Socio-Ecological Practice Research (2021) 3:17–36
https://doi.org/10.1007/s42532-020-00069-w

RESEARCH ARTICLE

Overcoming barriers to transfer of scientific knowledge: integrating biotelemetry into fisheries management in the Laurentian Great Lakes

Vivian M. Nguyen[1,2] · Caleigh Delle Palme[2] · Brian Pentz[3] · Christopher S. Vandergoot[4] · Charles C. Krueger[4] · Nathan Young[5] · Steven J. Cooke[1,2]

Received: 28 June 2020 / Accepted: 9 October 2020 / Published online: 23 November 2020

Abstract

The science–practice divide is a stubborn problem in environmental management. Existing research tells us that a range of factors affects the uptake of new science into practice and policy, including socio-organizational, individual, and evaluative variables. Here, we seek to understand the variables influencing the uptake of biotelemetry-derived information in the Laurentian Great Lakes fishery management system. To do so, we used semi-structured telephone interviews ($n = 50$) to capture the views of managers, researchers, and assessment biologists affiliated with the Great Lakes Fishery Commission (GLFC). Our results suggest that biotelemetry offers epistemological value (generating new and important information), but faces barriers tied to perceptions concerning practicalities of the technology, such as its cost. The practical limitations facing the use of biotelemetry evidence were more specific and potentially more easily resolved than the entrenched individual and socio-organizational challenges of using types of knowledge other than biotelemetry. The persistence of the science–practice divide was evident in our findings. Formal entities and boundary organizations such as the GLFC and inter-sectoral networks that promote interactions, meetings, and connections among researchers and practitioners can help overcome this gap. The Great Lakes Acoustic Telemetry Observation System (GLATOS) network can play a boundary role in facilitating biotelemetry science transfer by focusing on overcoming its evaluative limitations (e.g., costs, technological limitations). Further, the GLFC and GLATOS are well positioned to play a greater role in science transfer by facilitating interactions among scientists and practitioners to help reconcile differences in perceptions.

Keywords Knowledge transfer · Knowledge exchange · Fishery management · Technology diffusion · Great Lakes · Science–practice divide

1 Introduction

Timely, up-to-date, and relevant scientific information is widely seen as an essential input for effective environmental policy and decision-making processes (Pullin and Knight 2003; Sutherland et al. 2004; Young et al. 2013; Nguyen

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s42532-020-00069-w) contains supplementary material, which is available to authorized users.

✉ Vivian M. Nguyen
Vivian.nguyen@carleton.ca

1 Institute of Environmental and Interdisciplinary Science, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S5B6, Canada

2 Biology Department, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S5B6, Canada

3 Department of Physical and Environmental Sciences, University of Toronto Scarborough, 1265 Military Trail, Toronto, ON M1C 1A4, Canada

4 Department of Fisheries and Wildlife, Michigan State University, Center for Systems Integration and Sustainability, 115 Manly Miles Building, 1405 S. Harrison Rd, East Lansing, MI 48823, USA

5 School of Sociological and Anthropological Studies, University of Ottawa, 120 University Private, Ottawa, ON K1N 6N5, Canada

et al. 2016). Ideally, decisions based on the best-available scientific evidence can promote sustainable outcomes for resources, ecosystems, and the individuals, communities, and industries reliant on resource access (i.e., an evidence-based approach; Sutherland et al. 2004; Rousseau 2006; Pfeffer and Sutton 2006). However, research suggests that management decisions are often based on non-scientific types of evidence, such as personal observation and experiences, anecdotal evidence, organizational traditions, or collectively held 'conventional wisdom' (Pullin and Knight 2003; Pfeffer and Sutton 2006; Young et al. 2016a; Nguyen et al. 2017a; Cooke et al. 2017). Consequently, it is not sufficient for researchers to simply publish in academic peer-reviewed papers and expect evidence to be 'transferred' and taken up by decision-makers. A growing body of literature suggests that to enhance the role of scientific evidence in environmental decision-making, greater effort needs to be invested in understanding the human dimensions of knowledge use, including the views, motives, and preferences of knowledge users (Nguyen et al. 2017a; Young et al. 2018).

1.1 Theoretical framework: challenges in narrowing science–practice gap

The challenges involved in integrating new knowledge into policy and decision-making contribute to the disconnect between the state of scientific evidence and its use in practice. This disconnect is called the 'science–practice gap' and exists among other disconnects in environmental policy and decision-making, including research–implementation and knowledge–action gaps (Nguyen et al. 2017a; Bertuol-Garcia et al. 2018). The obstacles to bridging the science–practice gap can be broadly categorized into three major categories: social–organizational challenges, individual-level challenges, and evaluative challenges (see Young et al. 2018, p. 52).This framework presents the theoretical basis of our study and analyses.

Social-organizational challenges relate to how structures and practices within organizations may influence a user's receptiveness to new information and data. These include bureaucratic practices and norms, incentive structures, and capacities of key personnel to understand and apply information, political considerations, and communicative limitations. For example, Rose et al. (2018) conducted a global survey capturing perceptions of different stakeholders about the relative importance of barriers to considering evidence in conservation decisions. Social–organizational barriers emerged as being highly significant, specifically in organizational cultures that downplayed conservation as a political priority, resulting in mismatches in timescales, lack of funding, and attention to other priorities (Rose et al. 2018, p. 4).

Individual-level challenges refer to capacities and preferences held by key individuals in the context of dealing with evidence or data. Examples of individual-level challenges include a person's skills, educational background, level of familiarity with new knowledge, prior experiences, and/or preferences that may encourage or discourage engagement with new forms of evidence. Interviews conducted with government employees and stakeholders responsible for co-management of the Fraser River salmon fishery in Western Canada highlighted individual-level challenges that included motivations of individuals such as: 'lack of political will,' being unable to 'teach old dogs new tricks' or decisions that are found to be constrained by previous decisions and incentive structures (Nguyen et al. 2018b, p. 468).

Lastly, *evaluative challenges* refer to perceived strengths and weaknesses of the evidence or data. Knowledge claims are evaluated by potential users based on a range of criteria. These include its *epistemological value* (the degree to which the information or knowledge is deemed accurate and credible); its *practical value* (the degree to which it is applicable to known problems, with minimal costs, trade-offs, or limitations); and lastly, its *perceived fit or departure from current practices* (the degree to which adoption of the knowledge or information would disrupt existing views and/or processes) (Young et al. 2018, p. 52). Nguyen et al. (2018b, p. 469) and Rose et al. 2018 (p. 4) also found evidence that evaluative challenges are significant for the uptake of scientific evidence, particularly if uncertainty exists about the reliability or credibility of new knowledge, the lack of policy relevance and applicability of scientific findings to knowledge users, or complexity and uncertainties related to the knowledge or problem.

1.2 The science–practice gap: biotelemetry research and fisheries management

Given that fisheries are closely tied to culture, livelihoods, economics, and politics, the use of new evidence or knowledge in fishery management can present unique challenges. Fish are highly accessible relative to other natural resources and make important contributions to food security and livelihoods (Holmlund and Hammer 1999; Lynch et al. 2016). A variety of socioeconomic and political challenges surround the management of fisheries resources, including the needs and rights of Indigenous fishers, as well as the interests of recreational and commercial fishers (Lackey 1998; Hardin 2009; Nguyen et al. 2016). Additionally, a major scientific challenge complicating management is the vastness and complexity of aquatic environments, which has represented a major barrier to acquiring information about fish population dynamics required for effective management (Hussey et al. 2015).

Recent advances in biotelemetry (i.e., remote monitoring devices; reviewed in Hussey et al. 2015) have opened new avenues to observe and understand aquatic organisms.

Electronic tags are smaller and can be attached to free-ranging animals, passively providing information about their movements in space and time to listening receivers. With this technique, animals must be caught, handled, and physically tagged, but unlike traditional tagging methods, the animals do not have to be recaptured to provide information on their movement and locations. As such, many research and management questions can only be answered through this approach (Hussey et al. 2015; Cooke et al. 2016; Lennox et al. 2017). The growing repertoire of global telemetry-derived data recorded in the oceans and inland waters has led to novel information about the ecology of many species and their response to changing environments. These telemetry tools and data have made important contributions to fishery management, including improved understanding of habitats, invasive species control monitoring, and stock assessment, and have informed the design of marine protected areas (Crossin et al. 2017; Brooks et al. 2019). Still, examples of improved policy and management measures are rare considering the relatively large investment of resources into telemetry research (McGowan et al. 2016; Young et al. 2018). Biotelemetry array networks (networks of listening receivers) have been established worldwide, including in Australia, the USA, Germany, South Africa, and Norway. They have also been deployed in binational contexts, including in the Laurentian Great Lakes. Given the resources allocated to biotelemetry and the wide geographic range where the technology has been installed, it is important to understand how telemetry research informs fishery management decisions, and what barriers the technology faces. Understanding what barriers exist and how they might be resolved is a crucial part of understanding how return-on-investments can be maximized.

Hesitation in applying telemetry-derived data to fishery management often relates to technological and procedural limitations, the study design and analysis, and capacity and interpretation challenges. For example, uncertainties-associated limitations of the technology have included limited size and number of animals' tagged, false detections, limited detection ranges, and potential effects of tags on animal behavior (reviewed in Brownscombe et al. 2019b). Other reported barriers to incorporating biotelemetry into fishery management include: skepticism and distrust of biotelemetry, competing priorities, inflexible institutional structures, challenges in interpreting complex data; lack of awareness and access to new findings; or lack of management relevance in study design (Young et al. 2013, 2018; Mcgowan et al. 2016; Krueger et al. 2018; Nguyen et al. 2018a, b; Brownscombe et al. 2019a, b). Of course, many of these challenges are not unique to biotelemetry and have been commonly documented in various other contexts (Rose et al. 2018, 2019). However, rapid technological improvements have resulted in an accelerated use of biotelemetry, allowing the generation of novel information that traditional approaches cannot offer (Lennox et al. 2017).

Biotelemetry research has found success in influencing fishery management most often when researchers and practitioners worked together (Brooks et al. 2019, Brownscombe et al. 2019a; Nguyen et al. 2019). Brooks et al. (2019) described three case studies in North America where biotelemetry data were successfully used to inform fisheries and habitat management, highlighting that in each of the cases, biotelemetry was coupled with other evidence and research techniques such as genetics, physiology, and traditional knowledge, demonstrating that multiple lines of evidence presented a stronger case for policy reform (Cooke et al. 2013). Further, researchers in these cases were actively engaged with managers and stakeholders, which was identified as an enabler to successful integration of findings in decision-making (Nguyen et al. 2018a; Brooks et al. 2019).

To date, few studies have sought to examine and resolve the relationship between biotelemetry's unrealized potential and the growing consensus that knowledge uptake is a function of the knowledge users' perspectives and experiences. Previous work in this area investigated perspectives of knowledge users in the Pacific Salmon fisheries in the Fraser River, British Columbia (Young et al. 2016a, b, 2018, Nguyen et al. 2018b), but case studies remain rare.

1.3 Case study: Laurentian Great Lakes fisheries management and biotelemetry

The management of fisheries in the Laurentian Great Lakes (herein referred to as the Great Lakes) is coordinated across jurisdictions by the Great Lakes Fishery Commission[1] (GLFC), established by Canada and the USA through the Convention of Great Lakes Fisheries (1954). The GLFC's core duties include developing, funding, and coordinating binational research programs, providing recommendations to governments, implementing a control program for the invasive sea lamprey, and disseminating information critical to sustain the fishery (Gaden et al. 2012, p. 312). The GLFC also serves as a forum for communication among fishery managers, assessment biologists, and researchers and also fosters the sharing of stakeholder views and feedback (Gaden et al. 2008, p. 56). The GLFC's geographic scope includes the eight US states and the Canadian province of Ontario (Fig. 1).

The GLFC employs a Joint Strategic Plan[2] as a framework to facilitate the management of transboundary fish stocks by federal, provincial, state, and tribal jurisdictions (Gaden and Krueger 2018). The execution of the Joint Strategic Plan

[1] www.glfc.org.

[2] http://www.glfc.org/pubs/misc/jsp97.pdf.

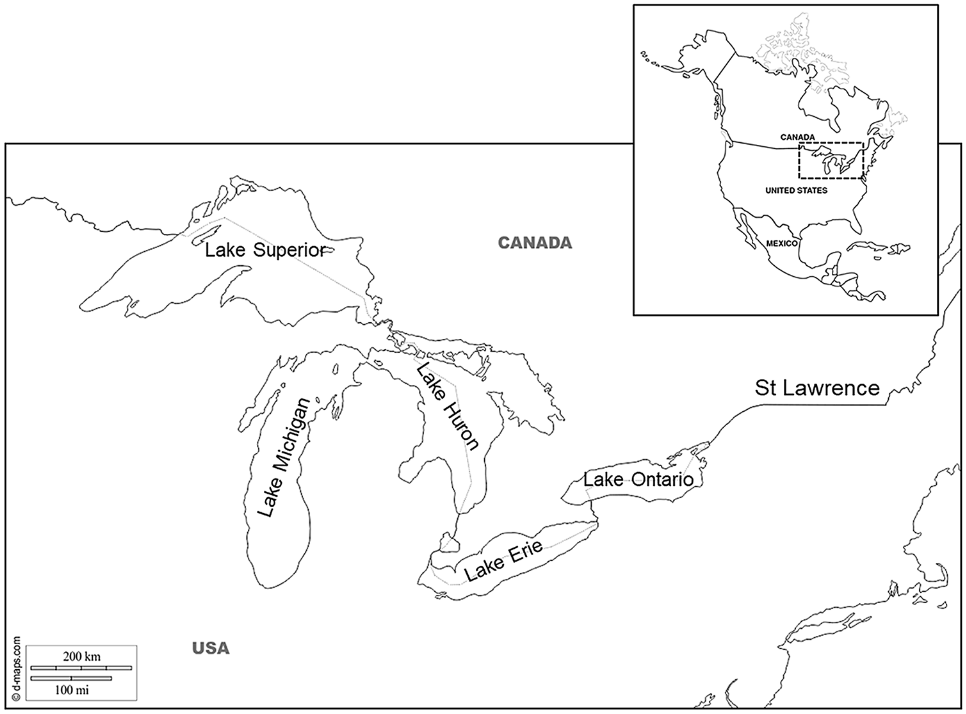

Fig. 1 Map of the Laurentian Great Lakes relative to North America (adapted from d-maps.com)

has produced a non-binding inter-jurisdictional governance structure that is highly cooperative, where fishery management decisions are made by consensus among jurisdictions who strive to produce decisions informed by science (Gaden et al. 2008, p. 56). This structure includes Lake Committees and Lake Technical Committees,[3] which consist of representatives from the provincial, state, and tribal agencies with fishery management authority (Fig. 2). The Lake Committees are comprised of high-ranking managers with decision-making authority from each lake's fishery agency who meet to address shared needs (Gaden et al. 2012, p. 57). Fishery researchers and assessment biologists contribute to the Lake Technical Committees, which also include individuals with relevant expertise from universities and federal agencies. The technical committees advise the Lake Committee managers of information important for resource-related decision-making. Given that the responsibilities of fishery managers, researchers, and assessment biologists on these committees cover the provision of scientific advice, policy advice, and include decision-making authority (described in Fig. 2), these fisheries professionals constitute an important population to investigate and understand the science–practice gap.

The GLFC has actively promoted and supported the use of acoustic telemetry within the Great Lakes through sponsorship of the Great Lakes Acoustic Telemetry Observation System[4] (GLATOS; Krueger et al. 2018). GLATOS was founded in 2010 and funded by the GLFC via funds provided by the US Great Lakes Restoration Initiative as administered by the US Environmental Protection Agency. GLATOS's purpose is 'to advance and improve conservation and management of Great Lakes fishes by providing information on fish behavior, habitat use, and population dynamics' (Krueger et al. 2018, p. 1760). To support this goal, GLATOS supports a network of more than 200 investigators using telemetry in the basin representing over 45 agencies and universities via coordination meetings; workshops; the Web site and a database; consultation services; data archiving and management; lending of acoustic telemetry equipment; and promotes science transfer (Krueger et al. 2018, p. 1760). Results of ongoing and completed telemetry studies associated with GLATOS have been presented annually within the GLFC's committee structure of Lake Committees and Lake Technical Committees as part of GLATOS's science transfer efforts.

The Great Lakes Basin is a crucially important case to examine, as it is one of the only basin-wide systems with an established biotelemetry network, and this network has been associated with more than ten years of biotelemetry research. We seek to explore and capture perspectives of knowledge users on the integration of biotelemetry into fishery management in the Great Lakes. To do so, we pursue two central objectives: First, we seek to understand how knowledge users view the role, potential, strengths, and limitations of biotelemetry as applied in the Great Lakes. Specifically, we sought out the viewpoints of three types of vocations—resource managers, researchers, and assessment

[3] http://www.glfc.org/joint-strategic-plan-committees.php.

[4] https://glatos.glos.us/.

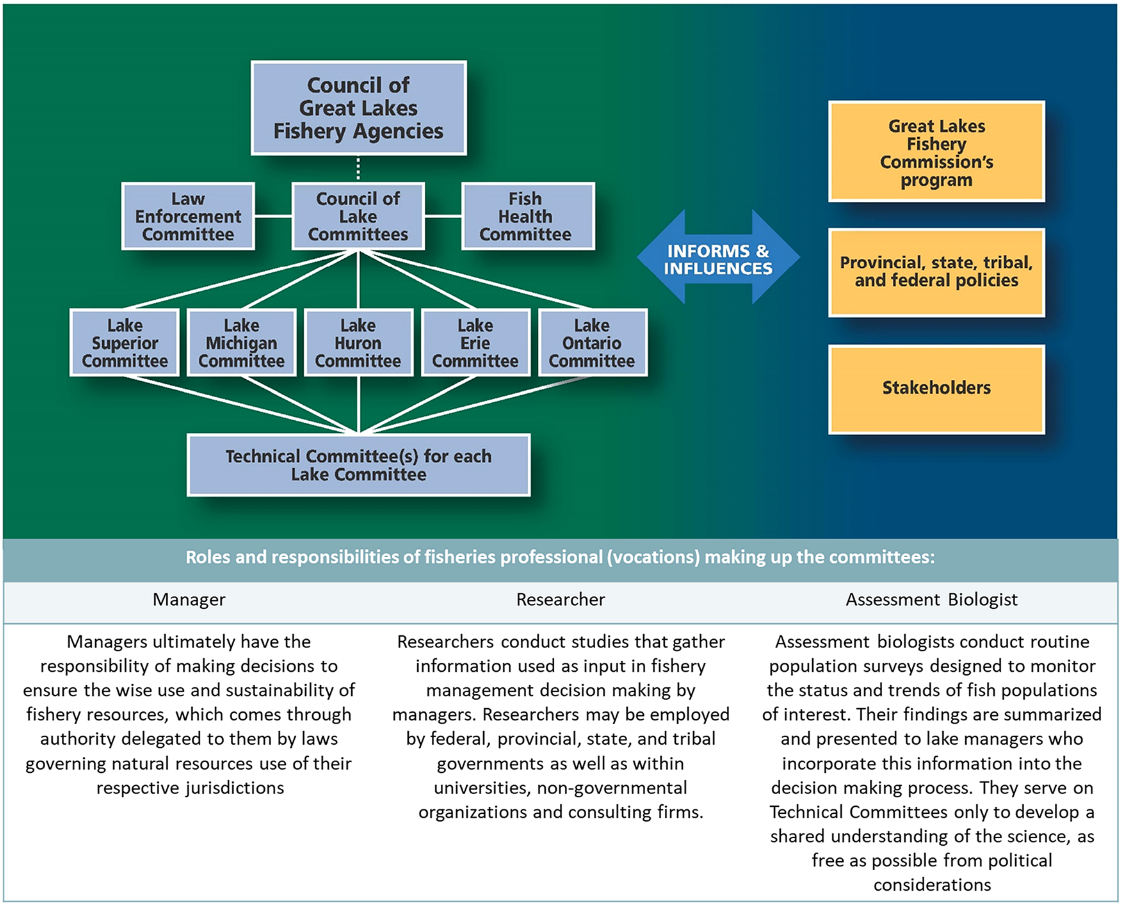

Fig. 2 Organizational structure of committees that inform and influence the GLFC's programs; provincial, state, tribal, and federal policies as well as stakeholders (adapted from Gaden et al. 2008 and http://www.glfc.org/joint-strategic-plan-committees.php). Committees are made up of fisheries professionals that broadly fit into three vocation types: managers, researchers, and assessment biologists. The roles and responsibilities of each vocation are described

biologists—held by members of science-based management organizations within the Great Lakes. Second, we seek to understand what barriers face the uptake of biotelemetry data in the research and management community. In doing so, we hope the study offers practical information concerned with improving the uptake and mobilization of evidence produced by biotelemetry. Our study contains two sources of novelty for this literature. First, our research provides basin-wide perspective with multiple jurisdictions. Second, reported successes associated with biotelemetry have often come from the perspective of researchers (e.g., Nguyen et al. 2018a, 2019; Brooks et al. 2019; Brownscombe et al. 2019a, 2019b), and here we broaden the vocational scope to include fishery managers and assessment biologists.

2 Methods

This research is part of a larger study on knowledge mobilization supported by the GLFC's Science Transfer Program.[5] Our research design was exploratory and used semi-structured telephone interviews to elicit views of fisheries professionals (managers, assessment biologists, and researchers) associated with the GLFC Lake Committee structure. The study received ethics approval from the Carleton University Ethics Board (#106530).

2.1 Interview development

The interview instrument contained 25 questions developed using the knowledge–action framework by Nguyen et al. (2017a) as well as advice from collaborators and key

[5] http://www.glfc.org/science-transfer.php.

Table 1 Summary of interview questions analyzed in this study

Question	Type	Results summarized in:
Have you used biotelemetry in your own work?	Open-ended	Table 3
What are the strengths of biotelemetry?	Open-ended	Tables 5, 7
What are the limitations of biotelemetry?	Open-ended	Tables 6, 7
Likert-type questions concerned with biotelemetry research	Likert type	Table 4, Fig. 3
In your experience, what do you think are barriers to using new scientific knowledge in fisheries management?	Open-ended	Table 8

informants from the GLFC and GLATOS (see Supplementary Information for full interview instrument). Interviews consisted of a series of open-ended questions as well as a set of closed-ended Likert-type opinion questions. Open-ended questions (Table 1) sought to elicit information about participant backgrounds, their views about the role of biotelemetry in the Great Lakes Basin, the benefits and limitations of biotelemetry, and barriers to mobilizing new scientific evidence into policy and decision-making. The closed-ended Likert-type questions covered a variety of topics regarding production, use, value, and sharing of biotelemetry science (Fig. 3). We asked participants to indicate their level of agreement on a five-point scale with a sixth option of 'I don't know' also available. To assess our interview instrument, we conducted two test interviews with individuals possessing expertise in biotelemetry techniques and research but who were not from the Great Lakes arena. No adjustments to the interview question guidelines or procedures were made after these tests.

2.2 Data collection and analysis

We identified interviewees from a list provided by the GLFC which contained contact information for members of the Commission's Lake Committees and Lake Technical Committees ($n = 94$). In addition, we identified several other key informants, including GLFC staff ($n = 12$). Interview invitations were sent by email on June 6, 2017, and three reminders were sent. Interviewee affiliations were self-reported (by committee and vocation, see Table 2).

We conducted a total of 49 semi-structured interviews by telephone and conducted one interview by e-mail for a total of 50 interviewees (out of 106 contacted individuals). The remainder of the population (56) did not respond to the invitation after several reminders. During the semi-structured telephone interviews, the interviewer followed a predetermined set of questions but allowed respondents to diverge from the script (Axinn and Pearce 2006). The interviews took place between June 2017 and October 2017 and lasted between 35 and 70 min. All interviews were audio-recorded with the consent of participants.

We transcribed audio-recorded interviews with Transcribe[6] an online transcription service. We reviewed interview transcripts to ensure accuracy and to increase our familiarity with the transcripts to prepare (i.e., to identify potential emerging themes) for the coding step. To analyze the data obtained from open-ended questioning, we used NVivo 12 (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12, 2018) and inductively coded the data following a three-step qualitative analysis procedure (Thomas 2006, Sutton and Austin 2015). Specifically, we assigned codes to responses, then merged similar codes, and finally assigned codes into relevant thematic categories. We reviewed all categories to ensure they were mutually exclusive. These thematic categories were then classified into evaluative, socio-organizational, and individual-level strengths, the core themes of Young et al. (2018)'s framework used as the basis of our qualitative analysis. For open-ended questions, the percentage of respondents citing a particular theme was calculated rather than the total number of times interviewees cited a theme. For closed-ended, Likert-type questions, the percentage of respondents selecting a particular Likert-type option was used. Percentages were calculated out of 50 total respondents, except (1) where explicitly noted or (2) where results are summarized by vocation type (Table 2). Our qualitative inductive analysis allowed for themes to emerge. The qualitative analysis was used to understand patterns or recurrences in experience and thinking of individuals in order to map the landscape of participant's thoughts on topics of interest (Maxwell 2004).

3 Results

We organize the results into three sections. In the first section, we summarize the broad contours of the interviewees' viewpoints regarding their previous involvement with biotelemetry and their views on whether its role should be expanded in the Great Lakes. In the second section, percentages of interviewees who cited various benefits and limitations of biotelemetry are presented. While the first two sections of the results report both open-ended and closed-ended

[6] https://transcribe.wreally.com/.

interview questions specific to the use of biotelemetry in the Great Lakes Basin, the final section reports solely open-ended data to illustrate perceived barriers to the adoption of new scientific evidence by the respondents, providing context for understanding the barriers to science transfer in this system.

3.1 Understanding interviewee background experiences and perceptions on the role of biotelemetry

Most interviewees (84% of 50) had direct experience with biotelemetry through current or previous involvement in research (not necessarily as the one conducting the research, but as a collaborator, funder, or user). Only 16% of interviewees indicated they had not been directly or indirectly involved with biotelemetry research, suggesting that most of the sample population provided a good cross section of experiences with, and exposures to, biotelemetry (Table 3). The majority of interviewees (> 50%) thought that the role of biotelemetry in the Great Lakes fishery management should be expanded (Table 4). Only two out of 27 managers and one out of 11 assessment biologists disagreed with the statement.

3.2 What science transfer benefits and limitations does biotelemetry generate?

In analyzing the interviewee responses, we identified 16 types of strengths of biotelemetry data (Table 5) and 18 types of limitations (Table 6) through our coding of open-ended questions. The majority of strengths (14 of 16) and weaknesses (16 of 18) fell into the *evaluative* category, with *individual*-level strengths and weaknesses of biotelemetry cited by the fewest interviewees.

3.2.1 Evaluative strengths and limitations: epistemological

Within the e*valuative* category, interviewees cited e*pistemological* benefits most often (Table 5). Respondents frequently cited biotelemetry's ability to generate evidence useful for understanding several questions related to species biology, including species movement (mentioned by 78% of interviewees), life history and ecology (32%), habitat data (30%), and behavior (28%). Epistemological-type strengths of biotelemetry data also cited were for understanding environmental stressors (22%) and population ecology (24%). Examples of positive responses demonstrating evaluative value of biotelemetry information are illustrated below:

> *"It gives you an absolute understanding of where the fish go and when, and the route that they took to get there much more so than the traditional tagging method"* (Interview #5, Manager).

> *"They* [biotelemetry researchers] *are doing migration* [studies], *spawning fidelity, doing a mix stock analysis, life history events, temperature preferences. There's a lot to be learned by it."* (Interview #37, Manager).

Aside from the types of questions biotelemetry can help answer, several interviewees (34%) noted that biotelemetry yields high-quality data. For example, we illustrate a positive comment on data quality here:

> *"You get a more continuous data set you can't get in other ways. For instance, you can get the temperature of where the fish is at every 15 s. That is way more continuous than the point you get with a gill net at a spot at a certain time. You get a better dataset with much more continuous data."* (Interview #47, Manager).

The *epistemological* limitations cited most were that biotelemetry data often rely on a small sample size, potentially limiting confidence in results (26%), and that it produces data more relevant for understanding individual fish behavior rather than population-level behavior (14%) (Table 6). A smaller proportion of interviewees expressed concern that biotelemetry can produce skewed evidence with respect to age distribution (6%) and abundance (4%). We illustrate the more negative sentiments about the limitations on sample size and population-level assessments below:

> *"The sample sizes can be low and that's also another statistical problem. Fifty fish may not actually tell you everything you need to know about a whole population. I see those as very strong limitations."* (Interview #5, Manager).

> *"When you are thinking about management at a population scale as large as the Great Lakes, if you have a population of 50 million walleye and you got 400 tags out there, what do you really know about the population? Extrapolating from your frame of reference is a pretty big leap that I think both researchers and managers just really need to be cognizant about as they talk about what insights they're making coming from various research projects."* (Interview #8, Manager).

Five of the nine Likert-type opinion questions (Fig. 3) investigated *epistemological* perceptions of biotelemetry data. Two of these Likert items generated agreement among vocations in support of the reliability of knowledge generated by biotelemetry: Interviewees noted that knowledge generated about fish behavior was reliable and that the fish handling process (i.e., catching and tagging the fish) did not impair data reliability (Fig. 3). The other three epistemologically focused Likert-type questions revealed disagreement both within and across vocation types. Although most interviewees agreed that biotelemetry contributes reliable information on fish behavior, we found variability in the opinions of its reliability in generating ecosystem-level knowledge

Table 2 Affiliation of participants by committee membership and vocation

Great Lakes Fishery Commission Committee	Vocation			Total ($n=50$)
	Manager ($n=27$)	Researcher ($n=12$)	Assessment Biologist ($n=11$)	
Lake Ontario	2	0	0	2
Lake Ontario Technical	2	1	5	8
Lake Erie	4	0	0	4
Lake Erie Technical	1	1	0	2
Lake Huron	0	0	0	0
Lake Huron Technical	3	3	1	7
Lake Michigan	3	0	0	3
Lake Michigan Technical	5	3	0	8
Lake Superior	4	0	0	4
Lake Superior Technical	2	2	5	9
Council of Great Lakes Agencies	1	0	0	1
Not on a committee	0	2	0	2

Table 3 Responses (in percentage) to the question 'Have you used biotelemetry in your own work?'

Experience with biotelemetry	Percentage of respondents ($n=50$)
Direct involvement	
Currently working on several projects involving biotelemetry	24
Currently involved in some projects	28
Have used biotelemetry in the past but does not currently use	26
Indirect involvement	
Via funding oversight	6
No previous involvement	
Have not been involved in projects involving telemetry	16

Table 4 Expanding the role of biotelemetry in the Great Lakes Basin (in percentage)

Biotelemetry should play a more standard role in fishery management than it currently does	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Manager ($n=27$)	4	52	33	7	0
Researcher ($n=12$)	0	67	33	0	0
Assessment biologist ($n=11$)	9	45	27	9	0

(Fig. 3). The perspective of managers was the best example of this contrast: While 100% of managers agreed that biotelemetry was useful for fish behavior, 52% indicated they were not convinced that biotelemetry was a reliable source of ecosystem data. Researchers and assessment biologists were much more positive on the ability of biotelemetry to help understand ecological factors. On whether 'biotelemetry information should be taken with a grain of salt' (Fig. 3), assessment biologists demonstrated more skepticism relative to the other vocation types. Despite some disagreements among researchers and assessment biologists about using biotelemetry data only after peer review, overall, these vocation types considered this approach acceptable. Managers, however, noted the strongest disagreement, indicating that using non-peer reviewed biotelemetry data in some circumstances was acceptable (48% of 27 managers disagreed or strongly disagreed with this statement (Fig. 3).

Managers and researchers offered more positive comments about the *epistemic value* of biotelemetry than other vocation types, with 56% of managers and 42% of researchers offering positive-only comments (Table 7), while only 36% of assessment biologist provided positive-only comments. None of the vocation types cited negative-only epistemological attributes of biotelemetry, but each vocation

Table 5 Positive or supportive comments (and percentage of respondents) about biotelemetry cited in open-ended questioning

Young et al. 2018 framework classification		Code	Percentage of respondents ($n=50$)
Positive or supportive comments about biotelemetry			
Socio-organizational strengths	Communicative strengths	Fosters collaboration	2
Evaluative strengths	Epistemological value	Movement (distance, migration)	78
		Produces high-quality data	34
		Life history and ecology	32
		Habitat data	30
		Behavior	28
		Population ecology	24
		Environmental stressors	22
		Mortality and survival	18
		Individual-level data	14
		Invasive species management	14
		Novel information	10
		Animal physiology	6
	Practical value	Low human resource demands	12
		High volumes of data	10
	Perceived fit or departure from current practices	Fosters scientific inquiry	6
Don't know			2

Table 6 Negative or less supportive comments (and percentage of respondents) about biotelemetry cited in open-ended questioning

Young et al. 2018 framework classification		Code	Percentage ($n=50$)
Limitations of biotelemetry			
Socio-organizational challenges	Communicative limitations	Coordination and communication	4
Individual-level challenges	Skills, communication, familiarity	Lack of necessary expertise or capacity	6
Evaluative limitations	Epistemological limitations	Small sample sizes	26
		Produces information at individual level not population level	14
		Receiver accuracy	10
		Study design flaws	6
		Lacks mortality data	6
		Can produce skewed/unrepresentative age data	6
		Can produce skewed/unrepresentative abundance data	4
		Data robustness	4
		Lacks physiological data	2
	Practical limitations	Cost is too high	38
		Collecting and processing data	28
		Limited receiver availability	20
		Recovering receivers	6
		Depth limitations of receivers	6
		Battery life	4
		High human resource demands	2
	Perceived fit or departure from current practices	Doesn't replace current practices, tools, or approaches	4
Not aware of any limitations			6

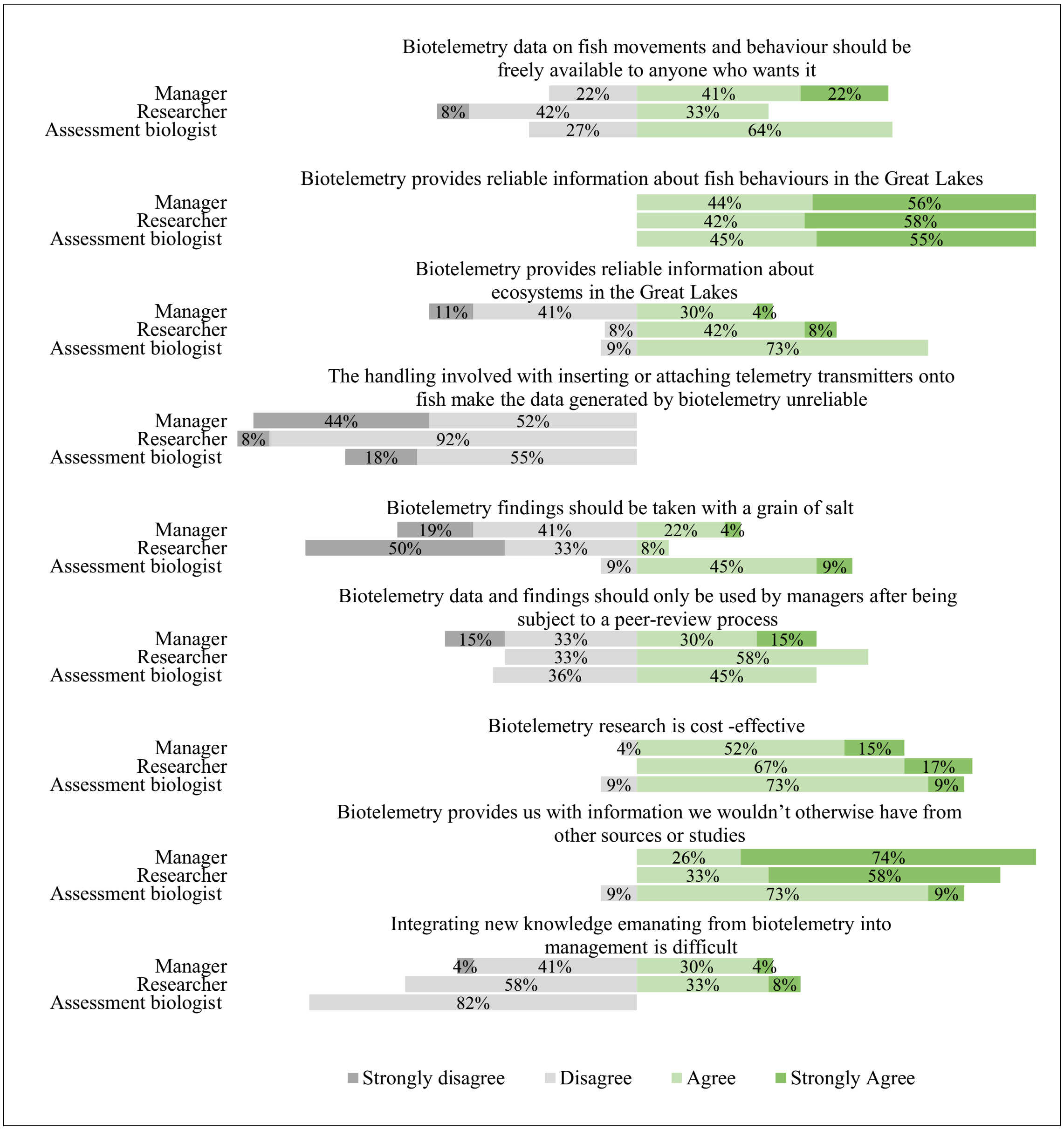

Fig. 3 Responses to Likert-type opinion statements by vocation type. We only include answers provided that contain a degree of polarity (i.e., agree or disagree) and omit neutral answers (including 'neither agree nor disagree' and 'I don't know')

type provided mixed positive and negative comments about biotelemetry, including 44% of managers ($n=27$), 50% of researchers ($n=12$), and 6% ($n=11$) of assessment biologists.

3.2.2 Evaluative strengths and limitations: practical

Overall, all vocations held negative views of the *practical* attributes of biotelemetry with 51% of managers ($n=27$), 67% of researchers ($n=12$), and 92% of assessment biologists ($n=11$) citing at least one practical drawback of biotelemetry without citing any practical benefits (Table 7).

Interviewees cited *practical limitations* of biotelemetry most often but named fewer types of practical limitations relative to epistemological concerns, which may suggest common thoughts about biotelemetry's practical limitations. Thirty-eight percent of all interviewees noted that the cost to conduct biotelemetry research was a barrier to use and uptake of biotelemetry data (i.e., science transfer), while 28% of interviewees noted that collecting and processing the volume of data yielded by biotelemetry created significant practical challenges. Twenty percent identified that receiver

Table 7 Perceptions of the evaluative strengths and limitations (by percentage) of biotelemetry by polarity of answer and across vocation types

Vocation	Positive only	Mixed	Negative only	Not mentioned
Manager ($n=27$)				
Epistemic value	56	44	0	0
Practical value	4	26	51	19
Fit	7	0	4	89
Researcher ($n=12$)				
Epistemic value	42	50	0	8
Practical value	0	0	67	25
Fit	8	0	0	92
Assessment biologist ($n=11$)				
Epistemic value	36	64	0	0
Practical value	0	0	92	9
Fit	9	0	0	91

Epistemic value refers to the perceived as either flawed, irrelevant, and limited value, or novel, credible, and reliable with high value. *Practical value* refers to ease of use of information (e.g., cost, time lags, access, spatial coverage), and *Fit* refers to perceived fit or departure from current practices. These definitions follow the Young et al. (2018) framework

availability was limited. An example of a comment related to cost as a barrier is shown below:

> *"[Biotelemetry research] is very expensive, and in a large lake, I think a smaller barebones study required 150 receivers, which is a lot of money. And then it takes a lot of resources to get those set."* (Interview #34, Manager).

Not many *practical benefits* of biotelemetry were noted compared to practical limitations, with 12% of interviewees noting that biotelemetry requires low human resource demands and 10% of interviewees citing the high volume of data produced by biotelemetry as an important benefit (Table 5).

Among the Likert-type question examining the practicality of biotelemetry, we found positive consensus among all vocation types on the statement 'biotelemetry research is cost-effective.' Interestingly, this differs from the practical issue that biotelemetry cost is too high in the open-ended questioning. Further, high agreement occurred among respondents that biotelemetry produces data that cannot be produced through other methods (Fig. 3).

3.2.3 Evaluative strengths and limitations: perceived fit with existing structures and practices

The third type of evaluative strength/limitation from Young et al. (2018)'s framework is the *perceived fit* of new knowledge into existing management structures and practices, which was not mentioned often among interviewees (Table 8). Results did not produce a clear signal around this characteristic: Though 6% of interviewees suggested that biotelemetry worked within existing structures to promote scientific inquiry, 4% noted that biotelemetry does not replace current practices, tools, or approaches (Table 6). We asked interviewees to indicate whether they agreed or disagreed with the statement 'Integrating new knowledge emanating from biotelemetry into management is difficult' (Fig. 3), and found assessment biologists unanimously felt integrating biotelemetry data was not difficult, while researchers and managers differed, with mixed agreement and disagreement on this statement.

3.2.4 Socio-organizational strengths and limitations

Interviewees cited *socio-organizational* strengths and weaknesses related to biotelemetry far less frequently than *evaluative* characteristics. One interviewee noted that biotelemetry research fostered collaboration, while two interviewees suggested that the usefulness of biotelemetry was limited by complications arising from collaboration. We included one Likert-type question aimed at understanding socio-organizational characteristics, which was 'Biotelemetry data on fish movements and behavior should be freely available to anyone who wants it' (Fig. 3), to understand perspectives about data sharing. The majority of managers (63%, $n=27$) and assessment biologists (64%, $n=11$) 'agreed' or 'strongly agreed' with the statement, while a minority of researchers (33%, $n=12$) agreed with this statement (Fig. 3).

3.2.5 Individual-level strengths and limitations

No *individual-level* benefits were cited by interviewees, while 6% of interviewees noted only one type of individual-level barriers, a lack of expertise, as complicating the use and uptake of information generated by biotelemetry.

Table 8 Perceived barriers (by percentage) to using new scientific knowledge in fishery management

Young et al. (2018) framework		Code	Mngrs ($n = 26$)	Res ($n = 11$)	Biol ($n = 10$)	Overall percentage ($n = 47$)
Barriers to mobilizing new evidence into policy						
Socio-organizational challenges	Organizational inflexibility	Institutional inertia	15	18	0	13
		Legal context	4	0	0	2
		Management metrics	0	9	0	2
		Timeliness of evidence	4	0	0	2
	Absorptive capacity	Integration challenges	4	9	0	4
	Political considerations	Acceptance by stakeholders	22		10	14
	Communicative limitations	Communication between researcher and manager	19	27	10	19
		Communication with the general public	12	0	0	6
		Communication of complexity	0	9	0	2
Individual-level challenges	Skills, education, familiarity	Finding out about new evidence	12	9	20	13
		Access to journals	4	0	0	2
		Access to unpublished data	4	0	0	2
		Inability to process complex data	0	0	10	0
		Personal constraints	1	0	0	0
	Experiences and preferences	Prior experiences of key individuals	8	36	30	19
Evaluative limitations	Epistemological limitations	Confidence in evidence	12	0	10	9
		Relevance of evidence	4	9	0	4
		Limitations of evidence	4	0	0	2
		Knowledge complexity	4	0	0	2
	Practical limitations	Cost (unspecified)	15	36	10	19
		Time constraints (unspecified)	12	0	20	11
		Labor availability	0	9	10	4
		Gear and supplies	0	9	10	2
		Travel restrictions	4	0	0	2
	Perceived fit or departure from current practices	Fit with historical norms	4	9	0	4
Not aware of any limitations			4	0	0	2

Results are shown as a proportion of respondents citing the relevant barrier by vocation type and by proportion of complete interview set. Conceptual framework employed is based on that designed by Young et al. (2018). *Mngrs* managers, *Res* researchers, *Biol* assessment biologists

3.3 Barriers to the adoption of new scientific knowledge into management and policy

The final section of our results addresses how interviewees perceived barriers limiting the adoption, or uptake, of scientific data (generally) into use by managers and resource management institutions. While the data presented in Sect. 3.2 focused on strengths and benefits of the data produced by biotelemetry, here we provide an examination of barriers that can complicate or preclude uptake of new knowledge more generally.

3.3.1 Evaluative barriers

Ten types of evaluative limitations were cited, and as aforementioned, interviewees most commonly identified *practical limitations* as barriers to the mobilization of knowledge produced by biotelemetry (Table 6). Similarly, the interviewees also perceived practical limitations to be core barriers to the uptake and implementation of new evidence into policy (Table 8). The perceived cost to integrating new evidence was cited by 19% of all interviewees ($n = 47$), with researchers citing it most often (36% of 11; Table 8). Time constraints were the second most cited practical limitation, noted by 11% of interviewees ($n = 47$). Interviewees did not specify cost and time constraints and spoke about these concepts more generally.

Similar to results from biotelemetry uptake, *epistemological* factors were not predominantly cited as barriers to the uptake of new knowledge and evidence. The most commonly noted *epistemological* barrier was 'confidence in evidence,' with only 9% of all interviewees ($n = 47$) citing this barrier. The results of this category are perhaps most interesting when viewed as a function of vocation type—0% of researchers ($n = 11$) noted this *evaluative* limitation, while 12% of managers ($n = 26$) cited confidence as a barrier.

3.3.2 Socio-organizational barriers

Eight types of *socio-organizational* barriers to the uptake of new knowledge were cited by interviewees. Communicative limitations were the most often cited *socio-organizational* barrier, with 19% of interviewees ($n = 47$) noting that communication between researchers and managers was a key limitation. This limitation was cited more frequently by researchers (27%, $n = 11$) than managers (19%, $n = 26$). Other *socio-organizational* barriers cited by interviewees included institutional inertia (13%, $n = 47$) and the acceptance of new evidence by stakeholders (11% of all respondents ($n = 47$) cited this barrier, and 15% of managers ($n = 26$)). Interestingly, *socio-organizational* challenges associated with the public and stakeholders were most frequently cited by managers and rarely or never by researchers and assessment biologists (Table 7).

3.3.3 Individual-level barriers

Individual-level barriers featured more prominently in respondents' answers about mobilizing new evidence than individual-level benefits/limitations with biotelemetry (no individual-level strengths cited and 6% cited as a challenge; Table 6). Within this category, finding out about new evidence was cited most frequently (13% overall vocations, $n = 47$; Table 8), of which 20% (of 47) assessment biologists made up the respondents in this category. Second, prior experiences of key individuals (often termed as path dependence in the literature) were cited as a barrier by 19% of respondents consisting primarily of researchers and assessment biologists citing this barrier. Other individual-level barriers (only cited by about 2% of respondents) included access to journals, access to unpublished data, inability to process complex data, and (unspecified) personal constraints (Table 8).

4 Discussion

Overall, our results shed light on the challenges of integrating biotelemetry findings into Great Lakes fishery management by revealing how individuals possessing three vocation types perceived benefits and limitations of biotelemetry of three vocation types. First, we discuss biotelemetry-specific perceptions within the Young et al. (2018) framework. Second, we discuss the role of vocations and the continued science–practice divide, and lastly, we compare the barriers facing the uptake of biotelemetry evidence relative to the mobilization of new knowledge more generally.

We interviewed nearly 50% of our total target population, which consisted of fisheries professionals associated with the GLFC. Given this level of coverage, it is unlikely that any major thematic codes were missed at the population level (Guest et al. 2006, Francis et al., 2010). The fact that the GLFC established and sponsors GLATOS could mean that our sample population may be biased toward individuals already familiar and supportive of biotelemetry research and its application. Their familiarity with the information that biotelemetry provides may explain the more positive perceptions of biotelemetry's epistemological value than expressed by individuals or groups outside of the Great Lakes as documented in the Fraser River case (Young et al. 2013, 2018) where skepticism was recorded. In the Great Lakes Basin, the GLATOS network has played a crucial role in promoting knowledge sharing and exchange among fisheries professionals and in demonstrating the value and impacts of biotelemetry research (see e.g., Krueger et al. 2018, Fielder et al. 2020 for management impacts). Given that most of our sample population were generally positive, aware and supportive of biotelemetry research may signal that science transfer activities (i.e., annual meetings, committee presentations, relationship development, developing research-practitioner network) within the Great Lakes Basin are working. Other cases around North America examining the science transfer of biotelemetry have noted similar activities promoted the translation of findings into fishery management action, including integrating managers and stakeholders into the research, having applied research funding and objectives, having established relationships among researchers and practitioners, and presenting preliminary data in a timely manner (e.g., Brownscombe et al. 2019, Brooks et al. 2019).

4.1 Evaluative challenges: biotelemetry is perceived to offer high epistemological value but with practical limitations

We found that information and knowledge derived from biotelemetry research is highly regarded for its *epistemological* value, as noted in other Great Lakes-based GLATOS research (e.g., Hayden et al. 2014, Fielder et al. 2020) and elsewhere, particularly for understanding fish movement (distance, migration) and applying this information to management. The fact that interviewees also mentioned the value of biotelemetry in generating environmental and ecological information suggested that they felt biotelemetry data were useful for pursuing and answering a range of scientific questions (not only on fish) and for informing management. Young et al. (2018) conducted similar research on Pacific salmon fishery management in Fraser River, British Columbia, and interviewed government employees including fishery managers, assessment biologists, and researchers (from Department of Fisheries and Oceans Canada) as well as stakeholders affiliated with the co-management of the salmon fishery (e.g., industry, First Nation organizations, consultants, and environmental non-governmental organizations). As with study participants in the Great Lakes, government employees involved in the management of the Fraser River demonstrated general support for expanding the role of biotelemetry in salmon management (72% of 16 respondents). Despite the more heterogeneous interviewees in the Fraser River salmon case study, we found similar areas of agreement and disagreement on the Likert-type opinion statements of biotelemetry. For example, both studies showed strong agreement that biotelemetry provides reliable information on fish behavior as well as offering information that was unattainable from other methods or sources (Young et al. 2018). Although high agreement occurred on reliability of information on *fish behavior*, mixed opinions existed about reliability of biotelemetry research on *ecosystem-level information* by both studies. Similar sentiments were found in the open-ended questioning of strengths of biotelemetry for both Great Lakes and Fraser River studies. Participants identified information on movement (timing, distance, and migration), fish behavior, and high-quality or original data among the epistemological strengths of biotelemetry. Overall, a fairly strong endorsement of the scientific knowledge output of biotelemetry technology occurred. However, our findings highlight the remaining question of whether individuals feel that the epistemological value of biotelemetry is worth the cost and other practical limitations that were cited.

4.2 Cost-effective and cost-prohibitive: a paradox of new technology

The finding that cost remained the most notable to greater deployment and uptake of biotelemetry in the Great Lakes contrasts with the results of other studies. Globally, a survey of just over 200 international fish telemetry researchers found that researchers perceived the challenges facing the uptake of biotelemetry findings to be limitations of the technology itself and its resulting data (Nguyen et al. 2018a) more so than cost. As with Fraser River managers (Young et al. 2018), GLFC fisheries professionals noted that the cost (of transmitters) and resource burden (labor capacity requirements for field work and data processing) associated with biotelemetry complicates the use of the technology. Interestingly, though interviewees cited cost as a major limitation to its integration in fishery management, the results of open-ended questioning showed that all vocation types nonetheless consider the technology to be cost-effective for research (especially once capital costs are amortized over time). Perhaps, this result was because of the perceived reliability of the data, the volume of the data produced, and perceptions about the variety of scientific questions the data can help answer.

In the Great Lakes, acoustic telemetry is often conducted by attaching a transmitter to the fish (either via surgery or externally) which transmits acoustic signals to a receiver that can be tens of meters away, or a few kilometers away. The signals are recognized as a code unique to each fish and recorded with date and time stamp by receivers (reviewed in Thorstad et al. 2013; p. 884). Acoustic receivers can be positioned as in lines or grid patterns and continuously listen for the movements of tagged fish. The initial investment for acoustic equipment (receivers, tags, and field work) can be large, but the equipment can function for several years, which lowers the cost of this method when amortized over the device's life span. Given that acoustic telemetry arrays are still relatively new to the Great Lakes (~ 10 years or less), some lingering sentiments of large initial costs and maintenance may exist. Thus, while biotelemetry can produce large volumes of trustworthy data capable of answering important scientific and management questions, funding this work remained a major challenge in the minds of the respondents. The fact that biotelemetry was viewed as both cost-effective and cost-prohibitive may reflect static research budgets within agencies and research funding organizations.

For the technology to be implemented more expansively under the scenario of static research budgets, biotelemetry would have to displace other research and assessment methods to free-up funds. As such, those looking for their biotelemetry research to be used and supported must demonstrate its impact. McGowan et al. (2016) discusses conservation return-on-investments from animal tracking (biotelemetry) data and offers a framework using the value of information for decision-making to help improve decisions on investing in more data collection or conservation action or other activities requiring resource trade-offs. They argue that new tools to weigh costs and benefits are needed to improve the return-on-investments of biotelemetry research for conservation decision-making (McGowan et al. 2016; p. 428). So far, little work has been done investigating the cost–benefits of biotelemetry (e.g., investigating cost relative to conventional or alternative methods), which may be a useful route for further investigation, especially considering our findings that biotelemetry was viewed as being both cost-effective and cost-prohibitive.

4.3 Socio-organizational challenge: Mixed views on data sharing and indication of reluctance from the research community

Fifty percent of researchers in our study disagreed that biotelemetry on fish movements and behavior should be freely available to anyone, which contrasted to the relatively positive views on data sharing held by managers and assessment biologists. This result was somewhat consistent with other findings concerned with the sharing of biotelemetry data. Previous work by Nguyen et al. (2017b) found about 39% of surveyed fish telemetry researchers, globally, were less agreeable to sharing biotelemetry data. Many concerns were related to loss of opportunity/ownership over data or misuse of data (i.e., misinterpretation or inappropriately exploiting animal information). Nguyen et al. (2017b) reported that individuals who are part of telemetry networks were 2.8 times more likely to share their data. Relevant to our study, GLATOS data policy reflects these concerns and is as follows:

> GLATOS is a collaborative network for the exchange of data owned by individual members. Each principal investigator (member) determines who can access their project's detailed biological tagging data and subsequent detections of those tagged fish, consistent with their own agency or funding source policy. To facilitate collaboration and planning, receiver locations and dates of operation are available to all members. (https://glatos.glos.us/faq; accessed June 16, 2020).

In practice, the GLATOS basin-wide database is used by a researcher to search across all existing receivers (receivers they deployed as well as receivers deployed by others) for tag detections within the scope of the researcher's project. Thus, finding detections of telemetry tags on other researchers' receivers is promoted and considered a form of data sharing. However, a researcher cannot search for tag detections that are not a part of their project; thus, data sharing via the GLATOS database has some restrictions. Given that GLATOS is a network embedded within the GLFC, we expected greater support for data sharing/collaboration among researchers. Although we did not explore the reasons for the concerns over data sharing, sociopolitical reasons may exist that explain hesitancies around data sharing. Further, our questioning did not specify sharing data with the public vs those within the network, which leaves some knowledge gaps. For example, telemetry data could be used to influence harvest or quota regulations among jurisdictions such as within the Lake Erie walleye sport and commercial fisheries (Vandergoot et al. 2019). Further, sharing data used to identify critical habitat of a species at risk may create the potential for data misuse (as noted in Nguyen et al. 2017b), as sharing this information could result in potential unintended consequences such as overexploitation of species at risk (Cooke et al. 2017).

4.4 Individual-level challenges: not a major barrier in the Great Lakes Basin

Few individual-level challenges were identified, with the exception of three interviewees describing lack of expertise and capacity with biotelemetry. This sentiment resembled those reported by a survey of fish telemetry researchers around the world noting that large and complex datasets generated by biotelemetry were a major barrier to integrating biotelemetry findings into management because of the lack of expertise to interpret them (Nguyen et al. 2018a). Nonetheless, as alluded to, the presence of GLATOS and its science transfer efforts may have played an important role in overcoming individual-level challenges such as skills, education, and familiarity with the technology.

4.5 The science–practice culture divide persists—how can it be overcome?

Participants in this study came from three vocation groups (fishery managers, researchers, and assessment biologists) within the GLFC's Lake Committees and Technical Committees. Interestingly, differences in sentiments were expressed across vocations on the evaluative strengths and limitations of biotelemetry. The answers provided by assessment biologists, who were Technical Committee members, were more negative across all themes than other vocation types, while managers held the most positive views about biotelemetry. For example, assessment biologists, unlike researchers and managers, were more positive about the ease of integrating biotelemetry-derived knowledge into management. These differences may be influenced by the nature of the role and responsibilities of different vocations, as assessment biologists are often on-the-ground and implementing strategies or integrating different sources of scientific information into assessment models, and thus may have greater direct exposure to, and experience with, the (im)practicalities associated with biotelemetry. Although the potential role of biotelemetry in stock assessment has been considered (Cooke et al. 2016), still relatively few examples exist of where this integration has occurred in practice within the Great Lakes (Landsman et al. 2011).

Our result was similar to the findings from the Fraser River salmon case study, where Young et al. (2018) found polarized sentiments relating to the epistemic value, practical value, and fit of biotelemetry and management between government employees and stakeholders. Stakeholders in that study were more critical than government employees about biotelemetry informing fishery management. Further, qualitative information from Young et al. (2018) illustrated that some managers view biotelemetry as a good tool for research, but not as useful for management purposes. Indeed, these inconsistent sentiments among Great Lakes user groups (i.e., useful for research, not management) of the value of biotelemetry may lead to disagreement over the potential role of biotelemetry research in fishery management as it did in Fraser River management (Young et al. 2018).

Our findings, when analyzed by vocation, were consistent with patterns of the cultural divide between researchers and managers previously identified in the literature (e.g., Olsson et al. 2004, Sunderland et al. 2009). In our study, practitioners or managers demonstrated greater political concerns relating to acceptance of evidence by the public and stakeholders than researchers, whereas no researcher listed these concerns as potential reasons for barriers to mobilizing telemetry evidence. Furthermore, managers reported a greater diversity of socio-organizational challenges than the other vocations. On the other hand, those in science-oriented vocations (researchers and assessment biologists) cited the prior or past experiences of key individuals as a key barrier to the uptake of scientific evidence; almost no manager acknowledged this issue. These findings were evidence of the persistence of the science–practice divide.

We speculate that our findings were an indication that fishery management and policy arenas and outcomes are still something of a 'black box' for researchers to understand. Thus, researchers need to better understand knowledge users and integrate manager perspectives into their research. To meet this need to integrate managers with research studies, the first four major telemetry studies conducted through the GLATOS network had fishery managers from agencies with jurisdictional authority as co-principal investigators (Krueger et al. 2018). Managers helped to ensure that Great Lakes telemetry research was relevant to their decision-making needs. A study funded by the GLFC in 2014 concerning climate change information identified the gap between research and practice where many opportunities to reconcile data and information demands of decision-makers with available future research were missed (Mulvaney et al. 2014). In that study, the authors identified preferred information channels that resource managers and policy decision-makers at the GLFC used to obtain information. E-mail was the most frequently cited medium used, while the preferred medium of receiving climate information was found to be presentations at meetings and conferences. This information is consistent with anecdotal evidence suggesting that GLFC meetings are a key activity for science transfer. The GLFC has an established form of knowledge exchange through their committee meetings that consists of an overnight stay with organized events to facilitate informal interactions and relationship building among the meeting participants. The emphasis on the importance of these meetings is a unique feature of the GLFC and GLATOS and has been identified for its success in promoting social ties and establishing relationships. These meetings are thought to increase the effectiveness of management coordination in the multi-jurisdictional Great Lakes (Leonard et al. 2011). Although the Joint Strategic Plan and coordination efforts from the GLFC have been viewed as an important and successful initiative for improving coordination and communication among management jurisdictions and researchers, room for improvement still exists to bridge across differences in culture and norms of science and practice.

Literature outside of fisheries on the science–practice or science–policy gap has highlighted the use of boundary organizations as a promising pathway to promoting the integration of science into practice/policy (Carr and Wilkinson 2005; O'Mahony and Bechky 2008). At present, boundary organizations are not yet well defined and are not formalized in agencies or other governing bodies. The GLFC and GLATOS are potential examples of how a boundary organization associated with multi-jurisdictional fishery management agencies can help with science transfer through facilitating and promoting awareness of biotelemetry research and studies, fostering collaboration and communication, and developing relationships and trust among researchers and practitioners (Krueger et al. 2018). Our findings highlight areas that may require reconciling among vocations including perceptions of challenges to narrowing the science–practice gap such as importance of stakeholder acceptance, awareness of new evidence, and prior experiences of key individuals (Table 8). Specific to telemetry, areas that GLATOS, as a potential boundary organization, could help address include perceptions of data use before or after peer-review, data sharing concerns, and reliability of biotelemetry information (Fig. 3).

4.6 How do the perceived barriers facing mobilization of biotelemetry data differ from the mobilization of knowledge more broadly?

We identified 25 unique barriers for mobilizing general scientific knowledge and found they were distributed evenly among the limitation category types: We identified nine unique socio-organizational barriers, six individual-level barriers, and 10 evaluative barriers (Table 8). Together, these results indicated that perceived barriers facing uptake and mobilization of findings from biotelemetry were fewer and more specific than barriers that face knowledge mobilization of new evidence. This finding is relevant because some types of barriers, including those falling into *socio-organizational and individual-level* barriers, are more easily resolved than others. For example, socio-organizational barriers (due to organizational inertia, path dependencies, and related established interests) are perhaps the type of barrier category most difficult to circumvent or resolve (Yang and Maxwell 2011, Nguyen et al. 2018b). Solving these types of barriers may require normative changes or legal changes in institutional approaches—fundamental changes that can be difficult if not impossible to engineer. Similarly, some individual-level barriers can also be thought of in terms of path dependency (i.e., past decisions or actions persisting through time leading to resistance to change). Although some individual-level barriers (such as access to evidence and research) can be resolved through minor and incremental shifts in behavior and policy, this approach is not true of all individual-level barriers. Specifically, the 'prior experiences of key individuals,' the most cited individual-level barrier, is characterized by a dynamic similar to socio-organizational barriers. Key individuals can understand problems and solutions in entrenched ways that can overlap with institutional contexts and prevailing incentive structures. Key individuals may rise to prominent positions precisely because of their subscription to a set of ideas and approaches commonly understood to be within institutional norms. Their perspectives can thus be difficult to change in ways that are profound or fundamental—types of change which are required to realize the promise of new technologies.

Resolving *evaluative* limitations, by comparison, is likely easier than addressing the *socio-organizational* barriers and *individual-level* barriers listed above. Evaluative barriers can (ideally) be addressed and resolved through continual refinement of new technology and corresponding increases in confidence in the accuracy of results. For example, limited sample size was the most cited evaluative barrier facing biotelemetry evidence. Resolving this barrier (i.e., by increasing sample size or demonstrating the sufficiency of existing sample sizes) would be an incremental change perhaps complicated by funding availability but is one that can be resolved if prioritized or enabled by cost decreases. Thus, evaluative barriers are fundamentally different from those emanating from legal structures or ideological positions and should be easier to resolve. Because socio-organizational and individual-level barriers are perhaps more intractable and more difficult to overcome than evaluative barriers, our results suggest that resolving barriers and improving uptake is likely more achievable for biotelemetry than for general types of new knowledge. This interpretation also suggests that the GLFC and GLATOS are well positioned to promote acceptance of biotelemetry evidence and that barriers to wider adoption of the technology and the evidence it produces were within our study more related to resource availability than organizational design.

5 Conclusions

Our study reinforces the epistemological value that biotelemetry brings to fishery management as highlighted by several key studies in this field around the world (e.g., Cooke et al. 2013, Thorstad et al. 2013, Mcgowan et al. 2016, Crossin et al. 2017, Lennox et al. 2017, Brownscombe et al. 2019). Biotelemetry possesses significant potential to answer questions relevant to both management and scientific enterprises and their intersection. The major challenge for biotelemetry to reach its fullest potential in informing fishery management lies within its practical limitations such as technological limitations, and most of all cost, which, from our findings, may be relatively more easy to overcome than challenges in using other types of scientific knowledge. As with other studies, our results suggested that the cultural divide between managers and scientists may be partly responsible for challenges to knowledge mobilization. Managers, researchers, and assessment biologists simultaneously considered the technology as both cost-effective and cost-prohibitive. This dual perspective can be considered as both confirmation of the significant potential of biotelemetry to resolve uncertainties and also a call for additional resources to collect, process, and disseminate knowledge generated by this method. Follow-up research to understand the evolving perceptions of knowledge users of biotelemetry would be worthwhile to understand the role of time (and implementation of recommendations to overcoming current barriers) in mobilizing scientific findings into practice.

The fact that socio-organizational and individual-level barriers to mobilizing biotelemetry knowledge were not commonly thought by interviewees as meaningful barriers was a noteworthy result of our study and was perhaps a function of an effective governance structure as well as shared norms and common goals. The mandates and activities, such as promoting trust, communication, relationship building, and networking that the GLFC and GLATOS prioritize, are in line with success stories and recommendations in the literature on overcoming the science–practice gap. Both organizations act as boundary organizations. To promote greater uptake of biotelemetry findings, GLATOS, in particular, should consider prioritizing activities that mitigate evaluative limitations highlighted in our study. Further, focusing on reconciling the science–practice divide by addressing misalignment in perceptions or understanding of fisheries prioritize, and shedding light on the policy or management 'black box' via continued meetings and platforms of networking may facilitate greater science transfer. To overcome the barrier of cost, GLATOS and GLFC could offer financial aid for start-up and maintenance cost of projects and continue to promote the epistemological value of biotelemetry in fishery management through continuous effective briefings and communication of research.

Acknowledgements We thank the members of the Great Lakes Fishery Commission community for their participation in our study. We thank the GLFC Science Transfer Program for funding this work (Grant ID#2013 BIN 44024) by way of Great Lakes Restoration Initiative appropriations (Grant ID #GL-00#23010). This paper is contribution 81 of the Great Lakes Acoustic Telemetry Observation System (GLATOS).

Authors' contributions All authors contributed to the study conception and design. Data collection was performed by Delle Palme. Material preparation and data analysis were performed by Pentz and Delle Palme with input from Nguyen, Cooke, and Young. The first draft of the manuscript was written by Delle Palme, Nguyen, and Pentz, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This work was funded by the Great Lakes Fishery Commission (Grant ID #2013_BIN_44024) by way of Great Lakes Restoration Initiative appropriations (Grant ID #GL-00E23010).

Availability of data and material Transcribed interviews are not available due to confidentiality and anonymity agreements

References

Axinn WG, Pearce LD (2006) Mixed method data collection strategies. Cambridge University Press

Bertuol-Garica D, Morsello C, El-Hani CN, Pardini R (2018) A conceptual framework for understanding the perspectives on the causes of thee science-practice gap in ecology and conservation. Biol Rev 93:1032–1055

Brooks JL, Chapman JM, Barkley AN, Kessel ST, Hussey NE, Hinch SG, Patterson DA, Hedges KJ, Cooke SJ, Fisk AT, Gruber SH, Nguyen VM (2019) Biotelemetry informing management: case studies exploring successful integration of biotelemetry data into fisheries and habitat management. Can J Fish Aquat Sci 76:1238–1252

Brownscombe JW, Adams AJ, Young N, Griffin LP, Holder P, Hunt J, Acosta A, Morley D, Boucek R, Cooke SJ, Danylchuk AJ (2019a) Bridging the knowledge-action gap: a case of research rapidly impacting recreational fisheries policy. Mar Policy 104:210–215

Brownscombe JW, Lédée EJI, Raby GD, Struthers DP, Gutowsky LFG, Nguyen VM, Young N, Stokesbury MJW, Holbrook CM, Brenden TO, Vandergoot CS, Murchie KJ, Whoriskey K, Mills FJ, Kessel ST, Krueger CC, Cooke SJ (2019b) Conducting and interpreting fish telemetry studies: considerations for researchers and resource managers. Rev Fish Biol Fisheries 29:369–400

Carr A, Wilkinson R (2005) Beyond participation: boundary organizations as a new space for farmers and scientists to interact. Soc Nat Resour 18:255–265

Cooke SJ, Midwood JD, Thiem JD, Klimley P, Lucas MC, Thorstad EB, Eiler J, Holbrook C, Ebner BC (2013) Tracking animals in freshwater with electronic tags: past, present and future. Animal Biotelemetry 1:1–19

Cooke SJ, Martins EG, Struthers DP, Gutowsky LFG, Power M, Doka SE, Dettmers JM, Crook DA, Lucas MC, Holbrook CM, Krueger CC (2016) A moving target—incorporating knowledge of the spatial ecology of fish into the assessment and management of freshwater fish populations. Environ Monit Assess 188:239

Cooke SJ, Nguyen VM, Kessel ST, Hussey NE, Young N, Ford AT (2017) Troubling issues at the frontier of animal tracking for conservation and management. Conserv Biol 31(5):1205–1207

Crossin GT, Heupel MR, Holbrook CM, Hussey NE, Lowerre-Barbieri SK, Nguyen VM, Raby GD, Cooke SJ (2017) Acoustic telemetry and fisheries management. Ecol Appl 27:1031–1049

Fielder DG, Hayden TA, Vandergoot CS, Krueger CC (2020) Large-scale fish movement affects metrics of management importance as indicated by quantitative stock assessment. J Great Lakes Res 46:633–642

Francis JJ, Johnston M, Robertson C, Glidewell L, Entwistle V, Eccles MP, Grimshaw JM (2010) What is an adequate sample size? Operationalising data saturation for theory-based interview studies. Psychol Health 25:1229–1245

Gaden M, Krueger CC (2018) Multi-jurisdictional governance of the shared Great Lakes fishery: can a non-binding agreement work? In: Brooks S, Olive A (eds) Transboundary environmental governance across the world's longest border. Chapter 4. Michigan State University Press, Lansing, pp 51–75

Gaden M, Krueger CC, Goddard C, Barnhart G (2008) A joint strategic plan for management of great lakes fisheries: a cooperative regime in a multi-jurisdictional setting. Aquat Ecosyst Health Manage 11(1):50–60

Gaden M, Goddard CI, Read J (2012) A history of multi-jurisdictional management of the share Great Lakes fishery: transcending conflict and diffuse political authority. In: Taylor W, Lynch A, Leonard N (eds) Great Lakes fishery management and policy. Michigan University Press, East Lansing, pp 305–337

Guest G, Bunce A, Johnson L (2006) How many interviews are enough? An experiment with data saturation and variability. Field Methods 18:59–82

Hardin G (2009) The tragedy of the commons. J Nat Resour Policy Res 1(3):243–253

Hayden TA, Holbrook CM, Fielder D, Vandergoot CS, Bergstedt RA, Dettmers JM, Krueger CC, Cooke SJ (2014) Acoustic telemetry reveals large-scale migration patterns of Walleye in Lake Huron. PLoS ONE 9(12):e114833.

Holmlund CM, Hammer M (1999) Ecosystem services generated by fish populations. Ecol Econ 29:253–268

Hussey NE, Kessel ST, Aarestrup K, Cooke SJ, Cowley PD, Fisk AT, Harcourt RG, Holland KN, Iverson SJ, Kocik JF, Mills Flemming JE, Whoriskey FG (2015) Aquatic animal telemetry: a panoramic window into the underwater world. Science 348:6240

Krueger CC, Holbrook CM, Binder TR, Vandergoot CS, Hayden TA, Hondorp DW, Nate N, Paige K, Riley SC, Fisk AT, Cooke SJ (2018) Acoustic telemetry observation systems: challenges encountered and overcome in the laurentian great lakes. Can J Fish Aquat Sci 75(10):1755–1763

Lackey RT (1998) Fisheries management: integrating societal preference, decision analysis, and ecological risk assessment. Environ Sci Policy 1:329–335

Landsman SJ, Nguyen VM, Gutowsky LFG, Gobin J, Cook KV, Binder TR, Lower N, McLaughlin RL, Cooke SJ (2011) Fish movement and migration studies in the Laurentian Great Lakes: research trends and knowledge gaps. J Great Lakes Res 37:365–379

Lennox RJ, Aarestrup K, Cooke SJ, Cowley PD, Deng ZD, Fisk AT, Harcourt RG, Heupel M, Hinch SG, Holland KN, Hussey NE, Iverson SJ, Kessel ST, Kocik JF, Lucas MC, Flemming JM, Nguyen VM, Stokesbury MJW, Vagle S, Vanderzwaag DL, Whoriskey FG, Young N (2017) Envisioning the future of aquatic animal tracking: technology, science, and application. Bioscience 67:10

Leonard NJ, Taylor WW, Goddard CI, Frank KA, Krause AE, Schechter MG (2011) Information flow within the social network structure of a joint strategic plan for management of great lakes fisheries. North Am J Fish Manag 31(4):629–655

Lynch AJ, Cooke SJ, Deines AM, Bower SD, Bunnell DB, Cowx IG, Nguyen VM, Nohner J, Phouthavong K, Riley B, Rogers MW, Taylor WW, Woelmer W, Youn S-J, Beard TD (2016) The social, economic, and environmental importance of inland fish and fisheries. Environ Rev 24:2

Maxwell JA (2004) Using qualitative methods for causal explanation. Field Methods 16:243–264

McGowan J, Beger M, Lewison R, Harcourt R, Campbell H, Priest M, Dwyer RG, Lin H-Y, Lentini P, Dudgeon C, McMahon C, Watts M, Possingham HP (2016) Integrating research using animal-borne telemetry with the needs of conservation management. J Appl Ecol 54:423–429

Mulvaney KK, Foley CJ, Höök TO, Mcnie EC, Prokopy LS (2014) Identifying useful climate change information needs of Great Lakes fishery managers. J Great Lakes Res 40(3):590–598

Nguyen VM, Young N, Hinch SG, Cooke SJ (2016) Getting past the blame game : convergence and divergence in perceived threats to salmon resources among anglers and indigenous fishers in Canada' s lower Fraser River. Ambio 45(5):591–601

Nguyen VM, Young N, Cooke SJ (2017a) A roadmap for knowledge exchange and mobilization research in conservation and natural resource management. Conserv Biol 31:789–798

Nguyen VM, Brooks JL, Young N, Lennox RJ, Haddaway N, Whoriskey FG, Harcourt R, Cooke SJ (2017b) To share or not to share in the emerging era of big data: perspectives from fish telemetry researchers on data sharing. Can J Fish Aquat Sci 74:8

Nguyen VM, Young N, Cooke SJ (2018a) Applying a knowledge–action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study. Can J Fish Aquat Sci 75:1733–1743

Nguyen VM, Young N, Corriveau M, Hinch SG, Cooke SJ (2018b) What is "usable" knowledge ? Perceived barriers for integrating new knowledge into management of an iconic Canadian fishery. Can J Fish Aquat Sci 76:463–474

Nguyen VM, Young N, Brownscombe JW, Cooke SJ (2019) Collaboration and engagement produce more actionable science: quantitatively analyzing uptake of fish tracking studies. Ecol Appl 29(6):1316–1330

Olsson P, Folke C, Berkes F (2004) Adaptive comanagement for building resilience in social-ecological systems. Environ Manag 34(1):75–90

O'Mahony S, Bechky BA (2008) Boundary organizations: enabling collaboration among unexpected allies. Adm Sci Q 53:422–459

Pfeffer J, Sutton RI (2006) Evidence-based management. Harvard Bus Rev 84:62–74

Pullin AS, Knight TM (2003) Support for decision-making in conservation practice: an evidence-based approach. J Nat Conserv 11:83–90

Rose DC, Sutherland WJ, Simmons BI, Ivory S, Steiner N, Wu W, Dias MP, Nunes MH, Robertson RJ, Durán AP, Di Fonzo MMI, Nyumba TO, Wauchope HS, Norris L (2018) The major barriers to evidence-informed conservation policy and possible solutions. Conserv Lett 11:e12564

Rose DC, Amano T, González-Varo JP, Mukherjee N, Robertson RJ, Simmons BI, Wauchope HS, Sutherland WJ (2019) Calling for a new agenda for conservation science to create evidence-informed policy. Biol Cons 238:08222

Rousseau DM (2006) Is there such a thing as "evidence-based management"? Acad Manag Rev 31:256–269

Sunderland T, Sunderland-Groves J, Shanley P, Campbell B (2009) Bridging the gap: How can information access and exchange between conservation biologists and field practitioners be improved for better conservation outcomes? Biotropica 41:549–554

Sutherland WJ, Pullin AS, Dolman PM, Knight TM (2004) The need for evidence-based conservation. Trends Ecol Evol 19:305–308

Sutton J, Austin Z (2015) Qualitative research: data collection, analysis, and management. Can J Hosp Pharm 68:226

Thomas DR (2006) A general inductive approach for analyzing qualitative evaluation data. Am J Evalu 27(2):237–246

Thorstad EB, Rikardsen AH, Alp A, Økland F (2013) The use of electronic tags in fish research—an overview of fish telemetry methods. Turkish J Fisher Aquatic Sci 13(5):881–896

Vandergoot CS, Faust MD, Francis JT, Einhouse DW, Drouin R, Murray C, Knight RL (2019) Back from the brink: sustainable management of the Lake Erie Walleye fishery. In: Krueger CC, Taylor WW, Youn S (eds) From catastrophe to recovery: stories of fishery management success. American Fisheries Society, Bethesda, pp 431–466

Yang T, Maxwell TA (2011) Information-sharing in public organizations: a literature review of interpersonal, intra-organizational and inter-organizational success factors. Govern Inf Q 28(2):164–175

Young N, Gingras I, Nguyen VM, Cooke SJ, Hinch SG (2013) Mobilizing new science into management practice: the challenge of biotelemetry for fisheries management, a case study of Canada's Fraser River. J Int Wildlife Law Policy 16(4):331–351

Young N, Corriveau M, Nguyen VM, Cooke SJ, Hinch SG (2016a) How do potential knowledge users evaluate new claims about a contested resource? Problems of power and politics in knowledge exchange and mobilization. J Environ Manag 184:330–338

Young N, Nguyen VM, Corriveau M, Cooke SJ, Hinch SG (2016b) Knowledge users' perspectives and advice on how to improve knowledge exchange and mobilization in the case of a co-managed fishery. Environ Sci Policy 66:170–178

Young N, Corriveau M, Nguyen VM, Cooke SJ, Hinch SG (2018) Embracing disruptive new science? Biotelemetry meets co-management in Canada's Fraser River. Fisheries 43(1):51–60

Vivian Nguyen is an Assistant Professor at the Institute of Environmental and Interdisciplinary Science and the Department of Biology at Carleton University. Her research focuses on the interface of science, society and policy within the themes of environmental change, natural resource management, and food insecurity. Dr. Nguyen also has expertise in the human dimensions of environmental issues and mobilizing ecological knowledge into decisions, policy, and practice.

Caleigh Delle Palme is a founder and director of Wild Roots Nature and Forest School and recently joined the Marine Conservation team at Parks Canada. Her research interests are diverse and include environmental education, conservation science, fisheries management, human dimensions, ecopsychology, and human connection to nature.

Charles Krueger is the T.F. Waters Professor of Aquatic Ecology and Conservation at Michigan State University and former Director of the Great Lakes Acoustic Telemetry Observation System. He is keenly interested in discovering the ecological characteristics of fish species of conservation concern and then linking those results to their restoration, conservation, and wise use in fisheries.

Brian Pentz is a PhD candidate at the University of Toronto Scarborough. He is a social scientist whose research is concerned with the sustainable use of renewable resources and barriers to its realization.

Nathan Young is a Professor of Sociology at the University of Ottawa, Canada. His recent research includes investigations of environmental debates and controversies, and the role of different types of knowledge in environmental governance.

Christopher S Vandergoot is the Director of the Great Lakes Acoustic Telemetry Observation System and an Associate Professor at Michigan State University. His research focuses on providing fishery decision-makers with information regarding the ecology and population dynamics of native fish stocks throughout the Great Lakes basin.

Steve Cooke is the Canada Research Professor at Carleton University where he leads the Fish Ecology and Conservation Physiology Laboratory and is the Director of the Institute of Environmental and Interdisciplinary Science. His work spans the natural and social sciences with a focus on solving conservation problems.