



Implementing and evaluating knowledge exchange: Insights from practitioners at the Canadian Forest Service

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ABSTRACT

While there is a growing body of work on the barriers to knowledge exchange (KE) and the development of actionable science, what remains more elusive is an understanding of what strategies and conditions lead to effective KE, how it is operationalized, or how different practitioners define successful exchange of scientific knowledge. We interviewed nine KE practitioners at the Canadian Forest Service (CFS), a national agency, to understand: (1) who at CFS is involved in KE and how they perceive their roles, (2) the strategies for KE used in the CFS and its distribution in a KE typology framework, (3) how KE practitioners define a “successful” exchange of knowledge and KE bright spots, and (4) what conditions enable KE within the CFS. We identified CFS KE practitioners roles as knowledge brokers. They use a cyclical KE strategy that integrates concepts of co-design in operationalizing KE. The CFS KE practitioners engage in a variety of KE activities, but outreach was the most frequently cited. We suggest organizations work closely with intermediaries individuals as they hold unique positions of building and maintaining relationships with knowledge users. They can also provide valuable insights in evaluating research impacts such as through contribution stories. The KE typology was a useful tool to inform decisions about KE strategies. Finally, our study emphasizes the need for organizations to adopt more qualitative evaluations to assess the full scope and impact of KE work, and recognizes the integral role of relationships and trust in all aspects of KE work.

1. Introduction

Over the past decade, one of the main goals of science-based government agencies has been to implement evidence-informed decision-making (Cook et al., 2017). Evidence-informed decision making refers to the inclusion of the best available evidence in developing policies or management strategies. The use of evidence in this way is an attempt to de-politicize decision making by using information that can be impartially and objectively evaluated (Haddaway and Pullin, 2013; Adams and Sandbrook, 2013). However, given the diverse values and objectives of science, policy, and economic actors, there is no universal agreement on what the best evidence is, particularly when that evidence is scientific in nature. Translating scientific information into actionable knowledge for policy development and implementation remains a challenge (Sarkki

et al., 2014; Young et al., 2014; Watt et al., 2019). To support actionable science (e.g., data, analyses, projections, or tools that can support decisions; Beier et al., 2017) and evidence-informed decision making, scientists must seek out strategies to make relevant science more accessible to decision-makers from non-scientific disciplines (Van Eerd and Saunders, 2017; Buxton et al., 2021; Singh et al., 2021).

Knowledge exchange (KE) is a dynamic and iterative process that generally involves the interactions of knowledge producers (individuals who produce specific knowledge available to others), knowledge users (individuals who apply knowledge obtained from others), and knowledge brokers (individual intermediaries who facilitate knowledge movement between producers and users) (Wang and Noe, 2010; Naylor et al., 2012; Nguyen et al., 2017). Given that the explicit goal of KE is the translation of discipline-specific knowledge from those who created it to

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those who can apply this knowledge in different contexts, KE is an emerging approach which could help scientists overcome the knowledge-action gap (Nguyen et al., 2017).

An area of particular concern for understanding the effective exchange of scientific knowledge into practice is natural resource management. Environmental, natural resource, and forestry management require collaborations with various actors, such as those belonging to science, economic, and policy sectors. The complex and sometimes conflicting values, resources, and management practices of these disciplines can make it difficult for practitioners to effectively exchange knowledge for evidence-informed decision making (Sarkki et al., 2014; Watt et al., 2019). As such, the disconnect between KE and action is particularly relevant in environmental and natural resource management.

Scholars have outlined a range of barriers to KE and the development of actionable science, such as discipline-specific communication differences between knowledge producers and users (Young et al., 2016), a disconnect between science and policy communities (Cvitanovic et al., 2016), and the tendency for scientists to produce information that is not immediately useable in non-scientific settings (Wurtzebach et al., 2019). What remains more elusive is an understanding of which strategies and conditions lead to effective KE or even how different practitioners define what is a successful exchange of scientific knowledge. Westwood et al. (2023), in a review of studies on KE in forestry and forest sciences, found

that most studies that generated recommendations for conducting successful KE are predominantly theoretical or suggestion-based, with very few examples where recommendations were based on evidence or empirically tested for effectiveness (but see Reed et al., 2014; LSE, 2019). There remains no universal understanding of how KE can be enacted or evaluated by scientists (Rubenstein-Montano et al., 2001; Hickey et al., 2013; Cvitanovic et al., 2016). To overcome this knowledge gap, the authors called for academics and practitioners of KE to design studies which capture robust empirical evidence about KE strategies and their performance, so that more specific guidance on KE practices and options that are relevant to specific contexts can be developed.

We address the empirical knowledge gaps highlighted by Westwood et al. (2023) in this case study of knowledge exchange in Canada's federal forestry agency – the Canadian Forest Service (CFS). The CFS has been a division of Natural Resources Canada – a federal governmental department – since 1899 (Government of Canada Natural Resources Canada, 2020). As a science-based agency, the CFS is both a producer of domain-specific forestry science, as well as a collaboration hub for researchers from different provinces, agencies, and disciplines (Government of Canada Natural Resources Canada, 2020). With six regional centres and three research forests (Fig. 1) the CFS is in a unique position to act as a knowledge brokering agency (i.e., boundary organization), that connects stakeholders from industry, government, academia, and



Fig. 1. The flags identify the six Canadian Forest Service (CFS) centres located across Canada in Victoria BC, Edmonton AB, Sault Ste. Marie ON, Ottawa ON, Quebec City QC, and Fredericton NB. The one additional CFS office that is located in Corner Brook NFLD is also identified by a flag marker. The three CFS research forests are identified by triangle markers located in Petawawa Research Forest (ON), Valcartier Research Station (QC), and Acadia Research Forest (NB).

the public.

CFS also maintains internal “Knowledge Exchange Specialists” and other individuals at the CFS whose jobs involve the explicit exchange of scientific knowledge with various knowledge users (i.e. individuals or groups interested in using or learning about CFS research). Although not explicitly called knowledge brokers, the CFS “Knowledge Exchange Specialists” fit the broad description of knowledge brokers in that they pro-actively facilitate processes to foster mutual learning among researchers, policymakers and practitioners (Cvitanovic et al., 2015; Maag et al., 2018). In this way, the CFS and their KE specialists provide a unique opportunity to study how a national agency conducts and evaluates knowledge exchange practices, and contribute information to literature on knowledge brokers and their role in bridging science, policy and practice. The knowledge brokering role and profession are still poorly specified with lack of recognition and institutional support (Cvitanovic et al., 2015; Maag et al., 2018). These individuals are often described as ‘invisible’ (Meyer, 2010) or ‘between worlds’ (Lomas, 2007). Thus, our study is also an important contribution to further understanding the role of intermediaries in knowledge exchange and its effectiveness.

1.1. Key theoretical aspects of knowledge exchange

A number of KE-related concepts associated with the social context of knowledge generation and application inform our study. *Boundary organizations* facilitate collaboration between scientific and non-scientific domains (Guston, 2001), and they engage in *boundary work* which involves actors creating knowledge in one domain and using often new-to-them knowledge from a separate domain in a distinctly new way across boundaries (Cash et al., 2003; Broniatowski and Magee, 2017). When artefacts are coproduced across these boundaries, it may result in *boundary objects*. Such artefacts are adaptable to different knowledge domains but maintain their identity across boundaries (Star and Griesemer, 1989; Nel et al., 2016; Karcher et al., 2021). Boundary objects help to overcome interpretative differences across the disparate knowledge domains (Boyes, 2019). In this study, we analyze the specialized role of knowledge brokers and their KE strategies which include coproducing boundary objects.

KE and boundary work can be approached from a social constructivist perspective on reality (Berger and Luckman, 1967). In this view, individuals and groups who interact in a social system generate concepts, ideas, and actions that, over time, construct an understanding of the world based on their shared assumptions of reality (Berger and Luckman, 1967). Our interpretations of KE are therefore informed by participants’ versions of reality at various levels of management within the CFS.

Lastly, KE may be categorized into a typology (henceforth, ‘the KE typology’) based on expert knowledge and systematic review of the KE in forestry literature, which divides specific KE activities into four unique approaches: one-way, solicited, network and participatory (Table 1, adapted from Westwood et al., 2021, 2023). These approaches provide a framework through which scientists can view their own KE activities, lend an outline for developing evaluation techniques, and provide a universally accessible terminology for different strategies. This case study is the first to use the KE typology to classify which KE approaches are most commonly used by an environmental management

agency. In this way, we test the applicability of this typology, in addition to providing a more qualitative assessment of KE in Canada’s forestry sector.

Overall, the research questions guiding this qualitative case study are: (1) who at the CFS is involved in KE and how do they perceive their roles?; (2) what are the strategies for KE used in the CFS and how are they distributed within a KE typology framework?; (3) how do KE practitioners define a “successful” exchange of knowledge?; and (4) what conditions enable KE within the CFS? By assessing the role of CFS KE practitioners and how they put KE to practice, we identify areas of strengths and improvement for KE, and offer empirical evidence and insights into effective KE. The application of the KE typology framework can help better understand the distribution of KE strategies that the organization uses, and may help inform the effectiveness of each type or potential gaps for future work.

Lastly, we identify “bright spots” (Cvitanovic and Hobday, 2018) by highlighting impactful KE examples outlined by CFS KE practitioners. Bright spots are important as they are examples of positive outcomes and help further define the meaning of successful KE and its impacts (Karcher et al., 2021, 2022). What constitutes KE impacts and success can vary, thus identifying these bright spots are important to build capacity for evidence-informed decision making and narrowing the science policy gap (Karcher et al., 2022). In following this line of thinking, we suggest that the CFS knowledge exchange practitioners effectively implement a series of practices and processes to enable the multi-directional flow of information among relevant actors.

2. Methods

This qualitative case study (Creswell and Poth, 2016) was reviewed and approved by the Carleton University Research Ethics Board (#112865).

2.1. Data collection

Our study involved initial and follow-up semi-structured interviews conducted by phone and/or video conference (see [Supplementary Materials Appendix A](#) and [B](#) for both interview guides) with individuals at the CFS who worked specifically on knowledge exchange for the organization. Participants were identified by our CFS partners and had a job title of *Knowledge Exchange Specialist* and/or were part of their Knowledge Exchange Group. At the time of data collection, there were twelve individuals who worked in the KE space at CFS (from the CFS Knowledge Exchange Group). Of these twelve, nine participated in our study, thus we believe this is a representative sample of CFS KE practitioners. The nine respondents provided perspectives from at least one person for each of the six CFS offices across Canada. Four additional participants were recruited through snowball sampling, where we asked participants if they knew of other employees who work predominantly on knowledge exchange at the CFS.

The interviews were conducted by CB, JH, and TK. They were audio-recorded and analyzed using NVivo software (version 12). All interviews were transcribed and anonymized. The follow-up interview focused primarily on discussing successful cases of KE and factors enabling successes with participants. These nine participants completed the initial interview. Seven of the nine participants also took part in the

Table 1

Description of KE typology outlining four KE approaches adapted from Westwood et al., (2021, 2023).

KE approach	Definition
One-way exchange	Where scientists independently produce a report/paper and deliver it to knowledge users.
Solicited exchange	Where a knowledge user expressly invites a knowledge producer to answer pre-identified knowledge gap.
Network exchange	Where two or more knowledge producers or users connect to share the knowledge that they have each produced independently.
Participatory exchange	Where prospective users of science are engaged and involved in the process of generating knowledge.

follow-up interview.

Interviews consisted of a mix of open- and closed-ended questions (provided in Appendix A). The initial interview was 40–60 min. Participants were asked questions that addressed their academic and professional backgrounds, their individual and institutional perspectives on KE, their approaches to KE work, and the techniques they use to evaluate the effectiveness of KE. The follow-up interview (Appendix B) was 20–30 min in length asked the participants to discuss a single successful KE project. Participants were asked what defined success at CFS, the strategies the participants employed for their project, what conditions (e.g., resources, expertise, capacity, etc) facilitated their success, and any barriers they may have faced. The research questions 1 and 2 were addressed using the findings from the initial interview. Our third research question was addressed using findings from the follow-up interview. The final research question (4) was addressed using findings from both initial and follow-up interviews.

2.2. Data analysis

Our analysis of the transcripts followed both inductive coding using emergent thematic codes and deductive coding using pre-determined codes (Saldana, 2016).

We first followed an inductive coding approach that involved labelling themes found in the transcripts. The codes were not determined in advance to allow themes to emerge from the data itself (Van den Hoonard, 2011). Coding was consensus-based, where four authors (MF, JH, TK, VN) individually followed an inductive coding approach to develop initial codes, then compared codes to develop a final codebook (Supplementary Material Appendix C). Consensus-based coding was an important practice to ensure that all possible themes in the transcripts were identified given the varied background knowledge and experience of the authors (Van den Hoonard, 2011). The major themes identified in this round of coding were the specialized roles of CFS KE practitioners, the strategies they employ for engaging in KE, and how they evaluate the effectiveness of their efforts.

Once inductive coding was completed, we applied a deductive approach using the KE typology. Each KE activity described by the participants was categorized into one of the four approaches (participatory exchange, one-way exchange, solicited exchange, and network exchange). All KE typology codes were applied to the transcripts after the inductive codes, meaning that the inductive codes did not influence the deductive codes. All of the *KE activity* codes fit at least one of the KE typology codes.

3. Results

3.1. Who and what is involved in KE?

Seven out of nine participants had academic backgrounds in forestry. All of the participants described their work as interdisciplinary – emphasizing the fact that they work with one or more fields of knowledge (e.g., science, economics, policy). The information they were responsible for exchanging was primarily scientific knowledge where the intended users were often professionals from a scientific discipline. The information exchanged was either for research programs within the CFS or for external organizations. All of the participants said the main use of scientific knowledge was to supplement research, develop new technologies, or develop research methods related to forest management and planning. Two participants emphasized the need to exchange scientific information related to forests and forestry with interdisciplinary sectors, such as policy and economics. However, the main goal of nearly all of the participants' (7 of 9) KE practices was to incorporate their knowledge into existing scientific research programs for CFS, industry, or academia. This does not mean that the participants never engaged in exchanging scientific information with interdisciplinary knowledge users; rather, the participants described their work objectives as

predominantly focusing on supporting the needs of scientific knowledge users, with interdisciplinarity as a secondary objective.

One participant suggested that the KE practitioners should not exchange information with forestry practitioners or industry users unless the KE practitioner themselves possesses a forestry-related background. According to this participant, this field-specific knowledge is necessary for practitioners to explain the research accurately and thus increase the effectiveness of KE:

I'm the only forester [among the KE practitioners in the region]. I'm the only domain knowledge person. We don't bring people on with domain knowledge anymore in our branch. (Interviewer: So, I guess that relates back in the sense that, by having the team have more forestry information that increases the effectiveness of the KE process?) Yes... So, you're trying to convert from a scientific person and move their language to more common language. I shouldn't say dumb it down, that's not correct, but simplify it towards more of a grade 12 reading or below that if you can. So, having that domain knowledge helps you have that conversation with them (Participant 7).

This demonstrates why it is important for practitioners to possess a certain degree of field-specific knowledge in order to exchange knowledge effectively between disciplines and sectors.

Based on interview transcripts of participants' job title, roles, and/or job activities, we classified nearly all the participants (eight out of nine) as knowledge brokers who facilitate KE across disciplinary boundaries. Participants reported specific strategies for exchanging knowledge with various knowledge users including: (1) collaborating with knowledge users to modify KE work to address specific project goals, (2) modifying research or in-person demonstrations to increase accessibility for knowledge users, and (3) sharing personal or team experiences across CFS regions, with private stakeholders, and with other relevant collaborators to expand or improve the understanding of KE work and strategies.

3.2. The CFS's KE processes and practices

Inductive coding of how participants described their KE work yielded three components or processes the participants identified for putting KE into practice at the CFS: KE planning, KE activities, and KE products. Our analysis revealed that these processes are cyclical and can provide a general strategy for conducting KE at the CFS. They can be described as follows: (1) *KE planning* – determining steps or developing a process to conduct a KE activity, (2) *KE activities* – engaging in projects or actions to enhance or facilitate the exchange of knowledge, and (3) *KE products* – developing physical artefacts or boundary objects that improve user uptake as a result of conducting a KE activity (Fig. 2). The general approach for implementing KE outlined by the participants highlighted the interdependent nature of KE planning, activities, and products. These are shown in Fig. 2, and we discuss each in turn below.

3.3. KE planning

KE planning involves determining steps or developing a process to conduct a KE activity. For example, some activities are engaging in collaborative communication, building relationships, establishing project goals, aligning objectives, among others. The participants identified various ways of planning and conceptualizing KE activities, ranging from small-scale method development to large-scale community engagement. One of the KE plans that was identified by nearly all of the participants includes engaging in collaborative communication with knowledge producers and users to align project objectives, identify target audiences for the KE work, and establish long-term goals:

It's really about working together, that collaborative, the communication, the actual conversations with each other, learning from each other...that I think really made this project successful. (Participant 4).

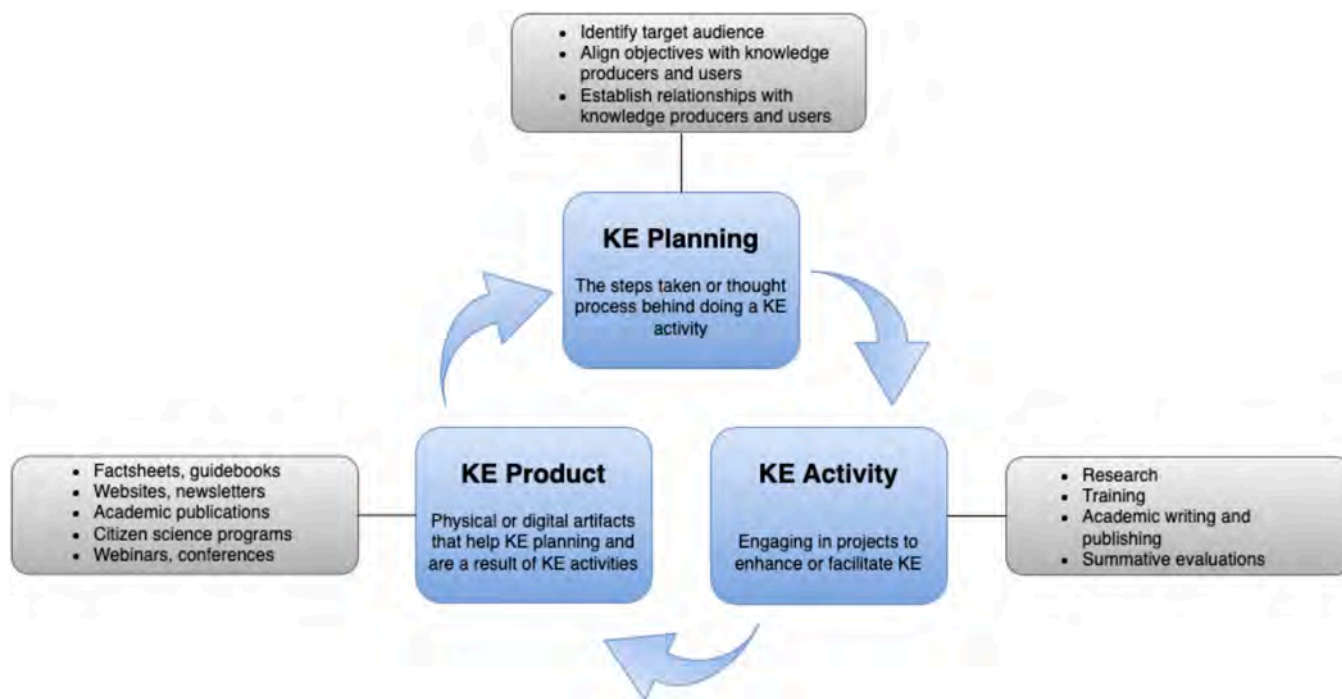


Fig. 2. The general approach for performing knowledge exchange (KE) work at the Canadian Forest Service, where definitions describing the three components (blue box) of the strategy were derived from the transcripts and were used in the codebook. Examples for each component were provided by the participants in the white boxes. This strategy involves cyclical process among KE planning, KE activities, and KE products, where each step in the strategy is interdependent on the other.

This quote highlights the importance of collaboration and open communication as part of KE planning to enable execution of KE projects. The KE planning described by the participant includes understanding and aligning the perspectives of knowledge users and producers, and encourages conversations that foster trusting relationships for more effective KE work.

Participants also frequently discussed KE planning as drawing upon established methods and strategies for executing KE activities. One participant utilizes an established mathematical tool for spatial climate modelling research where access to these systems is important for understanding historical data for research and KE purposes:

...We're not the creators of it [a mathematical tool], it's a guy named Individual 41, I knew him when I was in Region 31 and we brought him over here multiple times, and we're using the software we worked on with him. It's arguably one of the best methods in the whole world, 'cause his methods have been used by other people around the world.

But we've got, you know, our own sort of twist on it. (Participant 2).

Sharing KE strategies and tools as part of planning enabled practitioners to incorporate new information into their work to improve upon it. Four participants identified that they practiced sharing ideas and providing feedback to other KE practitioners across the CFS regional centres, resulting in an 'internal bank' of KE methods and strategies.

Other KE plans identified by the participants included establishing relationships with knowledge users to strengthen communication and performing in-person demonstrations of technology to increase the understanding and need for KE work:

...the key is to ensure that you interact with stakeholders in their environment at all levels... You need all levels of discussions to occur to create a vibrant knowledge exchange program. (Participant 5).

So, it's good to talk, but it's better to show. We had demonstration sites and field tours and things like that, and then we switched into even deeper analysis of what drove our clients away and what drove them to us. (Participant 7).

3.4. KE activities

At the CFS, *KE activities* involve engaging in projects or actions to enhance or facilitate KE. KE activities involve engaging in and performing KE by creating or developing a KE product (i.e., a physical or digital artefact). These specific activities are the units of measurement on which the typology of KE can be applied (Table 2). Participants identified many activities or ways to engage in KE, such as outreach, training, research, writing, publishing of peer-reviewed articles, and work evaluations (Table 2). Our results indicate that participants most frequently performed outreach as a KE activity. Our analysis revealed that outreach defined by participants fell into three KE types: one-way exchange; solicited exchange, and participatory exchange (Table 2). Some performance of outreach were defined by participants as using materials (e.g., newsletters, brochures, emails, videos, field trips, workshops, citizen science, etc.) that could be exchanged without a targeted knowledge user in mind, and can be considered *one-way exchange* in this case. Outreach materials (a KE product) could also be sourced by an organization, such as a school seeking citizen science programs, and can be considered *solicited exchange*. Alternatively, outreach materials could also be coproduced with the knowledge users and be considered *participatory exchange*. We also found that participants frequently engaged in daily correspondence, academic writing and publishing, and secondary research (see Table 2 for full descriptions). As such, we found that participants often adopted a one-way or a solicited exchange approach. Only few participants described knowledge management activities, summative evaluations, or formative evaluations as KE activities, resulting in fewer network exchanges.

3.5. KE products

Participants also identified *KE products* as part of their KE work, which includes physical or digital artefacts i.e., boundary objects (e.g., newsletters, factsheets, academic publications, etc.). *KE products* were identified as a tangible result of *KE activities* and help with *KE planning* by providing example deliverables of how KE practitioners can make

Table 2

A list of the activities identified by the Canadian Forest Service (CFS) participants when conducting knowledge exchange (KE) work. Frequency (not mutually exclusive) is the number of times a participant mentioned a KE activity, and the number of sources represents the number of interviewees who referred to the KE activity. The KE Type represents how the authors categorized each KE activity, where a KE activity can be classified as a different KE Type based on the context in which it was performed.

KE Type	KE Activity	Description	Frequency	# of Sources
One-way exchange Solicited exchange Participatory exchange	Outreach	This may include newsletters, brochures, emails, videos, field trips, workshops, citizen science, etc.	44	9
One-way exchange Solicited exchange Network exchange Participatory	Daily correspondence	Involves answering emails, phone calls to address requests, etc.	15	6
One-way exchange Solicited exchange	Academic writing and publishing	Involves publishing peer reviewed articles, writing academic literature	9	6
Solicited exchange Participatory exchange	Research	This may include gathering data, conducting research to help the knowledge producers, etc.	9	5
One-way exchange Network exchange	Training	This may include seminars, workshops, or conferences with CFS peers where individuals are learning	7	4
Network exchange	Knowledge management	Efficient handling of information and resources within CFS	2	2
Network exchange	Summative evaluations	Individuals reflect upon the merits or successes of KE activities at end of project	4	3
Network exchange	Formative evaluations	Involves reflection at end of KE project to improve and refine project activities	1	1

knowledge accessible to specific users (i.e., participants learn and use KE products as feedback for future KE planning and work; Fig. 2). Some of the KE products outlined by the participants included factsheets, guidebooks, websites, blogs, videos, publications, interviews, research maps, citizen science programs, conference presentations, e-lectures, lesson plans for schools, climate models, field tours, operational demonstrations, self-guided tours, articles in magazines, newsletters, and webinars. The variety of *KE products* that can be developed highlighted the uniqueness of each KE project and how *KE products* often cater towards the specific needs and objectives of the knowledge user, which are often identified during the *KE planning*. *KE products* can aid in *KE planning* by functioning as boundary objects to improve communication strategies, initiate new relationships, share research methods and expertise, and align project objectives.

3.5.1. Evaluating and assessing impact of CFS KE work

When asked how the impact of KE work is evaluated at the CFS, participants described indicators that can be categorized by their quantitative and qualitative nature. The participants were not aware of a singular definition for how to interpret the success of KE work at the CFS, focusing instead on the various indicators that can help interpret impact. The impact of KE was primarily described based on participant experiences working in this field.

Participants described quantitative indicators for KE evaluation that included: number of website clicks; number of people attending a seminar, workshop, or conference; number of papers produced or published through peer-review, and the number of times a peer-reviewed paper with CFS-affiliated authors is cited. Participants explained that these quantitative indicators were easily counted at the CFS. Further, participants identified adoption of a new technological product or policy by the knowledge user as an additional quantitative indicator for evaluating the impact of KE. However, the adoption of a technology or policy by the user was not something that the CFS actively quantified despite it being a tangible measure of success in KE.

Participants explained that qualitative indicators for evaluating KE were difficult to measure. Some attempts to qualitatively capture the impact of KE work included:

Assessing the influence that KE work had on human behaviour by considering whether individuals were inclined to act in a certain manner due to an increased understanding of a topic, evaluating whether

modifying a research project resulted in an increased number of positive outcomes, and observing whether a KE project influenced or encouraged similar work elsewhere in Canada.

All participants considered KE to be impactful when there was uptake of the knowledge by the user. Notably, uptake was defined differently by each participant, resulting in varied interpretations of successful and impactful KE across the CFS regional centres. For example, one participant described knowledge uptake to involve knowledge being incorporated into decision making, where the background knowledge of a specific topic can grow, and new insights or findings can be developed as a result:

... I actually think the research [people conduct] can contribute to the stock of knowledge that's out there about a subject. Researchers can also produce technology, that kind of thing, or data, things that are more involved mechanically into a decision process or something like that. (Participant 2).

In contrast, another participant described knowledge uptake to be successful when new technologies are adopted and put to use by the knowledge user:

Successful knowledge exchange has to link with the end users. So, the idea is to link technology with the end users and have potential uptake. So, success is having uptake by the end users of the knowledge or the technology that you're exchanging with them. (Participant 5).

These two views on KE uptake demonstrate how KE impact can be clearly interpreted by qualitative indicators (e.g. increase of knowledge domain, adoption of new tools).

One participant emphasized that impactful KE goes beyond positive outcomes such as knowledge user uptake and policy adoption, and that in order for KE work to be considered successful, it must encompass constructive feedback to improve KE practices:

So, a negative result is also a valid result, because I've had someone say that to me before in a way saying, 'it's good that you tried this Participant 7 cause now we know it doesn't work'. So, both negative and positive results are equally valuable to the forest sector to improve the way to manage Canada's forests. (Participant 7).

3.6. How is the impact of KE determined?

One way to learn about successful and impactful KE is to discuss and highlight ‘bright spots’ which are situations where environmental science has successfully influenced policy and/or practice (Cvitanovic and Hobday, 2018). When the participants (n = 7) were asked in the follow-up interviews to describe a perceived successful KE project that they previously worked on, all participants identified that building trusting relationships and aligning objectives with knowledge users enabled their KE project to be successful and achieve the most impact. One participant outlined that obtaining social license (i.e., the approval or acceptance of a community; Lowey, 2016) to conduct a KE project contributed to its success as it required the participant to build trust with the knowledge user (Box 1).

Additionally, all the participants outlined the importance of collaborating with both knowledge producers and users to build strong relationships that further establish trust. As one participant explained:

I think one of the key elements of success was that we were able to share information with all companies. We also worked closely with the region's government, and because of the collaborative nature, we were able to work together to deliver something that was needed and appreciated. We didn't just have this information and go 'here it is, now use it'... No, we tailored the information towards the knowledge-user. It's the listening and working collaboratively that was a key element of this success. (Participant 4).

Others explained that collaboration with knowledge producers and users is necessary to align project values and objectives (as part of KE planning) to develop KE products that have long-term usability (Box 2).

At the CFS, building and maintaining trusting relationships enabled impactful KE by fostering open communication and collaboration with all project stakeholders. In turn, this enabled the development of boundary objects that were relevant and accessible to the knowledge users.

4. Discussion

We have provided the second known empirical study of the KE activities undertaken by professionals in forestry and forest sciences (the only other example we are aware of being Klenk and Hickey, 2011). We provide empirical evidence and practical insights for learning about KE in practice by understanding the role of CFS KE practitioners, how they implement and operationalize KE, and how they evaluate and perceive successful KE. In this section, we discuss lessons learned and perceived strengths of the KE work undertaken by the CFS. We also look to best practices in the literature to make recommendations for strengthening KE efforts. Further, we highlight potential insights for other knowledge brokers throughout. We conclude by identifying areas for future research.

4.1. Role and characteristics of CFS KE practitioners: Knowledge brokering

We observed that CFS KE practitioners act as facilitators responsible for exchanging scientific knowledge across disciplinary and organizational boundaries, much like the roles of knowledge brokers (Naylor et al., 2012). Their roles included supporting knowledge producers to promote scientific knowledge – mainly through outreach activities intended for users of forest science, conducting secondary research, directing knowledge users to the appropriate knowledge or experts, and collaborating with knowledge producers and users to co-produce applicable tools and KE products. In the literature, knowledge brokers act similarly by utilizing a multi-directional approach to linking, collaborating, mediating, and exchanging context-specific knowledge with diverse knowledge users (Fazey et al., 2013; Bednarek et al., 2018), often through the use of boundary organization, social connections and networks, and knowledge co-production (Armitage et al., 2011; Cvitanovic et al., 2015; Karcher et al., 2021).

Box 1

A bright spot example highlighting the importance of transparency to obtain social license when engaging in KE work.

Box 1. Bright spot: Transparency to obtain social license

One participant described a successful KE project which involves addressing community concerns about impacts to a local watershed due to forestry-related uses of herbicides, pesticides, and insecticides. The KE practitioner first worked to develop relationships with community leaders, municipal councils, fisherman's associations, and woodlot owners. Relationship-building allowed the participant to identify areas of concern for the community, minimize knowledge gaps, re-evaluate herbicide application with the research team, and implement long-term water testing for continued safety – practices that were not established prior to conversations with the community. The participant emphasized that transparency with the community was an important component to obtaining social license to conduct this project: “...We tell people this (how high levels of herbicide effect wildlife), because if we don't, they're going to come back and say 'well, how about this?'... And that's the big thing it's transparency. And coming from CFS, our job is providing the science.” (Participant 1). In addition to obtaining social license, the participant felt that transparency helped establish trust, allowing the community to collaborate with knowledge producers to design an effective and useful project that addressed their specific needs.

Box 2

A bright spot example highlighting the adoption of a new technology.

Box 2. Bright spot: Adoption of a new technology

The goal of this KE project was to communicate alternatives to traditional clearcutting. The participant outlined that open discussions with the knowledge users was a key component to identifying what technology would help address their specific research needs. Through a hands-on demonstration, the participant communicated the need for a particular technology to all project stakeholders (knowledge producers, knowledge users, private industry, provincial government, and NGO's). By bringing together collaborators with varying backgrounds and perspectives, the participant was able to promote a shared value for the technology and align the objectives of all potential knowledge users. Developing a collective objective and value of a technology attributed to the success of this KE project: *"That was the important part of it and that's why it was successful because we brought the groups at different levels together, they could sit and look. Like an operational guide can look at it and go, 'yeah, that's a good idea we should try this!' And a supervisor could say, 'are you crazy? We're not paying that!'. And vice versa. Or 'Yeah, I agree this is a good idea and we should try this!'. So, it opens and starts the conversation at different levels with the industry as well as at different levels with us and it showed context."* (Participant 5)

The participant used quantitative indicators (i.e., adoption of a new technology) to frame the success of this project. The project was also impactful in terms of qualitative indicators (i.e., building social capital and changing human behaviour), although these were not easily measured or accounted for by the participant – highlighting the difficulty of qualifying the impact of KE work.

4.2. Current strengths of CFS KE

While knowledge brokers can be conceptualized differently and operate differently in various settings, the defining feature of their role is to develop relationships and networks with and between knowledge producers and users to facilitate KE and build capacity for evidence-informed decision making (Hoppe, 2009; Bornbaum et al., 2015). This requires knowledge brokers to build and maintain relationships (Cvitanovic et al., 2017), possess a strong understanding of the scientific knowledge they are exchanging, and possess an in-depth understanding of the knowledge users and the context they are engaging with (i.e., their operational environment, what KE products will best influence their research, and capacity) (Michaels, 2009; Saarela and Söderman, 2015). CFS KE practitioners highlighted the value of interpersonal skills and connections that allow them to interpret and frame knowledge user needs with knowledge producers. This is important in removing barriers to evidence-informed decision making and promoting a culture that values using the best available scientific knowledge for decision making (Cvitanovic et al., 2017; Dobbins et al., 2009; Meyer, 2010).

Further, although not explicitly stated, it appears that CFS KE strategies involve principles of co-design, which often involves all relevant actors in planning and designing services, research, or other activities to benefit all (Moser, 2016; Norström et al., 2020). The concept of co-design seems embedded in the CFS KE planning phase and should be acknowledged as a critical step. Principles of co-design and co-production have been highlighted in the literature as best practices for evidence-based practices and decisions (e.g., Moser, 2016; Mauser et al., 2013; Westwood et al., 2020; Steger et al., 2021) and is one of the important steps highlighted by CFS KE practitioners. Lastly, the cyclical nature of the KE work at the CFS is also worth noting, as it highlights the collaborative, co-creative, and adaptive nature of the KE work, which has also been reflected in knowledge brokering processes (Maag et al., 2018).

4.3. Opportunities for strengthening KE at the CFS

Most knowledge exchanges at the CFS occurred among the scientific community, with only few participants citing KE for non-scientific audiences resulting in potential implications on the knowledge base of knowledge users across organizational boundaries. (i.e., disciplines outside of the natural sciences). Addressing environmental management concerns requires knowledge brokers to draw on a wide range of disciplines and collaborate across organizations to align objectives with knowledge users and build capacity (Michaels, 2009). As such, opportunities may be missed to involve non-scientific actors, which could consequently limit policy development, industry objectives, and the capacity for knowledge brokers to build relationships or collaborate across research and policy areas (Dobbins, 2009; Bornbaum et al., 2015). Based on our analysis, it is uncertain whether the KE practitioners' roles at the CFS formally extends to influence disciplines and organizations outside of the natural sciences. It is also unclear whether the lack of uniformity around defining roles around KE may limit these opportunities to inform non-scientific sectors such as policy.

4.4. Approaches to KE

CFS KE practitioners employ each KE approach identified by Westwood et al., (2021, 2023) in various capacities (Table 2). Each of the KE Types has unique aims and offers unique results. As such, it is important that knowledge practitioners, generally, are aware of the four KE Types and their potential uses to effectively identify which KE activities may best supplement an approach or achieve a particular objective, and which KE products would be most impactful.

At the CFS, "outreach" was the most frequently cited KE activity. However, the nature of how outreach was described resulted in these activities being used as one-way exchange, solicited exchange, or

participatory exchange - depending on the context of the specific KE project. Outreach materials could be exchanged without a targeted knowledge user in mind (one-way KE), materials could be sourced by an organization (such as a school seeking educational workshops) (solicited KE), or materials could be co-produced with the knowledge users (such as an organization co-producing citizen science programs) (participatory KE). Based on our analysis, when performing outreach, the information being exchanged was not always tailored to a specific audience, but practitioners wanted it to be easily understood by all knowledge users.

Our observations demonstrate that simply knowing the type of a KE product does not determine which category of KE it falls into within the typology. To assess that, more must be known about the context through which the product was developed, how it was selected, and how knowledge users participated (or not) in the design of the KE product. KE practitioners should be aware of, and consider, which KE type is most relevant to their work to inform their decisions about KE activities and products. Taken together, this suggests that more research is required to validate and elaborate on Westwood et al.'s (2023) KE typology.

4.5. Current strengths in KE approaches

Outreach can vary in terms of the resources and effort committed (e.g., one hour online talk to citizen science initiatives vs. giving helicopter tours of experimental forest silviculture sites). It can also vary in its effectiveness (Varner, 2014). Further, outreach has been shown to have positive effects for both scientist and the public/audience (e.g., Webb et al., 2012). Yet, evidence still shows reluctance among scientist to participate in science outreach, often due to lack of skills or preparedness for public interactions (e.g., Royal Society, 2006; Jensen et al., 2008; Varner, 2014). The dedicated CFS KE Specialists who engage in outreach may be a good alternative to scientists conducting outreach themselves. These KE specialists are promoting research and its results on behalf of scientists, may have the time, skills and confidence required for effective outreach. This may particularly be true for outreach as an iterative, two-way process which can be more meaningful in building trust among scientists and the public (Varner, 2014; Cooke et al., 2017; Reincke et al., 2020). This lends some evidence to the existing calls for more knowledge brokers or boundary spanners at the science and society interface (Hering, 2016; Cooke et al., 2020). Indeed, suggestions of departments for knowledge exchange could provide institutional homes for knowledge brokers (similar to how many institutions and organizations have departments for communications or technology transfer; Hering, 2016) and recognize the importance of their role and work.

Overall, the KE strategy (Fig. 2) the CFS KE practitioners employ embeds interpersonal trust and relationship building at all stages of their process, from KE planning to products. The KE strategy involve a cyclical process among KE planning, activities, and products. This feedback loop is an important aspect of KE work as it encourages practitioners to continually evaluate and refine their work to maintain or improve trust and relationships with knowledge users. Developing and maintaining trust and relationships is an iterative process that requires learning and improving from past actions and outcomes (Fazey et al., 2014; Varner et al., 2014; Cooke et al., 2020).

To date, research suggests that participatory approaches to KE are most effective (Bautista et al., 2017; Saarikowski et al., 2017). One form of participatory exchange (as defined by Westwood et al.'s (2023) typology) is co-production, which scholars recommend as one of the best forms of research for actionable science as it involves designing, conducting, and disseminating research in relationship with partners (Beier et al., 2017; Westwood et al., 2020) The overall cyclical nature of the KE strategy employed by CFS KE practitioners (Fig. 2) is a participatory approach to KE that encourages collaborative exchange with all project stakeholders to produce actionable science.

4.6. Opportunities to strengthen KE approaches: use of KE typology to contextualize KE activities and products

The one-way communication model (or deficit model) continues to pervade science outreach and communication despite a large body of evidence demonstrating they are not effective (Davies, 2008; Dudo and Besley, 2016). We found a heavy reliance by CFS practitioners on one-way exchange and solicited exchange activities, which may limit opportunities to collaborate across diverse disciplines and limit the opportunities to build more meaningful relationships and trust with targeted audiences. Investing more into two-way or participatory KE activities could be considered. However, the KE Types are context-dependent and as such, a single KE Type cannot be considered more effective than the others without considering the perspectives and context of the knowledge producers and users. The unique positioning of CFS as a government organization with extensive connections both within and outside the government offers opportunities to engage in collaborative exchange with a variety of knowledge producers, knowledge users, industry, and community stakeholders and employ a variety of KE Types.

4.7. Evaluation of KE

KE can be evaluated through quantitative and qualitative lenses. While quantitative measures can provide instantaneous results that indicate the short-term impacts of KE, qualitative indicators often require more time to observe their impact or success (Bowen and Martens, 2005; Fazey et al., 2014). Although difficult to measure, qualitative indicators can provide greater insight than quantitative measures into the effectiveness and applicability of KE work (Fazey et al., 2014). In fact, previous assessments have determined that it often takes three to nine years to notice any observable impacts in interdisciplinary science, policy, and environmental management work (Cvitanovic et al., 2021), and as such, many studies do not empirically assess the effectiveness of KE work (Westwood et al., 2021, 2023). Even so, it may be unlikely to attribute impact to certain research projects as impact processes are complex, diffused and fuzzy (Meagher et al., 2008). Some scholars have suggested to focus on contributions rather than attributions of research to change or impact (e.g., Mayne, 2012). As such, it may be through understanding or leveraging the *process* through which research can lead to impacts, such as the process of KE, in order to promote research impact. It is therefore important to identify ways to evaluate qualitative indicators or other non-traditional evaluation approaches, which we further explore in the subsequent sections.

4.8. Current strengths of KE evaluation

CFS practitioners are experts of their work and possess tacit knowledge of knowing when a KE project is impactful based on their extensive experiences, relationships, and interactions with knowledge users. The cyclical strategy that they appear to employ has its own evaluation embedded into the feedback loop such that the KE products that are developed and its effectiveness supports KE planning. This is important as many scholars have expressed concerns of tracking impacts of research in absence of effective knowledge transfer or exchange strategies (Davies et al., 2005; Meagher et al., 2008). The cyclical approach used at the CFS encourages practitioners to continually evaluate their relationships and understanding of knowledge user operations to learn and improve upon past experiences and outcomes. Additionally, CFS practitioners use both quantitative and qualitative indicators to evaluate the impact of their KE work. However, more qualitative tools and practices are needed to ensure the full scope of a KE project can be evaluated, from short- to long-term successes.

4.9. Opportunities to strengthen: aligning evaluation methods with how KE is performed helps to ensure impactful KE work

With a heavy reliance on quantitative indicators by government institutions, there is natural incentive to perform KE activities that can be quantitatively evaluated. As such, there may be a disconnect in how impactful KE is evaluated and how it is actually performed in the CFS (i. e., KE is often quantitatively evaluated when it is often performed via collaborative work, relationships, and building trust). This can limit our understanding of the more humanistic and complex benefits of KE and can consequently limit improvements for future KE research that must consider the impacts of interpersonal relationships (Reed et al., 2020).

Some ways that researchers have evaluated qualitative indicators include *social impact assessment methods* which involves evaluating interactions that achieve certain pre-determined goals (Reed et al., 2021; Spaapen and van Drooge, 2011), and *evidence synthesis approaches* which involves conducting a review of existing data and literature to assess whether new research will provide impactful outcomes (Collaboration for Environmental Evidence, 2018; Reed et al., 2021). These methods have been successful in evaluating the qualitative indicators of KE by tracking progress towards a planned impact and providing formative feedback for KE practitioners, thus increasing the likelihood of producing impactful KE (Reed et al., 2021).

Potential qualitative indicators that the CFS may consider include dimensions of social capital, such as trust, mutual respect, collaborative capacity, and implementing and sustaining new practices (Szulanski, 2000; Fazey et al., 2014). Although these indicators were not explicitly mentioned by the participants, CFS practitioners allude to their KE work being more effective when they had the opportunity to establish trusting relationships and align project objectives with knowledge producers and users, which aligns with what many studies have found as impacts of KE or boundary spanning activities (see review by Posner and Cvitanovic, 2019). Further, the varied interpretations of impactful KE by the participants reiterates the importance for organizations to work alongside KE practitioners when evaluating KE due to the highly context-dependent work that is required to implement effective KE practices.

With the argument that KE practitioners (and other boundary spanning or intermediary or brokering positions) hold a unique and vital position to establishing trusting relationships, an alternative approach to evaluating KE is to combine 'process indicators' with contributions of these intermediary individuals (Maag et al., 2018). Process indicators pertain to characteristics of knowledge brokering or exchange processes themselves. In this case, the CFS KE practitioners could evaluate the extent of activities in their KE process (e.g., using dimensions or indicators relevant to their cyclical KE process in Fig. 2 such as number of correspondences, amount of time spent on a respective process; see Maag et al., 2018 and Posner and Cvitanovic, 2019 for more details on indicators and impacts of knowledge brokers and boundary spanner). Other intangible results (called attributable results indicators) such as team cohesion, group learning or alignment of objectives (common ground), increased trust, stronger and diverse social networks may be used to measure knowledge brokering effectiveness (Maag et al., 2018; Posner and Cvitanovic, 2019) and substantiate 'contribution stories' for evaluating research or intervention impacts (Mayne, 2012). Although identifying indicators is beyond the scope of our work, leveraging intermediary individuals and their process of KE or knowledge brokering may be an alternative worth exploring.

4.10. Enablers of effective KE: interpersonal relationships and trust

It was clear from our findings that building and maintaining interpersonal relationships and collaborations with knowledge users enabled successful KE projects. This was primarily because these actions built trust which is an important component to effective KE work and diffuses any power imbalances among KE actors as mentioned by one of our

participants (Boschetti et al., 2016; Chapman et al., 2017; Cadman et al., 2020). When conducting KE, specifically engaging in participatory approaches such as fostering trusting relationships with knowledge producers and users, allowed KE practitioners to co-design research projects to define clear and useable outcomes, participate in a two-way dialogue to keep knowledge users engaged (Cash et al., 2006; Beier et al., 2017), and encourage ongoing communication which can be important when determining the long-term impacts of KE work (Fazey et al., 2014; Laatsch and Ma, 2016). Trust continues to be an important component to effective KE when considering one-way exchanges. An individual's trust in an organization, individual, or even sector (for example, the entire scientific community) can influence their willingness to accept new knowledge and can be highly dependent on an organization, individual, or sector's reputation (Lacey et al., 2018).

Maintaining transparent dialogue with knowledge users allowed the participants to engage in open communication and further develop trust (Lemos and Morehouse, 2005; Frantzeskaki and Kabisch, 2016). This is because transparency with knowledge users helps clarify limitations of a project and can help users overcome uncertainties by contextualizing the work (Ellison, 2010). The participants also used informal face-to-face interactions to build trust by engaging in casual conversations in a safe space to promote commitment and ensure they have the knowledge user's best interest in mind (Holton, 2001; Few, 2003; Cvitanovic et al., 2021). The level of trust that is established amongst knowledge producers, users, and practitioners affect the extent to which knowledge is accepted and used by knowledge users (Andrews & Delahaye, 2000; Szulanski et al., 2004). Building and maintaining interpersonal relationships and trust are integral components to how practitioners design and implement KE, influences how KE work is evaluated, and is necessary for conducting effective KE.

5. Conclusion and recommendations

We have provided empirical evidence and practical insights for learning about KE in practice by understanding the role of CFS KE practitioners. Although not explicitly identified as knowledge brokers, the CFS KE practitioners' roles and active engagement in translating scientific knowledge to various audiences suggests they play an intermediary / brokering role, and thus our study contributes to our understanding of individuals in these intermediary and knowledge brokering spaces. We have identified a general strategy that practitioners at the CFS employ to implement and operationalize KE, which can be applicable and useful to KE practitioners or knowledge brokers in other disciplines and sectors.

Our study emphasized the importance of identifying and utilizing the KE typology (Westwood et al., 2021, 2023) to develop and execute relevant and accessible boundary objects. Additionally, we make clear the need to evaluate KE through both quantitative and qualitative lenses, emphasizing the need for organizations to adopt more qualitative evaluations to assess the full scope and impact of KE work. Finally, our findings recognize the integral role of relationships and trust in all aspects of KE work. At the CFS, we recommend more opportunities and investments into KE practitioners to expand their work to different audiences outside of the scientific community to take full advantage of their unique positioning within a government organization with extensive research and knowledge user connections. We recommend KE practitioners in forestry or forest science engage with stakeholders from multiple disciplines and sectors to establish broad networks and opportunities to share expertise across organizations. Further, we recommend practitioners maintain communication systems with other KE practitioners within their organization to ensure the best available strategies, expertise, knowledge and learnings are available to implement KE.

We encourage KE practitioners from all disciplines and sectors to become familiar with the KE typology (Westwood et al., 2023) to inform their decisions about KE activities, products (e.g., boundary objects),

and planning. We recommend practitioners consider the context of their KE work to determine which KE Type from the typology is most applicable to develop relevant and accessible KE products for knowledge users. Additional research is needed to understand how robust the KE Types are and to validate their use in KE.

Our findings suggest that there may be a disconnect in how we quantitatively evaluate KE versus how it is performed (i.e., KE is often evaluated by quantitative indicators that do not capture the impact of interpersonal relationships and trust). As such, we must discuss additional qualitative indicators to evaluate and fully grasp the impact KE work has. At the CFS, and potentially among other organizations, KE practitioners have unique positions and knowledge as they are intimately embedded with knowledge users. This is an important opportunity, at an organizational level, to work with and include KE practitioners in evaluating and ensuring impact of research, particularly through the process of KE itself.

Building and maintaining relationships and trust with all project actors is the backbone of KE work. KE practitioners must continue to foster relationships and trust amongst knowledge producers and users to ensure that effective and impactful KE is designed and implemented, and that continued communication is fostered for qualitative evaluations. Greater recognition and value of this type of work is needed at institutional levels to protect these activities that foster trust. Our findings, which highlight the knowledge of expert practitioners in KE in forestry and forestry sciences, may apply equally in other domains.

CRediT authorship contribution statement

This study was conceptualized with CFS partners by Nguyen, Young, and Westwood. Study design included Nguyen, Young, Westwood, and Falconer. Data analysis was conducted by Kapoor, Hutchen, Falconer, and Nguyen. Writing was led by Kapoor with guidance from Nguyen. All authors reviewed and edited final paper, and results were validated with participants at the CFS and disseminated to CFS partners.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Vivian Nguyen reports administrative support was provided by Natural Resources Canada. Vivian Nguyen reports financial support was provided by Social Sciences and Humanities Research Council of Canada.

Data Availability

The data that has been used is confidential.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.envsci.2023.07.009](https://doi.org/10.1016/j.envsci.2023.07.009).

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