviewed fire science that is typically hidden behind paywalls. This could include:
    - Highlighting websites and tools for accessing research without a fee (e.g., ResearchGate).
    - Featuring open access research in newsletters and other outreach.
    - Providing partial financial support for open-access publishing fees to support relevant or significantly needed fire science in the form of small scholarships.
- Continue or expand upon in-person events such as workshops and conferences; continued or increased provision of travel funding will increase access to these resources.

- Maintain popular virtual outreach such as the newsletter, webinars, and topical synthesis papers and fact sheets; expansion across new social media platforms may not be as necessary as previously thought.

2. Recommendations to scientists

- Engage in science exchange organizations like the SWFSC and aim to interact with other professional positions as much as possible.
- Consider producing free versions of your research to increase engagement including:
    - Whitepapers or factsheets can be published through science exchanges for free.
    - Webinars, science panels, and other methods to provide science for free.
- Take time constraints of managers and practitioners into account when producing research:
    - Executive summaries, and fact sheets can help professionals with limited time consume your science.
    - A-synchronous ways to consume presentations and talks may increase the number of professionals able to listen.
    - Budget for travel or salary support to increase the capacity for non-scientists to meaningfully engage in research design.
- Consider research needs identified in this research when submitting new proposals that are specific to the Southwest. This research suggests that the greatest needs include efforts designed to provide new insights on:
    - Firefighter health, safety, and wellbeing
    - Planning for fuels treatments

    - Post-fire ecological effects
    - Strategies or factors related to increasing inclusivity in fire science
- Share paywalled science to organizations or colleagues who do not have access where relevant.
- Ask questions to managers and practitioners, and work to produce applicable science that aligns with their needs and actions on the ground.

3. Recommendations to managers

- Engage in science exchange organizations like the SWFSC and aim to interact with other professional positions as much as possible.
- Consume consolidated version of science communication that highlight key findings to save time.
    - Whitepapers, factsheets, and executive summaries are produced to reduce time requirements.
    - Pick a one or several focal consolidated source of science to regularly check for updates (SWFSC website, JFSP, etc.) to minimize information overwhelm.
- Document which definition of best available scientific information you are using when making management decisions that require it to improve transparency around how specific BASI insights were chosen and applied.
- Encourage information sharing within your organization
    - Formal strategies may include workshops, science committees, shared drives etc.

    - Informal strategies may include discussions with colleagues and partner organizations and emailing research you found impactful to others who may be interested.
- Engage in opportunities to interact with the public and leverage these discussions to increase public support by sharing BASI and its relevance in place-specific contexts.
- Reach out to scientists and ask questions when you have them.
    - Building relationships with researchers can reduce the amount of time it takes to find scientific information and increase your trust and understanding in the science they share.

4. Recommendations to practitioners/outreach positions

- Engage in science exchange organizations like the SWFSC and aim to interact with other professional positions as much as possible.
- Consider these free sources of science when paywalls are blocking access:
    - Science exchange organizations (SWFSC, JFSP, etc.)
    - Treesearch and other agency-specific science databases that promote open access
    - Open access journals
    - Free online publishing locations (ResearchGate)
    - Asking questions directly to scientists
    - Email authors directly to request access
    - Extension/outreach programs
    - Find research published by federal researchers
- Use abbreviated versions and summaries of science to save time.

    - Whitepapers, factsheets, and executive summaries are produced to reduce time requirements.
- Build and maintain relationships with organizations that are required to use BASI to use as sources of science.
- Reach out to scientists and ask questions when you have them.
    - Building relationships with researchers can reduce the amount of time it takes to find scientific information and increase your trust and understanding in the science they share.

5. Limitations and conclusion

BASI use in fire management decisions will continue as fire seasons progress in the Southwest. Various barriers prevented our survey respondents from being able to implement BASI in their positions. It is unclear how these barriers compare to other geographical regions; additional research in other areas of the US can inform whether these barriers are unique to Arizona and New Mexico or universal. Additionally, we do not know if the barriers to implementing BASI are representative of all fire professionals in the Southwest or just those involved in a science exchange organization like the SWFSC. A social network analysis focused on science sharing relationships may help to answer this question by incorporating the thoughts and experiences of fire professionals beyond the SWFSC. Another limitation of this research is potential differences between respondents' definitions of BASI. If we used multiple definitions for BASI, or allowed respondents to self-described BASI definitions, it may have changed the types of barriers described. Finally, research needs, barriers to BASI use, and fire management in general are evolving rapidly; future research that reassesses needs may find different priorities.

Encouraging JFSP science exchange networks to engage in standardized assessments of regional research needs every 10 years at a minimum can help generate a clearer picture of BASI use and needs.

APPENDICES

1. Interview protocol

1.1 Introduction

- Tell me about your current job position and responsibilities?
  - How long have you held your current position?
  - Tell us about your career pathway to this position. (education)

1.2 Changes to fire science

- How has wildland fire science/information changed over the course of your career
  - (in the last 10 years)?
  - Has that varied across the different positions you've held?
- What do you wish you knew 10 years ago (if applicable)?
- What is a piece of information you hope to have access to in 10 years? Information needs
- How has your use of scientific information changed?
  - Access to it
  - Popular or primary ('hot') topics? New key resources?
  - Policies or guiding plans? As a result of individual perceptions and behaviors?
  - Which studies, or pieces of information have moved the needle most?

1.3 Access to scientific information

- What are the most accessible kinds of research or information on fire?
- Which wildland fire topics have the largest gaps in available research or info from your perspective?
- Do these gaps hold true in the Southwest, or are they region-specific?/What is the most challenging information to find related to fire in the SW?

    - Your state
    - Specific ecosystem/types, districts?
- How 'local' does the information you use need to be for it to be helpful?
    - Same watershed, forest service district, forest service region, general geographic area or statewide?
- Are there certain topics where it is more important to have locally specific information or research? If so, which types of topics or projects, and which types of research or information?
    - Examples of topics: Fire effects (on soils, vegetation, wildlife, etc.), fire regimes, fire history, fuels modelling, smoke modelling, impacts of forest management on fire behavior/effects, salvage logging, economic impacts of suppression and from fire damage, invasive species, threatened and endangered species, riparian areas, post fire erosion, impact of beetle/insect/disease on fire risk and effects
    - Social acceptability, economic impacts, policy implications?
- Are there certain topics where it is more difficult to find locally specific or regionally specific scientific research or papers?

<u>1.4 SWFSC</u>

- To what extent does the SWFSC address those local information needs?
- How accessible is fire-related research in your current position?
- How often/when do you look to SWFSC for scientific information or research?
    - Are there certain projects or types of projects where you rely more on scientific information? Or projects where you rely less on scientific information?

- Who uses SWFSC materials in your organization, and who doesn't?
- Do you get a sense for how SWFSC information is being used?
    - And by who? Job positions, GS levels, etc.?
    - How often?
- Are your research needs the same as ____ (managers/researchers? Other agencies) or different?
    - Are those research needs specific to you, or do others with your position in the SW share them?
- How long were you/have you been on the SWFSC board?
- What relationship did you have with the SWFSWC prior to being a board member?
- To what extent does/did your SWFSC position and your job intersect/interact
    - In what contexts do they interact?
- What do you see as the core goals of the SWFSC
    - Will that change in the next 10 years?
- What are the most useful outputs of the Southwest fire science consortium?
    - Which SWFSC products get the most traction among the managers you know?
    - Are there any other products or outputs that the SWFSC could create that would broaden the SWFSC's audience
- How does the SWFSC help you understand manager's/researchers needs?
    - Are there any groups or participants missing from the SWFSC - both the board and its audience?
    - Are you aware of the other party's needs?
    - How could the SWFSC help these two parties align

- What information does the SWFSC need about their audiences to improve partnerships in the SW?
- We are currently in the process of designing a broad survey for SWFSC audiences. What should we ask?

1.5 Close out

- Is there anything else you would like to tell me about how you use research to inform your job and your needs for locally based research?
- We are interested in talking to a wide range of people, is there anyone you can recommend that we talk to who might have a similar or different perspective on these topics we have discussed today?