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Examining and strengthening the role of science in wilderness decision-making

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ABSTRACT

Public land management decisions rely on science but there is a disconnect between research and practical application; this is referred to as the research–management gap. Within the context of the United States (US) National Wilderness Preservation System, this gap has implications across 111 million acres of land managed by four federal agencies. To better understand how to bridge research with management within the US wilderness context, we conducted facilitated conversations with 68 wilderness managers using interactive virtual whiteboards to guide conversations around decision contexts, the role of science in wilderness management decision-making, and opportunities to improve the use of science in wilderness management. We found that wilderness managers operate within four main decision contexts (operational, relational, informational, and policy), and that they rely on a variety of sources of information, with science as one of many sources, to guide management action and decisions, both directly and indirectly. Bridging the research–management gap requires a two-tiered approach: (1) bottom-up, working with local managers to develop, apply, and interpret relevant science in a co-produced manner; and (2) top-down, working with agency and wilderness leaders to champion the integration of research into policy and management directives. Better working relationships between managers and scientists could improve the adoption of science in wilderness management as well as improve how scientists understand the range of competing policies, programs, and priorities that guide wilderness managers.

INTRODUCTION

Both scientists and land managers recognize that decisions related to land management are supported by science that merges on-the-ground context with relevant information and spans disciplines and applicability (Watson and Armatas 2017). Science has been broadly defined as a "systematic set of empirical activities for constructing, representing, and analyzing knowledge about phenomena being studied" guided by normative philosophical commitments (Patterson and Williams 1998). Science can add rigor to decision-making, facilitate productive discussions among varying interests, focus discussion on choices and consequences rather than dogmas, and increase understanding around the scope of the decision space (i.e., the range of options considered feasible) as well as possible outcomes (Mills and Clark 2001; Fuller et al. 2020). Furthermore, the use of a

science-based rationale for management choices can increase public acceptability of decisions and reduce potential litigation (Szaro and Peterson 2004).

Although there are many reasons for integrating science into land management, there is a disconnect between research and practical application that is sometimes referred to as the research–management gap (Cooke et al. 2021). Reasons for this disconnect are myriad, including the different work cultures of scientists and managers; communication barriers; institutional barriers such as lack of time, funding, and personnel; and external barriers such as lack of public awareness or support (Wright 2007; Courtney and Schneider 2016; Hunter et al. 2020). Additionally, as scholars increasingly recognize that landscapes are both socially and ecologically produced, the research–management gap can become even more challenging to overcome as ecologists and land managers may not be versed in the social sciences or interdisciplinary studies (Robinson et al. 2019).

Historically, scientists have approached this gap by relying on technology transfer and science delivery methods that communicate new information and tools to potential end-users. Many of these efforts have been based on a knowledge-deficit model that presumes managers simply need to be given access to relevant research to improve the uptake of science for management (Simis et al. 2016). However, scientists and science communicators increasingly recognize that a multifaceted approach can better address the research management gap. For example, the science of actionable knowledge centers knowledge development as a social process that occurs between scientists and managers rather than a material good to be transferred from scientists to managers (Mach et al. 2020). When public land managers and scientists learn from one another about their respective decision spaces and available science, they also develop invaluable interpersonal relationships that can be leveraged for improved management and research (Stern et al. 2018). To close the research–management gap, scholars recommend prioritizing informal interactions, trust-building, contextual understanding, and institutional boundary-spanning to bring forth values and assumptions inherent to work priorities (Nel et al. 2016).

Research has examined the necessary elements to close the research–management gap across a variety of natural resource contexts, including the federal land management system, biological invasions, wildland fire, and wildlife, among many others (e.g. Renz et al. 2009; Merkle et al. 2019; Carter et al. 2023). Few studies have focused on this complex issue within federally designated wilderness in the United States (e.g., Watson and Armatas 2017; Taylor et al. 2023); here the gap between research and management has implications across 111 million acres of designated wilderness managed by four federal agencies, including the Bureau of Land Management (BLM), the National Park Service (NPS), the United States Fish and Wildlife Service (USFWS), and the United States Forest Service (USFS). Wilderness managers must navigate preservation-oriented land management values for natural and cultural resources, as well as maintain opportunities for solitude and unconfined recreation while using tools that are consistent with minimizing impacts in wilderness, as mandated by the Wilderness Act of 1964 (16 U.S.C. 1131–1136).

In addition to the Wilderness Act, wilderness managers must navigate other key federal legislation, including the Endangered Species Act (ESA; 16 U.S.C. 1531–1544) and the National Environmental Protection Act (NEPA; 42 U.S.C. § 4321), among others. These policies mandate the use of science in management. For example, NEPA requires federal agencies to use science for environmental planning and decision-making, the National Parks Omnibus Management Act (Public Law 105-391) requires the secretary of the interior to assure science is used to manage national parks (Harmon 1999), and USFS's 2012 Planning Rule requires the use of "best available scientific information" to inform forest planning (Ryan et al. 2018). BLM has also recognized the importance of applying science by developing a formal strategy to do so (Carter et al. 2023). USFWS and the National Oceanic and Atmospheric Administration are both required to "make biological decisions based upon the best scientific and commercial data available" as part of a cooperative policy for peer review in ESA activities (*Federal Register* Doc. No. 94-16021). Yet science that can be used to improve management decisions spans a wide array of potential disciplines, including ecological, biological, social, managerial, and more. As a result, it remains unclear precisely what are the decision-making contexts where wilderness managers already use science, and where opportunities exist to improve its use and applicability.

This paper seeks to address these knowledge gaps within US federally designated wilderness by advancing an understanding about the role of science and opportunities to strengthen the use of science in management. Specifically, we sought to address three research objectives:

1. Identify the decision-making contexts of wilderness managers;
2. Understand the role of science within those decision-making contexts; and
3. Examine opportunities to strengthen the use of science within wilderness management.

We share a novel approach to data collection, relying on virtual whiteboards and facilitated confidential conversations with relevant groups of managers. We present our findings in three sections, corresponding to the research objectives. We conclude with considerations of the research–management gap and opportunities to bolster science-informed wilderness management by bridging co-production of research with managers with championing integration of science into directives and policy.

METHODS

Data collection

To better understand perspectives and practices around applying science to wilderness management, we engaged wilderness managers representing a range of roles across all four federal wilderness management agencies, BLM, NPS, USFS, and USFWS, as well as management partners from the non-profit sector, in data gathering sessions. Specifically, we coordinated with agency leadership from across the National Wilderness Preservation System to organize facilitated conversations across agencies from May through October 2022. Within these agencies, wilderness leadership invited staff to participate in organized sessions, meaning we relied on convenience sampling whereby invited participants joined if they were interested and available (Bernard 2006). Additionally, we held a data gathering session at the 2022 virtual National Wilderness Skills Institute (https://wildernessskillsinstitute.org/nwsi/) with participants representing the non-profit sector and USFS. Combined, we held one 60-minute session with three of the agencies (BLM, USFS, USFWS), and three 30-minute sessions with NPS, in order to take advantage of existing meetings at different levels of the wilderness management organization. Given that not all sessions were of the same length, we relied on a shortened set of questions to ensure we addressed all research objectives in each session (Table 1).

In total, we held seven data gathering sessions with 68 participants. They represented a wide range of positions, federal agencies, and non-profit partners; years in service; and geographies. The average years of experience of the groups ranging from 11 to 23.5. Fifteen types of professional positions were represented, including interpreter, resource manager (natural resource scientist; cultural resources manager), trainer, ranger, facilities/trails manager, wilderness coordinator (national and regional), planner, commercial services specialist, refuge manager, recreation manager, wilderness program lead, state office program lead, wilderness character monitoring program manager (national), researcher, and compliance manager. Participants additionally held diverse levels of

TABLE 1. Science communication data gathering sessions, organized by date, participants' institutional affiliation, time allocated to the session, and total number of participants, along with questions asked for the three research objectives.

Session date	Participants' institutional affiliations	Time allocated (minutes)	Number of participants	Questions asked for Research Objective 1 (Q1)	Questions asked for Research Objective 2 (Q2, 3, 4)	Questions asked for Research Objective 3 (Q5, 6, 7, 8)
May 25, 2022	National Wilderness Skills Institute (USFS and non-profit partners)	60	11	Q1	Q2, 3, 4	Q5
August 16, 2022	BLM wilderness managers (general)	60	15	Q1	Q2, 3, 4	Q5, 6, 7, 8
September 13, 2022	USFS Wilderness and Wild and Scenic Rivers Program Managers	60	11	Q1	Q2, 3, 4	Q5, 6, 7, 8
October 4, 2022	NPS Intermountain Region Leadership Wilderness Executive Committee	30	13	Q1	Q2, 3, 4	Q5, 8
October 13, 2022	NPS Regional Wilderness Coordinators	30	7	Q1	Q2, 3, 4	Q5, 8
October 17, 2022	USFWS wilderness managers (general)	60	4	Q1	Q2, 3, 4	Q5, 6, 7, 8
October 19, 2022	NPS Wilderness Leadership Council	30	8	Q1	Q2, 3, 4	Q5, 8

Question #	Specific question asked on virtual whiteboard
1	What are the kinds of decisions or tasks you face on a day-to-day basis?
2	What types of information do you call on when making these various kinds of decisions, or addressing these various tasks?
3	When do you use science, more specifically, in your day-to-day work?
4	How do you use science in these decision-making contexts?
5	What successes have you had moving best available science into action?
6	What challenges have you had moving best available science into action?
7	What makes you trust or distrust scientists?
8	If you have been involved or could imagine being involved in research that was developed by scientists and managers working together ("co-produced"), what made that successful or unsuccessful?

management, authority, and subject-matter expertise, and had varying levels of interaction with the public. Collectively, they comprise a set of "wilderness managers," a diverse group responsible for stewarding wilderness for the American public.

We facilitated sessions among colleagues in peer groups (Bernard 2017). To maintain confidentiality within groups while allowing people to see and build on other participant responses, we used interactive virtual whiteboards (specifically, Google Jamboards) to collect data, ultimately adapting rapid community assessment methods to work within this virtual space (Chambers 2002). Prior to each session, we created virtual whiteboards with questions focused on wilderness management operations and decisions, the role of science in decision-making, situations where science is actively sought, successes and challenges of moving science to action, successful and unsuccessful examples of co-produced research, elements of trustful and distrustful relationships between managers and scientists, and elements of credible science. Since the sessions varied in length, we curated one short and one long list of questions that allowed us to address the research objective from each group in more or less depth, depending on the session length.

To maximize the comprehension of the questions, we read each question aloud, invited clarifying questions, and then instructed participants to add unidentified, virtual sticky notes with responses to each question. Where responses on the sticky notes were unclear to the facilitators or required further explanation, we asked participants either to explain orally or add an additional sticky note to clarify the meaning. Participants could add as few or as many sticky notes to the virtual whiteboards as desired, which meant we were unable to trace responses back to individuals. Participants could also respond to, duplicate, or contradict each other's responses, which may have enriched the data as participants could add detail or examples to underscore their responses.

All data were analyzed together, with context to responses in the findings provided by which agency or group the response was from. Although the use of virtual whiteboards offered a novel tool for data collection, the Google Jamboards program had some notable limitations in functionality. Most notably, each sticky note had a character limit that, when surpassed, erased the characters that exceeded the limit. As a result, some of the longer responses (20 in total) were clipped at the character limit, resulting in lost information.

Data analysis

We collated all responses into an Excel spreadsheet, moving responses from virtual sticky notes to columns corresponding to each question (see Redmore et al. 2024 for archived data). Where participants shared multiple thoughts in one sticky note, cells were duplicated to ensure each main idea was captured in a separate cell. We used an interpretivist epistemological approach for qualitative research, recognizing that knowledge is co-produced during interactions between researchers and participants, and followed recommendations to improve trustworthiness of data analysis and interpretation as laid out by Cofie, Braund, and Delgarno (2022). Specifically, two team members worked together to code the data: one member who helped collect the data and one member who was not involved with data collection. Coders used a two-phased coding approach, first independently coding all open-ended responses from the sticky notes using an in-vivo coding process, distilling the main idea from each response to as few words as possible. Next, working together, the coders discussed and deliberated to ensure agreement on the codebook and code selection (Cofie et al. 2022). This coding process requires personal experience and knowledge to identify relationships between wilderness management and science. As researchers without first-hand experience directly managing wilderness, we sometimes lacked this personal insight and so consulted with wilderness managers to ensure trustworthiness of interpretations of the responses (Stahl and King 2020).

After reaching consensus, each unique code was organized into higher-order, more-general themes, and secondary-order, more-specific themes. Themes were iteratively reorganized and condensed into the main, interrelated findings presented below (Bernard 2017). In this paper, we present findings that display relationships between themes and codes, and we also use quotes from codes to offer a deeper level of interpretation of the themes.

FINDINGS AND DISCUSSION

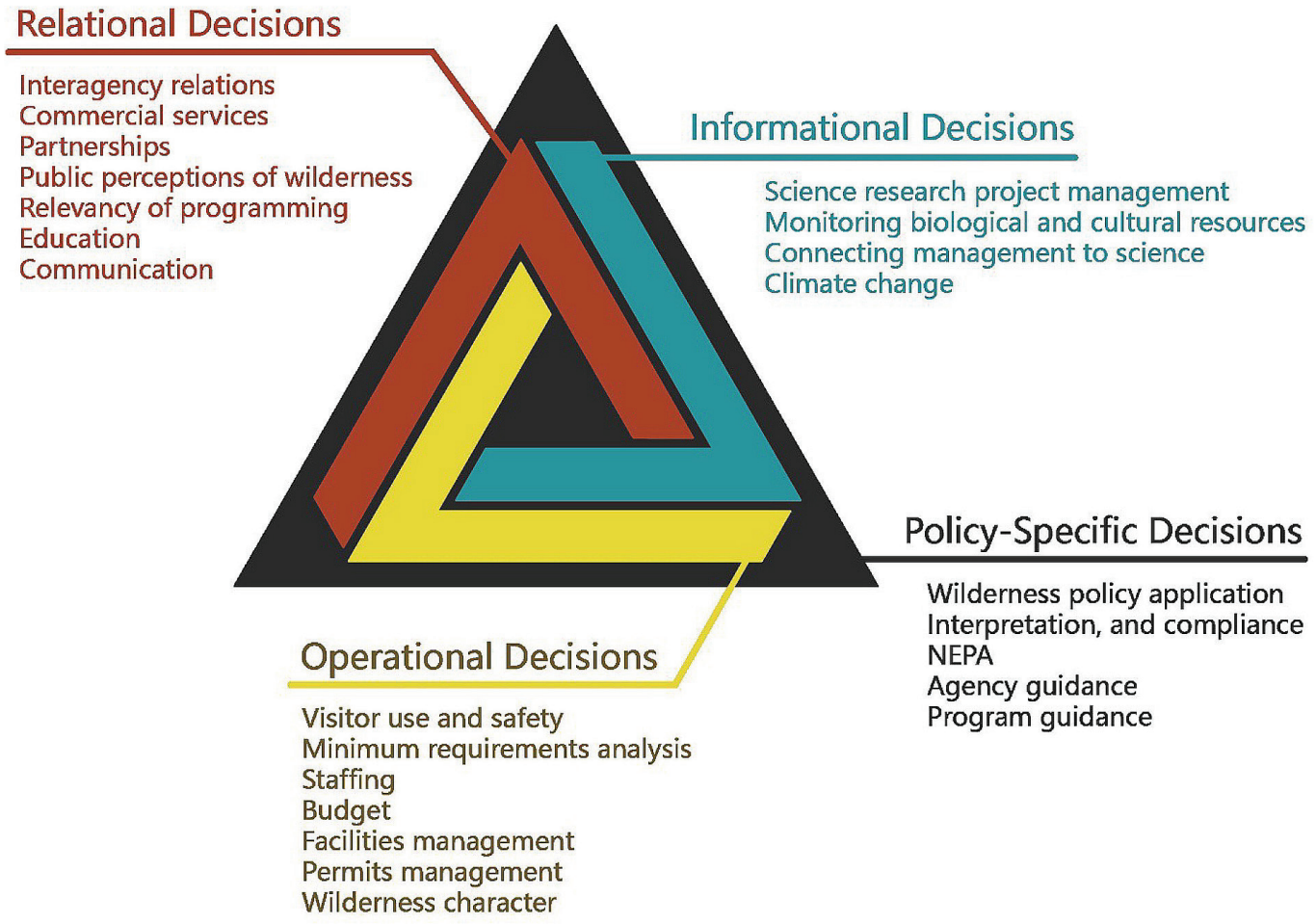
Wilderness management decision contexts

Wilderness managers regularly make a wide range of decisions within their work, ranging from daily recurring tasks such as scheduling clean-ups and managing budgets, to major long-term planning decisions, including long-term monitoring and ensuring relevancy and inclusion. Managers mentioned 66 decisions in total, of which 32 were coded as unique decisions, inclusive of education, communication, research, visitor use management, cultural resources management, climate change, program guidance, relationship building, and wilderness stewardship performance, among others.

We identified three major decision contexts, specifically operational, relational, and informational, all encompassed by an overarching policy decision context (Figure 1). *Operational decisions* referred to the ways in which managers oversee and manage resources, especially financial and human resources, but also natural resources. Examples of operational decisions included visitor use and safety (visitor use management, carrying capacity, preventative search and rescue, trail design and management), minimum requirements analysis and the minimum requirements decision guide, staff, budget, facilities management, program and project management, permit oversight, and wilderness character. *Relational decisions* referred to how agencies, wilderness areas, and managers themselves work in coordination with key partners, both internally and externally. These decisions ranged from interagency relations, commercial services, partnerships, public perceptions of wilderness and relevancy of programming and opportunities, as well as education and communication. *Informational decisions*, in contrast, concerned the identification and development of knowledge to make evidence-based decisions. Informational decisions included choices around scientific research projects, monitoring biological and cultural resources, connecting various aspects of management to science, and climate change impacts.

Encompassing all of these decisions are national *policy-specific decisions* based on directives that guide wilderness management practice. These are interagency wilderness manuals, handbooks, guidance, and NPS Director's Orders. Some examples include wilderness policy application, interpretation, and compliance, NEPA, agency guidance, and program guidance. Specifically, managers noted that legislative (e.g., the Wilderness Act of 1964) and administrative policies (e.g., procedures, manuals, and handbooks) influence management practice across operational, relational, and informational decisions. Although many of these policy-specific decisions or directives were informed by science when they were

FIGURE 1. Wilderness managers make a variety of relational, informational, and operational decisions, all of which are embedded within policy-specific decisions guided by law and agency directives (e.g. NEPA, agency guidance on wilderness, or intersecting policies like diversity, equity, and inclusion in the workforce). Many of these decisions are intersecting across contexts. For example, commercial services relate to both relational and operational decision contexts.



developed, managers tended to refer to them as policy rather than as scientific decisions that get incorporated into their work, an important point that comes up below.

Most tasks overlapped across decision categories. For example, setting a visitor use limit requires operational choices (e.g., level of use, enforcement approach), but also informational choices (e.g., deployment of a visitor experience survey, integration of past visitor use monitoring) and relational choices (e.g., education partnerships, public relations approach). In other words, these decision-making contexts are not mutually exclusive, and it is likely that many different wilderness management decisions interact in complex ways across decision contexts.

The role of science in wilderness management

Managers described a wide range of information types (i.e., sources) they use to inform their day-to-day tasks. Information types spanned the gamut, from colleagues and other key staff (e.g., wilderness coordinators) and institutions, especially the Arthur Carhart National Wilderness Training Center and Wilderness Connect; personal knowledge and past experience; goals and objectives; policy guidance, such as Keeping it Wild and Leave No Trace; case law; and maps, among others. Importantly, managers noted that science is just one of many knowledge sources they consider when making decisions. Sometimes managers are required to use these alternative sources of information, such as when making policy-specific decisions. Other times, managers may rely more on alternative sources, including their own personal experience, when there is a lack of site-specific science. For example, one NPS manager explained that "Ideally, all my decisions are informed by science. In practice, data are often lacking, and best professional judgement is required."

Globally, science represented just one of 46 different information types wilderness managers sought. This is not surprising given the often-wide range of day-to-day tasks and the necessity to work across needs and priorities to find the most optimal solutions. When science was used, managers shared a total of 37 different direct uses of science within their work, while expressing that it is used both directly and indirectly.

Direct uses of science

We expected to learn that managers actively sought science to support informational decision contexts, but instead found that managers directly use available science across all decision contexts. Managers shared that they use science to conduct background research for reports, fill knowledge gaps across decision contexts, and assess whether to permit research projects within wilderness, among other ways.

Managers used science across the project management cycle to inform a wide array of resource applications and justify decisions. For example, one NPS manager identified that science is used "at the start of a project or formulation of a project idea, to get a better sense of what's out there and some of the prevailing ideas/attitudes around the idea," specifying that this related to both bigger management projects as well as more conceptual ideas. Managers also expressed that they use science in several other management contexts, including operations, monitoring, and planning. For example, one BLM manager reported that they use science "when revising management plan[s], especially if looking at visitor use and monitoring trends, etc." In these ways, managers looked to science across the project management cycle within a variety of decision contexts.

Managers additionally shared that they turn to science for a wide range of uses beyond the typical project management cycle. Some examples included identifying best practices across a range of applications, developing and analyzing alternatives, identifying and monitoring resources, and determining indicators, standards, and desired future conditions. For example, some managers wrote that they use science for identifying and protecting resources, including cultural and archaeological artifacts, while one manager from BLM shared that they use science "to understand threats to [Wilderness and Wild and Scenic River] resources and effectiveness of management approaches to address different threats." Another manager from USFWS explained that "I turn to the models, projections, predictions when making the case that the future won't be like the past." In these ways, managers turned to science to get a better understanding of on-the-ground conditions across all decision-making contexts. While it might be relatively more straightforward to seek science to inform discrete problems—for example, setting thresholds for visitor use—one NPS manager articulated that "interdisciplinary work involves balancing all kinds of resources to find [the] least-bad solution. It's all science in my office."

Several managers also spoke to using science to justify decisions. For instance, one BLM manager explained that science "informs our decisions, for example less erosive soils for trails, would that French drain work in that trail/would it impact other areas or resources. Science-backed decisions give us more to stand on in court." Similarly, another BLM manager explained that "Science comes into play during project objections and lawsuits." In these

ways, managers turn to science to not only inform difficult decisions but also to defend decisions from legal action.

Indirect uses of science

Managers also articulated that they use science indirectly when it is infused throughout policy frameworks, reference manuals, technical guides, online toolboxes, NPS Director's Orders, and evaluations (i.e., wilderness stewardship performance, minimum requirements analysis). One manager from the BLM explained that "it's useful when the protocols and handbooks we use are rooted in science so we don't have to do 'science' every time we make a management decision." Another manager explained that "a lot of the tools we use like NEPA standards, MRAs/MRDGs [minimum requirements analyses/minimum requirements decision guides], handbooks, manuals, etc. were developed with science backgrounds." In addition to applied research or literature reviews to guide management practice, managers saw monitoring efforts as science-informed. For example, one BLM manager described how, "through our wilderness character monitoring measures, we are using science as those baseline studies are completed." In these ways, policy-decision contexts, in particular, are understood to be infused with science even when science is not directly sought or used.

In addition, managers explained that although they would like to use science, they often compromise when faced with limited capacity. For example, one NPS manager explained that time is too limited to make the most scientifically informed decisions. They acknowledged that when there is not time to fully explore science-supporting decisions, managers are sometimes left to go with their gut feelings. Further, there are other competing factors throughout the decision-making process, as one wilderness manager explained: "Our decisions in the field are guided more by safety concerns than science." This highlights the complex decision space managers navigate and the key role of more pragmatic decisions, such as those concerning safety, especially when operating with limited capacity.

Opportunities to strengthen actionable science for wilderness

Managers shared many constraints to finding and using science, in particular capacity-related issues around time, budget, and staffing. For instance, one manager shared that they would use science "if it was readily available. [I] don't have a lot of time for digging, finding research." Even when managers are able to locate science, one manager shared that "I feel like I need more guidance on how to use it sometimes. It would also be helpful to be able to connect the dots and see exactly how the data I collect is used, analyzed, etc." In addition, the time frame for scientific research might not align with the information needs of managers. One NPS manager lamented, for example, the "temporal disconnect between availability of research findings and need for decision making," while another shared the challenge as it related to "timeliness of OMB [Office of Management and Budget] review and approval of social science-related information collection." Similarly, one manager expressed that there is a "very lengthy time span for social science research in Wilderness, involving traditionally associated people. Relationships take a long-term investment." In these ways, the realities of management contexts may influence the ability of managers to identify, understand, and interpret science for their needs, or to adopt best practices for relationship-building.

In addition, some wilderness managers expressed frustration with trying to work with scientists who may not be available or willing to work on a specific problem in a specific site. For instance, one USFS manager wrote about difficulty they face in improving their use of science due to "lack of cooperation or availability of local specialists to assist with review and interpretation of data." This might be compounded in practice as managers try to find current research specific to their wilderness areas. Similarly, one NPS manager spoke to the challenge of relying "on old data and reports [as well as] lack of funding for continued monitoring." The perception that all data must be current and site-specific presents a challenge to scientists who face many of the same capacity issues as managers. Science teams are often small and unlikely to meet the challenge of developing a body of work with sufficient breadth and depth to meet the needs of all managers while also pursuing research of robust scientific integrity. Transferability of science to diverse contexts and situations is critical to maximize the impact of site-specific work.

Despite these constraints that can perpetuate the research–management gap, managers widely shared that they can co-produce applicable, reliable, and mutually beneficial research by working alongside scientists. This occurs when the goals of managers and scientists align, which can improve the applicability and trustworthiness of research. Managers also highlighted that it is easy to use science when it informs policy (Figure 2). In these ways, scientists can improve the adoption of actionable wilderness research by considering how they work with wilderness managers and policy-makers. We elaborate on these opportunities below.

Shared understanding through improved communication between managers and scientists

Managers widely shared the value of direct and prolonged interaction with researchers. Specifically, we found that when both parties have mutual understanding of

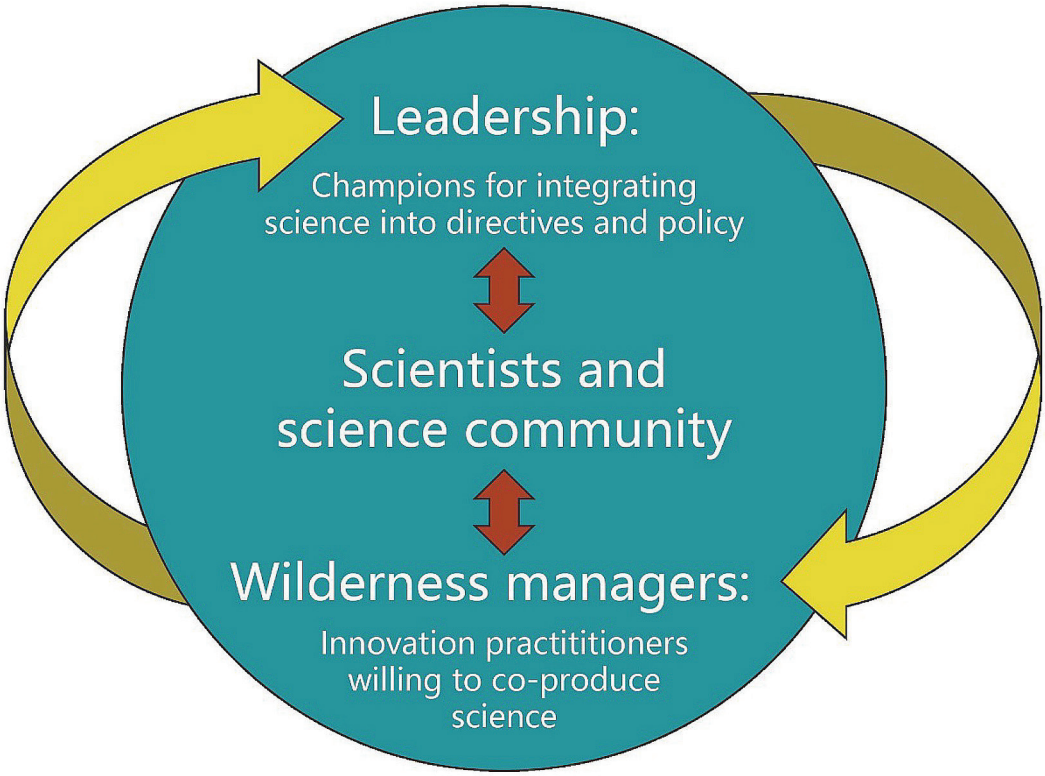


FIGURE 2. Scientists can improve the uptake of their work in wilderness management by developing relationships with managers who are "innovation practitioners"—that is, those who are willing to co-produce research—as well as with leaders and policy-makers who can integrate science into guidance documents. As managers and policy-makers share lessons with each other, they may transfer them to scientists, thereby improving the quality of science produced to inform wilderness management.

each other's goals, they are better able to align them across organizations and individuals. This is critical because managers are generally evaluated based on fulfilling agency objectives for wilderness character, while scientists are generally evaluated based on novel and applied contributions to science. For instance, one manager explained that they were able to successfully work with scientists when "success came from a shared vision, set of values, and series of questions. We all wanted the data for different types of analysis, [and] went in our own direction with the same data set."

Good communication provided a critical foundation to improving that shared understanding. For instance, one NPS manager wrote that a challenge to improving the uptake of science in management is "Researcher's speak [versus] manager's speak." But beyond shared understanding of goals, good communication can also clarify a manager's understanding of researcher objectivity and improve overall trust in the scientist and their work—a key point mentioned across all sessions. For instance, one manager explained that they distrust scientists when "science isn't applicable for management use." Another wrote that they "Often distrust [scientists] because ologists are treated as the [prima donna] employees of my outfit, which errantly presumes that decisions are based on science, not values." And a third wrote that they distrust scientists when they "get stuck in their niche field and don't see relationships to other field[s], or they drill down so far into one area that [it] stops being applicable." In this way, a perceived mismatch between the role of science in decision-making as well as differing underlying values may serve to prohibit the kind of goal alignment that can improve working relationships between scientists and managers. Conversely, one manager spoke to the trust that they have in scientists when "Their education and/or work experience is related to the subject matter at hand. Also, their humor and kindness help too." In this way, scientists and managers can foster relationships to build trust in the research process, ensure science is applicable to management, and improve the quality of research for management purposes.

Meaningful partnerships can improve on-the-ground outcomes

In addition to focusing on shared understanding, managers widely emphasized the value of meaningful partnerships built through on-the-ground collaboration, which sometimes resulted in co-produced research. Meaningful partnerships between researchers and wilderness managers may require an upfront cost, especially time and commitment to the process of developing a shared vision, but the payoff is that it may

help close gaps in capacity, including as they pertain to funding, availability of subject-matter experts, time, and staffing. For instance, one manager explained that a successful co-produced project they were involved in required a "significant amount of time, or enough time" to plan the work, as well as a "well-organized researcher who was committed to the effort" and a "shared vision." A key step in the project occurred when they "went into the field together to review questions and methods."

When managers have working relationships with scientists, they are able to innovate and trial co-produced science in federal land management and, in turn, become advocates for thoughtful, integrative science. For example, one BLM wilderness manager wrote positively about a collaborative process with the University of Alaska that resulted in a "great recreation management/social science research tool." It is in this co-production space that scientists and managers can build mutual trust and shared understanding. This can ensure that work is grounded in the management reality and that managers are involved in identifying relevant research questions. Furthermore, it is through meaningful partnerships that scientists can help managers understand transferable principles of science that can improve their work without needing empirical site-specific data.

Strengthening the relationship of science with policy-decision contexts

Finally, some managers shared the value of opportunities to improve policy through applied research. One NPS manager expressed the value of "research that has supported and informed the principles of Leave No Trace." Other examples managers shared included Assessment Inventory Monitoring (AIM), a climate change response program, and Wilderness Character Monitoring, among others. Given limited capacity for site-specific research by both scientists and wilderness managers, and the widespread use of guiding policy documents such as manuals and decision-support tools, wilderness leaders and policy-makers play critical roles in closing the research–management gap by effectively leveraging science to inform policy, directives, and goals.

CONCLUSIONS

Through facilitated conversations around virtual white-boards, we found that wilderness managers operate within a complex decision space, working across relational, operational, and informational decision contexts, all guided by overarching policy-specific directives. Although many unique decisions cut across two or more of these decision contexts, understanding them as discrete types can inform thoughtful integration of science into wilderness management. For example, managers use science in the informational decision context for monitoring climate change impacts, in the relational decision context for working with communities, and in the operational decision context around visitor use monitoring, though all of these decisions are guided by a policy-decision context that may be informed by science. Yet the distinction between monitoring, science, and policy is not clearcut, and this may present challenges given the temporal mismatch across monitoring (short time frame), science (medium time frame), and policy directives (long time frame). As a result, science plays an important role across many aspects of wilderness management, but managers are often constrained by other important factors that influence decision-making (e.g., budgetary and time constraints, operating agreements). This is consistent with barriers to fire science use identified by Hunter et al (2020) as well as those identified during two George Wright Society Conference interactive sessions focused on barriers to the use of science (Wright 2004; Wright 2006).

Also consistent with the literature, we learned that science application in wilderness is facilitated when managers and scientists embrace relationship-building, communication, and socialization (Wright 2007; Wilhere and Quinn 2018, Hunter et al. 2020). Actionable knowledge requires open learning spaces that provide opportunities to build trust and exchange ideas (Stern et al. 2021). When scientists engage in co-produced research with managers, the latter have greater trust in the work and may be more likely to implement local management changes as a result (Carter et al. 2021). Funding research that takes place in wilderness areas can also help scientists better understand the realities of land management (Renz et al. 2019). A bottom-up approach fostered through relationships between scientists and managers may be one important opportunity to reduce the research–management gap in wilderness. Future research could examine barriers scientists face developing effective projects alongside managers, and researchers could merge findings from both perspectives to identify pathways that improve the actionability of their work.

Our findings also underscore that science indirectly influences management, largely through policy, manuals, handbooks, online resources, and other guidance documents that shape management directives. Borrowing from Dearing (2009), who emphasized the value of high-ranking leaders to champion dissemination of knowledge, our work shows opportunities to improve communication with influential decision- and policy-makers to inform the use of science in wilderness management. By identifying and supporting innovative risk-takers and champions of science, it can be made actionable and transferable across contexts. In this way, a two-tiered approach emerges:

(1) bottom-up, working with local managers to develop, apply, and interpret relevant science in a co-produced manner; and (2) top-down, working with agency and wilderness leaders to champion the integration of research into policy and management directives.

As the United States government invests in bolstering science support for public land management, notably with USFS and US Geological Survey research programs focused on a wide range of topics (e.g., fire, water, wildlife, vegetation, recreation, wilderness), there are growing opportunities to establish and develop necessary relationships across roles. Through those relationships, scientists may not only improve the adoption of science in wilderness management, but may also develop a greater understanding of the range of competing policies, programs, and priorities that guide managers' work—leading to a shared understanding that can improve wilderness management and wilderness research alike.

REFERENCES

Bernard, H. Russell. 2017. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Lanham, MD: Rowman & Littlefield.

Carter, Sarah K., Lisa E. Burris, Christopher T. Domschke, Steven L. Garman, Travis Haby, Benjamin R. Harms, Emily Kachergis, Sandra E. Litschert, and Kevin H. Miller. 2021. Identifying policy-relevant indicators for assessing landscape vegetation patterns to inform planning and management on multiple-use public lands. *Environmental Management* 68(3): 426-443.

Carter, Sarah K., Travis S. Haby, Jennifer K. Meineke, Alison C. Foster, Laine E. McCall, Leigh D. Espy, Megan A. Gilbert, Jeffrey E. Herrick, and Karen L. Prentice. 2023. Prioritizing science efforts to inform decision making on public lands. *Frontiers in Ecology and the Environment* 21(10): 453–460. https://doi.org/10.1002/fee.2672

Chambers, Robert. 2002. *Relaxed and Participatory Appraisal: Notes on Practical Approaches and Methods for Participants in Pra/Pla-Related Familiarisation Workshops* (Vol. 353). Brighton, UK: Participation Group, Institute of Development Studies, University of Sussex.

Cofie, Nicholas, Heather Braund, and Nancy Dalgarno. 2022. Eight ways to get a grip on intercoder reliability using qualitative-based measures. *Canadian Medical Education Journa*l 13(2): 73–76.

Cooke, Steven J., Amanda L. Jeanson, Ian Bishop, Brett A. Bryan, Chundi Chen, Christopher Cvitanovic, Yang Fen, John Forester, Christine Fürst, Jie Hu, Daniele La Rosa, Colin Meurk, Vivian M. Nguyen, Michael Paolisso, Yunfei Qi, Faith K. S. Chun, Katrina Szetey, Xinhao Wang, Yuncai Wang, Carla L. Archibald, and Nathan Young. 2021. On the theory-practice gap in the environmental realm: Perspectives from and for diverse environmental professionals. *Socio-Ecological Practice Research* 3(3): 243–255. https://doi.org/10.1007/s42532-021-00089-0

Courtney, Arielle, and Ingrid E. Schneider. 2016. Toward effective science delivery among recreation personnel. *Applied Environmental Education & Communication* 15(2), 99–110. https://doi.org/10.1080/1533015X.2016.1164093

Dearing, James W. 2009. Applying diffusion of innovation theory to intervention development. *Research on Social Work Practice* 19(5): 503–518. https://doi.org/10.1177/104973150933

Fuller, Angela K., Daniel J. Decker, Michael V. Schiavone, and Ann B. Forstchen. 2020. Ratcheting up rigor in wildlife management decision making. *Wildlife Society Bulletin* 44(1): 29–41. https://doi.org/10.1002/wsb.1064

Harmon, David. 1999. The new research mandate for America's National Park System: Where it came from and what it could mean. *The George Wright Forum* 16:1: 8–23.

Hunter, Molly E., Melanie M. Colavito, and Vita Wright. 2020. The use of science in wildland fire management: A review of barriers and facilitators. *Current Forestry Reports* 6: 354–367. https://doi.org/10.1007/s40725-020-00127-2

Mach, Katharine J., Maria Carmen Lemos, Alison M. Meadow, Carina Wyborn, Nicole Klenk, James C. Arnott, Nicole M. Ardoin, Clare Fieseler, Richard H. Moss, Leah Nichols, Missy Stults, Catherine Vaughan, and Gabrielle Wong-Parodi. 2020. Actionable knowledge and the art of engagement. *Current Opinion in Environmental Sustainability* 42: 30–37. https://doi.org/10.1016/j.cosust.2020.01.002

Merkle, Jerod A., Neil J. Anderson, Danna L. Baxley, Matthew Chopp, Laura C. Gigliotti, Justin A. Gude, Tyler M. Harms, Heather H. Johnson, Evelyn H. Merrill, Michael S. Mitchell, Tony W. Mong, Jerry Nelson, Andrew S. Norton, Michael J. Sheriff, Eric Tomasik, and Kelly R. Vanbeek. 2019. A collaborative approach to bridging the gap between wildlife managers and researchers. *The Journal of Wildlife Management* 83(8): 1644-1651. https://doi.org/10.1002/jwmg.21759

Mills, Thomas J., and Roger N. Clark. 2001. Roles of research scientists in natural resource decision-making. *Forest Ecology and Management* 153(1–3): 189–198. https://doi.org/10.1016/S0378-1127(01)00461-3

Nel, Jeanne L., Dirk J. Roux, Amanda Driver, Liesl Hill, Ashton C. Maherry, Kate Snaddon, Chantel R. Petersen, Lindie B. Smith-Adao, Heidi Van Deventer, and Belinda Reyers. 2016. Knowledge co-production and boundary work to promote implementation of conservation plans. *Conservation Biology* 30(1): 176–188. https://doi.org/10.1111/cobi.12560

Patterson, Michael E., and Daniel R. Williams. 1998. Paradigms and problems: The practice of social science in natural resource management. *Society & Natural Resources* 11(3): 279–295. https://doi.org/10.1080/08941929809381080

Redmore, Lauren E., Jaclyn F. Rushing, Christopher A. Armatas, and Vita Wright. 2024. Wilderness acience application and delivery: Google Jamboard data from 2022 data gathering sessions. Fort Collins, CO: USDA-Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2024-0051

Renz, Mark, Kevin D. Gibson, Jennifer Hillmer, Katherine M. Howe, Donald M. Waller, and John Cardina. 2009. Land manager and researcher perspectives on invasive plant research needs in the midwestern United States. *Invasive Plant Science and Management* 2(1): 83–91. https://doi.org/10.1614/IPSM-08-109.1

Robinson, Kelly F., Angela K. Fuller, Richard C. Stedman, William F. Siemer, and Daniel J. Decker. 2019. Integration of social and ecological sciences for natural resource decision making: Challenges and opportunities. *Environmental Management* 63: 565–573. https://doi.org/10.1007/s00267-019-01141-2

Ryan, Clare M., Lee K. Cerveny, Terence L. Robinson, and Dale J. Blahna. 2018. Implementing the 2012 forest planning rule: Best available scientific information in forest planning assessments. *Forest Science* 64(2): 159–169. https://doi.org/10.1093/forsci/fxx004

Simis, Molly J., Haley Madden, Michael A. Cacciatore, and Sara K. Yeo. 2016. The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science* 25(4): 400–414. https://doi.org/10.1177/09636625166297

Stahl, Norman A., and James R. King. 2020. Expanding approaches for research: Understanding and using trustworthiness in qualitative research. *Journal of Developmental Education* 44(1): 26–28.

Stern, Marc J., David D. Briske, and Alison M. Meadow. 2021. Opening learning spaces to create actionable knowledge for conservation. *Conservation Science and Practice* 3(5): e378. https://doi.org/10.1111/csp2.378

Szaro, Robert C., and Charles E. Peterson. 2004. Evolving approaches toward science-based forest management. *Forest Snow and Landscape Research* 78(1): 9–20.

Taylor, Jason J., Teresa N. Hollingsworth, Christopher A. Armatas, Kellie J. Carim, Kira L. Hefty, Olga Helmy, Lisa M. Holsinger, Danette Paige, Sean A. Parks, Lauren E. Redmore, Jacyln F. Rushing, Erana J. Taylor, and Kathy A. Zeller. 2023. The future of wilderness research: A 10-year wilderness science strategic plan for the Aldo Leopold Wilderness Research Institute. *International Journal of Wilderness* 29(1): 50–73. https://ijw.org/the-future-of-wilderness-research/

Watson, Alan E., and Christopher A. Armatas. 2017. A mental model of science informed by public lands managers: Increasing the chances for management based on science. *Journal of Contemporary Management* 8(4): 1–17.

Wilhere, George, and Timothy Quinn. 2018. How wide is wide enough? Science, values, and law in riparian habitat conservation. *Natural Resources Journal* 58(2): 279–318.

Wright, Vita. 2007. Communication barriers to applying federal research in support of land management in the United States. In *Proceedings: International Conference on Transfer of Forest Science Knowledge and Technology.* Cynthia Miner, Ruth Jacobs, Dennis Dykstra, and Becky Bittner, eds. Gen. Tech. Rep. PNW-GTR-726. Portland, OR: US Department of Agriculture–Forest Service, Pacific Northwest Research Station, 55–62.

Wright, Vita. 2006. Overcoming barriers to the use of science in national parks (session summary). In *People, Places, and Parks.* Proceedings of the 2005 George Wright Society Conference. David Harmon, ed. Hancock, MI: George Wright Society. http://www.georgewright.org/0568wright.pdf

Wright, Vita. 2004. Barriers to science-based management: What are they and what can we do about them? (session summary). In *Protecting Our Diverse Heritage: The Role of Parks, Protected Areas, and Cultural Sites.* Proceedings of the 2003 George Wright Society Conference. David Harmon, Bruce M. Kilgore, and Gay Vietzke, eds. Hancock, MI: George Wright Society, 34–37. http://www.georgewright.org/0310wright.pdf