NRC Research Press

ARTICLE

Applying a knowledge–action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study[1]

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Abstract: Telemetry studies have produced fundamental knowledge on animal biology and ecology that has the potential to improve management of aquatic resources such as fisheries. However, the use and integration of telemetry-derived knowledge into practice remain tenuous, so we surveyed 212 fish telemetry experts to understand existing barriers for incorporating telemetry-derived knowledge into fisheries management practices. We apply a sociological knowledge–action framework to structure the findings, which revealed four primary challenges to integrating telemetry findings into management: (1) the perceived uncertainties and unclear relevance of telemetry findings; (2) the underlying motivations and constrained rationalities of actors that can lead to inaction or suboptimal decisions; (3) the constraints of institutions, governance structures, and lack of organizational support, and (4) time and mismatches in scale, culture, and world views. On a more positive note, the relational dimension (collaboration, trust, and relationship building) appears to be important for overcoming and avoiding barriers. We further provide recommendations to navigate these perceived barriers and argue that these lessons also apply to other fields of applied ecology, conservation, and resource management.

Résumé : Les études de télémétrie ont produit des connaissances fondamentales sur la biologie et l'écologie animales qui pourraient améliorer la gestion de ressources aquatiques telles que les ressources halieutiques. Parce que l'utilisation et l'intégration de connaissances découlant de la télémétrie dans la pratique demeurent toutefois limitées, nous avons sondé 212 spécialistes de la télémétrie appliquée aux poissons pour comprendre les obstacles existants à l'incorporation de connaissances découlant de la télémétrie aux pratiques de gestion des pêches. Nous appliquons un cadre sociologique de connaissances–action pour structurer les réponses, dont ressortent quatre principaux obstacles à l'intégration des résultats de télémétrie à la gestion, soit : (1) les incertitudes perçues et la pertinence non évidente des résultats de télémétrie; (2) des motivations sous-jacentes et des rationalités contraintes des acteurs qui peuvent mener à l'inaction ou à des décisions non optimales; (3) des contraintes imposées par les institutions, les structures de gouvernance et le manque de soutien organisationnel et (4) le temps et le mésappariement des échelles, des cultures et des visions du monde. Sur une note plus positive, la dimension relationnelle (collaboration, confiance et établissement de liens) semble être importante pour surmonter et éviter les obstacles. Nous formulons des recommandations pour négocier ces obstacles perçus et arguons que ces leçons s'appliquent également à d'autres domaines de l'écologie appliquée, de la conservation et de la gestion des ressources. [Traduit par la Rédaction]

Introduction

Innovation and investments in telemetry technology have opened a window to understanding the underwater world in ways that were impossible to fathom (Hussey et al. 2015). Telemetry technology is based on electronic devices attached to an animal that autonomously emit a signal to a receiver, thus allowing researchers to track and monitor animal movements and their interaction with their environment (Cooke et al. 2004; Hussey et al. 2015; Kays et al. 2015). Telemetry data emanating from studies in aquatic ecosystems are increasing exponentially as a result of growing interest from the scientific community fueled by innovations such as smaller tags, improved tagging methods, longer battery life, and the coupling of telemetry technology with other biological measurements like genetic analysis or physiological status (Hussey et al. 2015). In the last decade, telemetry studies have documented animal movements at scales and in regions that were previously impossible, including regions and harsh environments inaccessible to humans, thus providing ground-breaking findings and novel insights into how to better manage aquatic resources such as fisheries. The impacts and integration of telemetry-derived information and knowledge remain tenuous (McGowan et al. 2017), and understanding the barriers to mobilizing telemetry-derived knowledge into management or conservation action would be useful in improving conservation of aquatic ecosystems.

Fish telemetry makes an interesting case study because it has rapidly become a widely used technology in aquatic research, but is still relatively new in the world of fisheries and aquatic resources management (Crossin et al. 2017). The fish telemetry community is also one of the closest research communities to management because telemetry-derived data has great potential to influence management and conservation decisions (Crossin et al. 2017; McGowan et al. 2017). Potential applications include delineating critical fish habitats for the designation of protected areas, informing species–population threat assessments, generating mor-

Received 24 July 2017. Accepted 13 October 2017.

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[1]This article is being published as part of the special issue "The Ocean Tracking Network: Advancing aquatic research and management".

Published at www.nrcresearchpress.com/cjfas on 30 October 2017.

tality estimates, and directing habitat rehabilitation initiatives, among others (see Cooke 2008; Crossin et al. 2017; Cooke et al. 2016). However, little research has been done on the mobilization of telemetry-derived knowledge into management decisions and practices. Much of the published literature using telemetry technologies asserts the potential for application, but few observations of direct conservation and management actions have been documented (Cooke 2008; Campbell et al. 2015; Jeffers and Godley 2016). McGowan et al. (2017) offer a framework to integrate telemetry-derived data into decision-making and actions, but there is a lack of empirical evidence on the barriers to this integration. Here, we present empirical qualitative data from interviews and surveys with 212 experts in fish telemetry (mostly academic and government researchers) to uncover their views on the barriers to incorporating telemetry-based knowledge into fisheries management and conservation practices. Given the relatively high financial cost of conducting telemetry studies, telemetry-derived knowledge in fisheries management is important to maximize the benefits of these investments for conservation and fisheries management. (McGowan et al. 2017). In addition, we apply and evaluate a newly developed knowledge–action framework (i.e., Nguyen et al. 2017*a*) that aims to support knowledge mobilization and exchange research. We use this framework to help structure and provide greater context to our findings. Although we focus on fish telemetry, we submit that our findings have relevance to other fields involving the tagging and tracking of wildlife.

Methods

An international survey was conducted of fish telemetry researchers as part of a broader study on the mobilization of fish telemetry-derived knowledge that included both online questionnaires and semi-structured interviews. The questionnaire and interview schedule were designed together as part of a mixed methods approach to capture both depth and breadth of responses. The interviews allowed us to gather in-depth responses and explanations, while the questionnaire allowed us to reach a broader international population. The primary question analyzed in this article is open-ended and was identical in both the interview and questionnaire:

> *In your experience, what are the most significant barriers to incorporating telemetry findings into actual fisheries management practices? (If you have not encountered barriers, please tell us why it was easy for your telemetry findings to be used by end users?)*

We complemented these responses by asking respondents to discuss a project of their choice and asking them to elaborate on why they believed their findings were utilized or not ("Please describe why you believe your findings were utilized. If they were not, please explain why you believe they were not."). This question was modified into a more conversational tone for the semi-structured interviews.

Standard sociodemographic questions were collected, and information on respondents' expertise and experiences in fish telemetry research were gathered to understand the level of expertise of the sample. In this study, we restricted "telemetry" to acoustic, radio, or satellite technology, as these techniques address similar research questions and management issues. The online questionnaire was pretested with 11 individuals who have conducted research with fish telemetry. The interview was pretested with the first five interviewees and minor adjustments were made. The Carleton University Ethics Board approved the study on condition that the anonymity of respondents be maintained (102887).

Sampling

We built the initial sampling population for the interviews in consultation with two telemetry experts, who were also included in the sample. The original population was further supplemented by snowball sampling when participants voluntarily referred us to others. We opportunistically conducted 25 face-to-face interviews with fish telemetry experts at the International Conference on Fish Telemetry in Halifax, Nova Scotia, 13–17 July 2015. We supplemented this sample with 12 interviews at the meeting of the American Fisheries Society in Portland, Oregon, 16–20 August 2015. Phone or Skype interviews were also scheduled with nine individuals, totaling 46 interviews (including responses from the pretests).

The population for the online questionnaire was determined by extracting the e-mail addresses of authors who have published fish telemetry research as determined by citation records from the Web of Science online database. A search for articles between 2011 and 2015 was performed with the following search string to identify relevant authors in fish telemetry: (*telemetry OR track* OR tag*) AND (*sonic OR VHF OR radio OR acoustic OR satellite OR pop-up OR tag*) AND (lake OR river OR aquatic OR freshwater OR marine OR fisher*OR reef OR estuary* OR bay OR fish). The search was conducted on 29 September 2015 using Web of Science (consisting of Web of Science Core collections, Biosis Previews (subscription up to 2008), MEDLINE < SciELo and Zoological Record), which resulted in a set of records containing 2605 valid e-mail addresses. We identified 1908 unique e-mail addresses after removing duplicate e-mails and irrelevant records.

We sent e-mail invitations on 7 October 2015. There were 112 undeliverables, and 110 respondents notified us that they did not meet the criteria of a "fish telemetry researcher", resulting in a final population of 1686. We recognize that this number is an overrepresentation of the target population (e.g., it may include researchers outside of our defined scope), as we attempted to reach the whole population of fish telemetry researchers. We sent reminders on 4 and 14 November 2015 following the methods outlines in Gray and Guppy (1999). We gathered contact information for an additional 155 individuals using a snowball approach where invitations and reminders were sent on 4 and 14 February 2016, for a total sample pool of 1841. The online survey closed on 19 February 2016.

Data analysis

A total of 212 (166 online + 46 interviews) responses were used for data analysis. Responses from the online surveys and interviews were pooled for analyses. Although we received 348 responses from a sample pool of 1841 potentially relevant participants to the questionnaire, only 213 completed the questionnaire to the end, of which 166 responded to the focal question. The overall response rate for the online survey was 19%, which falls within the average range for expected response rates for online surveys (Deutskens et al. 2004).

Responses were read and coded deductively using the conceptual knowledge–action framework (Nguyen et al. 2017*a*). The framework enables comparison of case studies and can organize information about the mobilization of telemetry-derived knowledge. The knowledge–action framework is composed of three elements: knowledge production, the knowledge mediation sphere, and knowledge action (see Table 1 for details on framework). The mediation sphere is the interface between knowledge and action, in which factors exist that mediate or influence the movement of knowledge. We characterized the barriers and facilitators experienced and perceived by the respondents based on the components of the framework (Table 1; see also Nguyen et al. 2017*a*).

After sorting them into relevant framework themes, responses were read a second time to inductively identify key subthemes (Thomas 2006), which subsequently provided a list of potential codes to give more nuance to the framework themes. Finally, we sorted responses under these subthemes to provide a measure of their prevalence. A response may have multiple thematic codes if warranted, and responses are presented below in both quantitative and qualitative (by illustration of quotes) styles. Qualitative analyses were performed using NVivo 10 software. In this article,

Table 1. The relevant components from the "mediation sphere" of the knowledge–action framework adapted from Nguyen et al. (2017*a*) to structure and guide the coding of participants' responses.

Component	Description
1. Knowledge mediation sphere	A sphere that encompasses factors that influence the knowledge production and its fate. The sphere emphasizes the nonlinearity and dynamic processes of knowledge flow and movement.
a. Knowledge network	A complex social network of interactions between knowledge actors and the knowledge produced, as well as among the actors. The dynamics and interactions within the network can occur at multiple levels and time scales.
b. Knowledge actors	Players at various levels (individual, group, and institutional) involved in the exchange and mobilization of knowledge.
c. Characteristics and perceptions of actors	Who the actors are and where do they come from, their backgrounds, values, beliefs, and attitudes (e.g., motives, expertise, involvement, character, personality, etc.) and how they are perceived by other actors.
d. Relational dimension	The relationship and ties between knowledge actors.
e. Characteristics of the knowledge	The type and attributes of knowledge that are entering the knowledge network, which may influence on how it is perceived and mobilized.
f. Environmental and contextual dimension	Factors external to the knowledge network that can influence the movement of knowledge, such as culture, institutional norms, economic context, and political context.

we illustrate the prevalence of a theme or subtheme as the ratio of mentions for a specific code over number of all mentions for all codes (i.e., the number of times a theme or subtheme was coded relative to all passages that were coded).

Results

Characteristics of the sample

The respondents from this study were generally highly experienced fish telemetry researchers with 75% (of 209) having been principal investigator of at least one telemetry project and 33% having been principal investigator of more than five fish telemetry projects. Almost 40% of participants spent >25% of their research conducting fish telemetry work, and the majority (82% of 208) had at least 5 years of experience with fish telemetry (Table 2). The sample population, however, was highly skewed toward respondents from high income regions, particularly from North America (mainly the USA), followed by Europe and Australia–South Pacific. Responses were primarily from a younger and androcentric perspective given that 80% of respondents were aged 30–59, and 80% were men (Table 2). The study respondents were mainly affiliated with academia (51% of 210 respondents) or a government or government-related organization (40%), with the remainder of the respondents being from nongovernmental organizations (4%), industry, and private companies (5%). Findings presented likely reflect the inclinations and (or) biases of the demographics from the sample population. While a representative sample of all fish telemetry researchers would have been ideal, the obtained results were from a broad range of scientists in the field and deemed appropriate for the purpose of this qualitative study based on emerging themes.

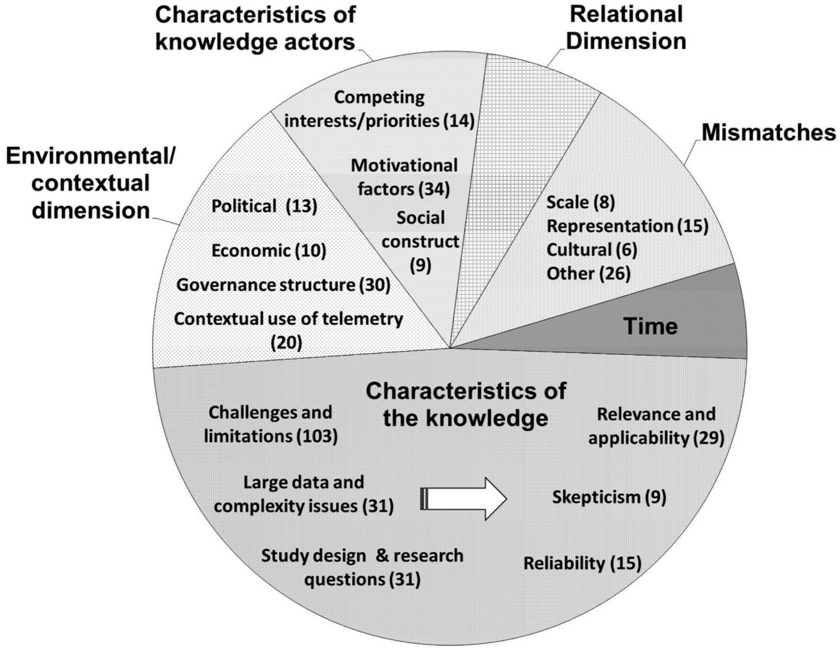
Table 2. Sociodemographic and other characterizing variables of the sample population.

Variable	%	*N*
Sociodemographic		
Age (*n* = 204)		
20–29 years	8	16
30–39 years	38	79
40–49 years	30	62
50–59 years	16	34
60–69 years	6	13
70–79 years	2	4
Gender (*n* = 209)		
Female	19	40
Male	80	168
Prefer not to say	1	1
Location (*n* = 193)		
North America	64	124
Europe	19	36
South Pacific (mainly Australia)	8	15
Great Britain	4	7
South and Central America	3	6
Asia	2	3
South Africa	1	2
Employer (*n* = 210)		
Academia	51	106
Government	40	84
Industry	0	1
NGO	4	9
Private	5	10
Telemetry experience and research		
Work environment (*n* = 205)		
Fresh water	22	46
Marine	40	83
Both	37	76
Telemetry technique (nonmutually exclusive)		
Radio	NA	106
Acoustic	NA	183
Satellite	NA	74
Years of telemetry experience (*n* = 208)		
1–4 years	18	37
5–9 years	34	71
10–20 years	37	76
20+ years	12	24
No. of projects as principal investigator (*n* = 195)		
1–4 projects	44	85
5–9 projects	18	35
10–14 projects	6	11
15+ projects	10	19
None	23	45
Percentage of telemetry-related research (*n* = 202)		
<10%	27	55
10%–25%	19	38
26%–75%	38	76
76%–100%	16	33

Coding based on the knowledge–action framework

Overall, for the case of fish telemetry, factors falling within the characteristics of telemetry-derived knowledge were the most cited barriers for incorporating telemetry-derived findings into management practices (48% of all coded responses fell into this

Fig. 1. Overview of application of knowledge–action framework (adapted from Nguyen et al. 2017*a*) for the exploration and identification of barriers to incorporate telemetry-derived knowledge into fisheries management practices. Numbers in parentheses indicate number of coded responses for each subtheme coded. The white arrow indicates that the attributes of the telemetry-derived knowledge may influence the relevance–applicability, skepticism, and reliability of the knowledge.



subtheme; Fig. 1; also see the online Supplementary Material[2] for illustrative quotes of barriers). This was followed by factors within the environmental and contextual dimension (16% of all coded responses), characteristics of knowledge actors (12% of coded responses), and the relational dimension (7% of coded responses). One theme that emerged, but did not fall within the knowledge–action framework, was the broad concept of "mismatches" (12% of coded responses) as well as that of "time" (5%). Some responses also offered proposed solutions and facilitators to integrating telemetry-derived data into management.

The characteristics of telemetry-derived knowledge: limitations, study biases, uncertainties, and complex data sets

Many researchers felt that the limitations and challenges of conducting fish telemetry research (e.g., costs, small sample size, tag effects, limited spatial or temporal coverage, poor detection efficiencies of receivers) are also carried through to the uptake and integration stage of these findings in the form of uncertainties and biases. Telemetry research can generate large data sets that are complex to interpret and can create incompatibilities with software employed by knowledge users and scales at which the knowledge producers and potential knowledge users work. The reliability, relevance, and applicability of telemetry findings have also been questioned by respondents and are often a result of a study designed in isolation from knowledge users (e.g., inapplicable research questions, lack of validation or calibration of study). These limitations were often perceived by respondents as a reason for inaction or for resource managers to dismiss research findings (Table 3). Interestingly, respondents were critical not only of knowledge users, but also of their own peers within the fish telemetry research community, as illustrated in the following quotation:

> *Getting beyond the simple story line I tag my fish and it swam this far. Far too much [sic] descriptive studies available and it doesn't help managers at all. Failure to develop cutting edge analytics use with data.* (Interview #260, male, academic scientist, 50–59 years old, North America)

Environmental and contextual dimensions

Inflexible and outdated governance structures and tools

Inflexible, nonadaptive, and stagnant governance and institutional cultures and structures were themes identified as undermining the integration of telemetry-derived knowledge (Table 3). One criticism included the lack of a mechanism for directly incorporating new and (or) "real time" results into the decision-making process. A second critique was that existing government structures create a disconnect between institutional leaders (i.e., centralized political decision-makers) and those at the regional levels who are "on the ground" dealing with the issues at hand. Third, some claimed that resource agencies are too preoccupied with administrative duties and requirements:

> *The government … [has] large bureaucracies, lots of people, and little money for doing things, and they come under a lot of pressure. For those reasons and others, they are extremely conservative and are pretty ready to accept uncritically information that fits the status quo or supports the status quo. Information that is counter to the status quo gets a much more critical ride. [It's a] very distorted system. They are afraid of doing something new because they might get criticized for it.* (Interview #243, male, private scientist, 60–65 years old, North America)

A fourth criticism by respondents was the traditional and outdated systems that governments use to manage natural resources impede the integration of new information. Lastly, the system on which stock assessment is built was viewed by fish telemetry

[2]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjfas-2017-0303.

Table 3. Summary of barriers identified using a knowledge–action framework (Nguyen et al. 2017*a*).

Broader barrier	No. of coded responses	Specific barriers	No. of coded responses	Description
Characteristics of the knowledge	224	Challenges and limitations of telemetry	103	The limitations and challenges of using and designing telemetry studies can lead perceived uncertainties and biases, as well as question the reliability and relevance of the telemetry-derived knowledge.
		Study design and research questions	37	The study design and research questions are not applicable to or do not align with management needs.
		Large and complex data sets	31	The complexity of the data analysis, the nuances, and variability of telemetry data can lead to challenges in interpreting and understanding what the data reveals, if anything at all.
		Relevance and applicability	29	The perceived lack of relevance and applicability of telemetry findings into fisheries management.
		Reliability	15	The perceived lack of reliability of the telemetry findings.
		Skepticism	9	The overall skepticism from potential knowledge users of telemetry-derived knowledge due to the characteristics (mainly limitations and uncertainties) of telemetry.
Environmental and contextual dimension	73	Governance and institutional structures	30	The established structural dimension can be a disincentive to change, to break norms, and to take risks (path dependence).
		Context of use of telemetry	20	Some questions and issues that telemetry can address appear to provide clearer answers than others.
		Economic parameter	10	Economic priorities can supersede what telemetry-derived knowledge recommends.
		Political context	13	Political agenda can supersede what telemetry-derived knowledge recommends.
Characteristics of knowledge actors	57	Motivational factors	34	The motivation of individual and institutional-level actors to mobilize telemetry-derived knowledge (e.g., lack of political will, institutional inertia, maintenance of status quo, rewards and incentives).
		Social constructs	9	Social constructs other than motivation, such as values, norms, and beliefs.
		Competing interests or priorities	14	Conflicting priorities, agendas, and interests of different knowledge actors
Relational dimension	30	Lack of collaborations and relationship building	30	The lack of collaborations or the lack of building meaningful relationships between telemetry researchers and resource managers or other potential knowledge users.
Mismatches	55	Scale	8	The spatial, temporal, and institutional scale mismatches.
		Representation	15	The mismatch of telemetry studies tagging individual fish and their representation of the overall population.
		Cultural	6	The cultural mismatch between different knowledge actors (e.g., researchers versus managers).
		Other	26	Mismatches described by respondents that did not fit into any other categories.
Time	24	NA	NA	The various aspects of time that impede the integration of telemetry-derived knowledge (i.e., process time, time to learn, time to invest in dissemination, etc.).

Note: See online Supplementary Material Table S1[2] for full descriptive table, including illustrative quotes.

researchers as too rigid to incorporate new data and improve the ecological complexity of the models:

> "*It's like the Titanic. It's not easy to turn when you know the iceberg is coming.*" (Interview #268, female, government scientist, 50–60 years old, North America)

Context in which fish telemetry methods are used

Respondents highlighted that sometimes the context in which telemetry techniques are used may facilitate or hinder the uptake of findings (Table 3). For instance, if fish telemetry is used to research a critically endangered species, there may be greater likelihood for the uptake of findings because specific legislation and regulations exist in this context. The use of fish telemetry to delineate critical habitats was claimed to be "easier" to incorporate into management because they were "direct observations of where the fish were found and which habitat types were preferred". In contrast, politically charged and controversial areas such as hydropower development or marine protected areas, in which large numbers of stakeholders may be affected, were thought to face greater challenges in integrating telemetry findings.

Sociopolitical and economic contexts

The sociopolitical context received less attention by respondents but was still regarded as an important factor in the incorporation of telemetry data in management practices (Table 3). Managers may be influenced by political factors in their decision-making, and priorities of governments currently in office were also thought to influence human and financial resource allocation and the level of attention granted to specific issues. Furthermore, the notion that "money makes the world go around" was highlighted by respondents, suggesting that economic factors drive the way scientific knowledge is used and mobilized. However, this was only mentioned by 10 respondents.

The knowledge actors: motivations, incentives, and competing interests

The greatest perceived barriers in the category of knowledge actors were related to motivations of potential users, particularly the "lack of political will" of individuals and the "institutional inertia" that exists at the organizational level (Table 3). The lack of rewards and incentives to pursue controversial or potentially contentious findings may also delay or impede new knowledge from moving forward to action. Knowledge that supports the status quo or supports an existing belief was considered to be more rapidly accepted and integrated than knowledge that appears to be an "inconvenient truth" or "socially and politically unpalatable". Knowledge that does not conform with current norms, values, and beliefs was seen as unlikely to be taken seriously or adopted. For instance:

> *It's a disruptive technology [i.e., telemetry]. It's coming in and doing something in a different way that hasn't been done before, which erects the possibility of exploitation of uncertainties. Doesn't mean it will happen nor does it mean there are necessarily uncertainties. What it boils down to is, within fisheries management activities, it's built on stock assessment. The agreed upon procedure is reached after long and anguished back and forth between scientists and managers and stakeholders involved. It becomes somewhat of an [inaudible] situation where new source of information comes in and it begins to change the stories that come out of stock assessments that has real consequences for some of the people who are stakeholders … there are winners and losers with that new information. The losers then harp in on the fact that it's an unproven technology, we haven't used it before, it's uncalibrated, all sorts of maybe, maybe, maybe, that are used, not because they are truthful, but because they are a point of attack to help those who stand to lose in the debate.* (Interview #248, male, academic and NGO scientist, 60–70 years old, North America)

On the other hand, some respondents argued that telemetry is sometimes glorified. One respondent described it as a "shiny new gadget" and that findings from telemetry research are overhyped, leading to managers jumping the gun in adopting the findings before considering all the caveats:

> *As a researcher, we have to be extra careful because when people [managers and stakeholders] see images and maps, especially if they are animated, they believe it. They love new technology, and they think it's bulletproof and answers all the problems. This is because they are not experienced with the technique and do not question the results. That is the main problem … to be cautious to deliver this information. Unfortunately, in many ways, [people in my country] think that gizmos are really interesting and they love it. Sometimes, we have to be cautious to provide them with information because they accept it.* (Interview #264, male, academic scientist, 50–60 years old, Europe)

Relationships among actors in the knowledge network

The lack of relationships among actors and lack of collaborations in the knowledge network were identified as barriers for integrating telemetry-derived findings (Fig. 1). The collaboration with managers in the early stages of a project was identified to be important, which goes beyond communication. One government scientist explained that

> *Many times, we think we are doing management relevant work. It's almost sort of a theoretical exercise. We might find out after the project that theoretically it might be management relevant but it's not really practical. Chances of affecting management with research are much better when we actually engage the managers. That is maybe a step beyond communication but communication is part of that.* (Interview #238, male, government scientist, 30–40 years old, North America)

Mismatches: population representation, geographical coverage, culture, and time

Mismatches associated with scales and culture were an overarching theme often mentioned alongside other barriers. There were several mentions of mismatches in scales. The first involves the difference between individually tracked fish and the populations they are assumed to represent. The second involves the difference in geographic scale between a localized project (e.g., array size) and scales of political or management importance (e.g., stock area). The third involves a mismatch in temporal scale such as different time horizons in research and management requirements. The temporal scale at which a telemetry study occurs is often dictated by the technology, such as battery life or tag retention. There were other aspects of time discussed in the responses, including the time it takes for the entire "process" to occur, such as data collection and analysis, the peer review, the decision-making process, and implementing the change (Table 3). Also, some researchers talked about the time investment required to translate and package the telemetry-derived findings in a comprehensible manner for policy makers. Finally, respondents discussed the time required for non-scientists such as managers to learn the technical aspects of incorporating telemetry into decision-making and understanding the nuances and complexities of telemetry data.

Participants' proposed solutions

Some of the open-ended responses mentioned facilitators or suggested solutions to mobilizing telemetry findings into fisheries management (Table 4; also see Supplementary Material for more information[2]). The most cited reason for successful uptake of telemetry-derived knowledge into fisheries management practices were personal relationships and engagement between researchers and potential users, particularly stakeholders and fisheries managers:

> *If you have a relationship with people then there is some level of trust, and they believe you. They are not afraid to ask questions. In an ideal world, it ought to be both ways. If science is going to survive, they had better be talking to managers.* (Interview #236, male, academic and NGO scientist, 60–70 years old, North America)

Relationships and collaborations were thought to aid in overcoming barriers. In particular, relationships were deemed to help in designing research questions relevant and useful to managers, as well as improving the overall transparency of the research process. Direct collaboration was thought to enhance the compatibility of telemetry research with existing management tools and perspectives. In other words, relationships and collaborations

Table 4. Summary of identified facilitators and solutions for the incorporation of telemetry-based knowledge into fisheries management using inductive coding.

Facilitators and solutions	No. of coded responses
Identified facilitators	
Relationship and engagement with stakeholders and managers from the onset and throughout the research process	14
Addressing management questions and ensuring research design will generate knowledge that is useful to managers	11
Transparency of study (e.g., being transparent about limitations and validation of studies)	1
Simple visualization and dissemination of results and explicit knowledge that telemetry research can produce	2
Suggested solutions	
Improve analytical toolbox for analyzing and interpreting telemetry data	4
Data sharing and standardization of data; compatibility of tag and receivers (codes and frequencies)	4
Adaptive management framework – structural flexibility – organizational support	4
Bottom-up pressure	1
Compatibility with existing approaches, values, and perceptions of knowledge user	1

Note: For full descriptive table with illustrative quotes, please see online Supplementary Material Table S2[2].

promote the saliency, legitimacy, and credibility of telemetry study findings, which result in facilitating their utilization (Cash et al. 2003):

> *We are now working with a bunch of management councils and commission, and they are now looking at using telemetry data to look at these population metrics. I think managers are becoming more open to that now that telemetry is starting to provide population parameters. I don't think there is a wall, I think it was a question of this is great, how do we use it. Now there are some real smart people figuring how can we use it [telemetry data in fisheries management]. For the most part, we started with studies that were historically not focused on populations, and now we are getting into that.* (Interview #278, male, academic scientist, 50–59 years old, North America)

One response illustrated that the simple visualization and dissemination of telemetry results (being able to make maps and show where fish are going) helped managers understand and therefore accept the validity of the findings (Table 4):

> *It's [telemetry data] immediately available. You track a fish, you know where it's gone … it's something that people can relate to … it's about the individual.* (Interview #254, male, 30–35 years, private scientist, UK)

Improving and expanding the analytical toolbox for interpreting telemetry data was a proposed solution. Sharing data was also suggested to increase sample size and provide greater weight of evidence and to develop and standardize metrics that fisheries managers can recognize and value. For example:

> *"Telemetry in fishery science" can be improved through the development of common modelling/data processing approaches that can produce outputs that a wide range of fisheries manager can relate to and apply … If a telemetry tool could be developed that fishery managers could recognize as a source of standard metrics (such as natural mortality, immigration/emigration, fishing mortality), which could be easily integrated with existing assessment processes, then telemetry would become a significant part of actual fisheries management.* (Survey #32, male, 40–45 years, government scientist, North America)

One respondent claimed they have had success through bypassing managers and the bureaucracy by involving fishers and user groups (i.e., bottom-up pressure) to make changes. Last, some respondents argued that management systems themselves need extensive reform to enhance flexibility, notably by implementing adaptive management frameworks (Table 4; also see Supplementary Material section for illustrative quotes[2]).

Discussion

The knowledge–action framework helped organize the reported barriers for telemetry integration into theoretical themes, where we can see that some barriers are longer-lasting and more indissoluble than others. We also note a dissonance across some responses, which captures the complexities of trying to integrate telemetry-derived information into practice. For instance, there were contrasting sentiments by respondents about wanting better visualization of telemetry data to aid managers in understanding the findings, but also fear that managers may respond too quickly and easily to visualizations. Another example is the desire to institutionalize science by creating processes for better incorporation of telemetry data, but also the critique that institutional structures, processes, and bureaucracy impede knowledge movement. This dissonance reminds us that every case has its nuances and there is no one-size-fits-all. With that in mind, the recommendations offered here are not silver bullets, but rather aids to navigate the barriers identified in this research. In the following sections, we briefly discuss the long-term barriers that are more challenging to overcome from a fish tracker's perspectives and focus most of the discussion on practical barriers that may have greater direct relevance to researchers and practical recommendations on how to navigate these barriers.

The characteristics of the actors involved, such as their underlying motivations, dissonance between existing beliefs and new information, and mental and physical constraints of knowledge users (e.g., fisheries managers, decision makers, stakeholders), can present long-lasting barriers to overcome (Bradshaw and Borchers 2000; Gezelius and Refsgaard 2007). Fisheries managers are often constrained by path dependence, a concept that describes how choices in the past have a constraining impact on choices in the present (Hegland and Raakjaer 2008). They may also be constrained by incentives or other social situations (e.g., stakeholder demands; Lodge and Wegrich 2016) and do not or cannot make optimal choices (from telemetry researchers' perspective). Respondents saw policy makers as motivated by the need to address ideological and practical goals, and therefore to favour research that is politically acceptable to current governments, that identifies "workable" solutions, that is demonstrated to work, that does not attract controversy, and that is effectively communicated. We argue that researchers must therefore navigate these priorities to make telemetry noticeable and acceptable to policy makers.

The environmental and contextual dimensions such as formal institutions and bureaucratic structures, including the inertia and lack of organizational support to incorporate telemetry science into fisheries management, are longer-term challenges. Hierarchical structures of bureaucracies create divisions of labour and authority that affect how knowledge is used or prioritized and can lead to a disconnect between managers on the ground and senior managers who set priorities, which create barriers to moving information (Yang and Maxwell 2011). The idea of institutional inertia on its own is complex and beyond the scope of this study. However, we look to the climate change policy literature for some insight. Five mechanisms of institutional inertia for climate regime have been identified that may shed light on our understanding of how it presents a barrier to integrating new knowledge (i.e., telemetry-based knowledge) into practice. These mechanisms include (1) costs of implementing changes or new policies; (2) uncertainty of the problem or recommended actions (e.g., uncertainties associated with telemetry findings); (3) path dependence such as the inability to change paths because of an attachment to historical ways, which constrains the use of new ideas (e.g., wide establishment of stock assessment approaches); (4) power of groups that can influence the course of actions or direction of change; and (5) legitimacy for action (e.g., reliability or legitimacy of telemetry findings and recommendations; reviewed by Munck af Rosenschöld et al. 2014). Understanding these mechanisms can help focus efforts toward breaking down barriers and leverage changes.

Mismatches in scales (e.g., the spatiotemporal scale of a given study is inconsistent with the scale at which managers work), as well as in perceptions, beliefs, and values between knowledge producers and users, are often difficult for an individual to influence and require collective effort and collaborations. Such mismatches can often delay or impede the utilization of fish telemetry if they are not reconciled, because fish trackers and managers cannot work together towards a common goal, or telemetry study findings are not useful because they do not meet managers' needs.

A number of the barriers identified by our respondents have been highlighted in other areas of natural resource and environmental management (Vlek and Steg 2007; Cook et al. 2010; Dilling and Lemos 2011; Eden 2011; Clark et al. 2016; Soomai 2017). We argue that the barriers related to the characteristics of telemetry-derived knowledge are the most relevant to animal trackers and the area in which they may have the most influence. We thus focus the remaining of the discussion on addressing barriers related to telemetry-derived information and knowledge.

McGowan et al. (2017) and respondents in this study challenged animal trackers to develop explicit management objectives in their study designs because the investments that have been put into telemetry science for conservation and the growing potential that telemetry data can offer for conservation leaves the telemetry community with an ethical and practical responsibility to maximize the benefits that telemetry can have on conservation and resource management. Respondents in this study also felt that the links to management actions were often not explicit at the point when telemetry studies are designed. Therefore, our findings highlight what McGowan and colleagues considered to hinder the impacts of telemetry, which is a lack of explicit management objectives.

How to overcome the challenges of incorporating telemetry findings to fisheries management and conservation?

From a researcher's perspective, the policy-making and management environments may seem distant or daunting. The fisheries and resource management decision interface is extremely complex and multifaceted, and organizational structures and cultures have been identified as hurdles for implementing new information and approaches to management (Dilling and Lemos 2011; Yang and Maxwell 2011; Soomai 2017). Often, scientific evidence only occupies a small part of the "decision space" of managers or policy makers, and other factors including values, judgment, pragmatics, competing interests, and path dependency also influence decision-making (Rose 2015; Barraza et al. 2016). Furthermore, government bureaucracy and organizational culture and structure often define communication pathways and uptake of information because they guide how relationships are maintained and how tasks are carried out in an organization (Damodaran and Olphert 2000; Soomai 2017). There is thus an urgent need to recognize that organizational structures and cultures can either enable or discourage communication across the science–policy interface and that a collaborative model (as opposed to a linear one) is required to use new and up-to-date information (Soomai 2017). Successful integration of some telemetry-derived information has been documented by researchers who accounted for the various factors in decision-making and were proactive in building relationships and gaining peer acceptance of not only their scientific findings but their research program (Patterson et al. 2016). We discuss ways in which researchers may improve their conservation return-on-investment, while navigating the multifaceted decision environment of knowledge users.

Improve the technology and the analytical toolbox

With the development of longer-lasting batteries, along with smaller and more affordable electronic tags, telemetry studies are beginning to increase their sample size, monitor fish for longer periods, and tag fish at various life stages to inform the bigger pictures. These improvements can potentially address present concerns of reliability and relevance to fisheries managers (Lennox et al. 2017). New modeling and statistical techniques have been developed to identify behaviours and environmental correlates of behaviours and habitat use (Gurarie et al. 2016; Cooke et al. 2016; Jacoby and Freeman 2016), which will be invaluable for fisheries management. Furthermore, one respondent hypothetically suggested a "common telemetry or movement model" that could be applied in a consistent way to demonstrate the value of telemetry-derived information to fisheries managers (Table 3). Fish trackers can partner with modelling experts to develop new analytical tools and approaches that enhance the legitimacy and credibility of their work. Such collaborations are also needed to find pragmatic solutions to the current conservation crisis that demands new tools and frameworks to link the growing telemetry-derived data of the aquatic world to conservation and management (McGowan et al. 2017).

Share and standardize data and metrics

Sharing telemetry data can maximize its impact through development of global collaborative efforts and better data-sharing practices and infrastructure. By sharing data, sample sizes are increased and data are extended beyond the reach of a given study, which can help researchers to ask more complex questions and test hypotheses on new scales, thus increasing relevance and reliability of telemetry-based knowledge in fisheries management (Hussey et al. 2015; Nguyen et al. 2017*b*). To help realize the potential of aquatic telemetry to inform governance of fisheries and aquatic systems, there needs to be a way to make use of the growing catalogue of telemetry-derived data across species and spatiotemporal scales (Crossin et al. 2017). The current lack of standardization across telemetry studies can make it challenging for managers to work across contexts and scales. As previously mentioned, new analytical and statistical techniques (e.g., state-space models, network analysis) will become a go-to source to help make useful population-level predictions from relatively small numbers of tagged animals (Crossin et al. 2017).

Progress towards standardizing metrics for data, metadata, and study designs can improve data quality for reuse and assimilation or synthesis to answer complex questions and provide more relevant evidence (Koslow 2000; Nguyen et al. 2017*b*). However, the nuances of field data are often not easily standardized but can be improved through global discussions of standardized data collection for aquatic telemetry research methods. Furthermore, there are inherent challenges in telemetry research with respect to standards given that the coding schemes of competing manufacturers are proprietary, not to mention the differences across telemetry platforms (e.g., radio versus acoustic). The broader community (including scientists, managers, and telemetry manufacturers) need to engage in dialogue regarding these divisions if telemetry is to reach its full applied potential.

Informal relationships and collaborations: making telemetry relevant and identifying where telemetry fits into fisheries management

A number of challenges can potentially be overcome through informal relationships among researchers, managers, and stakeholders. A considerable literature suggests that trust-building through genuine interactions and conversations over time is critical for fostering meaningful exchange of knowledge and information (Jacobs et al. 2005; Mitton et al. 2007; Gibbons et al. 2008; Groffman et al. 2010; Young et al. 2014; Patterson et al. 2016). Young et al. (2016*a*) reported that knowledge viewed as credible and reliable is more likely to be trusted and used by knowledge users. They found that assessments of knowledge reliability were associated with perceptions of the character and motivation of the person making a claim — assessments that were strongly influenced by factors such as reputation and personal interactions. Even more important is maintaining a close working relationship after the initial knowledge exchange, as this is when trust is built (Chapman et al. 2015). Roux et al. (2006) noted that researchers can be guilty of offering a "solution" and quickly moving onto the next project, without following through and maintaining the exchange. Spending the face-to-face time fosters mutual respect and trust.

The informal linkages between managers and scientists have been documented to be fruitful (Patterson et al. 2016; Young et al. 2016*b*). Managers and scientists are embedded in different institutional environments, with different mandates, pressures, and reward systems. Both also use different learning methods to achieve different outcomes — managers typically seek out information relevant to a specific policy or decision, while scientists prioritize general principles and understanding of a question (Patterson et al. 2016). These epistemological differences contribute to barriers for integration unless there are continual communication and coordination across this divide to better link management activities with science activities and advice. Close interaction between scientists and managers allows the latter to articulate the problems and the former to develop ideas and hypotheses that are oriented towards management problems (Patterson et al. 2016). An excellent example can be drawn from the case of ongoing collaboration among researchers, managers, and stakeholders of the Fraser River Pacific salmon fishery. These groups proactively maintain informal relationships through symposiums and targeted solution-oriented meetings, which have led to successful use of telemetry-derived and physiological information (Young et al. 2013; Patterson et al. 2016).

Collaborations and relationship building with stakeholders and grassroots community organizations can also put pressure on governing bodies via bottom-up pressure. Ostrom (1992) argued that better governance institutions can be "'crafted" by coordinating the efforts and differing skills, structures, and capacities of both policy makers and resource users. As such, empowering the wider user group such as fishers and nongovernmental organizations may prove to be an effective means of integrating fish telemetry-based knowledge into management practices, whether through bottom-up pressure by stakeholders or through voluntary institutions and collective action (Granek et al. 2008; Danylchuk and Cooke 2011; Cooke et al. 2013). This requires active engagement and participation by telemetry researchers to communicate their research as well as investing time and effort into building meaningful relationships with stakeholders and the wider public.

Formal relationships and collaborations: greater science–management interface within organizations and institutions

More formal collaborations can blossom from informal relationships. Co-production of knowledge, co-creation of solution-oriented research agendas, and transdisciplinary teams are all strategies to address the barriers identified in this study and help with designing management objectives in studies (Pohl 2005; Hessels and van Lente 2008; Hegger et al. 2012; Dick et al. 2016). For example, increasing joint government–university and (or) public–private partnerships may facilitate the reconciliation of scalar, cultural, and social mismatches between science and management. For instance, the Great Lakes Acoustic Telemetry Observation System (GLATOS) is a telemetry network and infrastructure established by the Great Lakes Fishery Commission (GLFC), a binational governmental institution responsible for the management of Great Lakes fisheries. GLATOS provides a formal platform and forum for telemetry researchers to share data and resources, as well as interact and collaborate with fisheries managers. Such forums can facilitate joint study design and co-production of knowledge that may be more socially robust and viewed as legitimate, credible, and salient by the knowledge users. A concerted effort to create forums for regular interactions and exchanges between science and management may go a long way towards reconciling mismatches and creating sustainable fisheries. In addition, GLFC offers a model that values relationships. Their budget provides direct funding for researchers and managers to come together at social events, including annual workshops to maintain the relationships built (Gaden et al. 2008).

Evaluation of the application of the knowledge–action framework

We applied the knowledge–action framework described by Nguyen et al. (2017*a*) in this study. The framework proved useful for the qualitative analysis, because it provided a structured guide for coding the responses provided. The framework also offered a platform for comparing qualitative data and providing context for the findings. The flexibility of the framework also allowed us to identify subthemes and gather more nuanced information from the data. However, there are also costs to using a framework. Researcher bias and interpretation may influence how the framework components are interpreted and how the data fit in each component. We also found that there was a lack of strategy for the investigator to deal with emergent responses related to mismatches, scales, and time because these concepts span across the entire framework and cannot be categorized into one of the dimensions described. As such, the framework could be improved to better capture interactions and overarching spatial–temporal scales. Nonetheless, we believe it is important that findings can accumulate in a manner that facilitates comparisons and synthesis to bridge the gap between knowledge and action.

Conclusion

This study revealed that fish trackers perceived certain characteristics and attributes of telemetry data, including uncertainties, incompatibilities, complexity, and lack of direct relevance to management needs, as undermining the usefulness of telemetry-derived information. This supports McGowan et al.'s (2017) argument that the lack of explicit management objectives designed into telemetry projects delays conservation impact of animal-borne telemetry investments. In this study, researchers were also critical of their own peers for designing studies that are too descriptive or without conservation applications. Co-production of knowledge and co-designing telemetry studies with managers and other users are important concepts that can address the barriers identified. Evidence has shown that the coordination and communication in the scientist–manager pairing model works and thus can be an avenue for fish trackers to explore to define the utility of their telemetry work in the context of fisheries management and conservation. The environmental and contextual barriers (i.e., structural barriers), on the other hand, are more challenging for researchers and potential users to address directly. Based on our findings, changes and innovations in institutional structures are needed for effective use of new knowledge, such as telemetry-derived knowledge, which may take more time and collective effort among all players (including funding, university, and publishing institutions).

Facilitating the mobilization of telemetry-derived knowledge is essential for informed decision-making and effective policy applications because of the variety of knowledge and insights they can offer about the animals and their interactions with the environment (Hussey et al. 2015; Crossin et al. 2017; McGowan et al. 2017). Telemetry-derived data are growing exponentially and in all regions of the globe, and effectively using this data is critical for addressing major environmental crises and human-accelerated environmental change worldwide. We hope that these findings can help the fish telemetry community better link their research to conservation outcomes, and we anticipate that these lessons are relevant to those tagging and tracking other taxa beyond fish, as well as providing greater empirical evidence to better understand knowledge mobilization processes and outcomes in the context of natural resource management and conservation.

Acknowledgements

Nguyen was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Ontario Graduate Scholarship. This project was supported by Ocean Tracking Network through a network project grant (NETGP No. 375118-08) from NSERC and part of ideasOTN (reference No. 18). The International Conference for Fish Telemetry provided logistical support. Thank you to Neal Haddaway for data collection support. We thank all of the participants who responded to our survey. We thank the anonymous reviewers for their insightful suggestions.

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