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Natural Resource Managers Use and Value Western-Based Science, but Barriers to Access Persist

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Abstract

Natural resources management (NRM) is complex and relies on decisions supported by evidence, including Western-based science (WBS) and Indigenous and local knowledge. However, it has been shown that there is a disconnect between WBS and its application, whereby managers often draw on non-empirical sources of information (i.e., intuition or advice from colleagues). This article focuses on the role of WBS in decisions made in management of rainbow trout (Oncorhynchus mykiss) in the province of British Columbia, Canada. We conducted open-ended interviews with NRM branches of Indigenous and parliamentary governments, as well as with nongovernmental stakeholder groups, to examine (a) sources of WBS consulted in decision-making and (b) barriers to accessing WBS by managers. We found that respondents involved with NRM relied on a diverse set of sources for WBS, seldom relying exclusively on one source. However, respondents relied more on internal sources (government databases) compared to external ones (peer-reviewed journal articles). We also found that respondents described WBS as valuable and generally accessible, yet barriers were identified with respect to the interface and organization of government grey data and literature, paywalls associated with peer-reviewed journals and articles, and institutional capacity, time, and support. We recommend strategies and tools to facilitate accessibility of WBS in support of bridging the knowledge-action divide, including increased publishing of open access data/articles, systematic reviews, use of knowledge brokers, specialized WBS training, and knowledge co-production. It is our hope that identification of barriers and the implementation of improved access to WBS will result in more effective NRM by giving managers access to the tools and knowledge they need for evidence-based decision-making.

Keywords Western-based science · Knowledge action space · Natural resource management · Evidence-based conservation · Science accessibility

Introduction

Management of natural resources such as wildlife and fish populations is complex and relies on decisions supported by evidence (Riley et al. 2002; Organ et al. 2012), including Western-based science (WBS) and Indigenous and local knowledge (ILK) (Kadykalo et al. 2021a). Historically, decisions on wildland and natural resources were based mostly on subsistence and profit until Aldo Leopold emphasized the importance of WBS in 1930, shifting focus to the long-term sustainability of populations (Organ et al. 2012). Since then, it has been increasingly emphasized that policies and actions based on WBS (e.g., population dynamics, surveys, statistics, habitat information, and behavioural studies) (Organ et al. 2012) serve as the foundation of the so-called "North American Model of Wildlife Conservation", the prevailing model of wildlife management of state, provincial, and federal agencies (Krausman and Cain 2013; Powell 2020). Despite the assertion that WBS remains the foundation for the North American Model of Wildlife Conservation, Artelle et al. (2018) found that often policy and decisions are seldom based on "hallmarks of science" including measurable objectives, evidence, transparency, or independent review. In this management model it is important to note that WBS can support decisions derived from empirical questions (e.g., how many fish

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are in this lake?) or empirical questions combined with value questions (e.g., what is the sustainable level of fish harvest for this lake), but not necessarily value-based decisions (i.e., those based on tacit knowledge, opinions or perspectives). Grounding natural resource policy and management decisions in WBS has been long claimed as a means to increase the efficacy and success of efforts to conserve fish and wildlife populations amidst a global biodiversity crisis (Pullin and Knight 2003; Sutherland et al. 2004; Nguyen et al. 2017; Ford et al. 2021).

Fish and wildlife populations face intense pressure due to habitat alteration, pollution, climate change, invasive species and overexploitation, which are projected to increase in the future (Steffen et al. 2015). These threats interact and are cumulative, presenting natural resource managers with daunting challenges. Natural resources management (NRM) also involves managing habitat and the people who engage and interact with fish, wildlife, and ecosystems such as hunters, anglers, and other increasingly diversified actors (e.g., industry, farmers, private landowners, conservation organizations, rights holders, non-profit organizations (ENGOs), environmental consultants, and community groups). Further, these actors may have high expectations for involvement in programs and decisions (Decker et al. 2012).

Salafsky et al. (2019) define evidence as information that contributes to the assessment of hypotheses related to a question of interest in the form of basic data, primary studies, syntheses, decision support systems, and/or theory. It was previously assumed that WBS had a ready audience among environmental managers and practitioners who would evaluate and use it in their work, yet this is not always the case (Cvitanovic et al. 2015). Practitioners have different preoccupations, constituencies, and responsibilities than conservation scientists (Decker and Enck 1996), which can lead them to base decisions on criteria other than WBS (Young et al. 2013). "Evidence complacency" is a documented phenomenon within environmental practice and policy, in which despite the availability of WBS, it is not widely sought out or used to make decisions (Sutherland and Wordley 2018). Despite the growing body of WBS (Kareiva and Marvier 2012), barriers remain that hinder its effective use in decision making (Pullin and Knight 2001; Walsh et al. 2019).

WBS is necessary for understanding the complex interactions and situations often encountered in NRM, as well as for directing and justifying policy decisions and management (Pielke 2007). However, it remains unclear how/when natural resource managers apply WBS to decisions and why they often fail to use empirical data (Cook et al. 2013). The accessibility of WBS has been identified as a key limiting factor or barrier to evidence-based decision-making in the environmental realm (e.g., Pullin et al. 2004; Pullin and Knight 2005; Cook et al. 2010; Kadykalo et al. 2021b). Moreover, there are empirical indications that locating and accessing WBS is limited by issues such as available time (Cvitanovic et al. 2014; Nguyen et al. 2018; Girling and Gibbs 2019; Sutherland et al. 2019), data that is formatted and stored to be useable and shareable (Pullin et al. 2004; Roux et al. 2006; Addison et al. 2016; Stephenson et al. 2017), funding (Walsh et al. 2015; Smith et al. 2017; Girling and Gibbs 2019), quantity of WBS (i.e., information overload) (Girling and Gibbs 2019), skills and abilities to evaluate the quality of available WBS (Walsh et al. 2015; Rose 2017; Nguyen et al. 2018; Sutherland et al. 2019), and incompatible time frames between research and management actions (i.e., urgency in decision making) (Young and Van Aarde 2011). In addition, managers and decision makers may not value WBS, in that research produced may not be relevant (Whitten et al. 2001), timely (Cook et al. 2013), or they may be more comfortable with experience-based evidence (Pullin et al. 2004; Cook et al. 2012). Many producers of WBS are aware of such barriers, and aim to generate science that will contribute meaningfully to decision making (Singh et al. 2014), suggesting that the gap between environmental research and practice endures despite efforts to close it.

As a result of all these pressures and limitations, decision making and NRM is not always based on WBS (Sutherland et al. 2004). Numerous studies have shown that NRM relies heavily upon other forms of knowledge, including anecdotes, 'tried and true' practices, personal experience, intuition, advice from colleagues, and expert advisers (Pullin et al. 2004; Cvitanovic et al. 2014; Sutherland et al. 2004; Kadykalo et al. 2021b). The knowledge-action space (also referred to as the knowledge-action gap, the theory-practice gap, or the research-implementation gap; Cooke et al. 2021) occurs when evidence derived from applied sciences (i.e., WBS) is not considered by decision-makers (Cook et al. 2013) resulting in the failure to use evidence during decision making and practice (Jarvis et al. 2020; Toomey et al. 2017). The knowledge-action space can result in decreased effectiveness, detrimental management actions (Walsh et al. 2015) and/or the squandering of resources (Cooke et al. 2021).

British Columbia (BC), the most westerly province in Canada, provides a relevant case for examining the accessibility of WBS during decision making and wildlife management. Rich in natural resources, BC is also under intense anthropogenic pressure and experiencing rapid biophysical changes with negative impacts on its diverse ecosystems. Local and national economies are reliant on these resources, which also support social and cultural well-being of BC's diverse population, including Indigenous peoples with deep connections to lands and waters as well as the organisms that inhabit them. If NRM is dependent on decisions,

policies, and practices becoming more evidence-based, then we collectively need to identify barriers to access WBS and improve how it is accessed by potential users. While we focused specifically on WBS, we recognize that other forms of evidence (e.g., Indigenous and local knowledge) are similarly valuable and important sources to support NRM decisions. However, nearly 20 previous studies that used surveys or interviews to understand how natural resource practitioners use WBS have identified gaps between existing WBS and its use in policy and decision making (Sutherland et al. 2004; Artelle et al. 2018; see Table 1 in Kadykalo et al. 2021b). The goal of this article is to examine barriers to accessibility of WBS in the context NRM within BC, specifically rainbow trout (Oncorhynchus mykiss), a native freshwater fish. We conducted semi-structured interviews to identify primary sources of WBS used to support decisions and issues with accessibility to WBS across natural resource managers including Indigenous governments, parliamentary governments and stakeholder groups. It is our hope that increasing understanding regarding use and accessibility of WBS in the context of conservation, will lead to improved decision making and management based on best available evidence.

Study Area and Background

Management of rainbow trout and freshwater fisheries in BC is complex involving both federal and provincial government agencies, as well as Indigenous communities and governments in specific territories. In addition, there are other non-governmental stakeholders, such as academic researchers, non-profit organizations, private consultants, and resource user groups, that are also involved in the management of rainbow trout in BC. The main agency responsible for management of wild freshwater populations of rainbow trout is the BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development (FLNRORD), hereafter "provincial natural resources ministry". Sport fishing and hunting occurs throughout the entire province of BC. Fisheries and wildlife management and conservation is divided into nine resource management regions (Region 1: Vancouver Island, Region 2: Lower Mainland, Region 3: Thompson-Nicola, Region 4: Kootenay, Region 5: Cariboo, Region 6: Skeena, Region 7 A: Omineca, Region 7B: Peace, Region 8: Okanagan) that cover all areas of the province.

Table 1 Open-ended interview questions analyzed in this article

Question
When looking for Western-based science or information about rainbow trout, where do you turn first?
What would make it easier for you [or your organization] to access and use Western-based scientific research or information?

Wildlife management decisions (e.g., fishing and hunting regulations, stocking hatchery fish) in BC are made by dedicated provincial natural resources ministry staff (statutory decision-makers; notably, Deputy Ministers, Directors, and Section Heads) possessing statutory (compliance and permitting) decision-making authorities under legislation. Decisions by statutory decision makers are purportedly evidence-based on the best available science (Government of British Columbia 2017), similar to other wildlife management agencies across North America (see Artelle et al. 2018).

Indigenous communities and governments manage Indigenous and non-Indigenous recreational and subsistence fisheries that take place on reserve lands and (in some cases) on traditional territories. Throughout the majority of BC, colonialization proceeded through direct land seizure in the absence of negotiated treaties. A system of geographically small reserves was imposed by the Dominion of Canada with the province of BC for the many First Nations (Indigenous) communities on lands not covered by treaty (Harris, 2008). Since the early 1990s, the province of BC and Government of Canada have sought to negotiate modern treaties with First Nations to rectify this historical injustice, with varying degrees of success. Further, the British Columbia Assembly of First Nations (https://www.bcafn.ca/) and the First Nations Fisheries Council of British Columbia (https://www.fnfisheriescouncil.ca/) are striving for reconciliation that includes rights-based fishing opportunities and management of fisheries on traditional territories.

The conservation and management of rainbow trout within BC is heavily influenced by various stakeholder groups. Specifically, a non-profit organization, the Freshwater Fisheries Society of British Columbia (FFSBC; https://www.gofishbc.com), is responsible for the province's stocking program, as well as various conservation services (including outreach and education), and has been contracted out by the the provincial natural resources ministry. These programs are aimed at diverting recreational angler pressure to hatchery raised fish in efforts to protect wild rainbow trout. BC Hydro (https://www.bchydro.com), a province-owned electric utility monitors impacts associated with hydro dams to inform wildlife mitigation programs including habitat protection for spawning fish, nesting and migratory birds, as well as fish salvage. Local environmental non-governmental organizations (ENGO) have broad goals aimed at ensuring the long-term sustainability of BC's fish, other wildlife, and outdoor recreational resources such as the BC Wildlife Federation (https://bcwf.bc.ca) and BC Conservation Foundation (https://bccf.com). The Habitat Conservation Trust Foundation (https://hctf.ca) receives 100% of the surcharge revenue collected from

hunting, fishing, trapping, and guide-outfitter licenses per BC legislation and in turn funds conservation projects on freshwater fish, other wildlife, and the habitats in which they live. There are also end-user special-interest groups that advocate for fish conservation, long-term sustainability of fisheries, and quality of fishing opportunities (often advocating for particular angling gear, bait, or fish species): BC Federation of Fly Fishers https://www.bcfff.bc.ca, BC Fishing Resort & Outfitters Association http://bcfroa.ca, The British Columbia Federation of Drift Fishers https://www.bcfdf.com, and The Steelhead Society of British Columbia (http://www.steelheadsociety.org). Various private environmental consultants and academic researchers throughout the province and North America also play important roles within the management of BC's fish and fisheries. They are often contracted throughout the province by Indigenous, federal, and provincial governments as well as FFSBC to carry out collaborative research on fish, fish habitat, or fisheries, or to provide advice. Finally, retired provincial government employees are also important actors as they frequently remain active within the realm of fish and fisheries issues, often as part of ENGOs described above, or as fishing guides, or informal government advisors or lobbyists.

Methods

We examined how decision-makers and other potential evidence users involved in the NRM of wildlife within BC use and access WBS building on complimentary articles from this research (Kadykalo et al. 2020; Kadykalo et al. 2021a; Andrachuk et al. 2021). This research was exploratory in nature and was intended to be primarily descriptive, and hypothesis-generating rather than hypothesis-testing. The data reported in this article were collected as part of a broader study titled "Sustaining Freshwater Recreational Fisheries in a Changing Environment" that aims to develop conservation genomic tools and policy recommendations to help manage and preserve the genetic diversity of rainbow trout within all nine resource management regions of BC. The study objective is to support and sustain healthy populations of rainbow trout and the recreational fishery that depends on them.

Interviews

Befitting exploratory research, we developed and employed an interview schedule of open-ended questions (Axinn and Pearce 2006; Creswell 2014; Young et al. 2018). Open-ended questions (see Table 1) allowed a wide range of respondents to explain their positions, priorities, and opinions freely. It also allowed participants to be precise in their answers, providing difficult to obtain and sensitive information on evidence use and decision-making processes. This study was 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. We performed a pilot interview after ethical clearance that showed no issues.

A three-step inductive coding process was applied to qualitative data collected from the interviews (Thomas 2006). First, responses were read to identify keywords, which became a list of potential codes. Similar potential codes were then grouped into themes. Responses were read a second time and sorted under these themes to provide a measure of their prevalence. A response may have multiple thematic codes if warranted. For details on the development of the interview population frame see Kadykalo et al. (2020).

A total of $N = 161$ individuals or organizations were contacted to request an interview. A total of 65 interviews (response rate of 40%) were conducted in-person ($N = 43$) and over the phone ($N = 22$) between April and November 2018 divided between three broad groups: members from NRM branches of Indigenous governments ($N = 4$), and parliamentary governments ($N = 33$), as well as representatives from non-governmental stakeholder groups ($N = 28$) involved in the management of recreational and subsistence rainbow trout fisheries in BC (affiliations of respondents are provided in Table 2). Among the respondents, 56 were male and 9 were female. Government employee respondents covered each of the 9 different resource management regions in BC. Interviews lasted between 18 min and 2 h, depending on the level of detail provided by the respondent.

Data Analysis

The qualitative data derived from the semi-structured interview were transcribed from audio to text using Trint (https://trint.com) and analyzed using NVivo 12 software (QSR International Pty Ltd., 2018). Subsequently, figures were produced in GraphPad Prism.

Limitations

We contacted and heard from a diverse set of actors from Indigenous governments, parliamentary governments, and non-governmental stakeholders (Table 2). However, there was relatively less representation from natural resources branches of Indigenous governments (4 participants, 21 non-participants). We received several responses from Indigenous governments who declined to be interviewed because their primary focus is on salmon populations, rather than rainbow trout. Further, we also had relatively less representation from senior civil servants (3 FLNRORD

Table 2 Affiliations of the 65 participants, grouped as members from natural resource management branches of Indigenous governments, and parliamentary governments, as well as stakeholders

Indigenous Governments (FN)	*N*	Parliamentary Governments (GOV)	*N*	Stakeholders (STKH)	*N*	Total *N*
Biologists	2	Biologists (FLNRORD)	17	Academia	6	
Fisheries Managers	2	Directors (FLNRORD)	3	BC Hydro	2	
		Fish & wildlife section heads (FLNRORD)	6	Environmental non-governmental organization (ENGO)	5	
		Human dimensions specialist (FLNRORD)	1	Freshwater Fisheries Society of BC (FFSBC)	6	
		Policy analysts (FLNRORD)	2	Private environmental consultants	6	
		Conservation science section (MOE)	3	Retired provincial government employees	3	
		Science branch (Department of Fisheries and Oceans Canada)	1			
Participant Sub-Total	(4)		(33)		(28)	65

Directors participants from 13 contacted; 0 FLNRORD Assistant Deputy Minister participants from 3 contacted), although we did hear from many Fish and Wildlife Section Heads (6 of 8 contacted). We received several responses from senior civil servants or their secretaries passing us onto more specialized or informed Directors or Fish and Wildlife Section Heads which we interviewed. In some cases, interviews planned with Assistant Deputy Ministers were cancelled due to busy schedules and last-minute ministerial meetings. This is an artifact of response rates rather than research intent. This respondent skew may have limited our interpretation of sources and accessibility of WBS within the context of NRM and decision making of rainbow trout in BC specifically for Indigenous governments and parliamentary statutory decision makers/senior civil servants. A possible methodological limitation of our approach is our reliance on open-ended interview questions, which could result in interviewer bias and influence on interviewee responses. However, open-ended interviews permit the collection of detailed data on complex issues, providing participants with open fora to explain their positions and opinions.

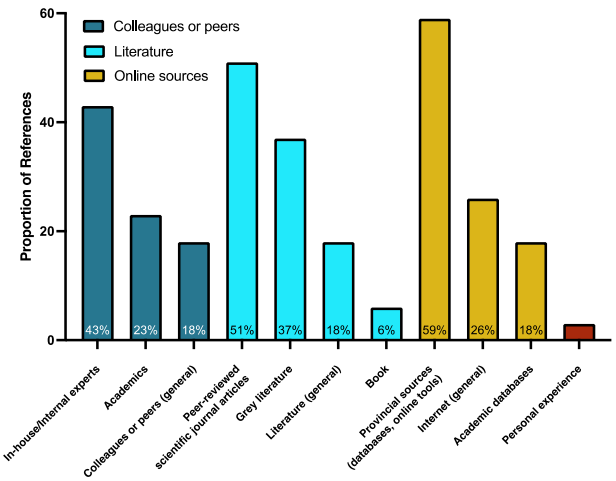

Fig. 1 Proportion of references in responses to the first question: when looking for Western-based science or information about rainbow trout, where do you turn first? Various sources (proportion % of references (i.e., mentions)) of WBS about rainbow trout consulted by $n = 65$ interview respondents. FN = 13 total references, GOV = 69 total references, STKH = 53 total references; 4 parliamentary government employees and 4 stakeholders respondents provided no answer

Results

Looking for Western-Based Science

We asked respondents When looking for western-based science or information about rainbow trout, where do you turn first? Very few respondents directly shared which specific source of WBS on rainbow trout they turn to first, therefore most respondents did not explicitly prefer one source over others. Rather, members from NRM branches of Indigenous governments, and parliamentary governments, as well as stakeholders consulted a diverse set of sources for WBS. For example:

> I use all the above and it's not a first. It really depends on the question. So, depending on the question I may use all those resources, I may use a few mentors or university knowledge centers, ENGOs, key people that I know throughout different fisheries forums and so forth. Databases and search engines and key web libraries. Depending on the question I also have a repository of [a number of] journals that I really key in on first. (Interview #22; Indigenous government natural resource branch affiliation).

Respondents thus consulted diverse sources of WBS not often prioritizing one source over others (see Fig. 1). These

sources included frequently mentioned peer-reviewed scientific journal articles,

> We'll spend time searching the current literature, seeing what's out there. That's a great resource for scientific information on rainbow trout. (Interview #18; FLNRORD).

> JStorr, Web of Science, or something like that. I'd go and dig right into scientific literature (Interview #26; FLNRORD).

> Journals, right away to journals. I read a ton of journals (Interview #37; FLNRORD).

> Our elders, we've got records from our elders on how they fished, where they fished and when. (Interview #11, Indigenous government natural resource branch affiliation).

> Staff. So, the folks responsible for managing those resources (Interview #58; FLNRORD).

> Well, I would turn to my staff at FSSBC (Interview #50; FFSBC).

In which sources may provide WBS that is more specific or relevant to the user,

> I'll go to colleagues. But then the question is no longer where do you generally go for information on mykiss in general it's like where do you go for information on Kootenay rainbows (Interview #19; FLNRORD).

Other external colleagues,

> Other agencies as well. We do cross-border collaboration with the US as well. We're looking to these other agencies for information because a lot of these other agencies have more of a background and more resources to do these kinds of things. (Interview #18; FLNRORD).

> There's a fellow at the University of Alberta who I'll give a call and talk with him. UNBC there are some researchers who I can call them and it's faster than trying to find a publication. Or they can point me towards a publication (Interview #10; FLNRORD).

> There're experts at the university that I can contact and bounce ideas off or ask questions in their experience that have been around for much longer than I have in this area (Interview #16; FLNRORD).

> For this area we would turn to our files and a lot of that's incorporated in the FIS (Fish Inventory Database). (Interview #4; FLNRORD).

> I turn first to EcoCat (British Columbia's EcoCat Ecological Reports Catalogue) for published reports that are posted on the ministry database because that's where you're apt to find the most applicable scientific information. (Interview #28; FLNRORD).

> I probably look first to Google. I'll admit it (Interview #25; FLNRORD).

> Probably the single best answer is Google Scholar. If I had to pick one answer. It's just more convenient than all the boxes of books I've got now. (Interview # 19; FLNRORD).

However, of those respondents that provided explicit statements about where they turn first for WBS on rainbow trout, parliamentary government employees primarily turned to provincial resources (i.e., databases/tools such as the EcoCat Ecological Reports Catalogue, Fish Inventory Data Queries, The Integrated Land & Resource Registry) and grey literature (i.e., government reports) (60%), a specific textbook (The Freshwater Fishes of British Columbia) (30%), and colleagues or peers within their own organization (10%). Thus, while parliamentary government employees see peer-reviewed scientific journal articles as important sources of information (see Fig. 1), they are rarely the first source consulted.

Similarly, the majority of non-governmental stakeholders with definitive responses about the sources they consult *first* mentioned provincial databases, tools, and reports (43%). In contrast to parliamentary government employees, peer-reviewed scientific literature (29%) was also cited as a primary information source, although these respondents were unsurprisingly academic-affiliated.

Members from NRM branches of Indigenous governments did not provide any explicit statements about where they turn

first for WBS on rainbow trout, only that they use a combination of sources with none more primary than any other.

Online sources

The majority of stakeholders with definitive responses about the sources they consult first mentioned online sources provincial databases, tools, and reports (43%), and general internet sources (e.g., google searches) (14%). Parliamentary government employees primarily turned to online provincial resources (i.e., databases/tools such as the EcoCat Ecological Reports Catalogue, Fish Inventory Data Queries, The Integrated Land & Resource Registry).

Personal experience

Most stakeholders cited personal experience (14%) as first sources of information on rainbow trout by stakeholders.

What Would Make It Easier to Access and Use Western Based Scientific Research or Information?

Many respondents (40%) described WBS as fairly accessible and readily available (e.g., "we have everything we need", "there's no shortage of information"). The advent of the internet, and in particular, electronic access to academic journals and articles, including cited web platforms like ResearchGate and Google Scholar, was credited for simpler and easier access to WBS. For example,

> Basically, the information is becoming easier and easier to get a hold of. So, if you really want a paper usually it's on LinkedIn or one of those ResearchGate sorts of things. (Interview #4; private environmental consultant).

> More and more you can find stuff for free on the Internet. In general, I mean we're in a great time when there's pretty good accessibility compared to when you used to have to order a journal article and wait for it for months (Interview #7; private environmental consultant).

Despite many respondents described WBS as available, several barriers to access and use were identified.

Grey literature

Respondents cited challenges with availability and access to grey literature (cited in 32% of interviews) such as government organized methodologies, data sets, reports, and web-based platforms (Fig. 2).

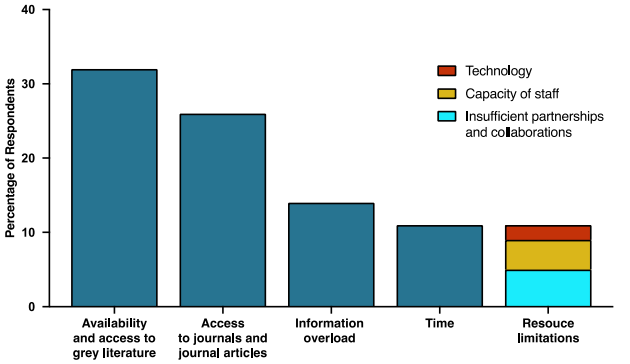

Fig. 2 Barriers to accessing and using Western-based science as identified by $n = 65$ interview respondents

Several of these responses described the "file drawer problem", of useful information getting lost or "sitting on a bookshelf somewhere", while others characterized current parliamentary government web interfaces as "clumsy" or "clunky". Recommendations focused on archiving parliamentary government WBS and meta-data into electronically, user-friendly, publicly available ("open"), searchable, centralized databases accessible for secondary use. This excerpt captures issues regarding inaccessibility of access to information:

> I think where we're currently falling short in a significant way around archiving our information in a way that's fully usable to meet the objectives often under which the data are collected. So, colleagues have access through a personal hard drive, which I think is valuable as historical context over about 40 years and it is not available otherwise. And so, a mechanism to share and provide all the metadata needed for additional analysis. We haven't been good at doing that. At least the system which is currently set up hasn't facilitated that in a large way. So, it may be feasible but not plausible and currently doesn't exist. (Interview #33; FLNRORD).

Journals and journal articles

A considerable number of respondents called for better access to journals and journal articles (26%) citing expensive journal and conference fees as specific barriers and more open-access journals, research, and data as potential solutions. Multiple respondents mentioned that they previously relied on access to journals via their university libraries, which became inactive sometime after graduation. Some respondents affiliated with universities, described being privileged with digital access

to journals. Here are two examples regarding limited access to journal and journals articles, as well as solutions:

> I have an adjunct appointment at (X University) so I can get on to the library through that, but all my other colleagues can't, and it's a big hassle. (Interview #21; FLNRORD).

> Well, what would make it easier is that if I can go online and get access to all the journal articles without having the pay for them. That would make it easier, open access. (Interview #38; ENGO).

Information overload

While there are clear benefits to increases in accessibility and availability of WBS, a recognized adverse effect is the challenge of managing so much information (14%) (i.e., information overload). These responses described the demands required of searching many sources (e.g., journals) for information, filtering that information for what is relevant, and "keeping up with technology". For example, the information overload sentiment is captured in the following quotations:

> There's never been a generation that's had more information yet been so poorly informed. (Interview #57; male; academic affiliation).

> Well, there's so much of it out there. I mean there's so many journals I can't keep them all straight and getting access to them all is a challenge and even just keeping the links current to them. It's just keeping up with the technology on searching things (Interview #42; Ministry of Environment).

> If anything, there's just too much information now. It's filtering out and finding out what you need. Because our access to information is so much greater now, you can scan through things and may dismiss papers that you wouldn't have historically just because it's so much easier to scan through so much. Whereas if you put all that effort to find it and get it by interlibrary loan, you're going to read the sucker. (Interview #15; academic affiliation).

Recommendations focused on training end-users in how to interpret information that could be used in decision-making and reducing technical and jargon-laden language.

Time

Correspondingly, the time required to access, search, read, and comprehend WBS (11%) was identified as a further limitation.

> I think totally it's time. My job itself doesn't necessarily lead to a lot of primary literature surfing, unless we're working on a specific issue. So, it can be a bit of a black hole. (Interview #51; FFSBC).

In addition, respondents mentioned that they may be limited to consulting only the abstracts of literature or that librarians were useful resources for selecting relevant information. To address such challenges, some called for in-house knowledge brokers (7%) and better library cataloging and research indexing systems (9%).

> There's a lot of research out there that doesn't necessarily fit our particular management scenario. I think having a dedicated fisheries research group as opposed to each region having their own specialist, having a more centralized research group that speaks to some broader questions and then develops those research initiatives out across the province would make it easier to access scientific research (Interview #18; FLNRORD).

> Probably knowing it's available or what's out there. I've read journals completely unrelated to my field that was actually interesting and relevant. So, where the information pops can be weird and wonderful but largely unavailable because we just don't know exists. So, whether that's an ability to create this, a library cataloging system of here's all the rainbow trout publications that came out in 2017 with hyperlinks to where they can be found or downloaded or accessed. Something like that would speed access to scientific research up (Interview #10; FLNRORD).

Resource limitations

Last, responses also focused on resource limitations, specifically, insufficient partnerships and collaborations (with laboratories, academics, institutes, FFSBC), capacity of staff (in collecting information and organizing, managing, synthesizing and analyzing it properly), and computer technology (e.g., tablets, laptops). For example,

> It would be easier to access and use scientific research or information if we had more partnerships and initiatives with labs, academics, institutes. Pooling and leveraging resources to achieve common objectives. (Interview #1; FFSBC).

> I'll tell you that the number one thing that impacts FLNRORD in terms of fisheries management is staff. We lack the capacity of staff to do anything other than put out fires. There is no capacity of staff to actually manage fisheries. (Interview #33; FLNRORD).

> Computers: everything is done on our laptops, computers, or iPads. We're teaching our band members and trainees to record everything on iPads, it's so awesome. You don't need paper or pen. So, all our fishing areas have been recorded through that. We document our water, snowpack, ice thickness studies on there, the whole nine yards. So, having that technology can help play a big role in our fisheries department (Interview #11, Indigenous government natural resource branch affiliation).

Discussion

Respondents involved with NRM and decision making in BC valued, consulted, and relied on a diverse set of sources for WBS, rarely leaning exclusively on one source. Colleagues and peers were important sources for WBS on rainbow trout, especially in-house (internal) experts who work in the same organization or community as the respondent. Literature including peer-reviewed journal articles, followed by grey literature and books were sought. In addition, online resources such as provincial databases and online tools were relied upon heavily by all respondent groups. Respondents used "in-house" grey literature slightly more frequently than from the academic literature or WBS from other jurisdictional government management agencies. Although WBS was described by most respondents as valuable and generally accessible, specific barriers emerge and persist: the storage and format of government grey data and literature, inaccessibility of peer-reviewed journals and articles, information overload, time limitations, and lack of institutional capacity and support (i.e., staff, expertise, experience, etc.). Other barriers to accessing WBS were insufficient technological support and partnerships/collaborations.

Our results demonstrate that there were a wide variety of resources sought for the incorporation of WBS into management of BC's rainbow trout. While the majority of respondents did not specifically identify colleagues or peers as a source they turn to first for WBS on rainbow trout, several parliamentary government respondents did. It has been shown that experience-based information sources (i.e., colleagues or peers) have been important to professionals working in conservation (Fabian et al. 2019), which was not consistent with our findings. Further, Andrachuk et al. (2021) determined that knowledge sharing among actors within their network was found to be influenced by the movement of individuals from one organization to another throughout their careers. We also found that a relatively high proportion of respondents mentioned literature including peer-reviewed scientific journal articles, grey literature, and books while searching for WBS. The vast majority of previous studies have found that peer-reviewed journal articles are underutilized or used less frequently in favour of other sources such as anecdotes, intuition, opinion, college advice, and/or personal experience (Pullin et al. 2004; Sutherland et al. 2004; Cvitanovic et al. 2014; Kadykalo et al. 2021b). Broadly, we found that there was a reliance on grey literature, rather than peer-reviewed journal articles, which suggests an informal use of WBS (see Koontz and Thomas 2018). This may be because grey literature may be easier to interpret for non-scientists (i.e., managers and stakeholders), relative to peer-reviewed WBS (Koontz and Thomas 2018). Further, grey literature and government science may be more targeted and relevant for decision makers, whereby consultants are commissioned by the government to generate targeted knowledge (Smith et al. 2017). A benefit to the incorporation of WBS derived from grey literature is that they may balance the problem of publication bias, whereby studies that find negative or non-significant results are less likely to be published (McAuley et al. 2000). We also found that respondents turned to online sources for WBS including provincial sources, the internet, and academic databases. Many respondents used provincial sources, however, they cited issues stemming from lack of standardization, minimal meta-data or decreased accessibility to external users. On the other hand, while specialist websites are accessible (e.g., EcoCat Ecological Reports Catalogue, Fish Inventory Data Queries, The Integrated Land & Resource Registry), it may be difficult for knowledge users to determine the type, age, credibility or robustness of information, which could potentially be detrimental during the decision-making process in NRM (Bayless et al. 2012). Finally, relatively few respondents cited personal experience as a source for WBS, which contrasts many previous studies.

Although many respondents described WBS as readily available, in part due to electronic access, various barriers to accessibility were identified. Broadly, we found that barriers to using WBS in decision making and management did not

stem from its inherent value (i.e., respondents did see the value in WBS) (Arlettaz et al. 2010; Cook et al. 2012), but rather barriers to accessibility. Some of these, including easier access to grey literature, the file drawer problem, inaccessible journals, have been described in previous studies (see Sutherland et al. 2019 for an overview). While many respondents described increased accessibility of grey literature relative to other sources of WBS, access to this information could be further improved with user-friendly interfaces, archiving documents (i.e., scanning of older documents), or centralized databases. Indeed, Sutherland et al. (2019) have noted that broadly, grey literature is not publicly available for external use (i.e., users beyond the government such as ENGOs or academics in the case of rainbow trout management) or that information has not been formally reported. Consistent with our study, it has been shown that grey literature is most often not standardized, with minimal meta-data or not digitized (Sutherland et al. 2019). A second barrier to accessing WBS identified by respondents was poor access to peer-reviewed scientific journals was mostly due to financial limitations, which has also been found in previous studies, particularly for practitioners and policy users (Arlettaz et al. 2010). Further, journal articles and/or books can be hidden behind paywalls, which may be too expensive for knowledge users (Sutherland et al. 2004). On the other hand, increased accessibility to WBS can lead to information overload, which can often be related to time and resource limitations. Moreover, there is a vast quantity of published literature, and each stage of the research process can be very time consuming: searching, locating, accessing, reading, interpreting, and/or digesting (Sutherland et al. 2019), and this can conflict with conservation decisions in practice, when evidence users are required to make decisions rapidly (Pullin and Knight 2005; Westgate et al. 2018). In addition, the immense volume of primary literature can be highly technical and difficult to interpret, requiring a specialized skillset that knowledge users may lack (Gossa et al. 2014). Similar to Heer and Girling (2020), the respondents identified issues stemming from capacity and resource limitations: that parliamentary government employees within BC feel that there has been a substantial decline in research capacity, as well as an increased reliance on external professionals, thereby compromising their ability to use WBS in policy and decision making. A barrier to use of WBS that has been previously identified that was not covered in the scope of our study was institutional culture (Lemieux et al. 2018), for example, some organizations may not promote reliance on WBS, thereby hindering use during management and decision making (Young and Van Aarde 2011). An additional barrier that was not specifically identified by the respondents in our study was the role of ideology and politicization of science. Kadykalo et al. (2021a, b, c) determined that despite high (and relatively diverse) evidence use, >40% of respondents perceived a diminishing role for WBS in final decisions concerning wildlife management and conservation in BC due to increases in socio-economic and political interference. Further, Smith et al. (2017) determined that 57% of government scientists believed that public service cuts compromise the government's ability to use the best available evidence in decision-making, and that 49% believed political interference has compromised their ability to develop laws, policies and programs based on evidence. Barriers identified in our study result in WBS that may not be used to inform practice and decision making.

There have been various solutions and practices proposed that could contribute to the increased use of WBS in NRM. While in general, respondents described grey literature as accessible, there remain issues regarding "the file drawer problem" and data and information interfaces that are user-friendly. Potential solutions include a better parliamentary government library catalog and research index system of grey literature (including better data reporting and/or archiving) (e.g., Rytwinski et al. 2019). One of the main barriers to using WBS identified by respondents was decreased access to journals and journal articles. A previous study by Gossa et al. (2014) found that amongst practitioners, open-access journals were the most important source of WBS to practitioners. Increasing accessibility of peer-reviewed scientific articles in journals by with open access publishing could facilitate improved flow of WBS from knowledge creators and users (Gossa et al. 2014). Systematic reviews and other forms of evidence synthesis have also been proposed as a solution that facilitates accessibility to best available WBS by minimizing barriers associated with information overload, time limitations and decreased resources or capacity. Specifically, systematic reviews provide summaries of evidence that reduce biases when relying on single studies, thereby supporting decision making and NRM by (Sutherland et al. 2004; Sutherland and Wordley 2018). In addition, Conservation Evidence maintains a growing database of "subject-wide evidence syntheses" (i.e., searchable synopses [Sutherland and Wordley 2018]) that has been integrated into several practitioner-focused resources and decision-support tools by "evidence champions" (Sutherland et al. 2019). A study on the use of Conservation Evidence's subject-wide evidence syntheses found that well-summarized evidence can direct management choices away from ineffective interventions when it is timely and packaged in a form the meets the needs of practitioners (Walsh et al. 2015). Similarly, a survey of environmental policy makers in Canada revealed that they were aware of the value of systematic

reviews and would use them preferentially over other forms of evidence if they were available for a given issue or topic (Thomas-Walters et al. 2021). In addition specialized training of practitioners and managers has been proposed as a solution to decrease information overload and mitigate time limitations (Cook et al. 2013; Downey et al. 2021), especially for WBS that is technical in nature and prone to using jargon (e.g., conservation genomics). Further, Downey et al. (2021) created a database of online teaching materials stored on the Applied Ecology Resources website, which include development courses aimed at improving skills related to appraisal and increased use of WBS in decision making and NRM. The use of knowledge brokers (i.e., bridging agents, evidence bridges—see Kadykalo et al. 2021b) embedded within agencies are (and were) recommended (see Cook et al. 2013; Cvitanovic et al. 2015; Roux et al. 2019) as a means of mitigating several of the barriers identified in our study: limited access to journals/articles and information overload, as well as resource and time limitations. Other mitigations strategies to removing barriers to accessing WBS in NRM include further-developed hyperlinked 'controlled vocabularies', one-page scientific summaries translated for multi-disciplinary audiences, and key visuals (Sutherland and Wordley 2018; Kadykalo et al. 2021c). For example,

> I'm noticing the younger generation really relying on visuals, and not so much the journals. YouTube. Those types of media. Like, series of 30 sec to three-minute videos with key messages of science information that keep them focused. That's how a lot of these folks learn now, just instructional on the web. (Interview #22; Indigenous government natural resource branch affiliation).

NRM occurs in a complex and fast paced environment, whereby decisions must be made in the face of uncertainty (Pahl-Wostl 2007; Brugnach et al. 2011; Rytwinski et al. 2021; Karieva and Marvier 2012), across diverse and multidisciplinary stakeholders (Riley et al. 2002; Decker and Enck 1996). Two-way interaction across agencies has been emphasized as a means of mitigating the knowledge action space (Nguyen et al. 2017) with a process called knowledge co-production (Cooke et al. 2020a; Norström et al. 2020). Knowledge co-production can be defined as the production of actionable science across involved agencies (i.e., knowledge creators and users) via collaborative and inclusive research throughout the entire process: identifying questions, study design, data collection, interpretation, and application (Cooke et al. 2020a). Though not specifically mentioned by respondents in our study, barriers to using WBS in NRM can stem from a lack of relevance or applicability (Kadykalo et al. 2020). Involving knowledge users throughout the entire process of knowledge co-production can ensure project objectives remain relevant, thereby producing actionable WBS (Cooke et al. 2020a, b). Additional benefits of knowledge co-production can include increased sharing and access to WBS throughout the whole process (Guan and Zhao 2013), which could facilitate the translation of knowledge into action within NRM. Some best practices for knowledge co-production and evolution include early initiation (Reed and Abernethy 2018), transparency (Young et al. 2016a), supporting of Indigenous and local community research leadership (Whyte 2017) and bi-directional communication (Mach et al. 2020; see Cooke et al. 2020a for additional best practices resources), and creating room in academia and scientific institutions for Indigenous research to grow and be recognized (Latulippe and Klenk 2020). Knowledge co-production is a promising process that can bridge the divide between knowledge generators and users, while also increasing accessibility to WBS.

Conclusion

Failure to underpin NRM with WBS can result in less effective or even detrimental decisions, further fueling the unanticipated consequence of jeopardising the biodiversity and habitat it is aimed to conserve. We found that respondents involved with NRM in BC valued, consulted, and relied on a diverse set of sources for WBS, rarely using exclusively on one source. Specifically, sources used included colleagues/peers, literature (including peer-reviewed scientific journal articles and grey literature), online sources (provincial databases and the internet), and personal experience. Further, we also found that most respondents described WBS as accessible, however, they did identify some barriers including better availability of government grey data and literature, decreased access to peer-reviewed journals and articles, and factors pertaining to institutional capacity and support. We propose various mitigation strategies to increasing accessibility to WBS in support of bridging the knowledge-action space, including increased open access data and articles, systematic reviews and other forms of evidence synthesis, searchable synopses, specialized WBS training, knowledge brokers, and knowledge co-production. Implementation of our recommendations could facilitate the (re-) discovery of the missing hallmarks of science in North American wildlife management and conservation (Artelle et al. 2018), by grounding wildlife management in North America (i.e., North

American Model of Wildlife Conservation) and beyond with WBS. Finally, it is our hope that identification of barriers and improving access to WBS will result in more constructive and effective management of natural resources including fish and wildlife populations.

Data availability

There are no linked research datasets for this submission because the data that have been used were collected from human participants with confidentiality and anonymity guarantees under our certificate of ethics approval: University of Ottawa Research Ethics Board (File Number: 02-18- 08). Archiving the data openly may compromise the confidentiality and anonymity of human participants.

Code availability

Thematic coding will be made available upon reasonable request from the corresponding author.

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Compliance with Ethical Standards

Conflict of interest The authors declare no competing interests.

Consent for publication All participants gave informed consent to publish results.

Consent to participate All participants gave voluntary and informed consent to participate in the study. A copy of the consent form will be made available upon reasonable request.

Ethical approval This study was conducted under the University of Ottawa Research Ethics Board (File Number: 02-18- 08).

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