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RESEARCH ARTICLE

Collaboration and engagement with decision-makers are needed to reduce evidence complacency in wildlife management

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Abstract There exists an extensive, diverse, and robust evidence base to support complex decisions that address the planetary biodiversity crisis. However, it is generally not sought or used by environmental decision-makers, who instead draw on intuition, experience, or opinion to inform important decisions. Thus, there is a need to examine evidence exchange processes in wildlife management to understand the multiple inputs to decisions. Here, we adopt a novel approach, fuzzy cognitive mapping (FCM), to examine perceptions of individuals from Indigenous and Western governments on the reliability of evidence which may influence freshwater fisheries management decisions in British Columbia, Canada. We facilitated four FCM workshops participants representing Indigenous or Western regulatory/governance groups of fisheries managers. Our results show that flows of evidence to decision-makers occur within a relatively closed governance network, constrained to the few well-connected decision-making organizations (i.e., wildlife management agencies) and their close partners. This implies that increased collaboration (i.e., knowledge co-production) and engagement (i.e., knowledge brokerage) with wildlife managers and decision-makers are needed to produce actionable evidence and increase evidence exchange.

Keywords Conservation evidence · Environmental management · Environmental evidence · Fish and wildlife management · Knowledge exchange · Natural resource management

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INTRODUCTION

There is growing recognition that environmental management and conservation are struggling with an evidence crisis (Sutherland 2022) in which evidence (i.e., relevant information used to assess one or more hypotheses related to a question of interest; Salafsky et al. 2019) is not used to support decision-making. A culture of 'evidence complacency' exists in many areas of environmental policy and practice (Sutherland and Wordley 2017), where, despite the availability of plentiful (Kareiva and Marvier 2012; Salafsky et al. 2019) and varied evidence from multiple (Indigenous, local, Western-scientific) knowledge systems (Tengö et al. 2014; Lemieux et al. 2021), relevant information is not sought or used to make decisions. Rather, environmental managers (including wildlife managers) are far more likely to draw on intuition, past experience or opinion to inform important decisions (Kadykalo et al. 2021a). For example, a review of purpoted evidence-based wildlife management agencies in the United States and Canada found widespread deficiencies in evidence use (Artelle et al. 2018). Consequently, this dearth of evidence use may be contributing to ineffective practices, policies, and decisions to the detriment of both people and nature while squandering limited resources (Cvitanovic et al. 2015; Walsh et al. 2015; Ford et al. 2021). Effective evidence use in wildlife management and conservation practice is vital to ensure that limited resources are not wasted on ineffective or harmful actions. The "Kunming-Montreal Global Biodiversity Framework" (GBF), adopted under the United Nations Convention on Biological Diversity, sets forth a 2030 target that emphasizes the need for access to information (Conference of the Parties to the Convention on Biological Diversity 2022). Target 21 succinctly states: "Ensure that the best available data, information, and knowledge are accessible to decision-

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makers, practitioners, and the public to guide effective and equitable governance… of biodiversity." Improved wildlife management outcomes through better use of evidence is especially pressing given the biodiversity crisis we face in which we are losing species and ecosystems faster than at any other time in human history (if not even before) (Díaz et al. 2019; IPBES 2019; WWF 2020).

There are many barriers to using evidence in environmental and wildlife decision-making, including time and resource constraints, but the use of evidence may also be contingent on the reliability of information that flows to decision-makers (Cash et al. 2003; Cook et al. 2013; Turner et al. 2016; Cvitanovic et al. 2021). Often overlooked in the evidence crisis is that evidence producers or holders (e.g., scientists, Indigenous elders and "knowledge keepers") are not exempt from making value judgements (Adams and Sandbrook 2013). When evidence and its producers are perceived as being influenced by political biases, distortions, or prejudices, it can result in a diminished level of trust and increased skepticism toward the evidence presented (Pielke 2002; Roux et al. 2006; Young et al. 2016a; Nguyen et al. 2018). Furthermore, these negative perceptions can also lead to suspicions that the information is not being communicated faithfully (Cvitanovic et al. 2021). Indeed, there is a contemporary degradation of trust in expert knowledge (Rose 2018). In highly politically charged situations, the demand for evidence-based decisions may counter-intuitively politicize evidence (Sarewitz 2004; Pielke 2006). In capacity-poor organizational settings (the case for many wildlife management agencies), large amounts of information and high rates of information flow may also overload and overwhelm decision-makers and practitioners (Lemieux et al. 2018). The type of evidence under consideration is also an important factor when probing evidence use. Information produced internally within management organizations is often given priority over academic, Indigenous, or local evidence (Koontz and Thomas 2018; Lemieux et al. 2018; Piczak et al. 2021).

Understanding the perceptions of evidence producers/holders and how information may flow among various actors is important in understanding how wildlife management decision processes could become more evidence-based and effective (Young et al. 2016b; Tengö et al. 2017; Auld 2021) and less evidence complacent. This would help to identify the key barriers (to evidence use in decision-making) and leverage points and strategies (that influence information flows which may in turn influence decisions). Here, we explore complex networks of information flow (i.e., evidence) among organizations and groups that make decisions about freshwater fish and fisheries management in British Columbia (BC), a province of Canada (See Supplementary Sect. S1 for a description of the domain). In practice, this means decisions around harvest regulations, implementing temperature closures when rivers exceed a certain threshold, gear and bait restrictions such as the prohibition of live fish for bait, setting stocking quotas to divert recreational fishing from wild/native fish, species listing decisions under the *Species at Risk Act*, designating species as "Endangered" or "Threatened" under the *Wildlife Act*, habitat remediation, conservation fish/aquaculture, artificially promoting immigration (gene flow), etc. The aim is to identify the key factors that exert the highest levels of influence on information flows in the system to gain insight into which of these factors may be playing key roles in decision-making processes.

We use fuzzy cognitive mapping (FCM, *pl.* FCMs), a participatory modeling methodology (Kosko 1986; Özesmi and Özesmi 2004) to represent hypothesized information flows within the system. Models were constructed from four perspectives associated with different Indigenous and Western (e.g., parliamentary democracies) fisheries management actor groups. Our results contribute to understanding evidence complacency and why decisions in environmental and wildlife management are often not evidence-based despite the availability of plentiful and varied evidence (IPBES 2019) in many environmental contexts.

MATERIALS AND METHODS

Fuzzy cognitive maps

A fuzzy cognitive map (FCM, *pl.* FCMs) is a graphical and mathematical representation of the relationships among elements of a system (or issue), as perceived and constructed by "experts," where an expert is an individual with knowledge of or experience with the system under scrutiny (Kosko 1986). FCMs can therefore be considered external representations of mental models which reflect an individual's internal perceptions of the structure and function of a given system or problem domain (Jones et al. 2011; Gray et al. 2015). FCMs comprise variables (or nodes/concepts) and relationships (or edges) between those variables, including feedback relationships. In FCM graphical representations, variables and relationship edges are illustrated as directed graphs (Axelrod 1976), in which variables are connected by arrows indicating the direction of the interaction between them. Each edge relationship in an FCM may be weighted by assigning a vector composed of values to indicate the relative interaction strength or magnitude of the putative relationship between variables, making FCMs semi-quantitative in nature.

The "fuzzy" aspect of FCMs is that edge relationships are weighted according to fuzzy logic, in which the true value of relationships is represented as a matter of degree along a spectrum of truth rather than certainty. In the context of FCM theory, edge relationship weights are usually bounded in a normalized range of [0, 1] or [− 1, + 1] along a quantitative ordinal scale. Because FCMs are derived from graph theory, the relationship between variables can be represented in mathematical terms. Graphical FCMs can be transformed and coded into adjacency matrices which take each vector assigned to each edge relationship and transposes it into a tabular matrix. An adjacency matrix's properties may be investigated using well-developed graph-theoretic tools and techniques (i.e., mathematical algorithms to explore the properties of the network diagrams). FCMs can then be compared, combined, and simulated to identify key concepts or relationships in the system or to explore how the system may react to different scenarios such as the effects of different management or policy interventions (Kosko 1986; Özesmi and Özesmi 2004; Gray et al. 2015).

Comparison of multiple FCMs, representing multiple perspectives, may be used to identify areas of agreement and controversy (Giles et al. 2008). A combined FCM derived from multiple sources may contain fewer errors and yield a better model of the system than individual FCMs (Taber 1991; Özesmi and Özesmi 2004).

FCMs are useful for environmental decision-making and management where public support is desired or even mandated by law, illuminating the assumptions and mental models held by the various stakeholders and actors with knowledge of the system (Özesmi and Özesmi 2004; Jones et al. 2011).

We chose FCMs because of their suitability as a means to probe our question—we were interested in evidence exchange and how (scientific) knowledge "fits" with governance and regulatory practices, i.e., how does evidence flow between actors in the system, how does it reach decision-makers, and how is it perceived. FCMs, like Social Network Analysis (SNA), permit graphical and mathematical representation of elements of a system. In our FCMs, the nodes, similar to the concept of SNA, were (groups of) individuals, but we were not interested in the social relationships (e.g., individuals that perform a specific role), we were interested in understanding more general rules governing the system (e.g., how evidence flows and influences decisions). The benefits of using FCM is that we can apply transitive closure algorithms to answer our question: which organizations are producing the best information in terms of both quantity and reliability, and how do those organizations influence the others over time through information sharing? Of course, both FCMs and SNA have limitations. FCMs represent only one moment in time and by encoding participants' knowledge of the system in question, they also include associated ignorance, misconceptions, and biases (Kosko 1986; Özesmi and Özesmi 2004; more in the section on study limitations in the discussion). In SNA, it can be a challenge to identify all individuals and groups and gather information about the relationships and interactions. Moreover, in SNA, the researcher must infer and establish causal relationships. Largely, we chose FCMs because the system is constructed based on the perceptions of individuals ('experts') within the system (i.e., it is participatory), not by researchers, as in the case of SNA.

Fisheries management focus group workshops

Twelve participants from four fisheries management groups participated in deliberative workshops. They detailed their knowledge and perceptions of the "type, amount, rate, and reliability of evidence influencing freshwater fish and fisheries management decisions in BC." With this in mind, they created FCMs (one per group), over the course of a day-long facilitated participatory mapping session. Thus, each separate FCM is a distinct perspective and represents the mental model of the group that built the map. Mapping was facilitated by 'the researcher,' the first author ANK. Having separate FCMs constructed by the different groups brought to the fore group differences among concepts (nodes) and causal relationships (edges), thereby reflecting differences in perceived system structure. This study, including all data collection methods and procedures, was approved by and conducted in accordance with the University of Ottawa Research Ethics Board (File Number: 02-18-08). All participants gave informed consent to participate in the study. Face-to-face focus group sessions took place in June 2019 in various cities in BC (Table 1). The groups were comprised of the following:

(1) The Freshwater Fisheries Society of BC (FFSBC; https://www.gofishbc.com) (*n* = 3).
(2) Natural resource management branches of First Nations Indigenous governments (*n* = (2).
(3) Headquarters (i.e., 'Branch') of the BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) (*n* = 3).
(4) Regional offices of FLNRORD (i.e., 'Regions') (*n* = 4).[1]

[1] At the time of research, this was the Ministry name, but as of April 2022 the Ministry was split into two, the 'Ministry of Forests' (FOR) and the newly created Ministry of Lands, Water, and Resource Stewardship' (WLRS). As of October 2023, Fish and Wildlife Sections have been officially transferred from FOR (formerly FLNRORD) to the new WLRS: https://news.gov.bc.ca/releases/2023WLRS0060-001618. So, the BC *Wildlife* Act is now administered under WLRS.

Table 1 Affiliations of the 12 participants, grouped as members from the Freshwater Fisheries Society of BC (FFSBC), natural resource management branches of Indigenous governments (FN), and provincial natural resources ministry the BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) Branch and Regions; and the location, date, and length of the focus group

Organization	Participants	*N*	Location	Date	Focus group length
Freshwater Fisheries Society of BC (FFSBC)	Officers and Executives	3	Victoria, BC	June 21, 2019	6 h 8 min
Indigenous Governments (FN)	Fisheries Managers	2	Prince George, BC	June 25, 2019	6 h 20 min
Provincial Natural Resources Ministry (FLNRORD) Branch	Biologists	2	Victoria, BC	June 20, 2019	5 h 52 min
	Policy Analysts	1			
Provincial Natural Resources Ministry (FLNRORD) Regions	Biologists	3	Kamloops, BC	June 27, 2019	7 h 15 min
	Directors	1			

For additional information on fisheries management groups, see Supplementary Sect. S2 for this and additional methods details.

An additional 57 individuals were contacted but did not participate because they (a) did not respond to our request or (b) declined to participate (affiliations of these individuals are provided in Table S1, Supplementary Information). Thus, our response rate was 17%. While some people prefer to draw individual FCMs (e.g., Özesmi & Özesmi 2004; Sparks 2018), we selected focus groups for logistical purposes—to get various experts from across BC who are highly limited by time to dedicate no more than one day to the process—and to encourage group brainstorming and deliberation, concept clustering, and multiple perspectives of the same system. Previous FCM exercises which used focus groups suggest that FCM facilitation works best with few (e.g., 3–5) participants as this allows for greater participation and reduces the required time to completion (Cole and Persichitte 2000; Giles et al. 2008). We therefore aimed for small groups and feel the sample is representative. See study limitations in the discussion describing where or how our sample could be biased. The time it took for each focus group to complete their FCM varied from 5 h and 52 min to 7 h and 15 min.

Fuzzy cognitive mapping procedures and facilitation

All maps were drawn by the researcher in the Mental Modeler software (see http://www.mentalmodeler.org; Gray et al. 2013) via a projector screen in front of each participant group. Participants discussed each component in detail, as well as associated edge relationships and strengths. They had the ability to modify any or all map components during the iterative mapping process. All participants were encouraged to voice their ideas, which were not edited or censored. See Fig. 1, for an example map. Face-to-face focus groups were recorded using a digital audio recorder. Recording was optional for each group, contingent upon participant agreement.

Nodes (evidence producers and consumers)

Participants were first asked to identify the evidence producers and consumers (i.e., organizations or groups of individuals) who generate, mobilize, or use information relevant to freshwater fisheries management decisions in BC. These organizations or groups of individuals formed the nodes (or concepts) in the FCMs. Participants were asked to limit maps to 20 nodes, because beyond this point, they tend to become too complex for useful insight (Özesmi and Özesmi 2004). To initiate the process, and to bound the exercise within the research objective, participants were provided with a list of eleven nodes based on the author's collective and preliminary view of the system (as per Özesmi & Özesmi) and previous interview work (Kadykalo et al. 2020, 2021b, 2022; Andrachuk et al. 2021). These eleven nodes included academia, BC Hydro, consultants, The Federal Department of Fisheries and Oceans Canada (DFO), FFSBC, FLNRORD, First Nations, The Habitat Conservation Trust Foundation (HCTF), The BC Ministry of Environment (MOE) retired fisheries managers, and stakeholder groups (for more details on these groups see Table S4, Supplementary Information). Participants had the ability to eliminate any of these initial nodes and could propose any additional nodes. This process continued until participants were satisfied with their (collective) set of nodes. Participants were also asked to group nodes of similar meaning to simplify maps. This resulted in the final set of nodes.

Edges (information flow)

In the constructed FCMs, two nodes are joined by an edge if there is specified evidence flow between them (information

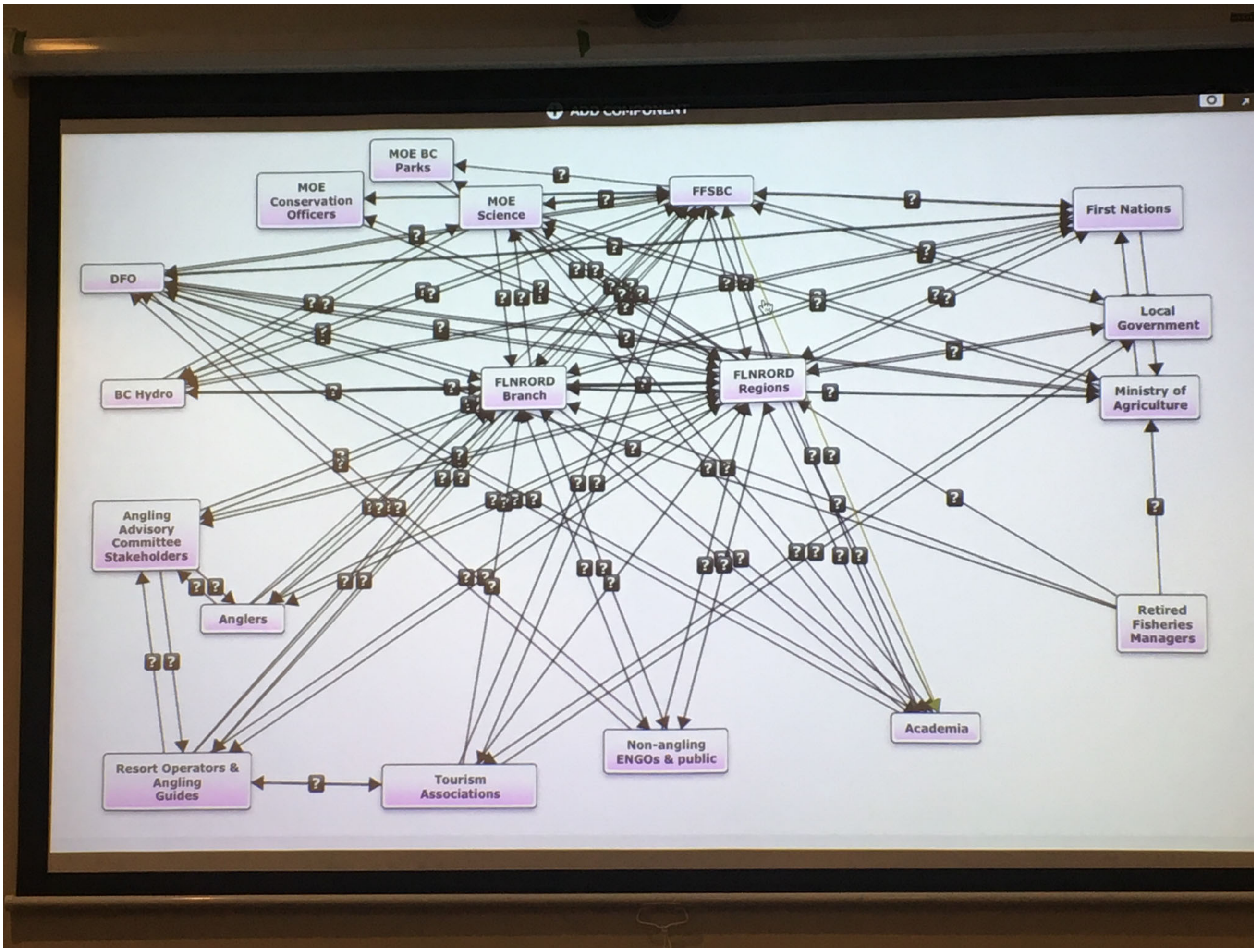

Fig. 1 Example of Mental Modeler projected in the construction of an FCM during a focus group workshop with FFSBC, Victoria BC (June 21, 2019)

exchange and/or mobilization). Participants were asked to discuss and indicate how the various nodes should be joined as well as the edge directionalities of the relationships, including whether the relationships represent uni-directional (information mobilization) or bi-directional (information exchange) links. Participants were then asked to assign weights to each connection (edge), as described below. In constructed FCMs, pure evidence producers are represented by nodes which only have arrows directed away from the node (outdegree) while pure evidence consumers are represented by nodes which only have arrows directed into the node (indegree). The subset of nodes between pure evidence producers and consumers (i.e., those hybrid nodes which have edges directed into and away from them) are presumably organizations or groups involved in information exchange.

Participants then classified edges by *type* of information: research/explicit (information easily codified, stored, and retrieved from data repositories, bibliographic databases, and published literature) or experiential/tacit (gained through experience) (Roux et al. 2006; Hulme 2014), or both. Participants were also asked to provide descriptions of information source(s). The relative strength of these edge connections was then weighted along three principal dimensions of the information being communicated (Table 2):

1. *Amount* of information flow
2. *Rate* of information flow
3. *Reliability* of the information flow (i.e., signal to noise ratio) which is comprised of a composite index:
    a. *credibility and reliability* (i.e., trust, faith, and confidence in the information)
    b. *distortion* (i.e., potential misuse or bias of the information)
    c. *hackability (generativity)* (i.e., the degree to which the information lends itself to tinkering, modification, exploitation, flexion)
    d. *availability*
    e. *political-ness*

Table 2 Scales for converting qualitative weightings into quantitative weightings for FCMs

Qualitative weighting							Quantitative weighting
Amount of evidence flow	Rate of evidence flow	Reliability of evidence flow					
		Credibility and reliability	Distortion	Hackability (generativity)	Availability	Political-ness	
Not at all	No flow	Very unreliable	Very distorted	Very hackable/flexible	Unavailable	Very political	0
Small amount	Slow flow	Unreliable	Distorted	Hackable/flexible	Little availability	Political	0.25
Moderate amount	Moderate flow	Neutral reliability	Neither distorted nor clear	Neither hackable/flexible nor secure/rigid	Moderate Availability	Neither political nor apolitical	0.5
Large amount	Fast flow	Reliable	Clear	Secure/rigid	Available	Apolitical	0.75
Very large amount	Very fast flow	Very reliable	Very clear	Very secure/rigid	Highly available	Very apolitical	1

Participants were asked to assign qualitative weightings to one of five Likert-style scale categories which were then converted into a quantitative ordinal weight in the interval [0,1] (Table 2). Likert-style scales give quantitative value to qualitative data by using ordinal data. A Likert-style ordinal scale positions data in a series, and those positions (e.g., "first," "second," or "third") retain their ordinal positions regardless of being expressed quantitatively (e.g., 1, 2, 3) or qualitatively; thus, there is no incorporation of uncertainty or arbitrariness. Participants are aware their responses may vary from one participant to the next and are measured along the same ordinal scale. Disputes among participants about relationship presence and/or weightings were resolved based on group consensus, but disagreements were noted and recorded.

The constructed FCMs thus represent networks which depict how information flows from organization/group to organization/group. As such, the edges are communication channels, which communicate a certain type of information (defined by type), communicate a certain volume of information at a certain rate (amount and rate), and communicate specific factors (reliability indices) that can prevent the information from being communicated faithfully (i.e., they are noisy).

Focus group workshops ended when participants were satisfied that the FCM accurately reflected their collective view of the type, amount, rate, and reliability of evidence influencing freshwater fish and fisheries management decisions in BC. The resulting FCM was then converted to an adjacency matrix for further analysis.

Analysis

Adjacency matrices were aggregated and concepts that were described by more than one group were reconciled and given standardized names. See Sect. S2 of the Supplementary Information for specific changes related to data hygiene and quality.

We computed several standard statistics for each graph, including the number of nodes (concepts) and edges (Table S3, Supplementary Information). We also computed per-node membership and statistics (Tables S4 and S5, Supplementary Information), including degree (the number of incoming or outgoing edges connected to each node) and centrality (how often a node is on the shortest path between all other pairs of nodes).

ANOVAs were performed to explore the variation among the five quantitative reliability variables on each edge. We also compared maps to characterize uncertainty (differences in perceived system structure) and to illuminate areas of agreement/consensus. Since it was found that the reliability indices had a high degree of correlation (mean $r = 0.5$; $n = 40$), we simplified them into a single reliability index (RI) that described the 'amount of evidence flow' (quantity) between two organizations. To compute this single index, we used principal component analysis (PCA) to map each 5-element vector to a single value on the first axis of greatest variability and normalized that value to the range of 0 to 1. This composite variable represented the ability of information to flow between organizations/groups. See Sect. S2 of the Supplementary Information to see how the 6 variables were computed in PCA and how they change with the composite variable. Thus, RI would be low when either there is not much information exchanged or the channels of communication reduce the quality of the information that is transmitted. RI would be high when a large amount of information can pass faithfully between organizations/groups. The 'rate of evidence flow' variable is used to represent five timescales (e.g., instant, days, weeks, months, years, decades) at which the information can flow: Not at All, Slow Flow, Moderate Flow, Fast Flow, and Very Fast Flow.

To answer the central research question, we need to understand which organizations are producing the best information in terms of both quantity and reliability, and how those organizations influence the others over time through information sharing. This requires consideration of all the parallel and sequential pathways through which information can be shared. It can be shared from A to B, but also from A to C in parallel, and then B and C could both share with D (therefore, A influences D through two transitive pathways). Some channels of communication may be slower to transmit information than others. Finally, there will be feedback loops (e.g., D can share information with A). In the steady state of this information-sharing system, some organizations will be more influential in terms of producing more of the information that others consume and trust.

To explore these ideas, we adapted a graph theory method called Communicability (Estrada and Hatano 2008, 2009) that has been applied to social networks, brain networks, etc. It is a method for assessing the steady-state transitive influence in complex networks, including those with feedback loops. We adapted this technique into a Temporal Communicability that can assess transitive influence at connected, but stratified timescales (i.e., fast interactions can influence slower interactions, but not vice versa). Temporal communicability results in a new dense directed adjacency matrix where we know the transitive influence of every node on every other node. In addition to being able to identify the greatest influencers in a network (in terms of information flow in the system), this algorithm can assess how soon after an influencer intervenes that the effects will be observable throughout the network. Likewise, given a specific target, we can assess how much and at what timescale each other node in the network will influence it. In terms of communicability, a node's "sourceness" is how much (transitive) influence it has in the network and its "sinkness" is how (transitively) influenced it is (in terms of information flow in the system). To this, Temporal Communicability expands sourceness and sinkness to have a value at each of the five timescales (i.e., Not at All, Slow Flow, Moderate Flow, Fast Flow, and Very Fast Flow).

For the first analysis, we produced communicability source/sink plots for all nodes (organizations/groups) in the network to understand the relative amount of information each node would contribute to or consume from the system. Secondly, we explored the transitive influence of the whole network on those organizations that possess (statutory) decision-making powers. As such, we chose the BC natural resources ministry (FLNRORD) and First Nations fisheries managers as the targets for this analysis. We performed this analysis on each of the FCMs.

All four FCMs were also then combined into one cumulative "union map" which includes any node (organization/group) and relationship thereof constructed in any of the FCMs. Thus, the final union map contained one node for each uniquely named node in any of the four FCMs. A set of relationships (across different maps) were judged to be the same if their source and target nodes were identical, and then they were merged by averaging each of their properties with a mean. Communicability and transitive influence were then also calculated on the union map. Where each of the base FCMs represent a specific perspective on how the system works, the union map averages those perspectives to form a more unified view (other analyses may also be helpful, such as variance analyses to assess discordant views). This helps to identify the barriers and leverage points—key factors that exert the highest levels of influence on information flow in this network system, which may in turn affect decision-making (to the extent decision-makers consider evidentiary information). It also provides information on the conditions under which new information could influence a management or policy decision, or the conditions under which a management or a policy decision could be reliably recommended based on the shortest/most efficient distance within the network. This could help to support decisions around where to intervene in the system in order to produce the desired effects.

RESULTS

Following the methods described in the methods and in Supplementary Sect. S2, we facilitated the construction of 4 FCMs, where each expressed one perspective on the freshwater fish and fisheries decision-making system in BC. The accompanying dataset which was produced and support these results can be found on Carleton University's Dataverse (a public data repository): https://doi.org/https://doi.org/10.5683/SP3/7VHCHM. Applying the analysis described in the methods, we arrived at the following key findings.

Indigenous and Western governance/regulatory groups produced similar maps

The participants produced structurally similar FCMs despite the high degree of complexity in each map. See Fig. 2 for an example of an FCM created by the Freshwater Fisheries Society of BC (FFSBC) (a private non-profit organization that delivers the provincial fish stocking program aimed at diverting recreational angler pressure to hatchery raised fish in efforts to protect wild fish). See Supplementary Sect. S3 for FCMs created by participants

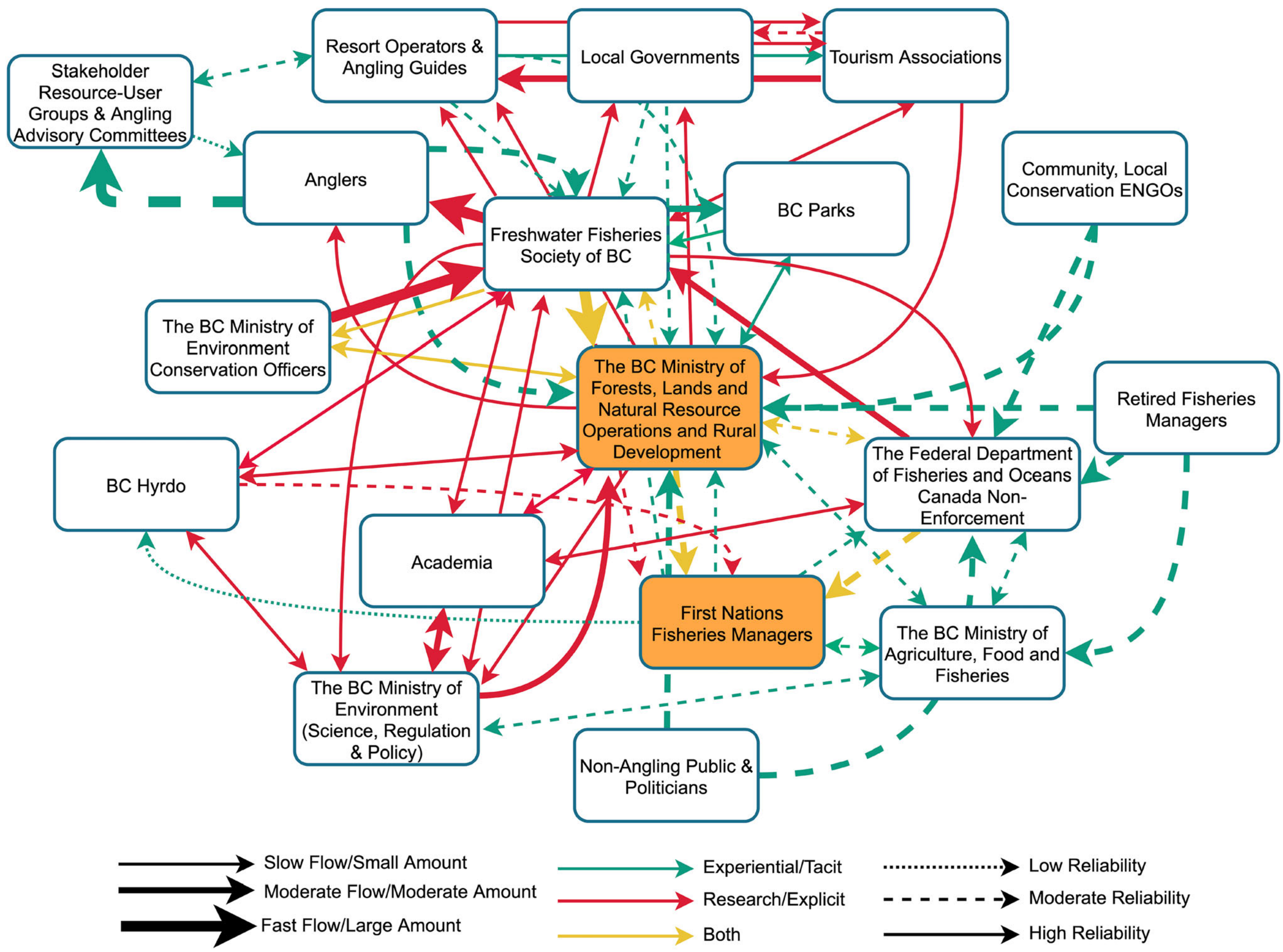

Fig. 2 Simplified, recoded fuzzy cognitive map of the type, amount, rate, and reliability of evidence influencing freshwater fish and fisheries management decisions in BC created by the Freshwater Fisheries Society of BC (FFSBC). Thickness of the lines denotes the amount and rate of evidence flow. Color of the lines denotes the type of evidence. Pattern of the lines denotes the credibility and reliability of the evidence flow. Nodes in orange are target variables that possess (statutory) decision-making powers, the BC natural resources ministry (FLNRORD), and First Nations (Indigenous) fisheries managers

from three other fisheries management groups, the dataset, and descriptive analysis.

Most information flows are a mix of explicit research and tacit experiential knowledge

Participants classified the type of information flowing in the system as research/explicit (24%) and experiential/tacit (15%). However, most information was classified as a combination of both these types of evidence (48%) (e.g., environmental/socio-economic data and expert-judgment). Participants were challenged to partition these two forms of evidence flowing between organizations/groups. Most information flowed in a small or moderate amount (73%).

Flows of evidence which may influence decisions occur within relatively closed governance and policy networks

The most frequently mentioned and central variables (nodes) across all FCMs were The BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) (the provincial natural resources ministry which manages wildlife), *First Nations (Indigenous) Fisheries Managers*, The Federal Department of Fisheries and Oceans Canada (DFO) (the federal ministry responsible for marine fish and tidal waters), *Academia*, *FFSBC*, *BC Hydro* (a province-owned electric utility), The BC Ministry of Environment (MOE) Science, Regulation & Policy (Government department that is responsible for the effective protection, management, and conservation of

BC's water, land, air, and living resources), and (*Private Environmental*) *Consultants* (See Supplementary Sect. S3, Tables S4 and S5). These had the greatest information flow into or out of them in the context of freshwater fish and fisheries information in BC which may influence decisions. Information that flowed in a large or very large amount (26% of information flows) also came from these same nodes. The union (i.e., cumulative, aggregated—see Methods) map resulted in 41 variable nodes and 237 connections (Fig. 3).

Transitive influence analyses indicate *FLNRORD*; *FFSBC*; *Consultants*; *Academia*; *MOE Science, Regulation & Policy*; *DFO*; *BC Hydro;* and *First Nations fisheries managers* have the largest influence on freshwater fisheries management decisions made by FLNRORD (Fig. 4A). The same organizations/groups have the largest influence on fisheries management decisions made by First Nations fisheries managers, except the influence of *Academia* was higher than *FFSBC* and *Consultants* (Fig. 4B). Individual transitive influence plots for each of the four FCMs on FLNRORD and First Nations fisheries managers are provided in Supplementary Sect. S3, Fig. S7–S8.

Local knowledge users perceived as less reliable

All FCMs assessed flows from *Local Governments*, *Anglers*, *Non-Angling Public & Politicians*, and *Stakeholder Resource-User Groups & Angling Advisory Committees* as less reliable. FLNRORD Branch and FFSBC perceived *Retired Fisheries Managers*; *Resort Operators & Angling Guides*; *The BC Ministry of Agriculture, Food and Fisheries*; *Community, Local Conservation ENGOs*; and

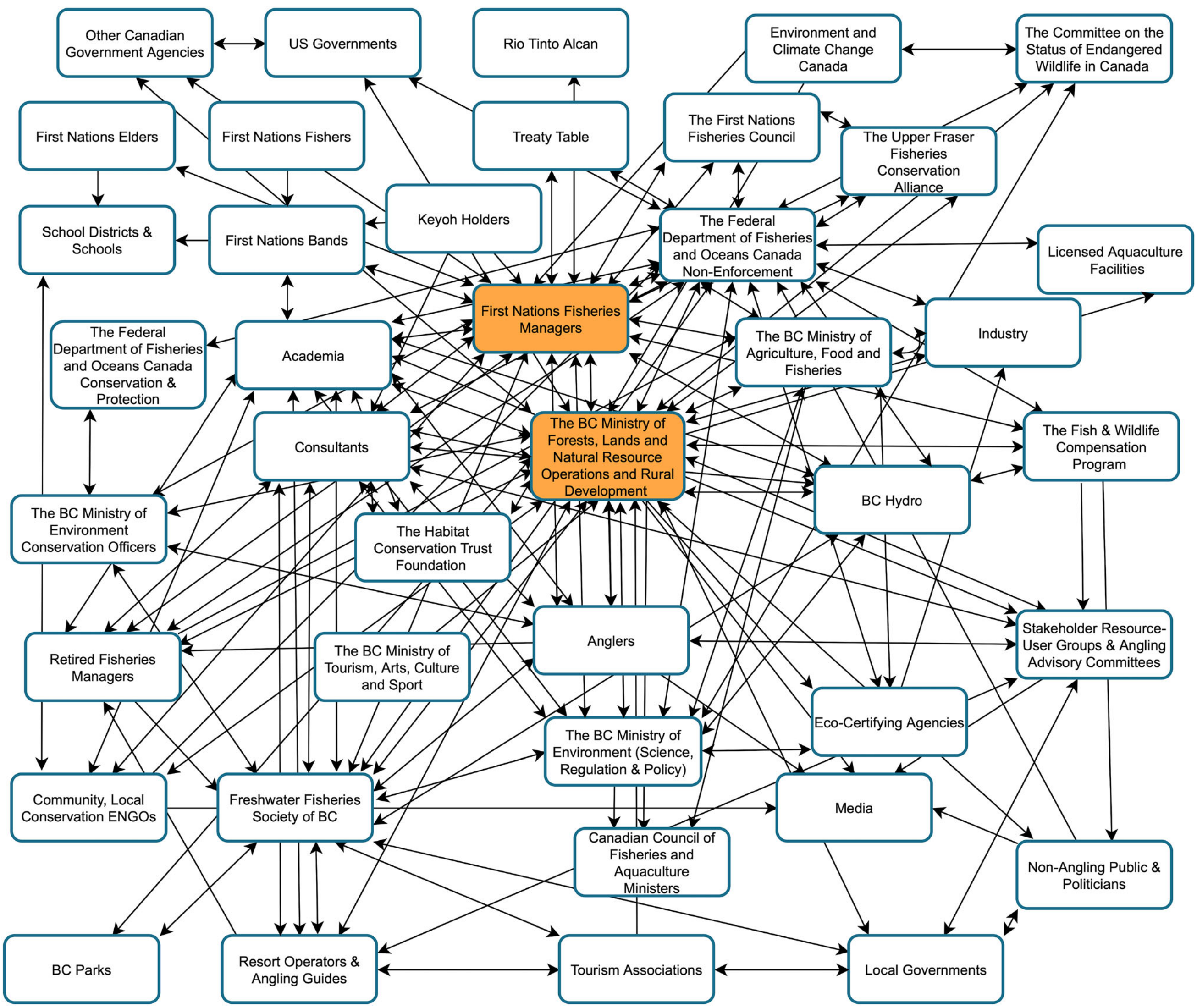

Fig. 3 Simplified, recoded union fuzzy cognitive map of the type, amount, rate, and reliability of evidence influencing freshwater fish and fisheries management decisions in BC created by four fisheries management groups. Nodes in orange are target variables that possess (statutory) decision-making powers, the BC natural resources ministry (FLNRORD), and First Nations (Indigenous) fisheries managers

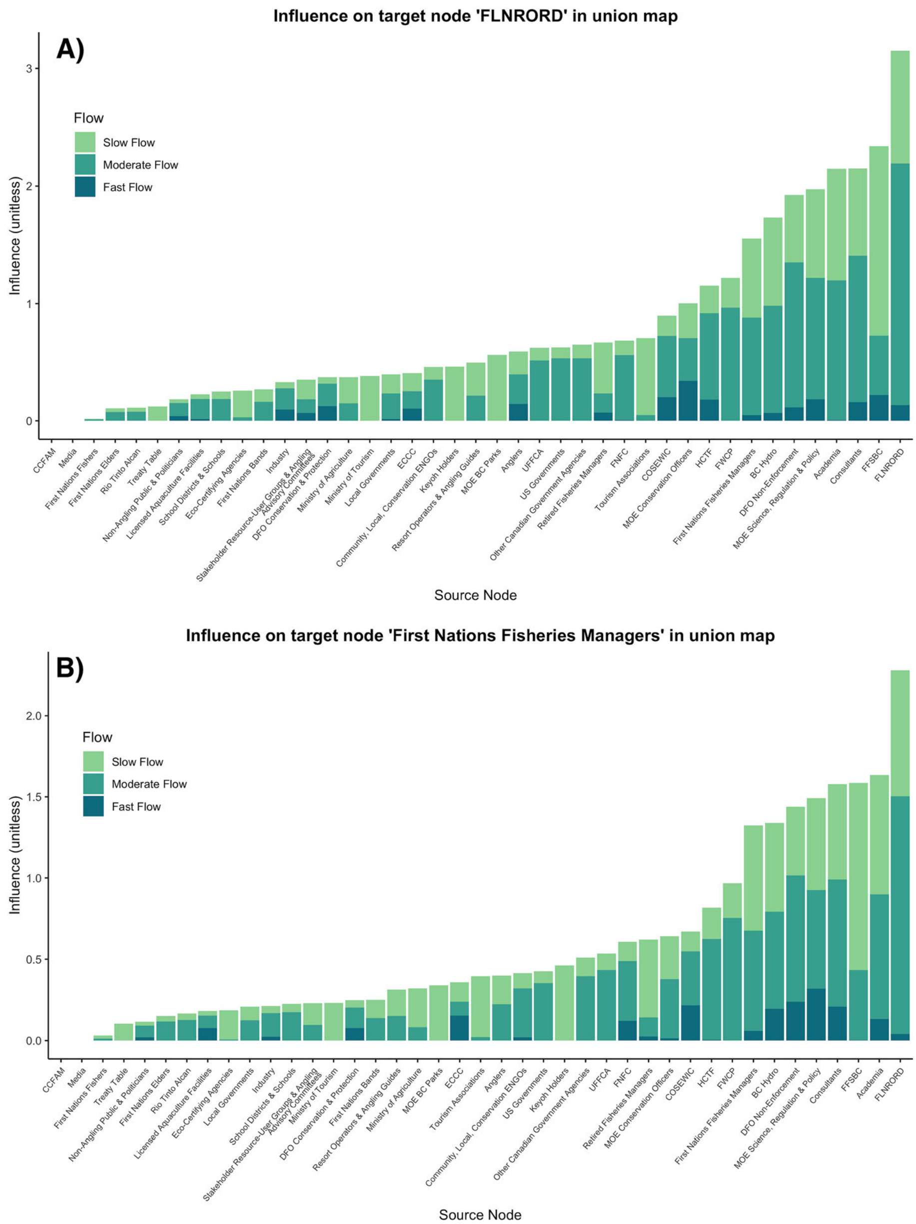

Fig. 4 Transitive influence of all nodes (organizations/groups) in the union map across the whole network for $N = 4$ FCMs on the target variable **A** BC natural resources ministry (FLNRORD) and **B** First Nations (Indigenous) fisheries managers. The 'rate of evidence flow' variable is used to represent five timescales at which the information can flow. For the union map, 'Very Fast Flow' and 'No Flow' were not calculated in the algorithm output and are thus omitted from the legend

First Nations Fisheries Managers as less reliable evidence producers.

Reliability of evidence does not depend on availability, but distortion, security, and credibility of evidence are highly co-dependent

Availability of evidence generally had low-moderate correlations with the other reliability dimensions (credibility, distortion, hackability, political-ness) (mean $r = 0.3$; $r = 0.33$–0.66) indicating that the scoring of other dimensions may not overly depend on the availability of evidence. *Political-ness* correlations with other dimensions were low–negligible for some FCMs, e.g., FNs ($r = 0.03$–0.25) and moderate–high for others, e.g., FLNRORD Branch ($r = 0.66$–0.84). Three correlations were consistently and unsurprisingly quite high: hackability and distortion ($r = 0.51$–0.89); distortion and credibility ($r = 0.56$–0.79); and hackability and credibility ($r = 0.4$–0.85). This indicates that perceived distortion, security, and credibility of evidence are highly dependent on one another.

DISCUSSION

Co-management and democratization of decision-making do not imply increased influence on final decisions

While the network of information flows among organizations that inform decisions about freshwater fish and fisheries management in BC, Canada, was dense and diverse, high levels of influence were centralized to a small number of groups or organizations, including Indigenous and non-Indigenous decision-making government agencies, partnered organizations like *BC Hydro* (a province-owned electrical utility) and *FFSBC* (who deliver the provincial fish stocking program). This is in contrast to trends identified in the environmental governance literature which suggest that, as co-management arrangements increase, the importance of governments as sources of decision-making decreases because alternative actors play more prominent roles in critical decision-making processes (Armitage et al. 2012).

Evidence exchange and mobilization may be taking place within a rather closed network

The number of organizations or groups that influence information about freshwater fisheries management decisions in BC is relatively small. Indigenous and non-Indigenous government departments and agencies—groups with decision-making powers—had the largest influence on information flow in the network, suggesting evidence exchange and mobilization may be taking place within a rather closed system that relies heavily on internal evidence.

Internal (institutional) sources of evidence are relied on more heavily than external ones

These results are consistent with previous research in this system suggesting that within environmental management agencies, internal (i.e., institutional) sources of evidence (e.g., government websites and databases, gray literature such as technical and government reports) are relied on more heavily and frequently than external ones (e.g., peer-reviewed literature, Indigenous knowledge) (Piczak et al. 2021). Such findings are also consistent with previous research involving protected areas managers in Canada (Lemieux et al. 2018, 2021), Pacific salmon fishery managers in Canada's Fraser River (Young et al. 2016b), and with environmental managers in many other jurisdictions (i.e., the United Kingdom, Australia, Kenya, Belize, the United States, etc.) (Pullin et al. 2004; Pullin and Knight 2005; Cvitanovic et al. 2014; Bayliss et al. 2012; Koontz and Thomas 2018; Fabian et al. 2019). This suggests that much available evidence is not being used by wildlife managers as they try to address the problems they face.

Evidence exchange depends on social networks

Sharing of information among actors in this network was found to be influenced by social networks and ties, which were shown to be critical to the ways that information moves among actors, both in the short term and in the long term (Andrachuk et al. 2021). Specifically, this information flow is largely dependent on a few (central) personal contacts and pre-existing ties, especially having a common employer. The same was found to be true in the management of Pacific salmon fisheries in Canada's Fraser River (Young et al. 2016a) and lake sturgeon (*Acipenser fulvescens*) in the Great Lakes (Leonard et al. 2011).

Implications

Our results further support the idea of 'evidence complacency' (Sutherland and Wordley 2017), providing empirical support to the notion that the availability of evidence has little influence on the way it is perceived and used. These results have several practical implications for freshwater fisheries and other wildlife management decisions.

Collaboration and engagement are needed to produce actionable evidence

Our findings support the idea that the linear "information-deficit" model of knowledge transfer from evidence producers to decision-makers is antiquated (Cvitanovic et al. 2015; Toomey et al. 2017). Environmental evidence is more accurately seen as embedded in collaborative social and decision-making processes and is not a purely scientific process for engaging society (Clark and Clark 2002; Adams and Sandbrook 2013). It is becoming increasingly clear that collaboration and engagement with wildlife managers and decision-makers are needed to produce actionable evidence (Cooke et al. 2020a). For instance, a survey of fish telemetry researchers found those engaging in extensive collaboration, research dissemination, and highly involved in and familiar with fisheries management processes experienced greater uptake of their findings (Nguyen et al. 2019). Knowledge co-production[2] is a promising strategy to create actionable evidence and

[2] An approach to research in which researchers and relevant partners (or) rights- or stakeholders some of whom are presumable end users, work together, sharing power and responsibility from the start to the end of the project, including the generation of knowledge.

benefits to the partners involved (Cooke et al. 2020a, b; Karcher et al. 2021). Increased collaboration and engagement can decrease the problems associated with value-laden evidence by increasing transparency and promoting inclusiveness in knowledge production (Pielke 2007).

Knowledge brokerage enhances evidence exchange processes

Consultants and academics, often contracted to (co-)produce evidence for, or work in research partnerships with fisheries managers and decision-makers are both highly influential, reliable, and well-trusted actors. These actors play an intermediary role as evidence bridgers (i.e., knowledge brokers; Kadykalo et al. 2021a) connecting fisheries managers with applied research results and scientists (Andrachuk et al. 2021). Knowledge brokers have also been shown to play important roles in underpinning successful knowledge exchange in climate change adaptation in Australia (Cvitanovic et al. 2017) and in the management of lake sturgeon (*Acipenser fulvescens*) in the Great Lakes (Leonard et al. 2011). Information flow networks depend on these sorts of actors that bridge communities by having connections to multiple networks that are otherwise poorly connected (Posner and Cvitanovic 2019).

Indigenous and local knowledge holders (e.g., resource-user groups) and industry have little influence on evidence flows

Indigenous, local (or stakeholder) evidence from resource-user groups (e.g., anglers, angling advisory committees, resort operators, angling guides, First Nations fishers) was rated relatively low in terms of reliably in exchanging evidence. As our research participants were fisheries managers and decision-makers frequently engaging stakeholders and Indigenous rightsholders, these results may be biased by 'engagement fatigue' and/or frustration, as well as power dynamics (more in study limitations below). Further, our results indicate Indigenous and local resource users are net evidence consumers (versus producers) within the governance network system relative to other organizations and groups. Thus, their information may be discounted/not considered as much by decision-makers. The same general patterns were also found in our results for industry, the non-angling public and politicians, and the BC Ministry of Agriculture, Food and Fisheries (who may be perceived as environmentally compromised by economic interests). Similarly, commercial fishers in Australia's Great Barrier Reef Marine Park were perceived by management agencies as low in terms of the legitimacy of and trust in their information (Turner et al. 2016). Resource-user groups who are outspoken are likely perceived by decision-makers as unrepresentative of the broader group and as 'issue advocates,' with particular agendas leading to 'agency capture,' i.e., undue influence of narrow special interests in agency decision-making (Bixler et al. 2016; Artelle et al. 2018). For these actors perceived to have low reliability, previous research suggests higher levels of trust and credibility are associated with openness about their views (i.e., 'honest brokerage') and high engagement with governing bodies, especially those with positive previous experiences and interactions (Pielke 2007; Crona and Parker 2011; Turner et al. 2016; Rose et al. 2018; Cvitanovic et al. 2021). Establishing relationships with staff of wildlife management agencies may be seen as a gateway for evidence flow to decision-makers (Andrachuk et al. 2021).

Limitations

It is important to note some limitations of FCMs. They represent only one moment in time and by encoding participants' knowledge of the system in question, they also include associated ignorance, misconceptions, and biases (Kosko 1986; Özesmi and Özesmi 2004). For these reasons, we added many FCMs together to synthesize the union map, which was informed by the local experts who constructed the maps. This aided in improving accuracy. It is not possible for a facilitator to remain completely detached from the process despite participating as little as possible in creating the FCM (Giles et al. 2008). Nevertheless, input by the facilitator was presented to the entire focus group and the final decision for any inclusion of FCM elements remained with participants. Moreover, using the same facilitator for all groups, in theory, should reduce the variation in the nature of the facilitation, helping control confounding variables in the skill of the facilitator and the duration of the focus groups (Eden et al. 1992). Relatively standardized focus groups provide some confidence when comparing variables and indices between/among FCMs.

We acknowledge that using focus groups to obtain FCMs creates power relationships among group members, and this may play a role in the results. Power dynamics, while present, were minimized by the facilitator by asking every participant in the focus group to weigh in on every FCM element. Lastly, coverage of natural resource branches of Indigenous governments was limited primarily to the regional perspective of FLNRORD resource management Region 7A: Omineca. Thus, the union map is missing several key First Nations natural resource management agencies in other parts of the province including the Skeena Fisheries Commission, The Lower Fraser Fisheries Alliance, and the Secwepemc Fisheries Commission (although many of these roles would be represented by the node 'First Nations fisheries managers').

We acknowledge that perceptions provided by participants during focus groups were likely biased as all four groups were fisheries management groups with decision-making powers over resource use and resource-user actions. Stakeholder and Indigenous rightsholder engagement are critical to fisheries management in British Columbia and managers and decision-makers likely suffer engagement fatigue or frustration from repeatedly being contacted by or contacting stakeholders and rightsholders. Moreover, stakeholders and rightsholders also likely feel fatigue from being repeatedly contacted resulting in lower levels of engagement to the point where managers and decision-makers find they are speaking only to those who are deeply interested, i.e., strongly supportive, or strongly opposed. This exacerbates "agency capture" and why evidence from resource users may be rated less reliable. Moreover, evidence from resource users may also be discounted by representation bias in which managers and decision-makers may perceive resource users and their evidence (i.e., experiences) as over-representative (i.e., exaggerated). The (mis-)use and weighting of evidence (i.e., evidence complacency) by fisheries managers and decision-makers is also likely influenced by deliberate ignorance bias (i.e., "I don't want to know"), associated with fatigue. Confirmation bias may explain why internal evidence was rated so highly (making decisions easier, or at least simpler).

CONCLUSIONS

In summary, this paper has reported on four models of information flow which inform and influence decisions about freshwater fish and fisheries management in BC, Canada, each representing a different perspective on the system. Of particular interest, we found that all four fuzzy cognitive maps were similar in structure. The information flow network maps represented heterogeneous actors embedded in collaborative social and decision-making processes that engage evidence. However, while the network of information flow was dense and diverse, the influence on information flow in the system, which may in turn influence decisions (i.e., political influence), was centralized to a handful of well-connected groups or organizations either with decision-making powers (e.g., wildlife management agencies such as The BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development (FLNRORD) and The Federal Department of Fisheries and Oceans Canada (DFO)), or closely partnered with decision-making organizations (e.g., other government departments, academics, consultants). This suggests that despite an abundance of available evidence, much of it is not immediately applicable ('actionable') and relevant to known problems faced by wildlife managers. This further implies collaboration and engagement with wildlife managers, decision-makers, and practitioners is needed to produce actionable evidence. Our work suggests improving evidence exchange and mobilization for wildlife management and conservation will depend on strategies like knowledge co-production and knowledge brokerage with wildlife management agencies. For evidence producers such as Indigenous and local knowledge holders, higher levels of trust and credibility are associated with openness about their views (i.e., 'honest brokerage') and frequent constructive engagement with wildlife management agencies. Future research could investigate whether implementing such evidence exchange strategies changes the structure and function of information flow in governance networks and ultimately makes decisions more evidence-based.

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Author contributions ANK conceived and designed the research, performed the research, analyzed the data, and wrote the paper. CSF conceived and designed the research. MS and CLC analyzed the data and wrote the paper. SJC and NY conceived and designed the research and wrote the paper.

Data availability The accompanying dataset which was produced and support these results can be found openly and freely on Carleton University's Dataverse (a public data repository): https://doi.org/10.5683/SP3/7VHCHM.

Declarations

Ethical approval This study, including all data collection methods and procedures, was approved by and conducted in accordance with the University of Ottawa Research Ethics Board (File Number: 02–18-08).

Informed consent All participants gave informed consent to participate in the study.

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