From Fish Movement to Knowledge Movement: Understanding and Improving Science Transfer Related to Acoustic Telemetry in the Laurentian Great Lakes

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Abstract

Over the past decade, telemetry science has generated new knowledge with the potential to inform fisheries management in the Laurentian Great Lakes of North America. Yet, new information and scientific evidence must be timely, understood, and viewed as credible and relevant by fisheries managers and policy makers for it to be ultimately used in decision making and integrated into policies. In this thesis, I explore the Great Lakes fisheries network by conducting 50 interviews, with questions based on a knowledge mobilization framework, with managers, researchers and assessment biologists involved in Great Lakes fisheries to identify facilitators and barriers to knowledge transfer and adoption of telemetry science, their awareness to the strengths and limitations of telemetry data as well as their opinion on the role telemetry plays regarding fisheries management. Overall, there is a general awareness of the various strengths and limitations of biotelemetry research and technology in the Great Lakes. Mixed opinions emerged regarding the peer-review process, data sharing and integration of biotelemetry findings into management. There was slight uncertainty regarding the use of biotelemetry to reliably study ecosystems, its cost-effectiveness and biotelemetry's future role in standard assessments for the management of the Great Lakes fisheries. Overall, the largest perceived barrier of integration of new knowledge into management was characteristics of actors (e.g., understanding of science, change management issues, generational gap), followed by environmental and contextual (economical, government and institutional), knowledge transfer and characteristics of knowledge (applicability). I will discuss advice and recommendations for telemetry scientists and researchers to help them advance the understanding and incorporation of telemetry science into future decision making processes.

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Introduction

Timely, up-to-date and relevant scientific knowledge is essential to inform management decisions and ultimately increase the effectiveness of environmental management outcomes (Pullin & Knight 2003; Sutherland et al. 2004; Young et al. 2013; Nguyen et al. 2016). Ideally, management decisions would be based on the best-available and most up-to-date scientific evidence (i.e., an evidence-based approach; Sutherland et al. 2004; Rousseau 2006; Pfeffer & Sutton 2006). This is not always the case, as sociological research suggests that management decisions are commonly based on managers' personal experiences, patterns gained from experience, anecdotal evidence, long-standing traditions, obsolete knowledge gained during one's educational career and conventional wisdom, rather than the best-available science (Pullin &Knight 2003; Pfeffer & Sutton 2013; Nguyen et al. 2017; Cooke et al. 2017; Young et al. 2016). There is a growing recognition among conservation scientists that environmental managers and practitioners must be provided with scientific information in a clear and understandable way, for them to act appropriately and make informed decisions (Sutherland, 2009; Chapman et al. 2015).

Recently, there has been a shift in thinking across many fields (ie: health science, business, education) to incorporate evidence-based decision making to increase the likelihood of successful outcomes (Sutherland et al. 2004; Pullin & Knight 2003). Evidence-based management is a movement in which policy decisions are made using the most current and best available science to ensure the sustainability of natural resources (eg. fisheries; Cooke et al. 2017). Unfortunately, guidelines and recommendations stemming from scientific papers are rarely effectively implemented and thus leaving a major gap between conservation science and action (Arlettaz et al. 2010). This gap between research, implementation and action is a phenomenon that is described as the science-action, research-implementation or knowledge-action gap and is gaining attention amongst conservationists and researchers worldwide (Nguyen et al. 2017; Arlettaz et al. 2010). The main reasons for this gap are: 1) managers do not get the relevant information in a timely fashion 2) scientists are simply not pursuing relevant projects that are required by the management team 3) lack of support economically, politically and socially and 4) lack of commitment by the scientists themselves to promote their findings and engage in conservation implementation (Arlettaz et al. 2010). Natural resources, including fisheries, are often too complex to be managed by one individual or even agency alone (Berkes 2009). Neutral and trusted mediator groups, called boundary organizations (reviewed below), are often established to reduce the knowledge-action gap, while helping to initiate and foster successful knowledge transfer and mobilization (KTM) between scientists and policy-makers (Gustafsson & Lidskog 2018).

KTM is an iterative exchange of information between producers (ie: researchers, scientists, assessment biologists) and users of knowledge (ie: managers, policy-makers) (Kiefer et al. 2005; Mitton et al. 2007) The primary objective of the study of KTM is to increase the chance of study findings to be incorporated into policy while also enabling researchers to identify relevant and applicable management questions and needs (Mitton et al. 2007). Successful uptake of knowledge requires more than one-way communication from researchers to managers, but requires repeated interactions between both parties (Lavis et al. 2003; Mitton et al. 2007). Typical recommendations for knowledge mobilization of science into practice and policy usually require scientists to 1) collaborate and allow for input from knowledge users (ie: managers), 2) engage with stakeholders and the public, 3) enhance and increase their science communication techniques and to 4) develop trustworthy relationships with knowledge users (Brooks et al. 2018). Nguyen et al. (2017b) present a theoretical framework that can be used to assist in understanding knowledge movement and reducing the knowledge-action gap in conservation and natural resource management. In this study, I use an exploratory approach by using the framework as a guide in the research design and asked open- and close-ended questions to elicit views of fisheries professionals in the Great Lakes associated with a boundary organization (Great Lakes Fishery Commission), to find out what works and what does not work with regards to KTM.

Boundary Organizations and their Role in Reducing Knowledge-Action Gaps

The concept of boundary organizations emerged in the late 1990s, after observations of specific groups that put efforts into facilitating science that will inform management decisions, leading to more productive policy-making (Guston 2001; Gustafsson & Lidskog 2018). The primary role of boundary organizations is to facilitate collaborations, co-produce knowledge and mobilize new knowledge between researchers and policy-makers (Cook et al. 2013; Gustafsson & Lidskog 2018). With the growth and breadth of environmental issues, there has become a dependence on the expertise of researchers and an increased need for evidence-based management and policies (Gustafsson & Lidskog 2018; Beck et al. 2014, Mitchell et al. 2006; Nowotny et al. 2001; Cooke et al. 2017). Co-production of knowledge can facilitate trust between researchers and managers, ultimately increasing KTM and uptake of science information that can inform management actions (Fazey et al. 2014; Young et al. 2016b). Boundary organizations allow for a collaborative process between researchers and policy decision makers to achieve their goals but at the same time remains independent and ensures accountability to both sides (Cook et al. 2013). For example, boundary organizations support scientists and researchers by facilitating research projects and by demonstrating to politicians that their research is relevant. They support managers by ensuring integrity of research and that scientists are conducting projects that contribute to their needs and goals (Guston 2001). By boundary organizations remaining independent, it can help attract funding from a variety of funding sources and help bring various groups together who, in the past, have had an uncooperative relationship (Cook et al. 2013). Bridging the divide between science and management teams is essential as boundary organizations help facilitate co-production of study designs and research methods, as well as, providing platforms to increase face-to-face interactions. Boundary organizations host workshops and meetings, curating a collaborative environment to create useable, policy-relevant knowledge (Nguyen, 2018). There is a growing amount of conservation success stories from the integrated co-produced and co-managed approach (Chapman et al. 2015). Boundary organizations tend to work more effectively on specific issues in a specific region (Cook et al. 2013). The Great Lakes Fishery Commission (GLFC) and their associated acoustic telemetry network, Great Lakes Acoustic Telemetry Observation System (GLATOS), are excellent examples of boundary organizations that help to span the boundary been science and practice, as described in Table 1, and discussed in more detail below.

The case: Laurentian Great Lakes fishery

The Laurentian Great Lakes (LGL) of North America represent a vast reservoir of the world's fresh surface water of arguably the most important aquatic ecosystems in the world (Jones & Taylor 1999). The basin is situated in Canada and the United States of America and consists of 5 lakes – Lake Superior, Lake Michigan, Lake Huron, Lake Erie and Lake Ontario. It is the largest group of freshwater lakes in the world and comprises of ~ 150 species of fish (Landsman et al. 2011). The LGL are home to 30% of the Canadian and 10% of the American population and are an important resource socially, culturally and economically. The basin hosts three major fishing sectors: native/indigenous communities, commercial and recreational (Mulvaney et al. 2015). The fish and game industry generates approximately $18 billion US annually in the Great Lakes region (GLRC, 2005). Like many other freshwater ecosystems across the globe, the LGL are facing several environmental stressors and have experienced dramatic changes from pre-European settlement conditions

(Rothlisberger et al., 2010). For example, the LGL have been subject to toxic point source pollutants, nonpoint source pollutants from agriculture and forestry, invasive species (ie: sea lamprey), climate change, habitat destruction and fisheries decline (Smith et al., 2015). The resource extraction by humans over the past two centuries resulted in the overall decline of resources and species extirpation (eg. Lake Trout) (Mulvaney et al. 2015). The resources of the LGL are very complex to manage as the basin is vast geographically and is situated in two countries, Canada and the US, and boarders eight states and the province of Ontario. Historically, the poor management of the Great Lakes fishery during the first half of the 20th century, and the lack of cooperation from federal, provincial, state and tribal agencies has been said to have contributed its degradation (Gaden et al. 2012). However, with the help of the GLFC and 1997 Joint Strategic Plan, the Great Lakes has a unique path to transitioning to cooperative fisheries management as well as specific programs and procedures in place to facilitate the knowledge transfer process and to enable the information flow from researchers to managers (Gaden et al. 2012), making it an interesting and worthwhile case study.

The management of the Great Lakes fishery did not start off with a cooperative management model- there were several failed attempts between the late 1800s and 1950s to build a management structure based on cooperation from all eight states involved and Ontario (GLFC, 2018). It took the invasion of sea lamprey into the Great Lakes and the 1954 Convention of the Great Lakes Fisheries that finally initiated a cooperative model. During the convention, the GLFC was born with the mission to help agencies work together, control sea lamprey and advance science (See Table 1). In the 1960s, individual Lake Committees were formed as a place to share information and stay informed on issues. The Lake Committees consist of lake managers in which their main role is to create fisheries polices grounded in science. Technical Committees were then established by the Lake Committees and consist of federal officials and third party academics whose role is to provide biological expertise and the best science-based information possible without political and social pressures to the Lake Committees (Gaden et al. 2012). Today, the GLFC serves as a type of boundary organization to aid with the coordination of the multijurisdictional management arrangement and to provide advice and recommendations to partnering agencies (Mulvaney et al. 2015). Through GLFC and the 1997 Joint Strategic Plan for Management of the Great Lakes Fisheries, specific programs and procedures (such as the Science Transfer Board and Science Transfer Program) were created to facilitate the knowledge transfer process, enabling information to flow from researchers to managers and across international borders (Gaden et al. 2012).

Fisheries Management and Acoustic Telemetry in the Great Lakes

Management of fisheries has become a global priority due to the decline of the world's marine and inland fish populations (Pauly et al. 2005; Cooke et al. 2016b). The objective of fisheries management is often to allow for near-maximum sustainable yield by continued fish stock assessment and by regulating fish mortality (O'Farrell and Botsford 2006; Punt et al. 2014). However, there is also recognition of need to manage for biodiversity and consider interactions of different fish stocks (i.e., an ecosystem approach to fisheries management; McGowen et al. 2017; Brooks et al. 2018;).

There is a growing capacity for biotelemetry research in the LGL to aid with fisheries management objectives (Brooks et al. 2017). Electronic tagging techniques, otherwise known as biotelemetry, are transforming and improving our understanding of freshwater fish spatial ecology and thus providing the opportunity to make management and conservation initiatives more effective (Lennox et al. 2016; Hussey et al. 2015). Biotelemetry is considered one of the most effective tools for the study of individual animal behaviour and ecophysiology in the animal's natural environment. It has allowed for the study of fishes at vast depths, over large geospatial scales, in turbid waters, throughout all seasons including under ice and several other challenging environments (Cooke et al. 2013). With continued improvements to tagging and tracking technology, fishes can now be monitored across all seasons and life stages in a wide variety of habitats (Cooke et al. 2013). The use of acoustic telemetry (a specific type of technology within the sphere of biotelemetry) has quickly expanded in the LGL in the past decade (Krueger et al. 2017). Fisheries scientists and researchers are using acoustic telemetry to gather knowledge regarding native and invasive fish movement, migration patterns, spawning behaviours and population dynamics (Cooke et al. 2013). Acoustic telemetry is an electronic tracking tool that consists of two parts- 1) Acoustic tag- which is surgically implanted or attached to a fish and transmits a unique signal 2) Acoustic receiver- data logging computers that are anchored to the bottom of river/lake bed that decode the signals and adds a date/time stamp. An acoustic array consists of several receivers over a study area and identifies a fish in a specific location. The use of acoustic telemetry as a fisheries management tool in the Great Lakes had grown in popularity among fisheries scientists in the last 2-4 decades (Landsman et al. 2011).

The increased usage of electronic tagging and tracking technologies (ie: acoustic telemetry) could be partly due to the important coordination efforts and networking conducted by GLATOS (Great Lakes Acoustic Telemetry Observation System), which was established by the GLFC in 2010. GLATOS is an international initiative, that was established by the GLFC, which fosters multi-agency (62 agencies/institutions) collaborations between telemetry researchers and their projects while helping to overcome barriers and challenges (Crossin et al. 2017). Networks like GLATOS are particularly important as it increases the affordability and cost-effectiveness, allows for opportunities to share equipment and data, ensures study designs do not conflict while allowing for complementary objectives, having a centralized system for data warehousing as well as providing up-to-date scientific information to managers to help with decision-making (Crossin et al. 2017, Krueger et al.

2017). GLATOS supports transfer of information gained from studies to management agencies via Lake Committees, Council of Lake Committees and Sea Lamprey Control Board (See Table 1). The technology has also gone under several advancements in the past decade which allows for improved science and management of Great Lakes fisheries (Landsman et al. 2011). GLATOS allows for collaboration, input and assistance from management agencies in study designs to ensure that studies are relevant to the management team and that their needs are met. As of February 2018, GLATOS is associated with 60 projects and 8500+ fish released representing 40 species. These fish have been tracked using over 8300 receiver deployments and generating hundreds of millions tag detections.

The extent to which this new knowledge gained from acoustic telemetry studies is used and shared within the GLATOS and management community and ultimately used in decision-making is unknown. To achieve successful fisheries management, it is essential to understand human dimensions (the social attitudes, processes, and behaviours related to how we maintain, protect, enhance and use fishery resources) (Heck et al. 2016). Thus, we must not only account for environmental factors (biological and ecological), but social and economic factors as well. However, the integration of social sciences and the human dimension aspects to projects regarding sustainable fisheries management is currently limited. Research in the social sciences has found that sharing data within management communities is not an easy task, and uptake by various knowledge users is not easily embraced, and thus telemetry data may also prove difficult to transfer. For example, previous research conducted by Nguyen et al. (2017) in the Fraser River salmon fisheries in British Columbia, Canada, has found that there are barriers to adoption and implementation of new telemetry knowledge from institutional structures and government processes. Other studies found that there is controversy regarding the overall practicality of biotelemetry as a research tool, and main concerns include the cost of equipment, time lags, limited spatial coverage, tag effects on the behaviour and health of fish, high and complex data that is difficult and time consuming to interpret, as well as issues of accessing data and findings (Young et al. 2013; Young et al. 2018).

With millions of dollars being invested into biotelemetry projects and infrastructure, it is important to understand and track how new knowledge and findings gained from telemetry studies are transferred and understood by management agencies and, used in fisheries policies. Due to the very nature of telemetry technology, findings are generated rapidly and thus it is essential that new knowledge is effectively transferred and used to support evidence-based decision-making. For the sake of successful fisheries in the Great Lakes, it is critical that new scientific knowledge stemming from telemetry studies is generated and shared in a clear method so it is understood and accepted by fisheries managers and thus, incorporated into management plans and decision-making.

Table 1. Example of boundary organizations in the Great Lakes that facilitate the transfer of policy relevant science into management decisions and actions.

Boundary Organizations and Missions	History and Funding Sources	Duties	Science Transfer Initiatives and Programs
Great Lakes Fishery Commission (GLFC) Mission: -Advance science -Establish partnerships -Control invasive sea lamprey.	-Established in 1954 during the Convention of the Great Lakes after invasion of sea lamprey -Funded by both Canadian and U.S. federal governments	-Facilitates the *Joint Strategic Plan For Management of Great Lakes Fisheries* - Coordinates, conducts and communicates science -Fishery Research -Science Transfer	- Regular Lake Committees and Lake Technical Committee meetings -Science Transfer Board -Science Transfer Program -Annual March meeting

		- Sea Lamprey Control	
Great Lakes Acoustic Observation System (GLATOS) Mission: -Understanding fish behaviour relating to Great Lakes ecology - Providing up-to-date scientific evidence to support fisheries management decision making.	-Established in 2010 -GLATOS represents the Great Lakes node within the global tracking network, Ocean Tracking Network -Funded by GLFC and the U.S. Great Lakes Restoration Initiative.	-Created network of telemetry researchers - Facilitates project collaboration and coordination - Facilitate partnerships to share findings, data and equipment -Science Transfer -Educating the public on various projects -Data management and data sharing policies	-GLATOS Annual Coordination Meeting -Workshops -GLATOS R Manual Data and R-package

Thesis Objective

The overall goal of this thesis is to understand the mechanisms behind the facilitators and barriers of knowledge transfer of telemetry findings to Great Lakes fisheries managers, as well as, to investigate if the strengths and limitations of biotelemetry technology are understood by the management community. I used an exploratory research method based on interviews containing a mix of closed- and open-ended question, to elicit information on Great Lakes managers, researchers and assessment biologists' experiences, perceptions, beliefs, attitudes and values about the potential role of telemetry science in the Great Lakes. I also obtained information about the current level of interaction among parties within the knowledge network (managers and scientists), knowledge actors (who, what how many people are involved), characteristic and perceptions of actors (education background), characteristics of knowledge (relevancy to current work), environmental and contextual dimensions (social, economic etc.) It is my hope that information gained from this study can then be used to address knowledge gaps and barriers of biotelemetry research to then develop communication platforms and practices to better connect managers' knowledge needs and professional habits.

Methods

Interview development

I interviewed fisheries managers, researchers and assessment biologists (see Table 2) that are either a member of the GLFC's Lake Committees or Lake Technical Committees. The interview contained 25 questions that were developed with the knowledge-action framework as a guideline, as well as advice from collaborators and members of the GLFC (Andrew Muir and Jessica Barber) (See Appendix). The interview was part of a larger project "From Fish Movement to Knowledge Movement" and was divided into four main sections: (1) getting to know the knowledge actors (who, what, how many people are involved) and their basic characteristics (age, skills, personality, educational background); (2) understanding the knowledge network (the way in which one receives information, the people with whom they receive and share information with, who they seek/give advice to, who they consult with regards to who they work with); (3) understanding their perceptions regarding biotelemetry science; (4) understanding characteristics of knowledge (ie: local, traditional or scientific knowledge) to look at their views on new science and the best methods of delivery (best way to mobilize the knowledge). Questions analyzed in this thesis relate to parts (1) and (3), and were asked in order to gain insight on participants' experience and knowledge with regards to biotelemetry and included open-ended (participants were free to answer in any way they chose) and close-ended questions (5 point Likert-scale). The interviews were semi-structured and provided the opportunity for participants to speak in-depth about their responses.

In cases when a participant asked me to define biotelemetry, I answered with a prepared response: biotelemetry is referred to and the electronic tagging and tracking of animals remotely within their natural environment (Cooke et al. 2004). Two trial run interviews were conducted and was pre-tested with two members of the Fish Ecology and Conservation Physiology Laboratory at Carleton University, who have expertise in biotelemetry techniques and research. Their responses were omitted from results. There were no adjustments made to the interview guidelines following the pre-tests. The study kept the participants' anonymity and was approved by the Carleton University Ethics Board (#106530).

Data Collection

In consultation with the GLFC (Andrew Muir and Jessica Barber), a list of ~100 members of a Lake Technical Committee or Lake Committee was retrieved. Initial invitations to participate in the study were sent out on 6 June, 2017 via e-mail. There were 10 bounce-back e-mails and one response indicating that they were unavailable to participate. Reminder e-mails were sent out on the 30th of June and the 18th of July, 2017. I conducted 49 semi-structured telephone interviews and one e-mail interview, totaling 50 interviews (Table 2). The interviews took place between June- October 2017 and lasted between 35- 70 minutes. I used a mixed-methods approach and asked open and closed-ended questions (Axinn & Pearce 2006). Open-ended questions (Q1-7, Q9a-e, Q10, Q11a-e, Q12, Q14-25) included questions about participants' background, their knowledge network, biotelemetry science and the process of generating new science. Closed-ended questions (Q8, Q13A-K) included questions on how often participants seek out scientific information relevant to their work; and a series of Likert-style questions regarding biotelemetry science for which participants were asked to indicate their level of agreement on a five-point scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree) with an option to say “I don’t know”. Participants were asked to explain why they had chosen their response to the Likert scale questions. To avoid interview bias, I remained neutral (showing neither approval or disapproval to certain responses) during my interactions with participants. A great deal of care and thought was put into the ordering of questions, as to not give out any information that participants could use in subsequent responses. Double-barreled (questions that ask too many things at once) and loaded questions (a question that is written to lead participants to respond a certain way) were avoided. Likert-scale questions were worded and ordered to avoid ‘yea-saying’, which is the tendency for a participant to agree to all questions asked.

Data Analysis

Questions analyzed in this thesis include: Q10, Q11, Q11A, C, Q13A-K and Q17 (Table 3, Appendix). The interviews were transcribed into text with the help of Transcribe- an online transcription service. Qualitative analyses were conducted using the computer software, NVivo 12. I used the software to help effectively organize, manage, analyze and code the qualitative data. The coding process helps to identify main topics and issues that were discussed by participants (Sutton and Austin, 2015). I used the ‘Case Classification’ feature that helped to analyze differences in responses between the type of fisheries professionals (Researcher, Manager, Assessment biologist) (Table 2). I used an inductive coding strategy to analyze the open-ended questions and followed a three-step procedure (Thomas, 2006). Every question was read and key words were identified and were written down in a list of potential codes. Codes were created in the Nvivo software, and the responses were read a second time and quotes were highlighted, thus categorizing quotes into the various themes. Themes were measured by their number of prevalence. Likert-scale responses were tallied and given in percentages (Table 8). Responses are presented both quantitatively (how many times a code was highlighted) and qualitatively by providing quotes).

Table 2. Affiliation of Participants by Committee Membership and Position.

Committee \ Position	Manager (n=27)	Researcher (n=12)	Assessment Biologist (n=11)	Total (n=50)
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
Total	27	12	11	50

Table 3. Interview questions analyzed.

Question	Type	Reference #
Have you used biotelemetry in your own work?	Open-ended	Q10A
Do you think biotelemetry could play a role in managing fisheries in the Great Lakes? [If yes, how important is biotelemetry information in relation to other kinds of information in your decision making?]	Open-ended	Q11 Q11A
What are the strengths of biotelemetry?	Open-ended	Q11B
What are the limitations of biotelemetry?	Open-ended	Q11D
Eleven opinion statements on biotelemetry research	Close-ended, Likert style	Q13A-K
In your experience, what do you think are barriers to using new scientific knowledge in fisheries management?	Open-ended	Q17

Results

Use of Biotelemetry in their work

To gain an understanding of participants' familiarity with biotelemetry, we asked "Have you used biotelemetry in your own work?" (Q10A). In response to question 10A, a majority of participants have used biotelemetry in their own work (n=34) while a minority have not used it (n=16). Of those participants who have not used biotelemetry, 50% were managers (n=8), 25% researchers(n=4) and 25% assessment biologists (n=4).

Role of Biotelemetry in Managing Fisheries in the Great Lakes

In response to Q11, a majority of participants (n=37) enthusiastically responded positively to the role that biotelemetry plays in managing fisheries in the Great Lakes. Zero participants outright said no, while nine participants discussed that biotelemetry is currently helping to address specific issues/questions, six participants said biotelemetry will have a potential role in the future, while one person commented on having difficulties interpreting data and analysis. One participant had a mixed response stating 'yes and no' and went on to explain that biotelemetry information helps to *inform* management to be more effective but the information *itself* does not manage fisheries, as illustrated below:

Yes and no. Not in terms of direct management, but it could be extremely informative to help us understand how fish stocks move, spread out and intermix, what jurisdictions they are in and what the fisheries are being exposed to. All of that is very important information to have effective fisheries management. So, the information itself doesn't manage or necessarily manage but it will inform management to be more effective. (Interview # 40, Researcher).

The quotations below illustrate the positive responses regarding the role of biotelemetry in the Great Lakes, as discussed above:

Absolutely! Some of the great unknowns are what fish do, and where they spawn. Some things that have never been seen before have been discovered through telemetry. (Interview # 19, Assessment biologist)

Certainly, I think it is pretty important from the standpoint that it answers questions that are still out there right now and I think that that type of study and movement would be certainly beneficial. (Interview # 25, Researcher).

Yes, no doubt. The information we've been collecting already is directly applicable to management questions so it's a much more powerful tool than jaw tags, so yes absolutely! (Interview # 2, Manager).

Out of the nine participants who discussed that biotelemetry is helping with specific issues/ questions, six were managers. The quotation below illustrates this point:

It comes down to the particular issue, and the type of issue. I think for certain questions, it would be equally or more valuable than the kind of the standard information like assessment netting, commercial catch or recreational catch and stuff like that. I guess it comes down to what the actual issue is, and what you're trying to answer with all the data that is available. (Interview #23, Manager).

Importance of Biotelemetry in Decision Making

Findings from the open-ended question, Q11A, which asked about the importance of biotelemetry information in their decision making are found in Table 4 and Table 5. Positive or supportive comments are found in Table 4, while mixed or negative comments are found in Table 5. Compared to researchers and assessment biologists, managers expressed a greater range of response for both positive and negative comments. Many participants discussed that biotelemetry information is important for understanding distance and movements of fish (n=22) and helpful for identifying habitats and their usage (n=14) (Table 4). Other positive/supportive comments expressed by participants included that the technology help with stock assessments (n=11), better decision making (n=11) as well as increasing clarity and refinement of work (n=8). Most of the positive and supportive comments were expressed by all groups (researchers, managers and assessment biologists) with some exceptions. For example, managers were the only ones to discuss that biotelemetry helps with management models. The quotations below illustrate the positive responses discussed above:

To me what is exciting is this sort of information on individual fish movement which is what this thing gives you, it really, really captures the imagination of the public. Like I say, I speak and communicate to lots of different groups but it's often the public, and anglers in particular just love seeing the telemetry data and seeing you know, individual fish movement- it really speaks to them. So, I am excited to have as much data as we have now, and it looks like we're going to get even more. So, it's been really really good. (Interview #15, Manager).

Its important to see what different habitats they're using and from that information we may be able to have better regulations, so if a particular fish is vulnerable in a certain habitat during spawning we may be able to close a fishery in that area, or change the regulation seasons to help protect, if that's important to the species. (Interview #26, Manager).

The negative or mixed comments about the importance of biotelemetry information when it comes to the participants' decision making, can be found on Table 5. There were two common responses, the first type of response 'project dependent' (n=9) and the second response was 'biotelemetry is not as important as other fisheries tools' (n=9). Some participants acknowledged that 'in the future biotelemetry will play a larger role' (n=6), while one participant discussed that they struggle with data and analysis. The quotations below illustrate the negative responses discussed above:

> *Responses may vary by the type of project. That's a tough one, for example, for the walleye project it's definitely giving good information that's going to fine tune our management models so to me that's important, but it's not as important as a lot of the input data that we need to collect for our catch at age models. Versus the grass carp telemetry study that we have going on- we have no information on those fish so the information that we are collecting from that study is indispensable. (Interview # 2, Manager)*

> *It's early days for me on that. But I can see it being equally important as other types of information. It will be a part of it, but we do have a lot of information on the species already, and this is another part. But it wouldn't be the first thing I would start with if I didn't have any information. (Interview # 42, Assessment Biologist)*

Table 4. Positive or supportive comments about the role and importance biotelemetry information plays in participants' decision making when it comes to fisheries management the Great Lakes- in response to Q11A. Numbers reflect participants who discussed each category.

	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total (n=50)
Understanding distance and movement	5	12	5	22
Identifying habitat and habitat use	1	9	4	14

Helps with stock assessment	4	6	1	11
Helps with better decision making	3	7	1	11
Important management implications	2	7	1	10
Clarity and refinement of work increased	1	5	2	8
Learning sources and impacts of invasive species	1	2	1	4
Mortality estimates	0	2	1	3
Understanding behaviour	1	1	0	2
Helps with management models	0	2	0	2
Population parameters	1	0	1	2
Information collects itself	1	0	0	1
Understand impacts of climate change	0	1	0	1

Table 5. Negative or mixed comments about the role and importance biotelemetry information plays in participants' decision making when it comes to fisheries management the Great Lakes- in response to Q11. Numbers reflect participants who discussed each category.

	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total (n=50)
Depends on project type	0	7	2	9
Not as important as other tools	3	4	2	9
In-time will play larger role	0	4	2	6
Struggle with Data and Analysis	0	1	0	1
Unsure	0	1	0	1

Strengths of Biotelemetry

Findings from the open-ended question Q11B are given in Table 6, which demonstrates the range of discussed strengths of biotelemetry technology and research. In Table 6, the most commonly cited strength of biotelemetry by participants is that they gain a better understanding of the fine-scale movements of fish, including distance and migration (n=36). The ability of biotelemetry to generate various types of data is another common theme (n=32) that participants discussed as a strength, stating that biotelemetry can give you a 3D type picture of fish location (n=12), environmental parameters such as water temperature or pressure (n=11), and individual fish data (n=7). Data that is generated passively (n=6), continuously (n=6), in high volume (n=5) while being original (n=5) were discussed. Understanding habitat use (n=15), behaviour (n=14) using biotelemetry information in stock assessments (n=12) was seen as a strength by some participants. Understanding the geospatial and temporal distribution of fish (n=12), spawning locations (n=10) and helping with invasive species management (n=7) were discussed benefits (Table 6). The quotation below illustrates a common response of participants' regarding the strengths of biotelemetry:

> *Gives us actual data of fish movement- when and where and you don't have to guess or interpret from other tagging means. We know exact times and locations of where fish are moving. With that and some other data we can try and figure out why they are making those movements at those times. I know what some of the Telemetry stuff we can even determine, not only where they are moving within the lake, you can also learn what depth and temperatures they are using, and what the temperature is maybe at those depths, so that's important information as well. (Interview # 36, Manager)*

Table 6. Comments on the Strengths of Biotelemetry Technology and Research in response to Q11B (number of participants discussing).

	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total (n=50)
Understanding movement (distance, migration, fine-scale)	8	21	7	36
Data	8	19	5	32
3D picture of location	3	6	3	12
Environmental parameters data (information about)	1	8	2	11
Individual data	2	5	0	7
Passive collection	2	4	0	6
Continuous data	2	4	0	6
High volumes of data	1	4	0	5
Original data/ or information	1	1	3	5
Habitat Use	2	9	4	15
Behaviour	4	8	2	14
Stock Assessments (mixing of stocks)	4	7	1	12
Geospatial and temporal understanding of distribution	3	6	3	12
Spawning location	1	8	1	10
Invasive species management	0	5	2	7
Measuring mortality	3	2	0	5
Life History and ecology	1	3	1	5
Measuring survival	2	1	1	4
Ecosystem Interactions	0	1	2	3

Question generation	0	2	1	3
Physiological parameters (ex: heart rate)	2	0	1	3
Track individuals in natural setting	2	0	0	2
Fosters Collaborations	0	1	0	1
Not familiar enough with biotelemetry to answer	1	0	0	1

Limitations of Biotelemetry

Findings from the open-ended question Q11D can be seen in Table 7. The most commonly cited limitation of biotelemetry technology is high cost (n=19) and small sample sizes (n=13). Other limitations discussed by participants were that the number of receivers are limited (n=10) and that biotelemetry research requires a large time investment (n=8). A focus on individual fish rather than populations were seen as unhelpful (n=7) while some suggested that data sets were too large, causing data management issues (n=7). The quotation below illustrates a common response of participants regarding the limitations of biotelemetry:

> *The issue is because of the high cost, the sample sizes can be low and that's also another statistical problem and 50 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)*

Table 7. Comments on the Limitations of Biotelemetry Technology and Research in response to Q11D (number of participants discussing).

	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total (n=50)
Cost is too high	3	11	5	19
Small Sample sizes	2	6	5	13
Limited number of receivers	3	6	1	10
Requires a large time investment	1	4	3	8
Focus on individuals rather than populations is unhelpful	1	5	1	7
Data management issues because of large data sets	4	3	0	7
Require coordination and cooperation	2	2	1	5
Requires high amount of expertise to interpret	1	2	0	3
Retrieving receivers can be difficult	0	1	2	3
Can overwhelm receivers	1	2	0	3
Measuring mortality	1	2	0	3
Can't track fish in deep water	0	3	0	3

Study design flaws- not hypothesis driven	0	3	0	3
Cannot tag small fish/missing key life stages	1	1	1	3
Actually catching fish for a study	0	2	1	3
Not familiar enough with biotelemetry to answer	2	1	0	3
Concern with accuracy of movements	0	1	1	2
Battery limitations	0	1	1	2
Does not replace traditional tools	0	2	0	2
Not enough receivers /creates dark zones	1	1	0	2
Keeping up to date with technology is a challenge	0	0	2	2
Tag may affect fish behaviour	0	0	2	2
Invasive procedure	0	0	2	2
Lack of biological processes examined	1	0	0	1

Opinions and Perceptions of Biotelemetry Research, Data and Technology

Table 8 reveals findings from the eleven Likert-style opinion statements (Q13A-K) that were read aloud to participants during the interviews. All participants were unanimous for Q13A and Q13E, all agreeing or strongly agreeing that biotelemetry provides reliable information about fish behaviours in the Great Lakes, and information that they wouldn't otherwise have from other sources or studies (Table 8, A, E). When asked to elaborate on their answers the common responses were 'provides good movement and behavioural data'(n=11) and 'as long as the study is designed well' (n=5). For Q13C and Q13 K, the responses were consistent but with slight disparity. For the most part, there was general disagreement to the question, 'The handling involved with inserting or attaching telemetry transmitters onto fish make the data generated by biotelemetry unreliable', with 18% of assessment biologists (n=2) and 4% of managers (n=1) stating 'neither' and 9% of assessment biologist (n=1) stating 'I don't know'. When asked to explain, or elaborate on their answers, the most common responses were 'as long as proper procedures are followed' (n=11), 'from the studies and evidence that I've read, I believe its okay' (n=11) and 'from my own experience I believe its okay' (n=9). There was also a general disagreement to the question, 'I would be more comfortable using biotelemetry data and findings if the research was being conducted by researchers within my agency’, with 9% of assessment biologists (n=1) and 4% of managers (n=1) stating ‘neither’ and 4% of managers (n=1) stating ‘agree’. When asked to explain, or elaborate on their answers over half of participants (n=26) stated that ‘there are competent people elsewhere’, while other discussed collaborations/ networks in the Great Lakes are excellent (n=15) and that there is a great deal of trust (n=13).

Conversely, questions Q13G-J had a diverse spread of responses with regards to biotelemetry findings. For Q13G, Biotelemetry findings should be taken with a grain of salt, when asked to explain, or elaborate on their answers, the more common replies included that ‘all science should be taken with a grain of salt’ (n=13) and that one ‘must consider the strengths, assumptions and limitations’ (n=13). For Q13H, Biotelemetry data and findings should only be used by managers after being subject to a peer-review process, there were a range of replies from managers, while researchers tended to agree, assessment biologists tended to disagree more. When asked to explain, or elaborate on their answers, the most common reply for agreement was ‘it is best practice to go through peer-review’ (n=19) while the most common replies for disagreement were ‘not practical timing-wise’ (n=10), ‘results speak for themselves/ what you see is what you get’(n=11) and ‘you can still make decisions based on imperfect information’ (n=5). For Q13I, Biotelemetry data on fish movements and behaviour should be freely available to anyone who wants it, researchers tended to disagree, while managers and assessment biologists tended to agree. When asked to explain, or elaborate on their answers, the more common responses included ‘there are endangered and vulnerable species’ (n=11), ‘as long as the principal investigator has a chance to publish first’ (n=9), ‘need expertise to look at and interpret data’ (n=8) and ‘its best practice to share information’ (n=8). For Q13J, integrating new knowledge emanating from biotelemetry into management is difficult, assessment biologists all disagreed with 9% (n=1) stating ‘neither’ while a little over 1/3 of managers and researchers agreed. When asked to explain, or elaborate on their answers, the more common replies included ‘biotelemetry is not anymore difficult than other new methods to incorporate’ (n=12), that is was ‘situation dependent’ (n=7), ‘it’s easy to show people the results’ (n=6), ‘has direct application to management questions’ (n=6) and ‘new technology always has skepticism’ (n=6).

Finally, questions Q13B, Q13D and Q13F had a higher number of participants responses with ‘neither’ and ‘I don’t know’, although most participants still agreed to these questions. There was slight uncertainty to whether biotelemetry information can provide reliable information about ecosystems in the Great Lakes, whether it is cost effective and if biotelemetry should play a more standard role in fisheries management than it currently does. With regards to participants being uncertain to using telemetry to study ecosystems, seven participants discussed that ‘they have not seen studies that use telemetry to study ecological questions as a whole’ while three participants discussed that ‘you don’t glean enough information from telemetry studies to understand the ecology of the system’. Many participants who agreed discussed ‘that when biotelemetry is used in combination with other tools and techniques, some ecological information can be obtained’. Participants who discussed that biotelemetry is not cost-effective mentioned ‘that it’s still too expensive to do large scale projects’ (n=2), while seven people discussed that cost-effectiveness will improve over time. Comments to whether biotelemetry should play a more standard role include ‘depends on question that needs to be addressed’ (n=9), ‘it already plays a prominent role’ (n=8) and ‘biotelemetry is just another tool in the toolbox’ (n=8).

Table 8. Responses by Position type to Likert-style opinion statements about Biotelemetry (Q13A-K), percentages.

Question 13 (A-K)	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Don't Know
A. Biotelemetry provides reliable information about fish behaviours in the Great Lakes						
Manager	0	0	0	44	56	0
Researcher	0	0	0	42	58	0
Assessment	0	0	0	45	55	0
B. Biotelemetry provides reliable information about ecosystems in the Great Lakes						
Manager	4	7	11	56	11	11
Researcher	0	8	33	42	8	8
Assessment	0	9	18	73	0	0
C. The handling involved with inserting or attaching telemetry transmitters onto fish make the data generated by biotelemetry unreliable						
Manager	44	52	4	0	0	0
Researcher	8	92	0	0	0	0
Assessment	18	55	18	0	0	9
D. Biotelemetry research is cost-effective						
Manager	0	4	26	44	19	7
Researcher	0	0	8	67	17	8
Assessment	0	9	9	73	9	0
E. Biotelemetry provides us with information we wouldn't otherwise have from other sources or studies						
Manager	0	0	0	26	74	0
Researcher	0	0	0	36	64	0
Assessment	0	0	0	18	82	0
F. Biotelemetry should play a more standard role in fishery management than it currently does						
Manager	0	7	30	52	7	4
Researcher	0	0	33	67	0	0
Assessment	0	9	27	45	9	9
G. Biotelemetry findings should be taken with a grain of salt						
Manager	15	44	15	22	4	0
Researcher	33	50	8	8	0	0
Assessment	9	36	9	45	0	0
H. Biotelemetry data and findings should only be used by managers after being subject to a peer-review process						
Manager	15	33	7	30	15	0
Researcher	0	33	8	58	0	0
Assessment	9	73	0	9	9	0
I. Biotelemetry data on fish movements and behaviour should be freely available to anyone who wants it						
Manager	0	22	15	41	22	0
Researcher	8	42	8	33	0	8
Assessment	0	27	9	64	0	0
J. Integrating new knowledge emanating from biotelemetry into management is difficult						
Manager	4	42	19	31	4	0
Researcher	0	58	0	33	8	0
Assessment	9	82	9	0	0	0
K. I would be more comfortable using biotelemetry data and findings if the research was being conducted by researchers within my agency						
Manager	41	52	4	4	0	0
Researcher	45	55	0	0	0	0
Assessment	45	45	9	0	0	0

Barriers of Using New Scientific Knowledge in Fisheries Management

Next, I look at findings from Q17, regarding the potential barriers of incorporating new scientific knowledge into fisheries management. The knowledge-action framework from

Nguyen et al. (2017b), provided the structure for the coding of the open-ended responses. As shown in Figure 1, characteristics of actors was the most commonly discussed barrier to incorporating new scientific knowledge to fisheries management. Table 9 shows that there were 21 comments of themes related to characteristics of actors (n=21), with barriers to understanding science (and the strengths and limitations of it) (n=8), issues regarding dealing with change/ change management (n=7), generational issues (n=6) and social acceptance (n=1). Factors also included themes under environmental and contextual barriers (n=17), knowledge transfer (n=15), characteristics of knowledge (n=12), time (n=6), and one person responding with 'I don't know any barriers' (Figure 1; Table 9). In the discussion, I will expand on each theme and provide illustrative quotes.

Figure 1. Distribution of the number of respondents that identified barriers for incorporating new scientific knowledge in fisheries management based on an existing knowledge action framework (Nguyen et al. 2016).

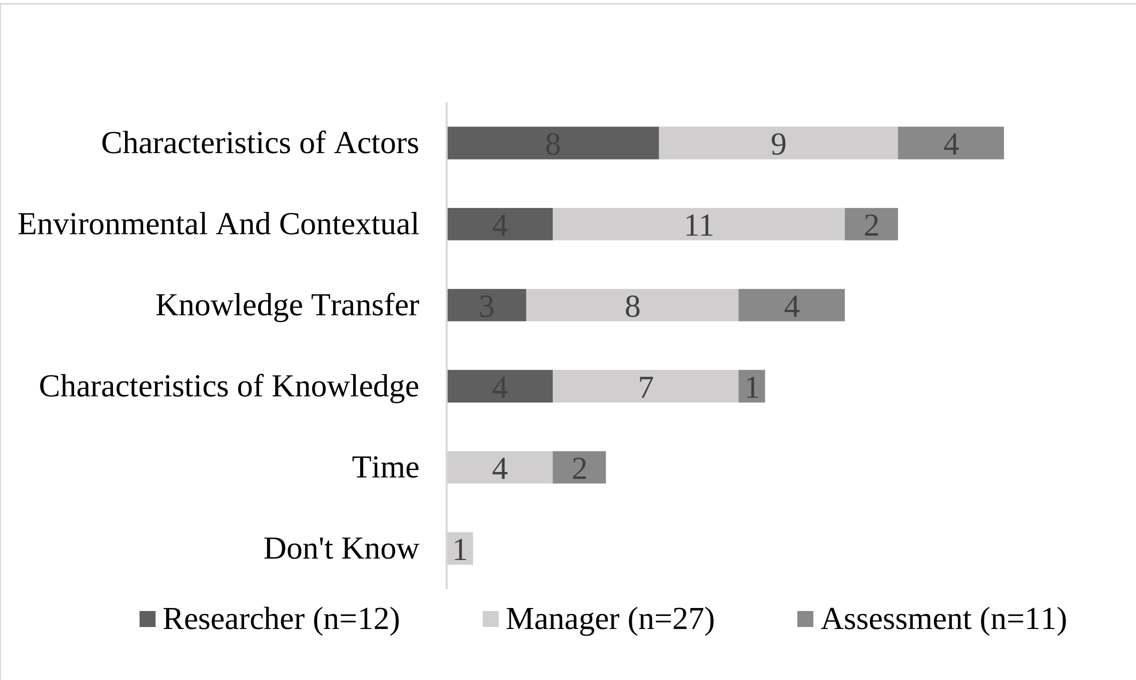

Table 9. Coded themes that emerged using a knowledge-action framework (Nguyen et al. 2016) with sub-themes that provide more description and context related to the framework categories. Numbers reflect participants who discussed each theme.

Barriers Coded	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total Partcipants (n=50)
Characteristics of Actors	**8**	**9**	**4**	**21**
Understanding science- limitations and strengths	4	3	1	8
Change Management	3	3	1	7
Age-Generational Issues	2	2	2	6
Social Acceptance and buy in of new knowledge by users	0	1	0	1
Environmental And Contextual	**4**	**11**	**2**	**17**
Economical	4	4	1	9
Government and Institutional	0	3	0	3
Social Impacts (Livlihoods)	0	5	1	6
Knowledge Transfer	**3**	**8**	**4**	**15**
Characteristics of Knowledge	**4**	**7**	**1**	**12**
Applicability-Useability-Relevance	3	4	1	8
Historical-Contradictory Evidence	2	2	0	4
Complexity	1	1	0	2
Reliability	0	1	0	1
Time	**0**	**4**	**2**	**6**
Don't Know	**0**	**1**	**0**	**1**

Discussion

Fisheries scientists need to understand the various components to how new information stemming from research studies enter the realm of management, and how managers view and use information in planning, decision-making and communication (Heck et al. 2016). Otherwise, managers and policy-makers may not use the information, or simply ignore it when making decisions, having deleterious consequences to biodiversity and the environment (Lemos et al. 2012). Our objective was to examine the GLFC’s network of fisheries professionals (researchers, managers and assessment biologists) to understand their perspectives on biotelemetry science, including their knowledge of the strengths and limitations of the technology and data, as well as, facilitators and barriers to incorporate new scientific information and ultimately increase KTM.

Participant Use and Opinions of Biotelemetry in the Great Lakes

First, my findings reveal that a majority of participants (68%) have used biotelemetry in their own work. This is not surprising as the use of acoustic telemetry has increased quickly in the LGL in the past decade, partly due to technological advancements of acoustic telemetry equipment, as well as research successes in the marine realm (Krueger et al. 2017). The GLATOS network established in 2010, helps to connect hundreds of researchers and provides a platform for collaboration on projects, data sharing, loaning of equipment, web-based data portals and aiding in science transfer to management (Krueger et al. 2017).

Second, participants are generally positive with regards to the role biotelemetry plays in fisheries management. When asked about the importance of biotelemetry information in relation to other kinds of information when making decisions, it was commonly discussed that biotelemetry has a role in: (1) the understanding of distance and movement of fish, (2) identifying important habitats and habitat usage, (3) helping with stock assessments and (4) overall improved and better decision making (Table 4). A review by Crossin et al. (2017) suggests that acoustic telemetry is an ideal technology for studying fish movements including migratory pathways, home ranges and, individual and population level variations in movement. Other applications of acoustic telemetry included in this review were habitat management and stock assessment which were also discussed by the participants. Habitat management is supported by acoustic telemetry as it can provide micro and macro scale information on how fish interact in various environments, helping with the study and conservation of imperiled or endangered species (Crossin et al. 2017). Evaluating stock structure and stock assessment parameters is also increasingly being studied with acoustic telemetry (Crossin et al. 2017). It is quite surprising that there were only two comments of acoustic telemetry helping with the study of fish behaviour, as the technology is commonly known for the study of animal behaviour (Payne et al. 2014; Cooke et al. 2004).

Third, only one participant said that they were unsure of the role of biotelemetry with regards to fisheries management in the Great Lakes (Table 5). Mixed comments include nine participants discussing that acoustic telemetry should only be used in certain projects, as well as, nine participants stating that biotelemetry is not as important as other fisheries tools (Table 5). Initially, biotelemetry studies tended to be more exploratory and descriptive (i.e. estimating movements patterns) and less hypotheses driven, which could be possibly explain the responses in Table 5. For science to be deemed relevant by fisheries managers, hypotheses and studies must be carefully tailored towards management goals and objectives and as of recent, studies have been more applicable to management (Crossin et al. 2017, Young et al. 2018). GLATOS has recommended researchers to have clear, concise study objectives, research questions and hypotheses (Krueger et al. 2017). When combined with other tools, disciplines and approaches, biotelemetry is a powerful tool to guide fisheries management, and is currently addressing relevant management questions of Great Lakes fisheries (Crossin et al. 2017; Krueger et al. 2017). Six participants discussed that acoustic telemetry is still too new of a technology and will play a larger role in fisheries management in the future. It certainly takes a lot of time and effort to understand and validate new technology, and there must be motivation from knowledge users to do so. Biotelemetry is still considered an emerging technology and requires that fisheries manages be trained to understand on how to use biotelemetry as a tool and well as a source of information (Crossin et al. 2017). Strong social relationships between knowledge producers and users is an important step to initiate this process (Young et al. 2016). It is recommended to continue having face-to-face communication venues such as meetings and workshops between researchers and managers, and to involve managers early in the research process, as this increases understanding, relevance and uptake of results (Krueger et al. 2017).

Last, there was only one negative comment when asked about the role biotelemetry plays in managing the Great Lakes (Table 5), even after stating ‘yes’ to biotelemetry playing a role. The comment was about the participant’s struggle with data and analysis:

There is a struggle of how to interpret data and what to do with all the spatial data. (Interview # 15, Manager).

This would be an impediment to knowledge movement of biotelemetry science. It first must accepted and understood by knowledge users for their opinion formation, and ultimately used in decision making. There is no doubt biotelemetry research is complex and thus researchers must work with management teams and be open and transparent about their methods and processes (Crossin et al. 2017).

Discussion of the Strengths and Limitations of Biotelemetry

Our findings reveal that participants have a general awareness of various strengths and limitations of biotelemetry data and technology (Table 6, Table 7). For example, there is a review of the strengths and limitations of biotelemetry technology in Fisheries Techniques (Cooke et al. 2012), and between all the responses of participants, they collectively captured all but one strength (non-invasive technique) as well as one limitation (sensor calibration is costly) that were discussed. There is a wider range of discussed strengths and limitations in this study, than in Young et al. (2018), with 22 strengths (compared to 16), and 23 limitations (compared to 19) discussed, although the Young et al. (2018) study also included stakeholders (not necessarily fisheries professionals). This collective knowledge could be in part due to GLATOS and their commitment to science transfer. Since 2012, GLATOS has encouraged researchers to present at the annual GLFC management meetings, which include lake managers in attendance. Lakes managers have also regularly attended to the annual

GLATOS meeting. The meetings have been successful and growing in attendance every year and offer opportunities to develop relationships and build trust between research and management (Krueger et al. 2017). Managers have been providing researchers with feedback regarding projects and study designs, and have initiated biotelemetry projects by themselves, securing funding from outside sources (Kreuger et al. 2017).

The most commonly discussed strength by participants was related to the benefits of understanding movement of fish (which includes fine-scale movements and distances travelled). Movement was discussed by 36 participants (72%), while in Young et al. (2018), speed/timing of movements was commented on by 19 % of participants, and migration routes was discussed by 13% of participants. This is not surprising in that in the Fraser River most work is focused on Pacific salmon which undertake long-distance migrations with issues of timing directly relevant to fisheries management (e.g., when to open and close a fishery). As previously discussed, movement patterns are commonly studied with the use of biotelemetry (Espinoza et al. 2011; Crossin et al. 2017). The fact that biotelemetry generates various data types and in high amounts was a common theme discussed among participants. Biotelemetry's ability to produce a high resolution picture of fish locations, as well as, coupling environmental parameter data was seen as a strength by some. The range of animal behaviours that can be studied using acoustic telemetry has increased with the addition of special sensors (pressure, temperature, acceleration) to tags (Crossin et al. 2017). Using biotelemetry to measure habitat use and to study behaviour was discussed and seen as a strength by 28% and 30% of participants. Acoustic telemetry is increasingly being used to study habitat preference and investigating behaviour (Krueger et al. 2017). Stock assessment parameters (i.e. mortality, timing) are now currently increasingly estimated using acoustic telemetry and used to evaluate stock structure (Crossin et al. 2017) and in which 12 participants discussed as a strength.

The biggest limitation of biotelemetry discussed by participants is its high cost. Funding is an issue for many researchers, and biotelemetry has high start-up costs. Young et al. (2018), also found the biggest limitation for biotelemetry research discussed by respondents on Canada's Fraser River in BC, is high cost. Data analysis can be expensive as biotelemetry projects create large and complex data sets that require full-time attention from a data manager (Krueger et al. 2017). With the help of networks like GLATOS, and their inventory of equipment, they can loan out acoustic receivers which allow for small projects to be conducted without a large investment (Krueger et al. 2018). The second most common discussed limitation was concern with small sample sizes, which was the fourth most common limitation in Young et al. (2018). As discussed above, tags are expensive and participants have concerns that a focus on individuals rather than populations is unhelpful (Table 7). The benefit of this limitation is that due to telemetry's high cost nature, it demands collaboration among researchers as they depend on each other for equipment sharing (acoustic array/receivers; Nguyen et al. 2016). Data sharing among researchers, along with smaller and more affordable tags being developed, aid in increasing sample sizes (Nguyen et al. 2016). However, it is also worth considering the costs of not knowing the answer to a given question.

Discussion of Likert-scale questions

Strengths and limitations were also assessed by asking a series of Likert-style questions. Participants unanimously agree that biotelemetry provides reliable information about fish behaviour in the Great Lakes as well generating unique data that no other sources or studies can obtain (Table 8, AE). As discussed previously, acoustic telemetry is increasingly being used for investigating behaviour (Krueger et al. 2017) and respondents in Fraser River in BC, most commonly discussed that a strength of biotelemetry is 'generation of original data’ (Young et al. 2018). Participants were generally comfortable with tagging techniques and the reliability of results stemming from tagging studies (Table 8), in contrast to results in Young et al. (2018). An abundance of recent studies have compared various tagging techniques with the objective to minimize stress and impact on animals (Cooke et al. 2013; Thorstad et al. 2013; Jepsen et al. 2015; Newton et al. 2016). Recent improvements have been made to tagging techniques along with the miniaturization of tags (Donaldson et al. 2014). Participants in this study also have a great deal of trust with each other and between agencies. Through the GLFC and GLATOS, there are platforms available for knowledge users and producers (i.e. researcher and managers) to interact, collaborate and increasing face-to-face contact which are known avenues for development of relationships and building trust (Krueger et al. 2017).

Diverse responses emerged when questions were asked about skepticism of biotelemetry findings, the peer-review process of biotelemetry findings, data sharing and integration of biotelemetry knowledge into fisheries management. When discussing the legitimacy of biotelemetry and if ‘biotelemetry findings should be taken with a grain of salt’, there seemed to be two common streams of thought by participants: 1) that all science should be taken with a grain of salt, not just biotelemetry (n=13) and 2) strengths, limitations and assumptions should always be considered (n=13). With responses like these, it implies that they are not biased towards biotelemetry, one way or another, but the first response may be taken as participants who may be skeptical of science in general. Study designs are taken into consideration by some (n=5) and others commented that they ‘just trust it’ (n=5). Stakeholders out in British Columbia on the Fraser River were also skeptical of biotelemetry as discussed in Young et al. (2018). Stakeholders had concerns with the high cost of biotelemetry, stating that there are other cheaper methods such as catch and escapement monitoring, as well as concerns to biotelemetry’s fit with current policy and management practices (Young et al. 2018). Complete transparency with assumptions made during biotelemetry research could also help reduce skepticism. Clearly stating assumptions and efforts to reduce violations as exemplified in Holbrook et al. (2016), would aid in reducing skepticism.

When discussing the peer review process of biotelemetry findings, it was commonly reported that having findings peer-reviewed is simply best-practice (n=19), while others expressed that the results speak for themselves (n=11) and some expressed concerns stating that the timing of peer-review is not practical (n=10). There is often expectation for academic scientists to publish their work in peer-reviewed literature and there are often rewards and incentives given to scientists to do so (Young et al. 2013). Others have criticized peer-reviewed scientific papers with them being too formal in style, difficult to access, and hardly ever read by policy-makers, therefore, rarely reaches its intended user group (Sutherland et al. 2013; Young et al. 2016).With this divide in opinion on peer-reviewed science among Great Lakes fisheries professionals, a suggestion for researchers would be to use multiple lines of evidence and to tailor communication to the intended knowledge group (Groffman et al. 2010, Young et al. 2016).

Unwillingness to participate in data sharing among biotelemetry researchers can be a challenge (Hussey et al. 2015; Nguyen et al. 2017). Issues arise such as possessiveness of data and skepticism of large data systems by researchers (Kreuger et al. 2017). Our findings suggest the challenge of data sharing is present among Great Lakes fisheries professionals, as opinions were divided. Concerns included issues with endangered or vulnerable species (n=11), having the right to publish first in peer-review (n=11), and that telemetry data requires a trained professional that fully understands it, to interpret it (n=8). Some participants stated that it is simply best practice to share data (n=8), while others agreed because of the Freedom of Information Act (n=4). Establishing a centralized data management system with data sharing standards and protocols are an essential step to take advantage of the large amount of telemetry data (Krueger et al. 2017; Nguyen et al. 2017). A generational shift is beginning to occur with regards to attitudes about data sharing, as a recent study found that early career researchers were viewed data sharing more positively than senior researchers (Campbell et al. 2018). Benefits include increased geographic coverage for projects and better assessment of the fate of tagged fish (Krueger et al. 2017). Sharing research data can be a difficult conundrum and must be curated before dissemination so that it can be interpreted and reusable by others (Borgman, 2012)

Incorporating new knowledge stemming from biotelemetry research can help evaluate fisheries management and conservation strategies and improve management outcomes (Cooke et al. 2016). The opinion of Great Lakes fisheries professional with regards to integrating new science stemming from biotelemetry research is divided. The most common response was that 'biotelemetry is not anymore difficult than other new methods to incorporate', implying that any new tool or change to techniques is a difficult task, and not mutually exclusive to biotelemetry alone. I discuss barriers of integration in greater detail in below.

Participants expressed slight uncertainty about biotelemetry's ability to provide information about ecosystems in the Great Lakes, whether it is a cost-effective tool and if biotelemetry should play a more standard role in fisheries management. With regards to biotelemetry providing information about ecosystems, many participants responded that ecological information is an addition and information can be generated when combined with other techniques (n=22), while some respondents commented they have not seen studies or were unsure if biotelemetry can address ecosystem questions (n=7). Perhaps in upcoming meetings or workshops, there can be a section on using biotelemetry in a more ecological context. The issue of cost is brought up here in this questions again (reviewed earlier) with the main response to this question being ‘biotelemetry is undoubtedly expensive, but there is no other way of obtaining this type of information’(n=15). Lastly, while the role of biotelemetry in the Great Lakes was discussed previously (in which a majority agreed to it playing a prominent role), this question eludes to the future of biotelemetry in the Great Lakes, and if it should be a more standard tool. While some participants were unsure of its future, some participants commented that more telemetry research is needed (n=11), while some commented it was already playing a prominent role (n=8), while others expressed that it was question dependent (n=9). With the uncertainty of future funding toward biotelemetry projects (Krueger et al. 2017), success stories and benefits that telemetry studies are providing, must be appropriately shared with management teams and funding sources.

Discussion of Barriers of Using New Scientific Knowledge in Fisheries Management

Characteristics of Actors

The most commonly discussed barrier by Great Lakes fisheries managers, researchers and assessment biologists was related to characteristics of actors and includes: understanding of science, how people deal with change (i.e. change of technique/technology), generational gaps issues (age), and social acceptance of new knowledge (Table 8).

Understanding of Science

Lacking understanding of science and how it can be used to enhance management outcomes can delay its integration (Nguyen et al. 2017). Knowledge gaps exist between fisheries managers and policy makers due to the lack of effective science communication, translation and accessibility (Crossin et al. 2017). Understanding of science and its associated strengths and limitations was a dominant theme identified by managers (9), researchers (8) and one assessment biologist, as exemplified here:

Probably just understanding the limitations of it and their certainty, for example the limitations with the Telemetry stuff, there's new techniques and new tools available so making sure they are being applied properly and understanding what the limitations are. (Interview # 2, Manager)

The barriers are in the scientists' ability to make understandable to policymakers and fishery managers. We make lots of presentations on stable isotopes and all that seems esoteric. I'm not certain that the managers listen, and not sure they know how to use the information all the time. Certainly with telemetry, that's a little bit easier to understand with fish, where fish move, when and how often, and that kind of stuff -people get. They may not get some of the other stuff especially when you're talking about things that are little bit hard to explain. Geneticists are the worst people to explain what they do. (Interview # 6, Researcher)

Change Management

People and organizations have a tendency to resist new practices, methods or technologies and continue using what is familiar, even when something better exists (Anastasiadis and Chukova, 2019; Ram, 1987). Cognitive dissonance theory explains why people experience deep emotional responses and psychological discomfort when their beliefs are challenged, as people are motivated to maintain consistency among their thoughts and actions (Elliot and Devine, 1994; Festinger 1957). Motivation for change occurs only when the perceived cost of change is less than the cost of continuing with familiar practices (Anastasiadis and Chukova, 2019; Ram, 1987). Change management was seen as barrier by some researchers (3), managers (3) and 1 assessment biologist as exemplified here:

Change management is a big barrier. People are always comfortable with the techniques they know the most about, and have become familiar with throughout their careers. Anytime you insert anything new you automatically have uncertainty about it. To help with change you got to tell people things multiple times, it's a getting them out there and exposing them to it, it's giving and promoting buy-in. Once you see people involved in the work you gotta learn about it. (Interview # 4, Researcher)

In terms of management, I think there is a resistance to change. Depending on how new the science is, there is a risk factor depending on the degree of change in management action and policy with new science. That's one of the trade offs- if it has a strong effect (utilizing new science in management) there's usually a delay until there's more confidence. – (Interview # 43, Assessment biologist)

Many of the Great Lakes fisheries professionals that were interviewed have been working in their positions for several years, with the average time of 13.2 years, with 23 participants having their position for 15+ years and 8 participants in their positions for 25+ years. Understanding Great Lakes fisheries professional's knowledge of the strengths and limitations of biotelemetry research and technology gives insight into their willingness and motivation for using biotelemetry.

Age and Generational Issues

In the 21st- century work force, there is a range of demographics and consists of four generations (The Greatest Generation, Baby Boomer Generation, Generation X and the Millennial Generation) (Green, 2008). Generations are defined as a distinct group of people with the similar coming-of age-years and are influenced by important events of their time, such as, technological innovations, economic changes and political ideologies (Park and Park, 2017). Distinct events among generations lead to distinct behaviours, attitudes and beliefs (Park and Park, 2017). Each generation is also known to have their own unique communication and learning styles (Green, 2008; Hart 2017). This divide in generations can cause organizational issues and challenges, exemplified below in the following quotes:

Probably just an older generation of decision-makers who are less inclined to adopt some of the new stuff. It's hard to teach an old dog new tricks. There's probably a huge number of reasons of why that happens, but it probably happens with every generation. I'm not that old, but my ability to work my smartphone is not nearly what the staff that I hire for summer work is. When someone has been dealing with hard core netting for a large portion of their careers and someone comes and says we could do this by tagging some fish, and setting up these hydrophones with, they may not have the interest or the willingness to take the time to understand what exactly is going on. (Interview # 27, Assessment Biologist)

The barriers I would say are partly related to people who went to college 30 years ago and they learn how to do things a certain way. And of course each cohort that goes through things progressed and technology changes, and knowledge changes. For example, hydroacoustics doesn't get a lot of traction with the older generation because they think it's all smoke and mirrors and hocus pocus. They are certainly like that within our agency in within other agencies, like hydroacoustics gets taken with a grain of salt- they are not real comfortable with it. So you have to convince people that aren't used to it, the technology or *technique to get them to buy into it versus someone who is coming out of college and it's been exposed to it, and knows more intimately as what it can and can't do. They are much more open-minded and more acceptance to use it (Interview # 12, Assessment Biologist)*

Generational differences and associated challenges have been studied in other disciplines (i.e. health care, business) and countries (Hart, 2017; Park and Park, 2018). Tailoring to each generation by having a broad spectrum of communication techniques could help in bringing down barriers to implementing biotelemetry research and technology into practice.

Social Acceptance and buy-in of new knowledge

Knowledge claims and information stemming from new scientific evidence must be socially-robust for as it will be judged and scrutinized by knowledge users (Nguyen, 2018). Social acceptance received less attention than the three previous barriers but one manager eluded to social acceptance as a barrier in the following quote:

In my position specifically, any decision I make based on scientific findings- I have to be able to justify it at the end of the day, if I'm going to make a regulation change or policy change based on research, I have to absolutely be able to justify it and show why the change was made and how its based on the research findings. I think a lot of it has to do with communication. Here are the findings, this is why we believe they're important, and here's a change we are making based on them. (Interview # 16, Manager)

Implementing an evidence-based approach, along with incorporating knowledge from other sources (e.g. by engaging stakeholders) is a step forward in developing effective strategies for management of natural resources (Sterling et al. 2017). Collaborations and commitment to outreach and engagement strategies are known contributors to formal integration and social acceptance of new scientific findings (Nguyen, 2018).

Environmental and Contextual

External factors can influence the movement of knowledge and uptake of new scientific research such as economic context, governmental, institutional and social norms (Table 9).

Economical

The notion that "money makes the world go around" was highlighted in Nguyen et al. (2018), conveying that economic factors play a role in how scientific findings are used and mobilized. Economic barriers were discussed by managers (4), researchers (4) and one assessment biologist. Costs of new equipment, funding and financial budgets were perceived barriers, for instance:

> *With new technology- you equate that to cost. New technologies are pretty expensive, especially in the early stages, that's probably a primary barrier. (Interview # 41, Researcher)*

> *Cost, new gear, a lot of state agencies have certain equipment and gear already established for doing assessments and sometimes new science requires new technology and new gear- so that's often a barrier. (Interview # 36, Manager)*

Government and stakeholders in Canada's Fraser River salmon fisheries expressed economical concerns regarding practical issues (e.g. cost) of biotelemetry as a hindrance to integration of biotelemetry findings into policy and management (Young et al. 2018). It is recommended to effectively communicate that costs of telemetry projects decrease when using a cooperative approach and share equipment, data and findings.

Social Impacts

A lack of social support can risk the chance of implementation of scientific findings (Roux et al. 2006; Arelettaz et al. 2010). The impact of new technology and scientific evidence on society and livelihoods of stakeholders and local people received some attention by some managers (5) and one assessment biologist. For instance:

The other thing we have is stakeholder input which can make things very difficult even though - we as managers, hundred percent believe in our approach- it takes time effort and diligence to convince stakeholders that our approach is of value to them as well. (Interview # 34, Manager)

Practical involvement of researchers, managers, stakeholders and the general public in guiding management initiatives can help with acceptance and ultimately lead to successful conservation outcomes (Arelettaz et al. 2010).

Government and Institutional

Stagnant and inflexible government and institutional cultures can undermine and slow down the integration of new knowledge (Nguyen et al. 2018) and was also seen as a barrier by some managers (3) in our study. It can be difficult to incorporate new or "real-time" findings into policy, as exemplified in this quote:

In some instances, the science might move faster than policy. So I work government environment- there might be instances where science is happening so quick- it's hard to implement it as quickly as you might like. (Interview # 22, Manager)

Government induced restrictions for out of state travel to meetings and conferences was also seen as a barrier:

Well I think the biggest barrier right now is (and this pertains to work that's not yet been published) travelling to meetings. The ability to attend conferences and technical committee meetings and things like that. That's our biggest barrier right now- travel restrictions. Only when its published and in report form we can see it. But if there's something that's been planning or something that's been on going -we may not be aware of it because we may not be able to travel. Basically, government travel restrictions based on physical restraint. (Interview # 7, Manager)

Knowledge Transfer

Flaws and disconnect with the knowledge transfer process and communication was discussed as a barrier by managers (8), researchers (3) and assessment biologists (4). Having effective communication strategies on the effectiveness and applicability of new technologies, accessibility to journals and having platforms for interaction between managers and researchers are known to help with the knowledge transfer process. Many alluded to the fact that the knowledge transfer process as a barrier:

The barriers I see are about science transfer and that sometimes methods that we use in research are complex and there has to be a lot of effort and work devoted to making a new research tool understandable people that are very busy (often managers with full workloads). So science transfer is probably the biggest obstacle and making sure that it's done thoroughly and done the point where users are really well informed so that they can avoid pitfalls. So yeah, the biggest obstacle I see is science transfer. (Interview # 32, Researcher)

Characteristics of Knowledge

Attributes and the type of information can influence how knowledge is perceived and used, for example, if the information is simple or complex; local, traditional or scientific; new or historical (Nguyen et al. 2017b). New scientific evidence and its perceived applicability, congruency to historical information, complexity and reliability was discussed by participants to influence integration into management and policies. Applicability of research was an important theme and was discussed by eight participants, including four managers, three researchers and one assessment biologist. Undertaking applied projects to help address management questions and having researchers effectively demonstrate how the research is relevant to management is needed for knowledge to be incorporated:

Some new scientific knowledge is so technical that the people collecting it can't adequately demonstrate its relevance to management, so the managers don't take it in and incorporate it. Sometimes the research that is done is interesting but it's not relevant to management- it's something interesting and new and it hasn't been done before, and then a lot of the newer statistical techniques are just over everyone's heads- from the management end, and they don't know how to use it. They've just been consistent of what they've been using for the last 40 years (Interview # 24, Researcher)

Applicability was the most discussed and a major theme when asked about giving advice to researchers (n=36) (See Supplementary Material, Table 11). Relevant and applicable science is needed to answer questions that address management issues.

Time

Various aspects of time can impede integration of knowledge and used in practice (Nguyen et al. 2017b). Time was a theme discussed by managers (4) and assessment biologists (2), but not researchers. Barriers discussed with regards to time include: 1) the time it takes to read the literature; 2) the time it takes to attend conferences; 3) time to learn a new tool. Nguyen et al. (2017b) also found that time was a barrier to some, including the time it takes for the entire research process to be conducted (data collection, data analysis, peer-review process, decision-making and implementing change), translating findings to policy-makers in a comprehensible manner and the time it takes to learn technical aspects. Providing information at the right place and the right time is critical to retain its value to decision (Jacobs et al. 2005). Placing efforts into building communication platforms to better connect managers and policy makers' knowledge needs and professional habits would be beneficial to help with the overall understanding of new technology and information. Another suggestion would be to have brief summaries in "plain" and "simple" language of new research available in a variety of communication styles to reduce the time-investment required by managers and policy-makers (See Supplementary Material, Table 12).

Advice

After approximately 3000 minutes and hundreds of hours transcribing and analyzing interviews with Great Lakes fishery professionals, what advice can I give to telemetry researchers and applied ecologists looking to increase the effectiveness of science transfer to managers and policy-makers? For anyone in the realm of telemetry science or applied ecology, the recommended choice of action to increase KTM is to establish a boundary organization as it would aid in the production of useable knowledge by facilitating interactions. It is important to acknowledge that achieving solutions to complex environmental issues requires an interdisciplinary approach by incorporating human dimensions along with biological research (Kaplan and McCay 2004, Saunders 2003). The advice described in Table 10, should increase the chance of successful science transfer outcomes.

Table 10. Four pieces of advice to help facilitate the uptake of telemetry findings into Great Lakes fisheries management with illustrative quotations.

1. <u>Address management questions by keeping research applied and relevant:</u> • Be inclusive, collaborate and involve managers into project *early* in the process to allow for co-production of knowledge • *Listen* to their ideas, input and feedback *"As a manager, although I'm not opposed to basic ecological studies, I like to see the management implications. I'd like to see the applications more, there's a limited pool of funding and there's a lot of people out there doing things. There's a lot of information that comes out and it's nice to have the management connection. I think they're doing a great job right now and I give a lot of credit to the Great Lakes Fishery Commission and the structure that they set up with the lake committees as part of the joint strategic plan, that's very helpful. They have a science transfer program, that is also very helpful and useful. There is thought put it in to it doesn't just happen. I feel like the researchers right now are very willing and helpful to connect with the managers and provide us what we need related to the research."* (Interview #9, Manager) *"I think my biggest criticism is usually just when research occurs that doesn't incorporate the perspectives of folks that have good information to contribute or help with that, or ignore the actual goals and needs of the folks who are doing the actual research management."* (Interview #34, Manager). (Arlettaz et al. 2010; Young et al. 2016b; Cooke 2018)
2. <u>Improve communication of results:</u> • Use a wide variety of communication techniques that cater to different generations and learning styles • Include social media, quick briefing notes and try to publish in open-access journals

- Improve presentations skills: get trained (ex: Alan Alda Centre for Communicating Science), translate scientific jargon, use plain language and simplify without 'dumbing it down'

"We get a lot of the academic folks who come to a group full of lay people and their way just too heavy on graphs and technical jargon. They need to be able to gear it and phrase and show the appropriate level of information in detail, but doesn't swamp and overwhelm. We've just recently revamped our program because we're done bombing people for 3 hours with pie charts and graphs. You can see towards the end eyes just glazed over. We cut down from that- we drastically reduce the number of presentations took away the raw scientific stuff and made it more user-friendly so to speak."(Interview # 12, Assessment biologist).

"It's just in the messaging and how we start stories. At the New York chapter of AFS (American Fisheries Society) we just had our annual meeting we had a gentleman from Alan Alda Center for Communicating Science. They came and gave training and it was eye-opening. These are trained professionals that teach scientists on how to communicate with the general public and tricks and stuff on how to hook them on stories. It was just one after another, if you ever have the opportunity to take that or sit in one of those its very enlightening. I found just one six-hour workshop has changed the way we interact with the public." (Interview # 13, Researcher).

(Bik and Goldstein 2013; Young et al. 2016b See Supplementary Material)

3. <u>Share success stories to create motivation:</u>

- Promote buy-in by effectively communicating the benefits and successes at the science-policy interface
- Motivation for change only occurs when the perceived cost of change is less than the cost of continuing with old and familiar practices.

(Cvitanovic and Hobday 2018; Anastasiadis and Chukova, 2019; Ram, 1987)

4. <u>Be adaptable and appreciate interdisciplinary work</u>

- The world and technology is changing so quickly, that it is the people and the organizations with multiple skill sets that can synthesize ideas, and adapt to change, that are going to find solutions to complex environmental issues.

(Saunders 2003)

Future Directions

Acoustic telemetry is a great electronic tracking tool that has provided new insights into freshwater fish spatial ecology, viability of fishery production and has led to changes in management actions in the Laurentian Great Lakes. The insights gained from acoustic telemetry are incredibly valuable ecologically, economically and culturally so it is critical that this type of information is funded and persists in the future, as to continue gaining the most up-to-date science to inform policies. Collaborations and effective communication between researchers and managers are indicators discussed by Great Lakes fisheries professionals that are perceived to lead to successful incorporation of scientific findings. We as conservationists and applied ecologists, must adapt to these needs for our work to be of benefit and lead to sustainable use of natural resources. Investments into boundary organizations such as GLFC and GLATOS should continue as their efforts with science transfer programs and initiatives (meetings, workshops) are effective and noticed by participants in this study. Future investments may include training researchers in science communication, hiring of a social scientist or conservation psychologist (to help with the rapid rate of change of technologies and the environment) as well as investments into outreach and education of the public (having informed members of the public can lead to healthier and more sustainable communities as well as support for policies changes). It would also be beneficial to write a paper and add to the literature discussing exactly how to create a boundary organization, as there are no specific instructions. Topics of future research could include to study the associations between variables (age, educational background, amount of work experience, lake/geographic area, used/not used telemetry) on the impact on science transfer and uptake of knowledge.

Conclusion

This thesis examined Great Lakes fisheries professionals' opinions and beliefs regarding biotelemetry science and the barriers to knowledge transfer of new scientific findings into management. For new evidence to be used and successfully integrated into management initiatives, there must be motivation from natural resource managers to incorporate it. The world's fisheries, including the Great Lakes fishery, require policies based on the most up-to-date scientific evidence to maintain the biological and economic integrity of the ecosystems (Cooke et al. 2017). In the Great Lakes, biotelemetry science has recently been adopted, is currently generating large amounts of data, and has great potential to support fisheries management objectives. Therefore, it is essential that findings gained from biotelemetry studies are transferred and adopted by the management community. Fisheries professionals in the Great Lakes have a general understanding of the strengths and limitations of biotelemetry science and believe that biotelemetry plays a strong role in managing fisheries in the Great Lakes. There were mixed opinions regarding the peer-review process, data sharing and the ease of integration of biotelemetry findings into management. There was slight lack of understanding of 1) how biotelemetry can provide reliable information about *ecosystems* 2) the cost-effectiveness of biotelemetry and 3) how biotelemetry could be used as a standard tool in fisheries management. It is recommended that these issues are addressed to facilitate effective knowledge transfer. Centralized and collaborative networks, such as GLFC and GLATOS, can help facilitate biotelemetry knowledge transfer and ensure that managers have the knowledge to make appropriate decisions. These networks help to address management and conservation goals, as well as helping to increase the cost-effectiveness of projects, data sharing and warehousing, infrastructure maintenance, and ultimately help to create key partnerships between researchers, management teams and stakeholders (Crossin et al. 2017). Four pieces of advice for telemetry researcher are 1) address management questions by keeping it relevant and applied 2) improve communication of results 3) share success stories to create motivation and 4) be adaptable. It is well known that building strong collaborative relationships are key to successful natural resources outcomes. Through the GLATOS network, there are organized efforts to facilitate regular interactions between the research and the management community though meetings. Social events and workshops, hosted by GLATOS, are designed to help build relationships and foster collaborations. These types of interactions should persist in the future as they allow for the creation of more robust study designs and co-produced knowledge by researchers and managers, ultimately helping in the effort to create sustainable fisheries.

Supplementary Material

Table 11. Responses given by participants when asked what advice would they give to scientists about their research, Q9D, (number of participants discussing each theme).

	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total (n=49)
Address management questions -Keep it applied/relevant	**7**	**26**	**3**	**36**
Communication	**5**	**8**	**4**	**17**
Improve communication of results	2	6	2	10
Timely results	0	2	1	3
Don't oversimplify things	1	0	0	1
Use direct language- simplicity	1	0	1	2
Improve sloppy writing	1	0	0	1
Keep it simple	0	1	0	1
Collaborate- be inclusive	**2**	**7**	**4**	**13**
Consult managers first	1	3	0	4
Don't be possessive and territorial	0	0	1	1
Get into the field	1	0	0	1
Keep to science and stay out of politics	**0**	**1**	**0**	**1**
Stick with your ideas- Don't give up	**1**	**1**	**0**	**2**
No advice to give	**0**	**0**	**1**	**1**
Total	12	27	10	49

Table 12. Words of advice given by participants when responding to how effective researchers are at communicating their findings (number of participants discussing each theme).

	Researcher (n=12)	Manager (n=27)	Assessment (n=11)	Total (n=50)
Advice	**9**	**18**	**4**	**31**
Plain Language-Simplicity	5	10	2	17
Presentation Skills-Needs Improvement	4	3	1	8
Public Communication- Get Better	0	5	1	6
Face-to-Face-Public Meetings-Symposia	1	3	0	4
Add Social Media	1	0	2	3
Involve Managers Early On	1	2	0	3
Management Communication-Get better	1	2	0	3
Add Briefing Note-Summarize	0	2	0	2
Keep Yourself Informed	1	1	0	2
Make Recommendations	0	1	0	1
Reinforce your message	1	0	0	1
Free Access Journals	0	1	0	1
Total	9	18	4	31

List of potential future hypotheses derived from conducting interviews with Great Lakes fisheries professionals

1. Researchers that are a member of a boundary organization should have more success with uptake of their work.
2. Researchers who collaborate with management should have more success with uptake of their work.
3. Researchers who disseminate findings via multiple communication techniques should have more success with uptake of their work.
4. Projects that are relevant to management will have more success with uptake of their work.
5. The higher the sample size of fish telemetry projects should have more success with uptake of results.
6. Younger generations of researchers will be more adaptable to changes in technology.
7. Researchers who cooperate and share data should have more success with uptake of their work.
8. Research teams that are interdisciplinary should have more success with uptake of their work.
9. Researchers that are trained in science communication should have more success with uptake of their work.

Appendix

From Fish Movement to Knowledge Movement Interview Guide

Participant Name: ________________________________
Interview Date: __________________________________
Consent form signed? _________ Oral consent? _____________Anonymity ?_______
Audio consent?____
Audio number ___

Preamble: Thank you for agreeing to participate in this research. As you know, we are interested in hearing your views and experiences with integrating new science/telemetry findings into the management framework you are familiar with. We are seeking to understand and identify what promotes and/ or serves as a barrier to knowledge transfer when it comes to fishery managers adopting biotelemetry study findings into their management decisions. As you may already be aware of, advancements in biotelemetry technology now allow researchers to remotely track an animal's interactions with their environment at scales previously unattainable. Many of the questions we will ask relate to views on new scientific findings and telemetry research, as well as how it is communicated and used by various user groups **(researchers, fisheries managers, NGO's)**

Part 1: BACKGROUND

For the first part of our interview, I am going to start with some general questions about your background (getting to know the **knowledge actors** and some **basic characteristics of the actors)**

1. Please tell me a bit about your current position and responsibilities?
2. How long have you held this position? [Probe for past experience if relevant]

3. Please tell me about your educational background (ie: were you trained in management or in the natural sciences?)
4. Are you directly involved in fisheries management decision-making? [If yes, in what capacity? If no, can you briefly describe how your work relates to fishery management decision-making](Ask about whether they consult, advise ir how they might interact with managers during the decision making process)
5. Does your role involve a research component?
6. Does your work take place in any particular lake, river, or region? Please specify.

PART 2: KNOWLEDGE SEEKING HABITS AND PRACTICES OF USERS OF SCIENCE

For this part of the interview we are interested in your **knowledge network** (the way in which you receive information, the people with whom you receive and share information from, who you seek advice from, and who you consult in your day-to-day work).

7. Do you seek out new science regarding fisheries management within the Great Lakes?

8. How often do you seek out scientific information relevant to your work from the following sources? [For colleagues and researchers, ask and record "How do you typically communicate with them?" e.g, telephone, email, in person]

	Daily	Weekly	Monthly	Less than monthly	Never
News/Media reports (print, television, radio, press releases, etc.)	○	○	○	○	○
Scientific reports or publications	○	○	○	○	○
Reports from advocacy or other public interest groups	○	○	○	○	○
Colleagues (other managers I work with)	○	○	○	○	○
Researchers within my organization	○	○	○	○	○
Researchers outside my organization (e.g., universities, other agencies, private)	○	○	○	○	○
Government websites or announcements	○	○	○	○	○
Websites belonging to non-government organizations	○	○	○	○	○
Listservs or automated alerts	○	○	○	○	○
New media and social media (blogs, podcasts, Facebook, Twitter, LinkedIn, etc.)	○	○	○	○	○

Other, please specify... ______________________________	○	○	○	○	○
Other, please specify... ______________________________	○	○	○	○	○

9. In the past 5years, have you collaborated with investigators on a research project?
   a. [If yes] were the Researchers Internal or a part of your organization? [If they answer not internal] Where were the researchers from? (Probe: agency, university, consulting, other)
   b. How was your experience collaborating with investigators? [Probe: positive? What made it positive? Negative? Challenging? What were some challenges? Easy? What made it easy?]

   c. [If no] Why not? [Probe: Was this because of a lack of opportunity collaborate (not involved in projects)? Of interest? Not part of job duties/ requirements?] [Intentionally vague so as not to imply failure or deficiency]

   d. What advice would you give [fishery] scientists/researchers about their research [Probe: What are scientists/researchers doing right? What are they doing wrong?]
   e. How effective are researchers at communicating their findings?

PART 3: UNDERSTANDING THE PERCEPTIONS THAT GREAT LAKES MANAGERS HAVE ON TELEMETRY SCIENCE

Here we want to understand more about **your perceptions regarding** telemetry science.

10. How familiar are you with biotelemetry science? (Fish tagging and tracking)
    A. Have you used biotelemetry in your own work? If so, in what context (How did you use it?)
11. Do you think biotelemetry could play a role in managing fisheries in the Great Lakes? A. If yes, how important is biotelemetry information in relation to other kinds of information in your decision making?
    B. What are the strengths of biotelemetry? C. Are there special or unique types of information that biotelemetry can provide to management?
    D. What are the limitations of biotelemetry? E. What can't telemetry do?
    F. What are the ecological and political barriers to its implementation?
12. Are you aware of any networks/ researchers that are conducting biotelemetry projects? [If yes, probe and have them name specific programs or efforts that do this.]
    [If they don't name GLATOS specifically] – Are you aware of the GLATOS – Great Lakes Acoustic Telemetry Observation System?

13. Please indicate the extent to which you agree or disagree with the following statements [Interviewer: be sure to record explanations. Ask for elaborations]

	Strongly disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Don't know
Biotelemetry provides reliable information about fish behaviours in the Great Lakes						
Biotelemetry provides reliable information about ecosystems in the Great Lakes						
The handling involved with inserting or attaching telemetry transmitters onto fish make the data generated by biotelemetry unreliable						
Biotelemetry research is cost-effective						
Biotelemetry provides us with information we wouldn't otherwise have from other sources or studies						

Biotelemetry should play a more standard role in fishery management than it currently does						
Biotelemetry findings should be taken with a grain of salt						
Biotelemetry data and findings should only be used by managers after being subject to a peer-review process						
Biotelemetry data on fish movements and behaviour should be freely available to anyone who wants it						
Integrating new knowledge emanating from biotelemetry into management is difficult.						
[For managers only]: I would be more comfortable						

using biotelemetry data and findings if the research was being conducted by researchers within my agency [?]						

PART 4: UNDERSTANDING VARIABLES THAT INFLUENCE THE MOVEMENT OF NEW SCIENCE INTO PRACTICE

Here we want to understand the **characteristics of the knowledge**, to understand views of new science and the best methods of delivery.

14. In your opinion, what makes knowledge reliable? What criteria help you to believe or accept that the information is reliable?
15. In your opinion, how accessible is research and scientific findings?
16. When looking for scientific information, where do you turn first?
17. In your experience, what do you think are barriers to using new scientific knowledge in fisheries management?
18. Overall, what is your opinion on new science in general?

Science transfer is a process that occurs when research (from formal academic or government research institutions) is moved to practitioners/managers as information input for their decision making with the overall goal to improve outcomes (e.g., fishery management)

19. What is your opinion of the current science transfer of fisheries research in the Great Lakes basin? [Prompt: do you believe it is effective? How so? If not, why not?]
20. How effective and how important to you are the Lake Committee meetings in March of every year for the transfer of science to management?
21. Are you aware of Great Lakes Fishery Commission initiatives to facilitate science transfer? [If yes, probe and have them name specific programs or efforts that do this.]
    a. [If they don't name the Science Transfer Program specifically] – Are you aware of the Science Transfer Program?
22. In your opinion, what are research topics of highest priority to fishery management in Lake X OR Great Lakes Basin?
23. [If applicable] Do you believe the Science Transfer Program has addressed these topics?
24. [If applicable] In your opinion, has the Science Transfer program delivered research findings in an effective manner?
    a. If yes, provide example?
    b. If no, why do you believe they have not?
25. What forms of communication (webinars, workshops, lake specific technical committees, scientific meetings, etc) do you think would be the most effective

way for researchers to communicate study findings to managers/ policy makers?

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