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A systematic map of knowledge exchange across the science-policy interface for forest science: How can we improve consistency and effectiveness?

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Abstract

1. Knowledge produced by scientists is essential to the policy and practice of managing natural resources, including forests. However, there has never been systematic mapping of which techniques in knowledge exchange (KE) have been applied in the forest sciences, by whom, and to what effect. We examined KE techniques documented in the forest sciences globally.
2. We used standardized search strings in English and French across two academic search engines (BASE and Scopus) and a specialist website (ResearchGate) to locate relevant items. We screened items, extracted data, conducted qualitative and quantitative analysis, and built a network visualization diagram to demonstrate knowledge flow.
3. Our final map included 122 items published from 1998 to 2020, with most published after 2010. Items mentioned organizations from 66 countries as knowledge producers or users. The interactive network visualization diagram displays linkages between organizations, sectors and countries. We found that most of the KE activity involved the Global North (89%). Governments were the most common knowledge users, and industry was frequently reported as a user but rarely a producer. Academia was both producer and user. Indigenous, local, traditional or community knowledge was included in 24% of items, but these communities were not associated with any coauthor affiliations. Reported funders were universities, governments, non-profits or foundations. We found 90 unique terms in the items related to KE with less than 25% of terms used in more than one item. Fifteen per cent of item keywords related to KE. The most commonly identified enabling conditions for KE were trust, funding and established relationships, while major barriers were challenges for translation of science and lack of time.

4. To improve searchability of information related to KE and encourage a culture of considering KE in scientific research and forest management work, we recommend a common lexicon of 'knowledge exchange'/'échange de connaisances'. We recommend that more effort be given to forest science-related KE connections between the Global North and South as well as a deliberate collection of evidence for the effectiveness of KE techniques. Researchers and practitioners can use our KE typology to identify their goals and design appropriate evaluation measures.

KEYWORDS
forest management, forest science, forestry, knowledge exchange, knowledge transfer, science-policy interface

1 | INTRODUCTION

The management of forests globally includes a complex interplay of resources, values, stakeholders and governments. Forest management policy and practice is often informed by scientific knowledge (D'Eon & MacAfee, 2016). Scientific knowledge is used to guide tangible outcomes in forest management such as designing silvicultural prescriptions (which determine the approach to harvesting and regeneration of trees; e.g. Achim et al., 2022; MacLean et al., 2021) and conserving forest biodiversity (e.g. Scullion et al., 2019), among others. A long-standing global format by which scientific knowledge about forests is shared between producers of this knowledge and forestry practitioners and forest managers is the practice of 'extension', whereby academic and government knowledge producers provided outreach and education on forest sciences to landowners and forestry professionals (Association of Natural Resource Extension Professionals, 2022; European Forest Institute, 2022; Kandzior & Rivas, 2015; U.S. Department of Agriculture Forest Service, 1976).

One concept that has been used in forest management to understand the nature of how scientific knowledge is shared between its producers and users is 'knowledge exchange' (e.g. D'Eon & MacAfee, 2016; Hamunen, 2013). For our purposes, knowledge exchange is the multi-directional flow of ideas and information between producers and users of knowledge. Importantly for the forest management science-policy interface, producers and users of knowledge are not unique to either the domains of science, policy and practice. Actors on all sides of these boundaries incorporate knowledge from the corresponding side of the science-policy interface.

Westwood et al. (2021) introduced a new typology for categorizing knowledge exchange efforts and techniques (Figure 1; French translations of the terms, their definitions and the figure are given in Appendix 1). This typology includes four exchange categories: (1) 'one-way exchange', where scientists independently produce a scientific report or paper and deliver it to knowledge users; (2) 'solicited exchange', in which a knowledge user expressly invites knowledge producers to tackle a pre-identified knowledge gap; (3) 'network exchange', where two or more actors come together explicitly to exchange independently generated knowledge; and (4) 'participatory exchange', where potential users of scientific information are engaged and involved in the process of generating knowledge.

Still, in many cases, there is a knowledge-implementation gap (also called the science-policy gap) where knowledge produced is not used or implemented into policies or practices (Ferreira & Klütsch, 2021). There have long been calls to increase the effectiveness of communication between knowledge producers and prospective knowledge users in order to close this gap and maximize the value of generated scientific knowledge (Bradshaw & Borchers, 2000; Lubchenco, 1998; Snow, 1959). These calls have also been specifically made regarding knowledge about forests (Guldin et al., 2005; Kleine, 2009; Parrotta & Campos Arce, 2003). Previous work on the knowledge-implementation gap has focussed on describing barriers to effective knowledge exchange between knowledge producers and users (e.g. Cvitanovic et al., 2015). More recently, Cvitanovic and Hobday (2018) challenged researchers to focus on solutions for better integrating science into decision making.

Westwood et al. (2021) highlighted the need to conduct, and developed the protocol for, a systematic analysis of the four knowledge exchange techniques in forest science and forestry. In the current study, we seek to identify and capture the flow of knowledge (or multi-directional flow) between producers and users from across sectors. We investigate common knowledge exchange techniques described in relevant articles and we compare them to the previously described types of knowledge exchange (Figure 1). This novel approach represents the first attempt to characterize knowledge exchange literature in the forest sciences based on a literature review of global scale.

1.1 | Objectives

The purpose of our study is to map knowledge exchange techniques that have been applied to forest sciences to better understand KE at the interface of forest science and policy. We examine

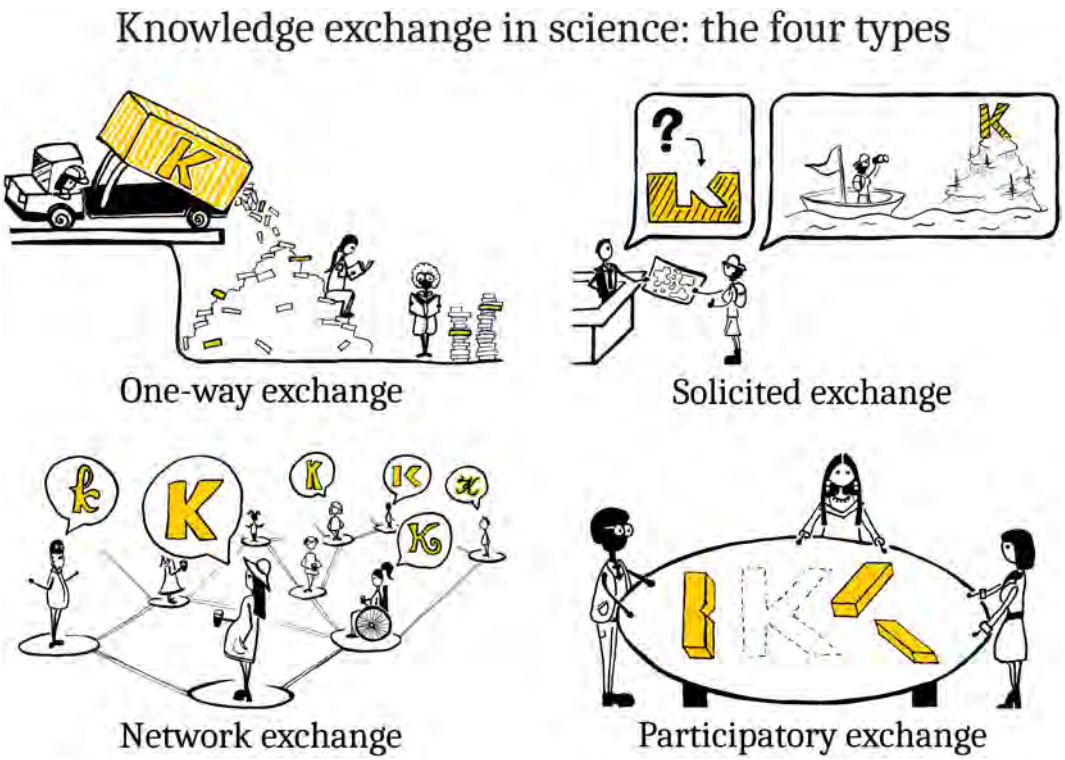

FIGURE 1 Four types of knowledge exchange in science. Figure by Sarah Perez (see Acknowledgements section).

peer-reviewed academic and grey literature relating to knowledge exchange and forest sciences, specifically looking at the knowledge exchange technique and frequency; the distribution of this technique within and among institutions and countries; and any reported evidence of its effectiveness. The study has four primary objectives: (1) provide guidance on the most common English and French lexicon for knowledge exchange, (2) characterize when and where knowledge exchange about forest sciences and forestry has occurred in published written works, (3) highlight limitations in past and present approaches to understanding knowledge exchange in the forest sciences and (4) summarize recommended best practices for knowledge exchange.

2 | MATERIALS AND METHODS

We used a Registered Report article format (British Ecological Society, 2022) in which the methods and proposed analyses are peer-reviewed and registered prior to the conduct of the research. Details of key background literature and experimental design are given in the Stage 1 report (Westwood et al., 2021), which was developed as a systematic literature map protocol in accordance with the Collaboration for Environmental Evidence's guidelines (Collaboration for Environmental Evidence, 2018) and the ROSES reporting standards (Haddaway et al., 2018; Appendix 2). With regard to the research question, database searching and data extraction, we repeat here key aspects of the methods to contextualize the Stage 2 article, with full details of materials and methods Westwood et al. (2021). We also include in this article methods for additional data analysis beyond those registered in the Stage 1 article.

The main research question is: what techniques have been used and/or theorized by those producing new knowledge about forests, forest ecology, forest policy, forestry and silviculture to engage in knowledge exchange with potential knowledge users? The subject of interest included cases of knowledge exchange in forestry and forest sciences reported in English or French, with emphasis on how knowledge exchange methods are categorized, described and evaluated.

2.1 | Database searches

We engaged in preliminary testing of the sensitivity and specificity of searches using 55 individual search terms (24 in English, 31 in French) combined in 36 search strings across five databases. We tested sensitivity and specificity of these searches and counted which terms were returned in relevant articles to determine the final search terms, final four search strings and final three databases (detailed search strategy is presented the Stage 1 article; Westwood et al., 2021). Based on results from test searches, our final search included four standardized search strings (Appendix 3; two in French, two in English) across three databases (Bielefeld Academic Search Engine (BASE), ResearchGate and Scopus) from July to August 2020. All four search strings were used in BASE and ResearchGate, whereas Scopus could only be searched in English (two strings).

For each search, one of four screeners (AW, JW, KK and TK) copied the title, author, year and language of each returned result into a Google Sheet and screened the title and abstract for relevance according to the eligibility criteria, which are given in the Stage 1 article. As described in Westwood et al. (2021), we were unable to use the typical comprehensive literature review approach of downloading the entire list of search results before commencing screening for two reasons. First, the general nature of our search terms meant that returned results ranged up to the thousands, but preliminary testing showed that specificity declined sharply based on the proportion of relevant results (Westwood et al., 2021). Second, ResearchGate does not display the total number of returned results nor can it be downloaded in bulk; however, this database is a source of relevant grey literature and showed the highest sensitivity and specificity in preliminary testing (Westwood et al., 2021). We addressed these issues by developing a custom stopping criteria that determined the endpoint of each search. The screener stopped reviewing the title and the abstract of returned results if: (1) all returned hits were screened, or, (2) 30 consecutive hits were deemed not relevant *and* the rolling average of specificity for the last 30 hits was below 20% (Figure 2).

Of the 10 searches, only one (search string 2 in Scopus) met the first stopping criterion of exhausting all returned results before specificity declined, with the remainder meeting the second stopping criterion. In total, we screened 1166 unique items across 10 searches, of which 230 passed title–abstract screening (Appendix 3). ResearchGate returned the most retained results (84), followed by Scopus (74) and BASE (72). No search string or engine clearly outperformed any others (Table 1), although BASE returned more results in French than ResearchGate.

When an item passed title–abstract screening, its full-text document was saved into a Mendeley (Mendeley Ltd, 2019) shared database. Full-text records were not always available in each database, and screeners used Google searches or directly requested records from authors to locate documents. After removing all duplicates, we uploaded the remaining items into the literature review program Covidence (Veritas Health Innovation, n.d.) for full-text eligibility screening. The removal of duplicates function was then applied again in Covidence, and we conducted full-text screening of the remaining 158 items (Figure 3).

At the full-text screening stage, one reviewer screened each item. If a reviewer was unsure about whether the item met the eligibility criteria, they discussed it with the project team during bimonthly team meetings. The study lead (AW) validated a random subset of 15% of full-text screening decisions (24 items) and consistency was observed in 96% of cases (Appendix 4).

2.2 | Data extraction

Data extraction was completed in Covidence by nine reviewers by answering a standardized 18-question form, which was designed to structure data related to the outcomes of interest (Westwood et al., 2021). All reviewers received training on data extraction led by AW and validation was performed on the extractions in accordance with the parameters (Westwood et al., 2021). A minimum of three items were validated per reviewer, with more validations occurring if any validations were rated as 'fair' or 'poor'. If an item was rated as 'fair'

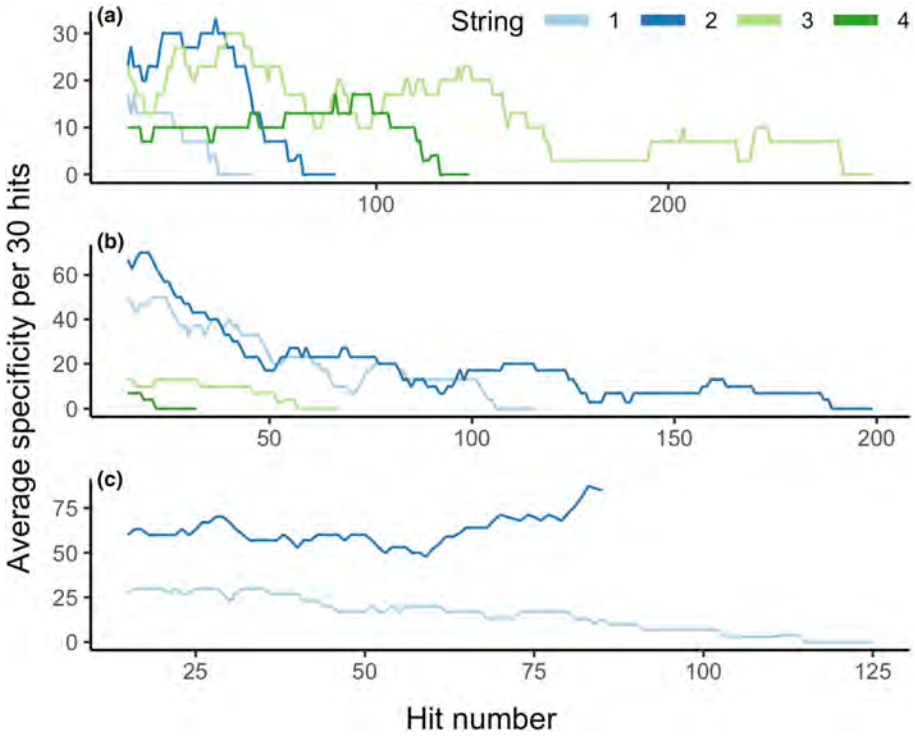

FIGURE 2 Rolling average specificity (proportion of returned results which pass title and abstract screening) per 30 search database hits for four search strings across three databases.

TABLE 1 Number of items screened and retained during title–abstract screening across three databases.

Database	Search string #	String language	Number of items screened	Number of items passing the title–abstract screening	Percentage of retained items per string in English
BASE	1	English	57	6	100
	2	English	83	17	100
	3	French	270	36	19
	4	French	132	13	31
ResearchGate	1	English	116	31	100
	2	English	199	44	100
	3	French	67	7	0
	4	French	32	2	50
Scopus	1	English	125	20	100
	2	English	85	52	100

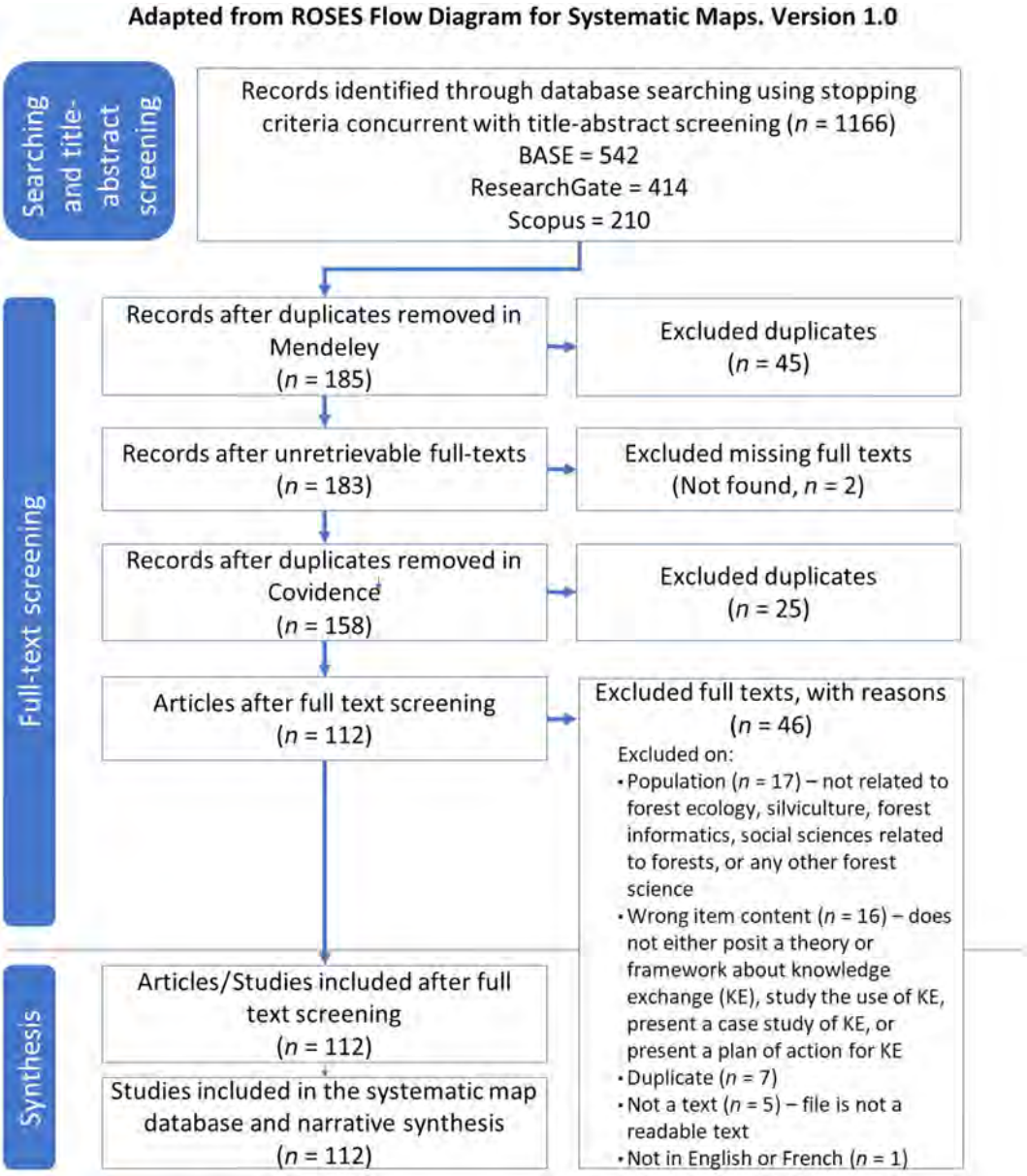

FIGURE 3 Flow diagram detailing stages for searching and screening items for the systematic literature review of knowledge exchange/échange de connaissances in forest sciences. Diagram follows in the ROSES reporting format (Haddaway et al., 2018).

or 'poor', the study lead discussed the discrepancy with the reviewer and corrected the recorded data. In total, 32 items were validated, with 84% scoring 'full' or 'good' agreement (Figure 4; Appendix 4). The data we extracted from full-text items were downloaded as a .csv file from Covidence (raw download given in Appendix 5), exported to a Microsoft Excel file, organized and cleaned to ensure standard spellings and to correct any typos or obvious data entry errors (Appendix 6).

2.3 | Data analysis

Following other systematic map examples (e.g. Alexander et al., 2019; McKinnon et al., 2016), we used a framework-based synthesis (Carroll et al., 2011) to structure the categorization of knowledge exchange techniques and identify trends through the use of descriptive statistics.

2.3.1 | Descriptive statistics

Data included nominal categorical variables (e.g. country, keyword) and scale variables (e.g. year). We did not test for statistical significance due to low sample sizes for the majority of the categories. We reported and described observed trends through numerical reports (counts and percentages) and graph summaries. We completed analysis and graphing using Excel (Microsoft, 2021), SPSS (IBM Corporation, 2020) and R (R Core Team, 2021).

2.3.2 | Network visualization diagram

We built a network visualization diagram using an open software, Gephi (ver. 0.9.2) (Bastian et al., 2009), to visualize the flow of knowledge between producers and users in relation to institution type. The network diagram includes 'nodes' representing organizations that are connected to one another by a series of links called 'edges' (Heyman, 2018). We assigned each organization with an identification number to build the network diagram in an .xlsx file (Appendix 7). We categorized the organizations by type of institution. These included government, academia, NGO, industry or international organization (which has countries as members, such as UNESCO World Heritage Committee and the European Union). We also recorded geographical location (i.e. latitude and longitude). Connections were made between the 'knowledge producer' organizations and 'knowledge user' organizations when the article was explicit that knowledge moved from the organization that produced it to one that would use it. The relationships between knowledge producers and users were represented in Gephi using an arrow, and we used the plugin 'GeoLayout' to display the network diagram atop a Mercator projection. We also tabulated the proportions of each institution type classified as knowledge producers and/or users.

2.3.3 | Qualitative text analysis

The data extraction process required reviewers to record long-form qualitative data including a restatement of the major findings of each publication (Westwood et al., 2021). The major findings were screened and compiled into a document that allowed for the qualitative data analysis team (TK, KK, MR and SL) to process this information. The qualitative analysis aimed to determine: (1) what knowledge exchange techniques the items recommended, (2) if the items noted a successful instance of knowledge exchange, how they described that success and (3) what conditions, according to the authors, enabled knowledge exchange to be successful (or were barriers to its success).

We used deductive coding based on the knowledge exchange typology (Westwood et al., 2021) to classify described knowledge

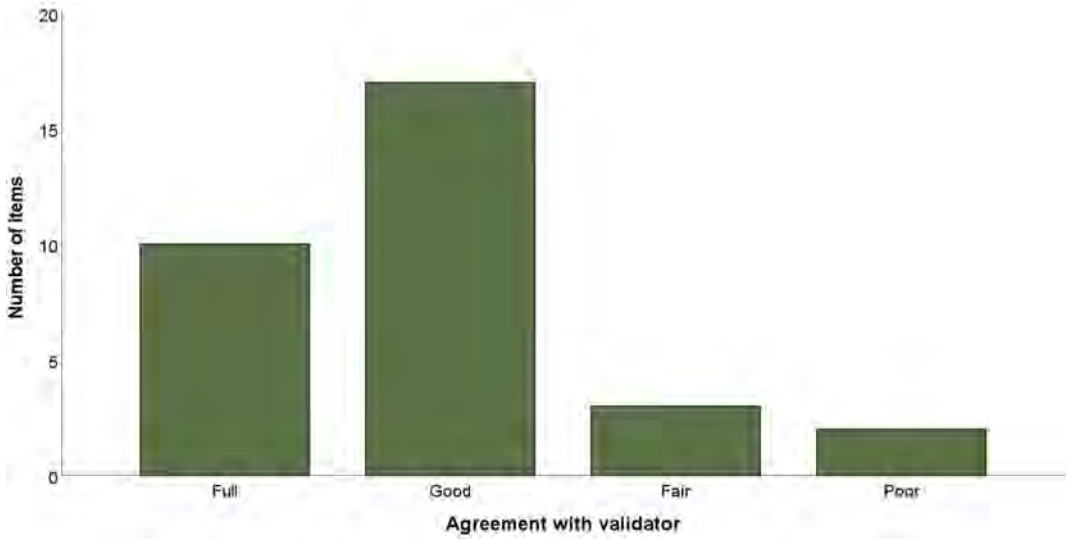

FIGURE 4 Number of validated full-text extractions and their corresponding level of agreement with the validator's assessment.

exchange activities into the four a priori codes. For the remainder of the qualitative analysis, an inductive coding approach (Saldana, 2016) was employed by the coders (TK, KK, MR and SL) whereby each 'code' served as a label for a theme present in the qualitative data. The codes were not determined in advance as this could misrepresent the data (Van Den Hoonard, 2019). Consensus-driven coding was applied to 30 items, where two coders (TK and KK) separately assigned codes following an inductive coding approach and then met with the coding team to determine a collective interpretation of the data (Van Den Hoonard, 2019) and develop a codebook (Appendix 8). Codes were grouped into four categories: knowledge exchange techniques used, enabling conditions for knowledge exchange, barriers to knowledge exchange and evidence of successful knowledge exchange. Once the codebook was established, three coders (TK, KK and MR) coded the rest of the data. Four coders (TK, KK, MR and SL) were involved in the verification process where 15% (approximately six findings) of each coder's work was verified by another coder.

3 | RESULTS

Raw data extracted from Covidence are given in Appendix 5, and the cleaned database which includes the full list of included items is given in Appendix 6.

3.1 | Item type and bibliometric characteristics

Of the 112 included items, 30% (n = 34) presented a case study of knowledge exchange within or between institutions, 30% (n = 33) presented recommendations for (or an evaluation of) knowledge exchange based on original research, 22% (n = 25) presented a theoretical framework for how knowledge exchange does or might operate, and 18% (n = 20) did not fit into any of these categories ('other'). All included items that were categorized as editorials (n = 4) were included in the 'other' category, and these predominantly described the history, purpose, objectives and/or plans of organizations which engage in knowledge exchange (e.g. de Arano, 2014, which summarizes the European Forest Institute's approach to the science-policy interface). Also included were proceedings from workshops that summarized discussions related to forest science or science policy but did not present a case study, recommendations or a theoretical framework related to knowledge exchange (e.g. Elliott, 2018). Several were empirical studies which solicited knowledge from communities and then reported it, but were not themselves examples of knowledge exchange (e.g. Nautiyal & Nidamanuri, 2012).

Most of the items were published after 2010 (64%, N = 72; Figure 5). The majority of the items were peer-reviewed articles (63%, N = 70), followed by conference proceedings (11%, N = 12) and theses (6%, N = 7).

We found 24% of items (N = 27) discussed Indigenous, local, community or traditional knowledge (henceforth shortened as 'IK'), with most of these being peer-reviewed articles (67%, N = 18) that presented theoretical frameworks (41%, N = 11) rather than case studies or empirical research. None of the items including IK had any of their authoring individuals or associations affiliated with Indigenous, local, community or traditional knowledge-related institutions. When IK was associated with one of the four types of knowledge exchange, collaborative was the most frequent (48%, N = 13) followed by network (15%, N = 4) and solicited (11%, N = 3) exchange, or multiple types of exchange (7%, N = 2). The frequency of items including IK appears to be increasing with time, with 2020 having the most items in this category (Figure 6). Fifty-four (48%) items reported one or more funding sources, and all

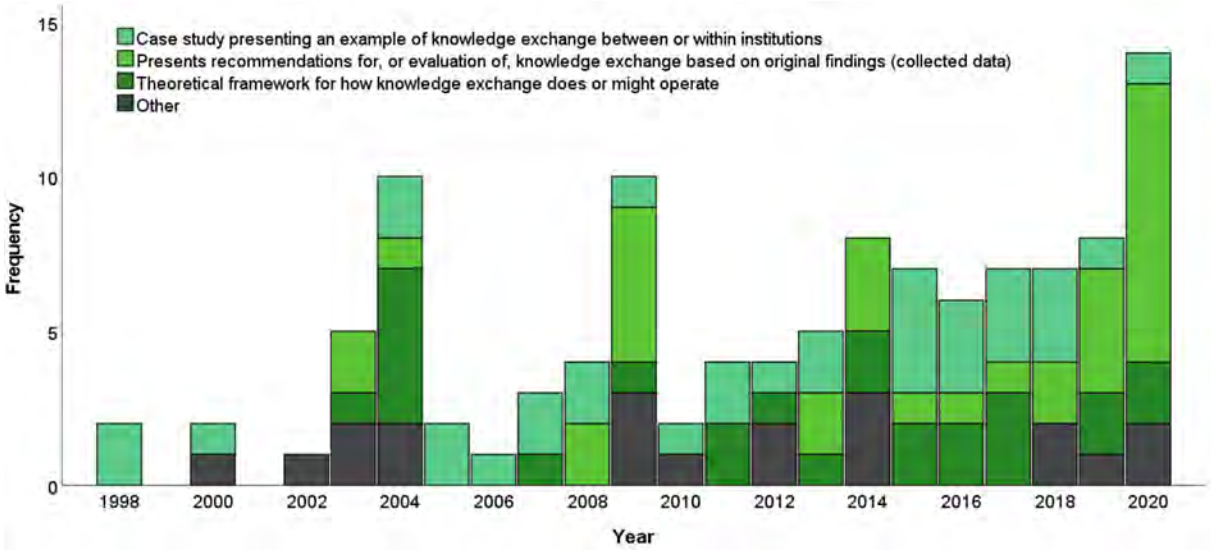

FIGURE 5 Items related to knowledge exchange in the forest sciences by publication year and item type.

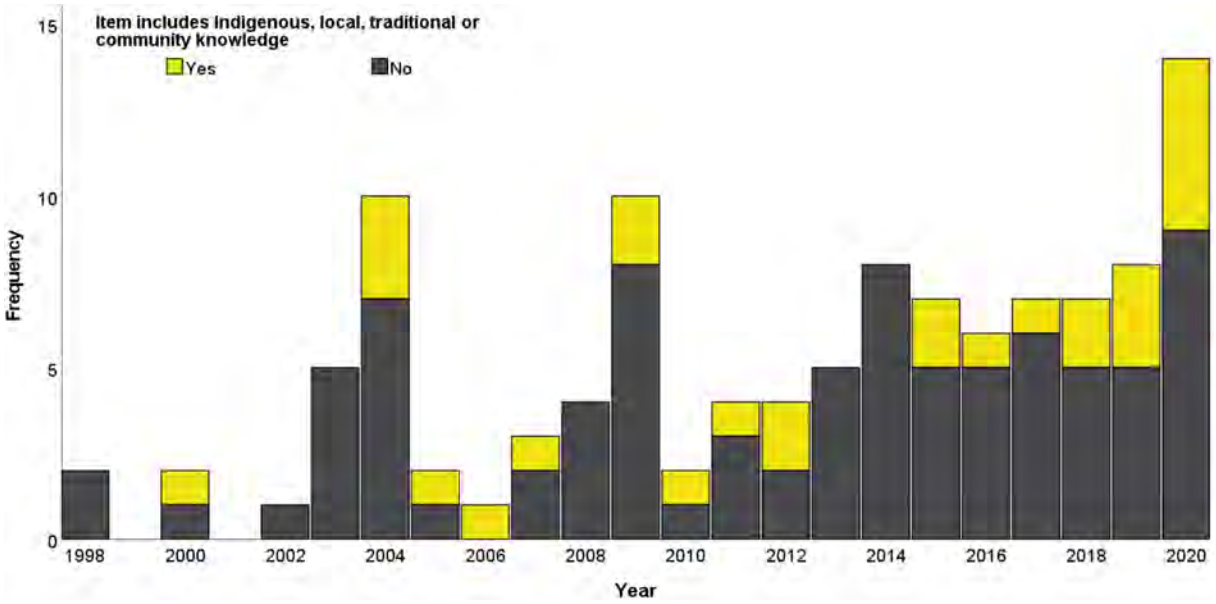

FIGURE 6 Items related to knowledge exchange in the forest sciences by year and whether they include elements related to Indigenous, local, community and/or traditional knowledge.

funding sources were from governments, academic units or non-profits (including foundations). There were no reported industrial or private funders.

3.2 | Keywords and terms used to describe knowledge exchange

After combining redundant terminologies used to describe knowledge exchange (e.g. in French, combining 'communication' and 'communication des résultats' into 'communication'; combining 'co-production' and 'coproduction of knowledge' to 'coproduction'; aligning plural articles in French; Appendix 6), there were a total of 90 unique terms in English and 14 in French. Of these, only 20 English terms and five French terms were used by more than one study. The four most frequently used terms in English (accounting for 38% of all English terms used) were 'knowledge transfer' ($n = 28$), 'knowledge exchange ($n = 20$), 'science-policy interface' ($n = 15$) and 'coproduction' ($n = 8$). The four most frequently used terms in French (accounting for 58% of all French terms used) were 'transfert des connaissances' ($n = 6$), 'partage de connaissances' ($n = 3$), 'intégration des savoirs' ($n = 3$) and 'échange de connaissances' ($n = 3$). Terms used in at least five items were observed more frequently after the year 2010, with only 'science-policy interface', and 'communication' being common prior to this date (Figure 7).

Of the 301 unique keywords recorded from the items themselves (e.g. identified in a 'keywords' section in a peer-reviewed article), only seven were in French, and as such we analysed both languages together. Of these, we deemed 44 keywords in some way indicative of knowledge exchange (Appendix 6). Only 46 of 301 unique keywords (15%) were used in more than one item, with the three most common keywords related to knowledge exchange being 'science-policy interface' ($n = 18$), forest policy ($n = 12$) and knowledge exchange ($n = 6$).

3.3 | Knowledge exchange type, technique and evidence of effectiveness

We categorized the knowledge exchange techniques, qualitatively analysed the individual knowledge exchange techniques used, and examined for evidence of whether knowledge exchange was effective. When comparing to our typology of knowledge exchange in science (Figure 1), 3% of items were categorized as one-way exchange ($n = 3$), 10% solicited exchange ($n = 11$), 29% network exchange ($n = 32$) and 40% participatory exchange ($n = 45$). This was supported by the qualitative analysis results, which showed that of the 14 items whose major findings included mention of a knowledge exchange type, most ($n = 10$) were coded as participatory exchange.

Two items (2%) were case studies which included multiple types of knowledge exchange, and the typology was not applicable to 17% of items ($n = 19$). Of the items which did not fit the typology, most did not describe any instances of knowledge exchange between or among producers or users of knowledge ($n = 14$). Many ($n = 5$) proposed new software and technology tools (e.g. Innis, 2002; Regolini et al., 2010), but these were focused on addressing management and governance issues rather than knowledge exchange. Other items which did not fit the typology described local or Indigenous peoples' knowledge or knowledge systems but did not address knowledge exchange (e.g. Gonzalez & Kroger, 2020; Savari et al., 2020). There was no clear trend in knowledge exchange type as compared to publication year (Figure 8).

From the qualitative analysis, we inductively coded 13 unique techniques for knowledge exchange with 215 instances of these in

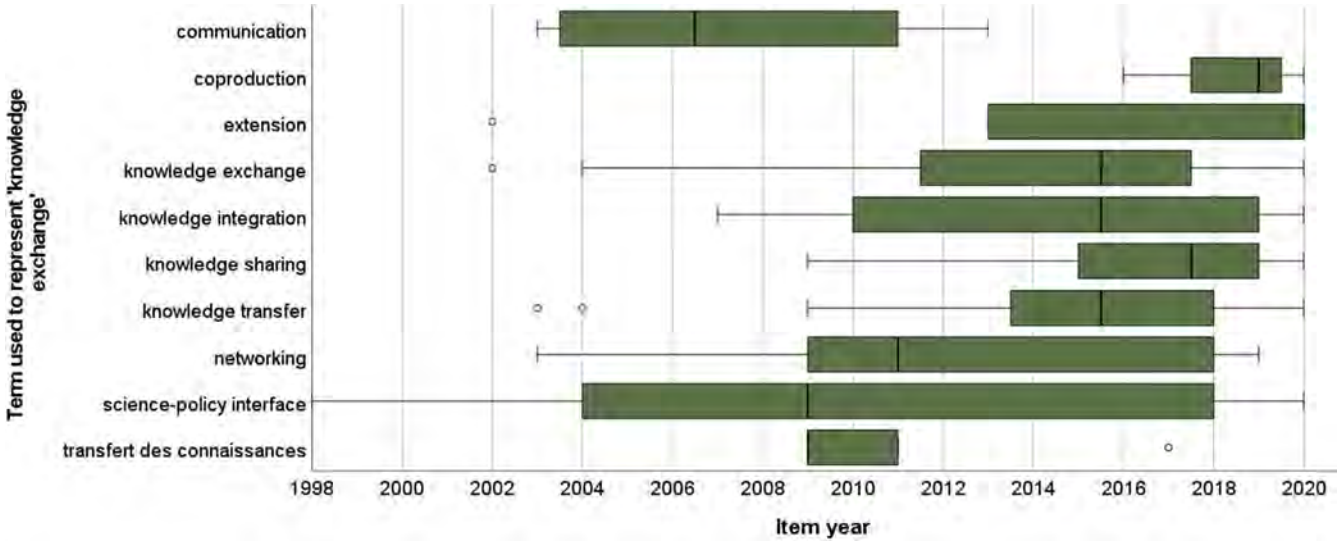

FIGURE 7 Distribution of terms used in at least five items to represent or approximate 'knowledge exchange' by publication year of item.

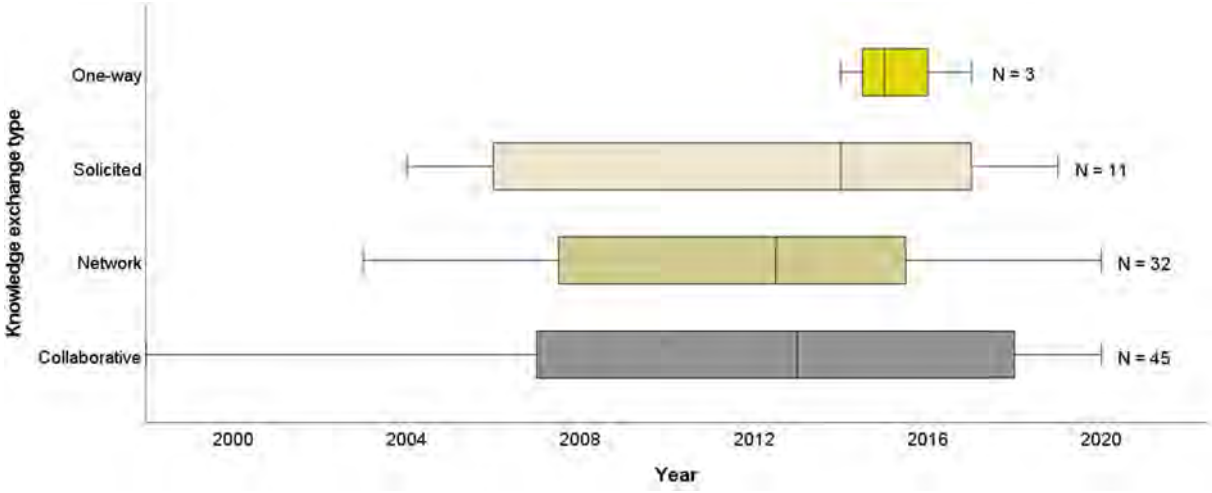

FIGURE 8 Distribution of retained items categorized by the four types of knowledge exchange to year of publication.

the items. The most common technique was 'collaboration' (n = 44) followed by 'multidisciplinary' (n = 31), 'targeted research' (n = 23) and 'relationship building' (n = 21; Appendix 8).

Some measure of effectiveness (qualitative or quantitative) of the knowledge exchange was present in 20% (n = 22) of items. Of the studies that measured the effectiveness of knowledge exchange, 73% (n = 16) were published after 2010. We qualitatively examined the major findings of all items to identify codes describing enabling conditions for knowledge exchange, barriers to knowledge exchange and markers of success (Appendix 8). We identified eight codes for enabling conditions which were observed 43 times in the major findings, with the most frequent being 'trust' (n = 12), 'funding' (n = 9, and 'established relationships' (N = 8). We only identified three barriers ('science translation', n = 8; 'time', n = 2; competing terminology, n = 1) which were coded a total of nine times. We identified six markers of success, and these were coded 16 times across all items. The most commonly identified markers of success were 'influence human behaviour' (n = 4), 'influence research' (n = 3) and 'increased knowledge exchange' (n = 3).

3.4 | Geographic distribution and knowledge flow between producers and users

We found 77% (n = 86) of the items explicitly listed organizations from at least one country as a knowledge producer or user. Of the items that included information linked to the country, 25% (n = 22) were multinational with institutions in more than one country. In total, institutions from 66 countries were mentioned. The most frequently included countries were Canada, the United States, France, Finland and the United Kingdom; most countries were mentioned in only one item (Figure 9). Of the 66 countries, 27% (n = 18) were included in items that also included IK in some capacity.

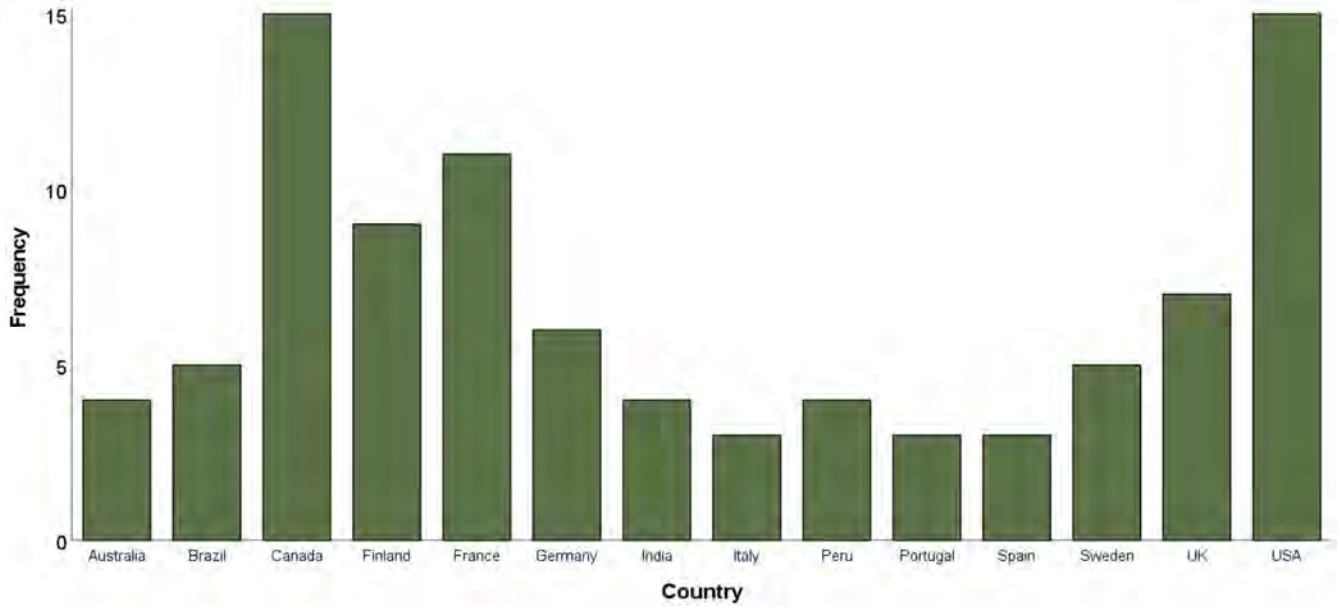

FIGURE 9 Count of countries whose organizations were named as knowledge producers and/or users in at least three items.

Twenty-six countries from five continents had organizations that are actively participating in knowledge exchange with other organizations, whether producing and/or using knowledge. Of the 82 organizations documented exchanging knowledge between each other, 43% were from Europe ($n = 34$), 44% were from North America ($n = 35$), 5% were from Asia ($n = 4$), 4% were from Africa ($n = 3$) and 3% were from South America ($n = 2$). The United States had the largest number of organizations of any individual country (30%, $n = 24$) and the greatest number of connections between organizations (38%, $n = 176$) actively participating in knowledge exchange. The most highly connected individual organizations (≥10 connections) are listed in Table 2. In our analysis, most of the English- and French-language knowledge exchange in forest science is occurring within North America and Europe (Figure 10), with strong collaborations between north–north countries and less north–south collaborations.

When looking at the organization types identified as producers of knowledge, users of knowledge or both (Figure 11), academic institutions and NGOs emerged as sole producers of knowledge or both producers and users. Governments were the most common knowledge users, and industry was identified as a knowledge user but rarely a producer. Funding agencies were never defined as producers of knowledge and occasionally as users.

4 | DISCUSSION

Our study examined the nature of peer-reviewed academic and grey literature related to knowledge exchange, the terminology used therein, the types of knowledge exchange, the relationships between knowledge producers and knowledge users, and whether the items qualified themselves as providing evidence of the effectiveness of knowledge exchange examples or techniques described therein.

4.1 | Moving towards a shared language

We identified 90 unique terms to describe knowledge exchange across 112 items (with many items using multiple terms). While the published items had a high diversity of unique article keywords, only 15% of those keywords were indicative of knowledge exchange. Based on our findings, searches based on article keywords alone would not have been sufficient to identify the items related to knowledge exchange.

To maximize the discovery of information related to knowledge exchange and encourage a culture of reflection relating to knowledge exchange and its effectiveness when engaging in scientific work, we encourage both researchers and practitioners to be mindful of their choice of words and move towards a shared language. When publishing peer-reviewed academic or grey literature, researchers should select a single term for knowledge exchange and also include it as an article keyword. Although 'knowledge translation', 'knowledge transfer' and 'knowledge synthesis' have recently been adopted by major influencers of research such as granting agencies, these terms should only be used if they intend to describe a unidirectional model whereby knowledge producers and users are separated.

We encourage researchers to consider a multi-directional underpinning for how knowledge moves between users and producers. For those working in the forest sciences, we encourage English speakers to use 'knowledge exchange' and French speakers to use 'échange de connaissances' to describe the movement of scientific knowledge between producers and users, as these terms allow for

TABLE 2 List of organizations showing at least 10 connections with other entities in peer-reviewed and grey literature showing case studies of, or theories about, knowledge exchange in the forest sciences in English and/or French. NA, North America.

Continent	Country	Organization name	Number of connected organizations
NA	United States	US Forest Service	20
Europe	Scotland	University of the Highlands and Islands	11
Europe	France	National Research Institute for Agriculture, Food and Environment	11
Europe	Finland	University of Eastern Finland	11
Europe	Finland	Natural Resources Institute Finland	11
Europe	Romania	University 'Stefan cel Mare' Suceava	11
Europe	Scotland	University of Aberdeen	11
Europe	Poland	Forest Research Institute	11
Europe	Sweden	Swedish University of Agricultural Sciences	11
Europe	Belgium	Wildlife and Forestry Department	11
Europe	Finland	Karelia University of Applied Sciences	11
Europe	Estonia	Estonian University of Life Sciences	11
Europe	Latvia	Latvia University of Life Sciences and Technologies	11
NA	Canada	Natural Resources Canada	10
NA	United States	National Park Service	10
NA	United States	Bureau of Land Management	10
NA	United States	US Fish and Wildlife Service	10

bi- or multi-directional movement of knowledge, and thus are inclusive of all four knowledge exchange types we have identified (see Figure 1).

Although there are certain schools of pedagogy which use the term 'transdisciplinary' to describe participatory knowledge exchange, particularly in German-speaking and Nordic countries (Pohl, 2008), 'transdisciplinary research' is also a term used in sciences to describe work beyond and between disciplines. Research which crosses disciplines, and research where producers and users of knowledge participate in a collaborative research process, are not mutually exclusive definitions. Pohl (2008) studied research projects self-described as transdisciplinary and found that some, but not all, included elements of collaborative exchange. The Oxford English Dictionary defines 'transdisciplinary' as "of or pertaining to more than one discipline or branch of learning; interdisciplinary", and other recognized definitions of the word do not mention, imply, or include knowledge exchange between producers and users of knowledge (Cambridge University Press, 2022; Harvard School of Public Health, 2022). Rigolot (2020) characterizes transdisciplinarity in several different ways—some of which include elements of collaborative exchange, and most of which do not. Thus, although 'transdisciplinary' as a term may sometimes infer or describe collaborative exchange, it does not necessarily include it. Given this lack of precision, we do not recommend the use of this term, and encourage researchers to use the term 'participatory knowledge exchange' to describe deliberate, collaborative knowledge exchange efforts between knowledge producers and knowledge users.

4.2 | Determining best practices for effective knowledge exchange in forest science

Few of the items in our study drew conclusions about whether the knowledge exchange approaches they described were effective. Based on qualitative data analysis, we found that items categorized success as influencing human behaviour, influencing research, increasing knowledge exchange, improving relationships between actors, influencing products or policy (which includes perceptions that human or environmental welfare were improved) and when knowledge users felt a sense of ownership over the project or process.

We also identified enabling conditions, barriers, and markers of success. Enabling conditions we identified most often related to trust, collaboration, access to dialogues which bridge science and policy and interpersonal relationships. For example, Bayne et al. (2016) state that "it appears that the key success factor in enhancing uptake and learning may require an environment that encourages relationship building, particularly trust building between parties in developing informal and formal relationships. Informal interactions, though not often acknowledged in business, foster the conditions conducive to good knowledge exchange co-ordination, co-operation and communication."

These are consistent with methods of science production that recognize that knowledge is embedded in social relations and embrace participatory and interdisciplinary approaches to problem-solving and knowledge generation (Kirchhoff et al., 2013). Informal communication was noted as an important enabling condition (n = 15; Appendix 8). This is consistent with

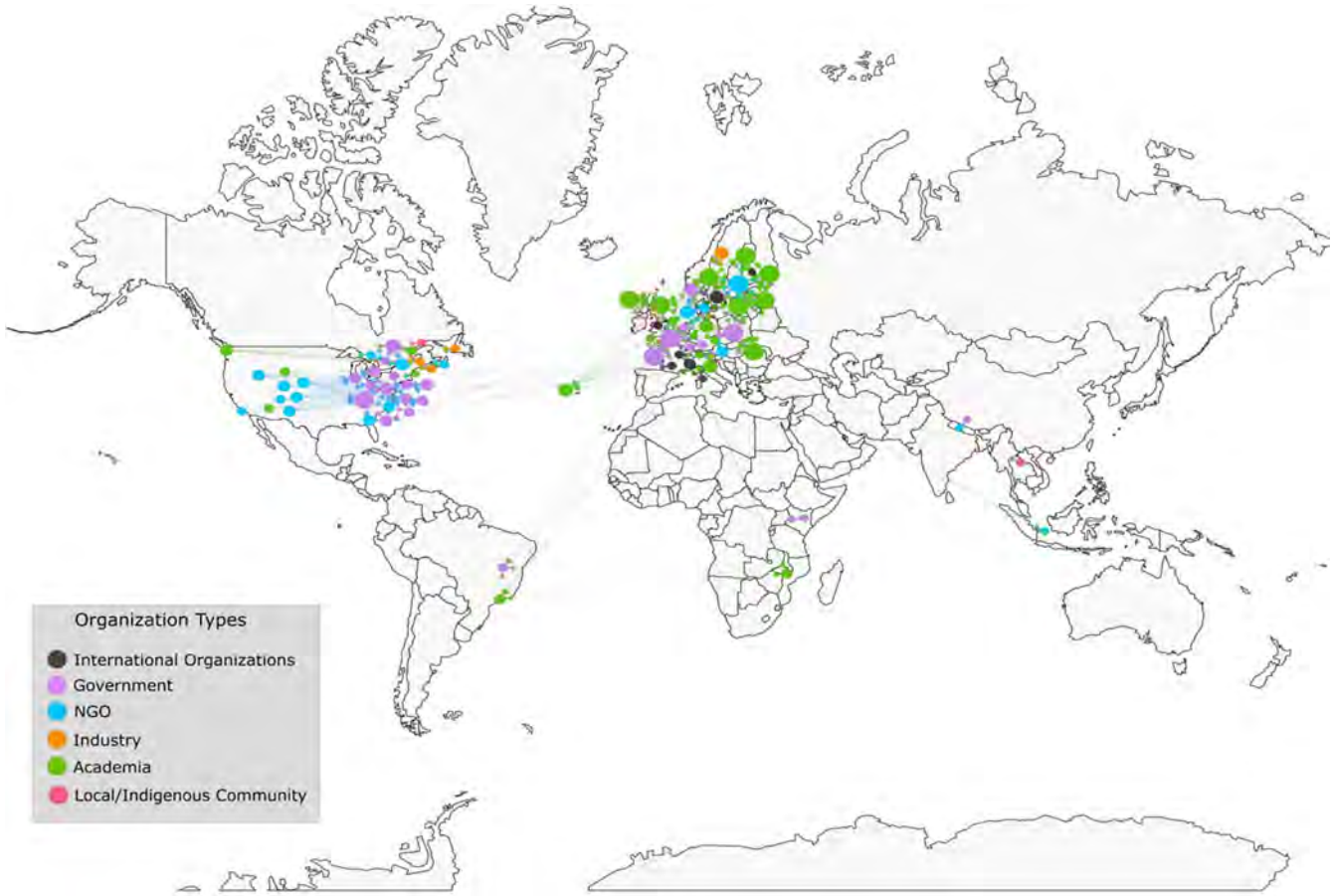

FIGURE 10 Network diagram visualizing the flow of knowledge between producers and users based on their institution type. Arrows indicate the direction of knowledge transfer from producer to user. An interactive online version of the network diagram can be found at https://westwoodlab.github.io/KE_NetworkDiagram_2022/network/.

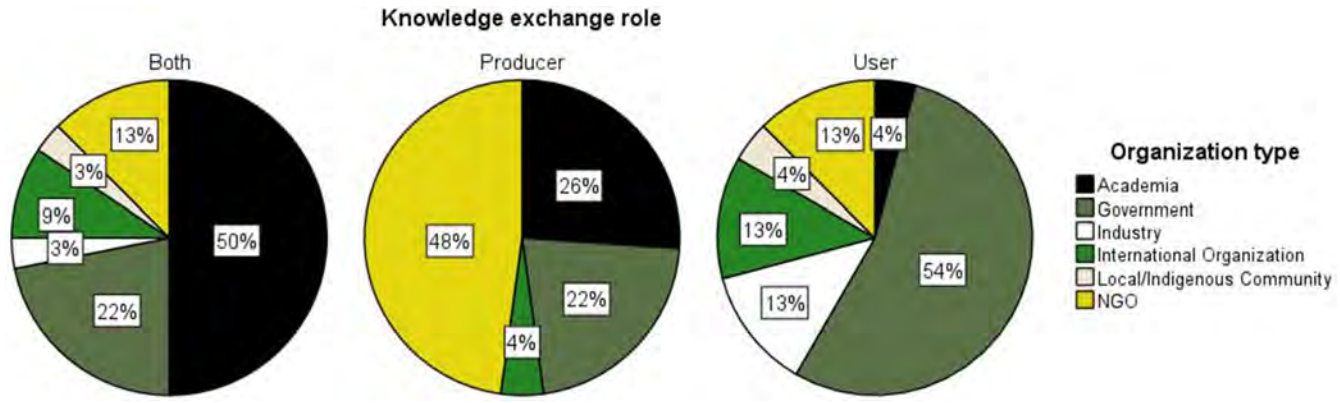

FIGURE 11 Of items where knowledge exchange was documented between producers and users, we report the proportions of organization types identified as both producers and users of knowledge in the same item (left), only producers of knowledge (middle) or only a user of knowledge (right).

Klenk and Hickey (2011), who interviewed staff in government forestry departments and found that participants felt face-to-face conversations were most effective for knowledge exchange. Ongoing relationships between managers and policymakers have also been cited as a key necessity for knowledge exchange to bridge the science-policy divide within government institutions specifically (Bradshaw & Borchers, 2000; Girling & Gibbs, 2019; Natural Resources Canada, 2015, 2019). We identified difficulty in translating science to policy as the most common barrier, which is thought to be a pernicious difficulty for researchers and policymakers to reconcile or translate their differing conceptual frameworks (Kimmins et al., 2005; Pennington, 2008).

Participatory models of knowledge exchange have often been presumed to be superior to one-way models (Beier et al., 2017; Ferreira & Klütsch, 2021; Westwood et al., 2020). By improving the relevance, salience and legitimacy of the knowledge, participatory models increase the likelihood of uptake into policy and practice (Cash et al., 2003; Cvitanovic et al., 2015). Increasingly, there have been calls for researchers and decision-makers tackling environmental problems to consider multiple ways of knowing, including Indigenous and local knowledge (Council of Canadian Academies, 2019; Schang et al., 2020). Both to improve the quality and applicability of environmental research, as well as to pursue goals of reconciliation between colonial institutions and marginalized peoples, co-production of research (a type of collaborative exchange) with Western-trained scientists and Indigenous and other local peoples is increasingly seen as a way forward (Ban et al., 2018; Popp et al., 2020; Schang et al., 2020). Although nearly a quarter of our retained items mentioned Indigenous, local or community knowledge, none clearly attributed members or organizations from those communities at the level of item authorship. Alexander et al. (2019) conducted a systematic map of studies in the discipline of freshwater research that included Indigenous knowledge, and found that 44% of included publications had authors whose attributions indicated they were Indigenous or represented Indigenous communities, organizations and/or governments. Since items concerning knowledge exchange in the forest sciences are increasingly including local and Indigenous knowledge in recent years, and yet we observed no author attribution, we urge researchers in the forest sciences to use best practices when working with Indigenous and local communities, including recognizing and crediting the contributions made by communities, representatives and participants (Théberge et al., 2019).

Based on our analysis of funding sources, the forest industry has not yet been engaged in contributing towards research and theory about knowledge exchange. However, the forest industry including companies, woodlot owners and forestry practitioners may be interested in obtaining the products of scientific knowledge that can help them achieve their own goals. These goals may be tied to a variety of values that include efficiency, stewardship, optimization, conservation, profit or others. Industry is sometimes required to adopt methods informed by scientific knowledge to achieve forest certification (e.g. Sustainable Forestry International, 2022) or to meet government mandates for employing science-informed forestry techniques (e.g. McGrath et al., 2021). Although our findings suggest industry has been under involved in knowledge production to date, we note that it may benefit from supporting or participating in research aimed at enhancing the exchange of forest knowledge between users and producers.

4.3 | The next step: Setting goals and measuring outcomes

Although there has been an abundance of theoretical articulations regarding knowledge exchange, Chilvers and Evans (2009) noted a lack of clear methodologies for attempting and measuring these activities. In our retained items, we did not find methodologies for empirically measuring knowledge exchange success, rather, assessments of effectiveness were subjective. Our common lexicon and typology for knowledge exchange presents a starting place for identifying and, in future, measuring knowledge exchange efforts. We suggest that research teams determine their knowledge exchange goal, select a knowledge exchange type and associated techniques likely to achieve their goal, and develop metrics to measure their success (see Fazey et al., 2014 for a discussion of knowledge exchange evaluation approaches, and see Belcher et al., 2016 for an overview of evaluating the quality of research done in a collaborative fashion). Communication tools and techniques, as well as evaluation methods, will vary depending on the knowledge exchange goals of the research team and the context in which the knowledge is being generated, including cultural context, norms, cultural values and the hierarchy of actors (both producers and users) involved in forest management (Elliott, 2018).

No matter what form of knowledge exchange is used, findings and information should be disseminated in a way that meets the needs of researchers, practitioners and policymakers alike and should be tailored to the correct audiences (Mouradian et al., 2001). When engaging in collaborative exchange, all parties should be engaged in planning knowledge exchange and should be credited appropriately (Sobell, 2016). We recommend research teams engage practitioners and academics in the domains of evaluation to develop specific communications and knowledge exchange experiments, as well as engage boundary spanners/knowledge brokers (Driscoll et al., 2011; Rose et al., 2017) to maximize the utility of their knowledge exchange efforts.

4.4 | Limitations

A hallmark of systematic maps conducted using the CEE approach is that they are transparent, repeatable and comprehensive. Our approach is transparent and repeatable. Although the protocol for the present study was approved by peer review (Westwood et al., 2021), our search may have had limitations to comprehensiveness. Overall, we have attempted to define an undefined field, and used general search terms which yielded very large numbers of returned results from search engines (see appendices of Westwood et al., 2021). One search engine (ResearchGate, which was important in identifying grey literature) does not indicate the number of search results and cannot be searched comprehensively. To feasibly screen these, we developed stopping criteria whereby the search was ceased when one of the following conditions was met: (1) all returned results were screened or (2) a moving window of average relevance declined below a given threshold. It is likely that we have missed some relevant items and not captured the entire body of items related to knowledge exchange in forest sciences.

We did not include Web of Science because of its high rate of cross-indexing with Scopus (Martín-Martín et al., 2021), however,

the addition of this or other databases may have increased the number of retained peer-reviewed items. We did not include general terms in our searches such as 'research' and 'evidence' because we expected these to greatly inflate the returned number of hits while not improving their overall relevance. However, we recognize that terms like 'evidence use' and 'knowledge uptake' may be related to knowledge exchange concepts, and recommend these terms be tested in future knowledge synthesis efforts on this subject.

In addition, we were unable to screen returned results in languages other than English or French. We also made no effort to assess the validity of the retained items. This would likely not be possible for many items, particularly those reporting on conference proceedings or consisting of reports. Relatively few of the retained items were original research papers. We hope that studies of knowledge exchange in forest sciences become more prominent, and in future, it will be useful for those conducting systematic reviews to assess the internal validity of such studies. Finally, we reported on findings related to knowledge exchange specifically, but did not report on the retained items' implications for the science-policy studies more generally. Our database of retained items could be used as a resource for future characterization of the science-policy boundary in forestry and forest sciences, including its actors and governance.

5 | CONCLUSIONS

Historically, forest management has been dependent on personal (e.g. forest professionals) and institutional (e.g. research organization) experience for guidance (Kimmins et al., 2005). Calls have been to improve the uptake of knowledge about forest science in forest management and policy (Guldin et al., 2005; Kleine, 2009; Parrotta & Campos Arce, 2003). We have provided the first-known characterization of the knowledge exchange process in forest science based on a comprehensive analysis of the available literature.

Our findings characterize the approaches by which forest science has been shared among producers and users. In reviewing the wide diversity of approaches, we have distilled the various concepts into a digestible, evidence-based typology that can be used by forest scientists to strategize based on the audience how to effectively exchange knowledge.

The novel approach presented in this study may be applied to knowledge exchange work landscapes in other domains. We highlighted the importance of developing research projects that carefully assess and select the most effective knowledge exchange type. In doing so, we emphasized the importance of using a shared language, building trust and maintaining open communication with all parties involved when trying to overcome the science-policy gap. In particular, we encourage the international community of forest scientists, managers and policymakers to establish a common terminology for describing the ways we approach knowledge exchange.

AUTHOR CONTRIBUTIONS

The study was conceived by Alana R. Westwood, Vivian M. Nguyen and Matthew Falconer. Preliminary searching and database testing were conducted by Alana R. Westwood, Tyreen Kapoor, Jonathan Wang and Kimberly Klenk. Alana R. Westwood facilitated bimonthly project guidance meetings with Matthew Falconer, Tyreen Kapoor, Jonathan Wang, Kimberly Klenk, Jacquelyn Saturno, Vivian M. Nguyen and Jenna Hutchen attending and providing direction. Data collection was conducted by Alana R. Westwood, Felicitas Egunyu, Francesco Cortini, Jacquelyn Saturno, Jenna Hutchen, Jonathan Wang, Kimberly Klenk, Manjulika Robertson, Matthew Falconer and Sophie Le Noble, and data analysis by Alana R. Westwood, Effah K. Antwi, Jacquelyn Saturno, Kimberly Klenk, Manjulika Robertson, Sophie Le Noble and Tyreen Kapoor. Alana R. Westwood and Jacquelyn Saturno developed figures and tables. The manuscript was drafted by Alana R. Westwood and all authors provided comments and revisions on all manuscript drafts. Author order is as follows: (1) study lead and co-principal investigator, (2) core research team, arranged alphabetically by last name, (3) additional research team, arranged alphabetically by last name and (4) co-principal investigators. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

Vivian M. Nguyen is an Associate Editor of *Ecological Solutions and Evidence*, but took no part in the peer review and decision-making processes for this paper.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/eso3.12210.

DATA AVAILABILITY STATEMENT

The article will be open access, and accompanied by appendices including all retained results, extracted data and summary statistics. All of these materials will be archived through Dalhousie University's data repository (Westwood et al., 2023): https://dalspace.library.dal.ca/handle/10222/80512.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix 1. Traductions françaises pour les types d'échange de connaissances dans le domaine scientifique.

Appendix 2. ROSES form full report Westwood et al.

Appendix 3. Final strings and retained title-abstract results.

Appendix 4. Validation of full-text review & data extraction.

Appendix 5. KE in forest science Covidence download 2021-04-29.

Appendix 6. Quantitative analysis dataset.

Appendix 7. Network visualization diagram data.

Appendix 8. Qualitative analysis dataset.

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