From animal movements to knowledge movement: knowledge mobilization associated with rapid developments in electronic tagging technology and its application.

by

Vivian M. Nguyen

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Biology

Carleton University

Ottawa, Ontario

Abstract

The conservation of biodiversity and sustainable management of natural resources should be built on evidence-based decision-making principles and policies. The application of scientific evidence, however, is imperfect, especially in the realm of fisheries management. I propose a knowledge-action framework to understand the gap between knowledge production and utilization. The framework provides a sociological perspective to understanding the movement of knowledge into conservation and resource management actions, and is grounded in theories of knowledge mobilization and exchange. The framework provides a roadmap for scholars to organize and synthesize research related to the knowledge-action gap in conservation and natural resource management. This thesis evaluates what roles do components of the knowledge-action framework, for example, environmental and contextual factors, characteristics of knowledge actors, the relational dimension, and the characteristics of the focal knowledge have in influencing the uptake of knowledge. I addressed this research question by using a sociological approach and applying a mixed-method strategy to evaluate case studies and model systems using both qualitative and quantitative analyses. First, I evaluated a case study with complex environmental and contextual factors, the Fraser River Pacific salmon fisheries in British Columbia. Second, I evaluated the barriers to the application and use of a relatively new technological tool in fisheries management – telemetry technology – from both a qualitative and quantitative approach. In the Fraser River case study, the greatest perceived barriers to using new knowledge were institutional barriers and constraints. The quantitative study revealed that researchers who are committed, collaborative and engaged in outreach and dissemination activities achieved greater knowledge uptake such as formal integration or social acceptance of their work. The qualitative study that evaluated perceived barriers to using fish telemetry

revealed that researchers perceived the limitations and challenges of telemetry itself (characteristics of the focal knowledge) as a barrier to integration. Together, the components of my dissertation applied and evaluated the proposed knowledge-action framework to evaluate how scientific knowledge moves in the context of fisheries management. This is important to inform an era of evidence-based decision making and I believe has implications for the broader community of conservation and natural resource management.

Acknowledgements

I am tremendously grateful to have worked under the supervisions of Dr. Steven Cooke and Dr. Nathan Young, who have both shaped my development as a scientist and as a person. Words cannot describe how lucky I have been to have the immense support from Steve throughout my entire academic career from being a wee little lost undergrad to a more confident doctoral student (apparently 12+ years now). His enthusiasm, energy and accomplishments are inspiring, and continue to motivate me to continue to improve my daily endeavors. Steve's mentorship, support and trust in me has led me to broaden my research career and interest, and to enter foreign territories such as the social sciences to explore complex environmental problems. Working with Nathan has opened my eyes to a new world of research in the social sciences. His patience, understanding, and mentorship has helped and inspired me to walk the lines between the natural and social sciences more confidently. Nathan's trust in my abilities have helped me grow and take on new opportunities. I am indebted to both supervisors, and thank them for the opportunities they have given me through my graduate career, and for positively shaping my personal and professional development (and letting me rant about all sorts of things).

I thank my advisory committee for providing thought-provoking discussions and scholarly questions that pushed intellectual discourse. I thank Dr. Root Gorelick, Dr. Rees Kassen, and Dr. John Dettmers for their support, encouragement, and dedication toward my thesis. Each of their perspectives have enlightened my experience as a graduate student. Thank you to Sue Bertram for her support as my TA supervisor and helping me develop as a teacher. Thank you to Jennifer Lee for providing me with more learning opportunities at the Department of National Defence.

The input and contributions of my collaborators were critical to my thesis work. I thank Marianne Corriveau, Scott Hinch, David Patterson, Neal Haddaway, Rob Harcourt, Jill Brooks, Jake Brownscombe and Fred Whoriskey for their valuable input and ideas. My intellectual and personal development were also significantly shaped by my peers. Thank you to Lauren Stoot, Shannon Bower, Jill Brooks, Jacqueline Chapman, Taylor Ward, Jake Brownscombe, Graham Raby, Natalie Sopinka, Aaron Zolderdo, Mike Lawrence, Laura Elmer, Lee Gutowsky, Andrea Reid, Chris Elvidge, Petra Szekeres, Robert Lennox, Lisa Donaldson, Sarah Laroque, Charles Hatry, Tara Macdonald, Jon Midwood, Maja Cvetkovic, Nick Lapointe, Jessica Taylor, Caleigh Delle Palme for their friendship, intellectual (sometimes not) discussions, mentorship, and support. Thank you for shaping my graduate experience, for the life-long lessons, and lifetime memories.

Thank you to my partner Joshua Shaw, and my family for their support. Thanks Josh for being chauffeur and cook, and keeping me grounded when cortisol levels were high. Thanks for being my partner in crime (especially when I try to do too much), for helping with my slumlord activities, and teaching (or trying to teach me) me how to say no. Thanks to my sister, Jackie, for her unconditional support and sending me on a writing holiday for the last push. Thanks to my parents for their support whether it'd be feeding me, allowing me to grocery shop in their refrigerator, or helping me with the house. Without all of their support, I would not have been as productive and motivated as I have been for my doctoral studies. Special thanks to Jayden for reminding me of the curiosities of the world, and listening to my poor explanation of all things. Thanks to the Ottawa Swans AFLC and the Northern Lights for maintaining my discipline and hard-work ethics, and helping me develop routine and set goals.

During my Ph.D. I have been part of so many great networks of wonderful people who have broadened my perspective, my knowledge, and my opportunities. Thank you to everyone at the Ocean Tracking Network (and ideasOTN) for their contribution to my thesis, both financially and logistically, and for the Network's contribution to my development as a researcher. Thank you to the IN FISH crew; our monthly meetings have insightful, and our collaborative work have assisted in my learning. Thank you to Lisiane Hahn and NeoTropical Consulting, Maria Clara Bezerra, and Gustavo Hallwass for the wonderful learning experience in Brazil.

During my Ph.D. I have received financial support including a Natural Sciences and Engineering Research Council (NSERC) PGSD scholarship, Ontario Graduate Scholarship, Ocean Tracking Network Travel Award, Carleton University Wyndham Scholarship for Excellence in Biology, CARS Peter A. Larkin Award in Fisheries Excellence, and the American Fisheries Society Skinner Memorial Award. Thank you to all participants who participated in my study, without them, I would not have data to conduct my research.

Thesis Format and Co-authorship

This dissertation contains one theoretical chapter and four data chapters written in manuscript format, which are at various stages of the publication process in peer-reviewed journals. For this reason, there is some repetition between chapters to remain consistent with my contributions to the scientific literature. While this thesis contains my research, many co-authors contributed to the data chapters. Here, I list my contributions to each chapter, as well as that of my co-authors.

Chapter 1. A roadmap for knowledge exchange and mobilization research in conservation and natural resource management.

Nguyen, V.M., Young, N., & Cooke, S.J. 2017. A roadmap for knowledge exchange and mobilization research in conservation and natural resource management. *Conservation Biology* 10.1111/cobi.12857

I developed the conceptual framework, conducted the literature review and synthesis, and manuscript preparation. Young and Cooke contributed to the development of the conceptual framework and manuscript preparation.

Chapter 2. What is 'usable' knowledge? Perceived barriers for integrating new knowledge into fisheries management of an iconic Canadian fishery

Nguyen, V.M., Young, N., Corriveau, M., Hinch, S.G. & Cooke, S.J. In Prep. What is 'usable' knowledge? Perceived barriers for integrating new knowledge into fisheries management of an iconic Canadian fishery. In prep for *Canadian Journal of Fisheries and Aquatic Sciences.*

I assisted in designing the study, conducted the data collection, data analysis, and manuscript preparation. Young led the study design and contributed to manuscript preparation. Corriveau assisted with data collection. Hinch and Cooke contributed to study design and manuscript preparation.

Chapter 3. Science action starts with collaboration and engagement: an empirical exploration into factors influencing knowledge uptake from fish tracking studies around the globe

Nguyen, V.M., Young, N., Brownscombe, J.W., & Cooke, S.J. In Prep. Science action starts with collaboration and engagement: an empirical exploration into factors influencing knowledge uptake from fish tracking studies around the globe. In preparation for *Journal of Applied Ecology.*

I designed the study, conducted the data collection, data analysis, and manuscript preparation. Young and Cooke contributed to study design and manuscript preparation. Brownscombe and Young assisted with the data analysis.

Chapter 4: Applying a knowledge-action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study

Nguyen, V.M., Young, N., & Cooke, S.J. In Review. Applying a knowledge-action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study. Referee reviews received from *Biological Conservation.*

I designed the study, conducted the data collection, data analysis, and manuscript preparation. Young and Cooke contributed to study design and manuscript preparation.

Chapter 5: To share or not to share in the emerging era of big data: Perspectives from fish telemetry researchers on data sharing

Nguyen, V.M., Brooks, J.L., Young, N., Lennox, R.J., Haddaway, N., Whoriskey, F.G., Harcourt, R., & Cooke, S.J. 2017. To share or not to share in the emerging era of big data: Perspectives from fish telemetry researchers on data sharing. *Canadian Journal of Fisheries and Aquatic Sciences* 10.1139/cjfas-2016-0261

I designed the study, conducted the data collection, data analysis and manuscript preparation. Young and Cooke contributed to study design. Brooks and Young contributed to data analysis and manuscript preparation. Lennox, Whoriskey, Harcourt, Cooke contributed to manuscript preparation.

Table of Contents

Abstract ... ii

Acknowledgements ... iv

Thesis Format and Co-authorship ... vii

Chapter 1. General Introduction and Theoretical Framework ... 1

1.1. Knowledge Movement from a Sociological Perspective ... 7

1.2 The Need for a Knowledge-Action Framework ... 10

1.3 A Knowledge-Action Framework ... 10

1.4 Three Elements of the Knowledge-Action Framework ... 11

1.5 Scales, Levels and Interactions ... 19

1.6 Model for Applying the Knowledge-Action Framework: Fisheries Management and Telemetry Technology ... 24

1.6.1 Telemetry technology: linking scientific knowledge and fisheries management ... 25

1.7 Hypotheses and Objectives ... 27

Chapter 2. What is 'usable' knowledge? Perceived barriers for integrating new knowledge into fisheries management of an iconic Canadian fishery ... 30

2.1 Abstract ... 30

2.2 Introduction ... 30

2.3 The case: Fraser River Pacific salmon fishery ... 33

2.4 Managing Pacific Salmon in the Fraser River ... 34

2.5 Methods ... 37

2.6 Results and Discussion ... 40

2.7. Synthesis ... 56

2.8. Lessons Learned ... 59

2.9 Conclusion ... 62

Chapter 3: Science action starts with collaboration and engagement: an empirical exploration of factors influencing knowledge uptake from fish tracking studies around the globe ... 63

3.1 Abstract ... 63

3.2 Introduction ... 64

3.2.1. Context: Telemetry Science and Fisheries Management 65
3.2.2. Theoretical Framework 66
3.3. Methods 69
3.3.1. Instrument development and data collection 69
3.3.2. Data Collection 70
3.3.3 Data Analysis 71
3.4. Results 77
3.4.1 Characteristics of the sample 77
3.4.2. Principal Component Analysis 77
3.4.3. Random Forest Classifier 81
3.4.4. Researcher attributes explaining formal and social uptake of telemetry study findings 81
3.4.5. Project attributes explaining formal and social uptake of telemetry study findings 81
3.4.6. Insights from bivariate associations and correlations analyses 82
3.5 Discussion 87
3.6 Supplementary Information 96
Chapter 4: Applying a knowledge-action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study 108
4.1 Abstract 108
4.2 Introduction 109
4.3 Methods 110
4.4 Results 114
4.5 Discussion 129
4.6 Conclusion 138
4.7 Supplementary Information 140
Chapter 5: To share or not to share in the emerging era of big data: Perspectives from fish telemetry researchers on data sharing 149
5.1 Abstract 149
5.2 Introduction 149

5.3 Methods.......... 153
5.3.1 Semi-structured interviews.......... 154
5.3.2 Online questionnaire 154
5.3.3 Quantitative data analysis.......... 156
5.3.4 Index variables 157
5.3.5 Qualitative data analysis.......... 158
5.4 Results and Discussion 158
5.4.1 Characteristics of respondents in the study 158
5.4.2 Current data sharing in fish telemetry 159
5.4.3 Characteristics of individuals more likely to share data: logistic regression 160
5.4.4 Concerns with sharing telemetry data 162
5.4.5 Benefits to sharing telemetry data 172
5.5 Conclusion 176
5.6 Supplementary Information 181
Chapter 6: General Discussion 184
6.1 Synthesis and Future Research Directions 184
6.1.1 The influence of environmental and contextual dimension on knowledge action outcomes.......... 185
6.1.2 The influence of dimensions within the knowledge network on knowledge outcome 190
6.1.3 Scales and Levels 196
6.2 Assessment of the Application Knowledge-Action Framework: Lessons Learned and Future Research Directions 197
6.3 Way Forward: Guide for knowledge exchange and mobilization research in conservation and natural resource management.......... 199
Appendix A. Abstracts of non-thesis publications during doctoral studies.......... 202
Appendix B. Online questionnaire for Chapters 3-5..........219
References.......... 228

List of Tables

Table 1.1: Summary of the components of the *knowledge-action framework* and potential variables hypothesized to influence KMb/KE with example sources from the literature……..…17

Table 2.1: Components of the knowledge-action framework used to help code and structure the qualitative data analysis (adapted from Nguyen et al. 2016, Chapter 1)……...…………………36

Table 2.3: Coded themes that emerged using a knowledge-action framework (Nguyen et al. 2016) with sub-themes that provide more nuance and description related the framework categories. …………………………………………………...…………………………..38

Table 2.4: Five solutions and facilitators discussed by knowledge users in the Fraser River salmon fisheries with illustrative quotations. ……………………………………………………50

Table 3.1: Demographics and other relevant covariates describing the sample population of fish telemetry researchers. ………………………………………………. …………………….74

Table 3.2: Rotated Structure Matrix for PCA with Varimax Rotation of Two Component Questionnaire………………………………………….. ……………………….....……75

Table 3.3: Correlation coefficients from the final four multiple linear regression models (researcher attributes x formal uptake; researcher attributes x social uptake; project attributes x formal uptake; project attributes x social uptake). ……………………………………...….…80

Table 3.4: Descriptive statistics for significant explanatory variables for regression models: Researcher attributes x formal uptake; Project attributes x Formal uptake; Researcher attributes x Social uptake, and; Project Attributes x Formal Uptake. …………………….…………….…81

Table 3.5: Statistically significant ($p<0.05$) bivariate associations and correlations between outcome and independent variables using simple t-tests, chi square and regression analyses. Results grouped into researcher and project attributes. ………………………...……………82

Table 4.1: Socio-demographic and other characterizing variables of the sample population....112

Table 4.2: Summary of barriers identified using a knowledge-action framework (Nguyen et al. 2016)...……………………………………………………………………………………….116

Table 4.3. Summary of identified facilitators and solutions for the incorporation of telemetry-derived knowledge into fisheries management using inductive coding. ………………………124

Table 5.1: Socio-demographics and characteristics of the respondents in frequencies and percentages………………………………………………………….………………..…159

Table 5.2: Results of the binary logistic regression to test for significant effects of independent variables that were included in the model exploring relationships between individuals who shared vs. have not shared their fish telemetry data……………………………..………..…160

Table 5.3: Results of the binary logistic regression to test for significant effects of 15 criteria for respondent choice of research questions/agendas on the whether respondents have shared or have not shared fish telemetry data………………………………………………………………..161

List of Figures

Figure 1.1: Conceptual diagram of the "knowledge-action" framework depicting the processes of knowledge mobilization within a knowledge system at a dynamic temporal scale and including individual and institutional levels……………………………………………………………8

Figure 2.1: Distribution of the number of respondents that identified barriers for incorporating new knowledge into fisheries management practices based on the knowledge-action framework themes……………………………………………………………………………………37

Figure 3.1: Conceptual model of a knowledge-action framework that guided the development of the quantitative models built to test the predictions……...………………………………………64

Figure 3.2: Flow chart of statistical analyses undertaken using R and SPSS statistical packages……………………………………………………………….……………………………71

Figure 3.3: Top ten variables based on Gini measure of importance (shown as Increase in Node Purity) in the random forest analyses. ……………………………………………………..…….72

Figure 4.1: Overview of application of knowledge-action framework (adapted from Nguyen et al. 2016) for the exploration and identification of barriers to incorporate telemetry-derived knowledge into fisheries management practices……………………………………..……114

Figure 5.1: Flow chart breaking down the responses of respondents who have participated in data sharing relative to those who have not………...……………………………………..162

Figure 5.2: Infographic illustrating the reported concerns with, and benefits of sharing telemetry data...……………………………………………………………………………………163

List of Chapter Supplementary Information

3.6 Supplementary Information for Chapter 3…………………………….……………………..91

S3.1. List of predictions derived from the hypothesis of Nguyen et al.'s knowledge-action framework………………………………………………………………………………… 92

S3.2: List of explanatory variables tested grouped by categories based on the knowledge-action framework with description of the variable type, the coded name for analysis or the construct used for analysis, and the associated question number from the interview/questionnaire found in Appendix B………………………………………………………………………………………94

S3.3: Details on construct variables and Cronbach's alpha test for reliability………………......98

4.7 Supplementary Information for Chapter 4…………………………….……………………136

Table S4.1 Detailed descriptions with illustrative quotes of identified barriers to the incorporation of telemetry-based knowledge into fisheries management using the knowledge-action framework……………………………………………………………………...……136

Table S4.2 Detailed descriptions and quotes illustrating identified facilitators and solutions to the incorporation of telemetry-based knowledge into fisheries management through qualitative inductive coding. ……………………………………………………………………………….143

5.6 Supplementary Information for Chapter 5…………………………………………….………177

Table S5.1 Intercorrelations matrix for logistic regression analysis………………..….………177

Table S5.2: Concerns described by respondents with regards to sharing telemetry data in public databases……………………………………………………………………………………..178

Table S5.3: Benefits described by respondents as a result of sharing telemetry data in public databases. …………………………………………………………………………………....179

List of Appendices

Appendix A: Abstracts of non-thesis publications during doctoral studies…….…………...…198

Appendix B: Online questionnaire used for data collection in Chapters 3-5…………….…….212

Chapter 1. General Introduction and Theoretical Framework

Nearly twenty years ago, Gary Meffe (1998: 741), a pioneer in conservation science, suggested that: "if we—the premier conservation scientists in the world who seek and possess the best scientific information on the state of nature—do not actively and aggressively put our knowledge to use in development of public policy and legislation, and do not do it soon, then we are failing society and posterity in what should be a major responsibility". There is little doubt that conservation scientists want their research to influence conservation and environmental policies and practices (Cooper 2009, Singh et al. 2014). However, this has not been an easy task, particularly because policy makers, resource managers and stakeholders often rely on experiential, tacit, and informal knowledge rather than scientific knowledge in formulating their opinions and in their decision making (Pullin et al. 2004; Sutherland et al. 2004; Roux et al. 2006; Cook et al. 2010; Cvitanovic et al. 2014). The difficulties experienced by both scientists and potential knowledge users in mobilizing conservation science suggests that significant cultural and structural barriers are impeding the flow of information and knowledge into action (Roux et al. 2006, Gibbons et al. 2008, Cook et al. 2010, Young et al. 2013). This phenomenon has been described in several ways (e.g., as a *science-action*, *research-implementation,* or *knowledge-action* gap) and has recently gained significant interest among conservation science scholars (Cowling 2005, Knight et al. 2008, Cook et al. 2013, Young et al. 2013). In this thesis, I define "information" as a tangible, factual output of scientific research produced through data analyses; "knowledge" as a body of information learned and conveyed through scientific and policy processes, which is shaped by the perceptions and experiences of the "knower" (Eliot 2004; Posner et al. 2015). I choose to focus on knowledge because it differs from data or information such that it is not a discrete ‘entity’ that can be stored, processed, or deposited. Knowledge involves interpretation and a cognitive process that is shaped by individual experiences and worldviews. Therefore, I focus on *scientific* knowledge because it generally informs decision makers in conservation natural resource management but is often influenced by social processes (Estabrooks et al. 2006, Greenhalgh 2010). Furthermore, I am interested in knowledge mobilization in both the context of conservation and natural resource management because, both have intertwined objectives and natural resource management often involves a conservation mandate.

While existing research on the knowledge-action gap has been fruitful, scholars in the field believe that they are only scratching the surface in gaining a comprehensive understanding of the causes and potential remedies of the knowledge-action gap (Cowling 2005, Cook et al. 2013, Fazey et al. 2012, Reed et al. 2014). Much of the existing research involves in-depth examination of case studies. While these are highly useful, they often lack an overarching conceptual framework to aid with generalization and connect findings to the wider community of theory and practice (Fazey et al. 2012, 2014, Reed et al. 2014). For this reason, I argue that there is a deficiency in our understanding of the knowledge-action gap, hence a gap within the knowledge-action gap. Here, I propose a framework for identifying, synthesizing and comparing context-specific research on knowledge movement and implementation that currently defines the literature, and connecting this research to broader analyses of relevant social processes. The proposed framework is rooted in concepts and lessons learned from the sociology of science (Pinch and Bijker 1984). It is intended as a starting point that may offer a theoretically-informed roadmap for research into the knowledge-action gap, and assist in advancing our understanding of knowledge movement in conservation and natural resource management as more empirical evidence accumulate.

1.1. Knowledge Movement from a Sociological Perspective

Research on the knowledge-action gap across multiple fields has shown that scientific knowledge has less of an impact on decision-making than is generally assumed (Artlettaz et al. 2010, Rose 2016). The impacts of knowledge are, however, difficult to trace. In some cases, impacts are immediate and direct, but most of the time the impacts of knowledge unfold indirectly and over a long period of time (Levin 2013). The frustrations that many scientists feel that their findings are not implemented or taken seriously makes more sense when we consider knowledge from a sociological perspective (Fazey et al. 2014). Sociologists view knowledge as embedded in social structures and relations. This means that people rely on one another to access knowledge (via social connections and networks), and also that people interpret knowledge based on shared social constructs such as beliefs, values, culture, norms and other social influences (Pohl 2008, Levin 2013, Clark et al. 2016). Knowledge that is communicated through peer-reviewed journals is unlikely to enter the social networks of relevant user groups, for instance, because of its social nature (it is often a people-people process) (Young et al. 2016a, b). Similarly, knowledge that does not connect immediately with users' priorities and practices is not likely to have a substantial impact on their opinions or decision-making (Yamamoto 2012). My approach uses these insights from sociology and the broader social sciences as a starting point for building the conceptual framework.

In the realm of conservation and natural resource management, research on the knowledge-action gap is lagging behind and is less developed than other sectors such as the social sciences, health sciences, education, and business management (reviewed in Fazey et al. 2012). Although we have seen a marked upswing in research on knowledge movement in the conservation literature over the last few decades, the portrait remains incomplete. The effectiveness of knowledge on conservation practices and natural resource management depends on how knowledge moves, how it is exchanged, how it is used, and how it interacts with the social world (Pullin & Knight 2003, Cash et al. 2003, Francis and Goodman 2011**,** Fazey et al. 2012). Researchers increasingly recognize that knowledge is not an inert object that can trickle down, transfer and translate through a linear "pipeline model" from the knowledge producers to the knowledge users (van Kerkhof and Lebel 2006, Roux et al. 2006), but rather moves in a dynamic, iterative, and non-linear fashion. Thus, I bring attention to two concepts that capture the fact that moving knowledge across social boundaries is challenging and is a multi-way exchange between the knowledge generators and potential users (Gainforth et al. 2014, Young et al. 2013). These concepts are knowledge exchange (KE), which has recently been adopted in the environmental management literature (Fazey et al. 2012), and knowledge mobilization (KMb), which is more commonly used in the social sciences and education literature (e.g., Bennet et al. 2007, Levin 2013). Knowledge exchange and knowledge mobilization both attempt to capture the social dimensions and contexts of knowledge creation, diffusion, and application (Cash et al. 2003, Fazey et al. 2012, Young et al. in press) and are terms that describe the *process* and *mechanisms* of knowledge movement, while I use knowledge action to describe the *issue* at hand: the knowledge-action gap in conservation and natural resource management. Here, knowledge action does not necessarily mean an action is required. Various perceptions of appropriate action or inaction exist, and "knowledge-action" is thus situational and defined by the context.

A wide range of terms and concepts has been presented across disciplines and literatures to describe the process of knowledge movement. These include (but are not limited to) knowledge transfer, knowledge translation, diffusion of innovation, and knowledge management. Each have their own nuances, emphases, and applications (see Greenhalgh and Wieringa 2011, and Fazey et al. 2012 for comprehensive reviews). At root, however, each of these terms has a similar referent and purpose: to facilitate analysis of the conditions in which knowledge moves and is applied by a range of social actors. In the context of conservation and natural resource management, the term knowledge management merits particular attention. As a concept, knowledge management originates in the business and organizational studies literature, and refers to practices for managing intellectual capital and information flows to achieve organizational objectives, particularly enhanced market competitiveness (Alavi and Leidner 2001, Bennet and Bennet 2007). However, the term has recently entered the environmental management literature, but with a slightly different connotation. Reed et al. (2013, p. 311) defined knowledge management as the "process of generating, storing and circulating *new* knowledge and identifying [and] bringing together and applying *existing* knowledge to achieve a specific objective." This definition is more in line with KE/KMb research, and with the core dilemma at the heart of the knowledge-action gap, namely how to integrate new knowledge into practices that are highly influenced by existing bodies of experiential, tacit, and informal knowledge (including local and traditional knowledge)– knowledge that is gathered from experience and difficult to convey. For the sake of conceptual clarity, I elect to use the terms

KE/KMb, but in full acknowledgment of the existence of other terms that have similar meanings, particularly that of knowledge management.

1.2 The Need for a Knowledge-Action Framework

Although there has been an increase in KE and KMb research in the field of environmental management, little synthesis exists of lessons learned and actions required (but see Fazey et al. 2012, Reed et al. 2014). For instance, the majority of new information and early research is case-study based and context specific. Case-based findings related to KE and KMb have not been reported in a manner that can assist the wider community of theory and practice to improve on KE and KMb processes in the future. This makes it challenging to organize new knowledge on KE and KMb so as to facilitate comparability and applicability across different contexts and situations (Ostrom 2009, Fazey et al. 2012). Frameworks are therefore needed to help organize and compare results of new research on the processes of KE and KMb so as to improve understanding of the knowledge-action gap and provide guidance for future research in conservation and natural resource management.

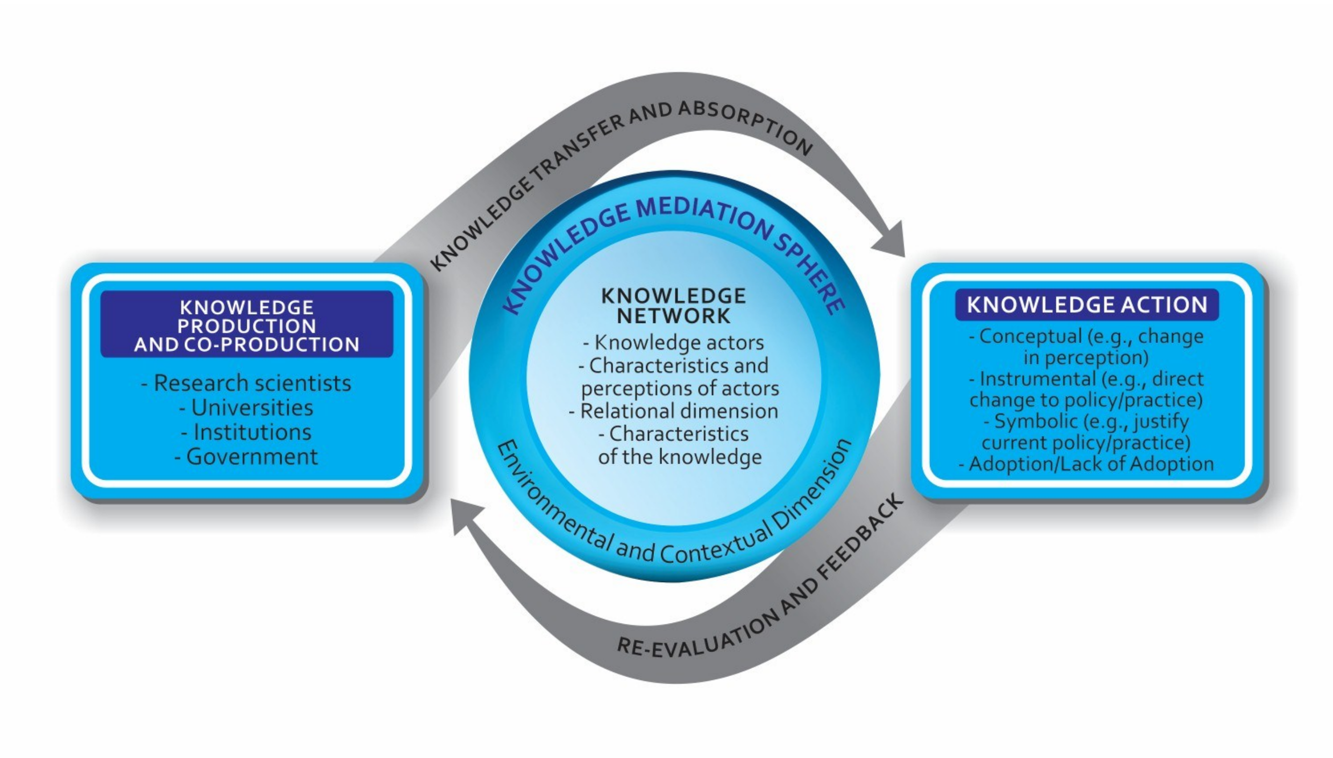
1.3 A Knowledge-Action Framework

The goal of a framework is to provide structure to a field of ideas and research in a way that demonstrates applications and provides guidance for future work (Ostrom 2009). Without a framework to organize relevant KE and KMb information, isolated observations and findings from KE and KMb research are unlikely to result in a coherent body of knowledge. The knowledge-action framework I devised is based on my reading of the broader literature on knowledge exchange, mobilization, translation, transfer, and management across multiple fields and disciplines (e.g., business management, education, health sciences, social sciences, and others). The framework is not meant to be prescriptive or a complete systematic review of knowledge-action research. Rather, I sought to provide a dynamic framework to help build empirical evidence in an organized manner and further understanding of knowledge movement in the context of conservation and natural resource management.

1.4 Three Elements of the Knowledge-Action Framework

Three core elements form the basis for moving knowledge into action: the knowledge production; an intermediary where knowledge is acquired, retained, and processed; and a knowledge action or inaction (Argote et al. 2003, Contandriopoulous et al. 2010, Phelps et al. 2012, Fazey et al. 2012). I adapted the three core elements to my proposed framework (Fig. 1.1.1) as knowledge production or co-production; the knowledge-mediation sphere (i.e., the knowledge-action gap); and the knowledge-action outcome, respectively (Fig. 1.1). There are nonlinear processes that connect these three elements such as the strategies used to mobilize and exchange knowledge and capacity to absorb the knowledge (i.e., absorption and transfer [Fig. 1.1]) and social learning as a byproduct of re-evaluation and feedback of the knowledge exchange and mobilization processes (Fig. 1.1). The components of the framework are summarized in Table 1.1.

Figure 1.1: Conceptual diagram of the "knowledge-action" framework depicting the processes of knowledge mobilization within a knowledge system at a dynamic temporal scale and including individual and institutional levels. The center circle indicates the *mediation sphere,* which encompasses factors that ultimately influences whether knowledge is absorbed and transferred, adopted into a knowledge action, re-evaluated and looping back to the knowledge producers, or absorbed and transferred but not adopted. The entire framework operates on a temporal level where processes are dynamic and time sensitive, as well as on various levels, which are broken down into individual, group and institutional levels.



1.4.1 Knowledge Production

In the world of conservation science, academic institutions and other researchers (e.g., governmental, environmental consulting industry) are typically the source of scientific *knowledge production* in a knowledge system or social network (Fig. 1.1, Table 1.1). However, the recent trend toward co-creation and co-production of knowledge involving collaboration between scientists and knowledge users have blurred the lines and transcended boundaries (Berkes 2009, Phillipson et al. 2012, Hegger et al. 2012, Schuttenberg and Guth 2015). Additionally, there has also been an increased inclusion of citizen science and local/traditional ecological knowledge in tackling conservation and natural resource issues (Raymond et al. 2010). This recent shift does not necessarily mean that changes in practice have occurred. Many scientists continue to work in traditional ways with clear and hierarchical divisions between producer and user, an approach that continues to be favored by current institutional norms, structures, and reward systems (Shanley and Lopez 2009). Nonetheless, knowledge production in this framework can also include co-production with the end-users in anticipation of increased participatory approaches in conservation and natural resource management (Cash et al. 2013, Fazey et al. 2014).

1.4.2 Knowledge mediation sphere

In my proposed framework, knowledge that is produced enters a *knowledge mediation sphere* (Fig. 1.1.1), in which knowledge can be absorbed, retained, bounced around, transferred, re-interpreted, shared, and also potentially misappropriated or become stuck (Reed et al. 2014). The mediation sphere is essentially that gap between knowledge and action. The sphere is metaphorically “the anatomy” of the knowledge-action gap. The mediation sphere follows the concepts of knowledge exchange and mobilization by stressing the multi-directional and iterative movement of knowledge in forms such as *re-evaluation and feedback*, which may begin co-currently with *knowledge production*, as under participatory approaches and knowledge co-production (Cvitanovic et al. 2015, Schuttenberg and Guth 2015). The factors that make up the mediation sphere may influence the destination of the knowledge that enters the sphere and may also include and/or form boundary objects. Boundary objects are artifacts such as best practices, strategies, and plans that exist at the frontiers of two social worlds and help bridge them (Star 2010). In other words, the sphere includes the processes that influence and mediate the flow of knowledge from the *knowledge production* to *knowledge action* such as a development or change to policy or practice, which will be discussed in more detail below.

1.4.2.1 Knowledge mediation sphere: the knowledge network

The knowledge mediation sphere is comprised of components that may help us understand the mechanisms of knowledge flow. First, knowledge can enter a *knowledge network* (Fig. 1.1.1), which is a social network composed of complex interactions of *knowledge actors* with the knowledge itself and with each other at potentially multiple levels (Crona and Bodin 2003, Inkpen and Tsang 2005, Phelps et al. 2012, Reed et al 2014). The multilevel actors in the network range from individual-level to group- and institutional-level. The actors (e.g., creators, brokers, practitioners, users) individually and collectively all have a role in the mobilization and application of knowledge (Phelps et al. 2012, Young et al. 2016a). Recent research has emphasized the importance of social capital (i.e. the networks and norms that facilitate social engagement) for collective action (Ostrom 2014) in conservation action and potentially knowledge action. Thus, the structure and content of social relationships and interactions influence the access, transfer, diffusion and application of knowledge. Furthermore, each actor has characteristics (i.e. *characteristics and perceptions of actors*) that have been suggested to have an impact on knowledge flow (Table 1.1). The role and social status of the actor, their positioning within their social network, power, credibility, and each of their own social networks can influence the flow of knowledge (Borgatti and Cross 2003, Argote et al. 2003, Bodin and Crona 2009, Fazey et al. 2013). For example, an actor with the status of an opinion leader could have important social influence and social interactions within their social network, and have large influence on whether a certain knowledge claim is viewed as credible or legitimate. Furthermore, the actor's motivational factors (to create, transfer, absorb or adopt knowledge), their background (i.e. expertise, experience, discipline), values, beliefs, culture, norms and habits – all play a role in shaping the perception of the knowledge (Argote et al. 2003, Estabrooks et al. 2008, Fazey et al. 2012, Young et al. 2016a).

Additionally, understanding the relationship among knowledge actors (i.e. the *relational dimension*) and the factors that influence these relationships, such as interpersonal trust, social norms, openness, contact (proximity and frequency, the intensity of communication, connection and social similarity, Argote et al. 2003, Mitton et al. 2007, Reed et al. 2014, Cvitanovic et al. 2015), is critical to understanding the underlying processes that mediate knowledge and action (Table 1.1). One example comes from the west coast of Canada and the contested Pacific salmon fisheries. Young et al. (2016a) reported that knowledge that is viewed as credible and reliable are more often trusted and used by knowledge users, and the perceived reliability of knowledge can be based on the perceived character and motivation of the knowledge claimant, thus reinforcing the importance of the social interactions among actors.

The *characteristics of the knowledge* contain factors that influence knowledge movement (Table 1.1). As an example, there are two types of knowledge: *tacit knowledge* (or knowledge that is difficult to articulate or formalize and communicate), which often is complex and exist in the mental models and expertise gained over time and through personal insight (Goh 2002, Collins 2010), and; *explicit knowledge* (or knowledge that is readily codified, articulated and captured), which is what is written or recorded in manuals, patents, reports, documents, assessments and databases and is easier to 'mobilize' as it is tangible and easier to articulate (Goh 2002, Collins 2010). Other dimensions or properties of knowledge include whether it is codified, ambiguous, internally or externally sourced, shared or uniquely possessed by individuals, soft or hard, public or private (reviewed in Argote et al. 2003). The perceived quality of the knowledge with respect to its credibility, legitimacy, accuracy, trustworthiness, and reliability may impact how it is received and communicated within a knowledge network (Cash et al. 2003, Jacobson and Goering 2006, Young et al. 2016a).

1.4.2.2 Knowledge mediation sphere: environmental and contextual dimensions

There are forces external to the knowledge network that may exert influence on the mediation of knowledge to action. Here, I label these factors as the *environmental and contextual dimensions* of the mediation sphere, such as political and economic circumstances, governance procedures, institutional structures, and other contextual factors such as social harmony or acrimony that may constrain or facilitate knowledge flow (Weingart 1999, Roux et al. 2010, Cvitanovic et al. 2015, Young et al. 2016a,b). The organizational structure of management agencies may range from centralized to relatively autonomous local decision making, which may ultimately affect knowledge flow and its impact on knowledge outcomes (Cash et al. 2003). More research is needed on the influence of context and external forces on knowledge mobilization outcomes.

1.4.3 Knowledge Actions

The goal of the knowledge-action framework is to use knowledge effectively for advancing conservation and maintaining long-term sustainability of natural resources. This requires interactions between the knowledge producers and potential knowledge users. In conservation and natural resource management, potential knowledge users can include, but are not limited to: conservation practitioners, resource managers, decision makers (including elected officials), resource users, researchers, and environmental educators. A successful knowledge-action outcome is not necessarily a one-way linear action, but more often than not, involves a multidirectional and iterative *re-evaluation and feedback* process whereby knowledge users and producers deliberate about research priorities and real-world constraints on management. This process often results in more salient and legitimate production of knowledge and conservation solutions because it is based on an extended exercise of problem-focused thinking that encourages collaborative, social learning (Pahl-Wostl 2006, Cook et al. 2013).

One example of a successful knowledge-action outcome could be the implementation of policy or practice based on scientific evidence (Pullin et al. 2004, Sutherland et al. 2004). For instance, the mission-oriented science conducted with support from a coordinated bi-national science-based organization (i.e., the Great Lakes Fishery Commission) to identify a selective lampricide treatment as part of the invasive sea lamprey (*Petromyzon marinus*) control program is heralded as successes in restoring native fish populations and supporting livelihoods (Wagner 2006). A second example of a successful knowledge-action outcome may involve the engagement and commitment of both scientists and practitioners to implement the conservation action. Artlettaz et al. (2010) demonstrated that the practical involvement of researchers, in close collaboration with stakeholders, in the implementation of the researchers' proposed recovery strategies for an endangered hoopoe (*Upopa epops)* population in the Swiss Alps was highly successful in bridging the knowledge-action gap. A third example of a successful knowledge action may involve changing behaviours of knowledge users that lead to long-term sustainability and conservation of the natural world (De Young 1993, Schultz 2011). Human behaviour and their choice of actions have increased anthropogenic pressures on the earth's ecosystems and natural resources (Vitousek et al. 1997). Thus, successfully changing human behaviour to pro-environmental and conservational behaviours (e.g., how they vote, how they purchase or consume, how they interact with the environment) may be considered a successful knowledge action. Overall, the knowledge outcomes and impact on conservation and natural resource management can be grouped in three broad theoretical categories: i) conceptual (raising awareness, behavioural change and changing beliefs and thinking); ii) instrumental (direct impacts on policy or practice); and, iii) symbolic (justifying existing policy and practice) (Amara et al. 2004, Rudd 2011).

Although examples of successful knowledge actions are highlighted here, a desirable knowledge action or outcome is nonetheless context-dependent, and a universal method to evaluate a “successful” knowledge action is likely not possible nor desirable (Hulme 2010, Fazey et al. 2014). Indeed, action is not always the goal and there are almost always varying objectives and measures of success held by different actors (Roux et al. 2010). The proposed knowledge-action is thus dynamic and varying with context to assist in characterizing what factors lead to what kinds of knowledge actions or inactions.

1.5 Scales (spatio-temporal), Levels and Interactions

The processes in this framework can occur at different scales and levels with potential interactions across them, and among the different elements of the knowledge-action framework. For instance, KE/KMb processes can occur at the individual and institutional/group level, and are dynamic through time, where both levels can interact (e.g. individual level perceptions can influence institutional level perceptions, vice versa). Thus, the level of analysis (e.g., interpersonal, intragroup, and intergroup) in KE/KMb research should be taken into consideration because, often, institutional norms and culture can play a significant role in fostering collective action, group thinking, and environmental stewardship (Ostrom 2014), which emphasizes the importance of considering influential factors of KE/KMb at both individual and institutional levels (Phelps et al. 2012, Mitton et al. 2007). It is important to look at the relationship between individuals, and among collective groups (e.g., stakeholders) to understand how knowledge moves within and between these multi-level actors. Cash et al. (2006) further describes the application of knowledge and knowledge of processes at varying scales. Although knowledge of ecological processes may be more useful at larger spatial and temporal scales, often it can only be applied at smaller scales and higher resolutions (i.e. zooming into a big picture), implying that scales and resolutions of knowledge application is important. As such, time and space are important concepts when evaluating knowledge movement.

Lastly, the various dimensions (e.g., actors, relationships, context) in the knowledge-action framework are not isolated from one another, but interact with each other in ways that may influence the knowledge outcome (Chen and Mohamed 2007). For example, the perceptions and values of the knowledge actors (activities within the knowledge network) may interact with the political context in which actors are embedded (Young et al., 2016a). These interactions (much like interactions in social-ecological systems) may be additive, synergistic or antagonistic in ways that may delay or enhance the integration and use of knowledge (Folt et al. 1999, Milner-Gulland 2012). Very little empirical research has directly addressed these interactions, as they are difficult to observe and document (but see Chen and Mohamed 2007). Given their importance, however, I expect that this will become a substantial area of research that can be used to improve the framework in the future.

Table 1.1: Summary of the components of the *knowledge-action framework* and potential variables hypothesized to influence KMb/KE with example sources from the literature.

Element	Description	Examples and hypothesized influential variables (individual, group and institutional levels)		Example sources across disciplines
1. Knowledge production	Generation of 'new' knowledge either in isolation by research institutions or co-created through participation and engagement with knowledge users.	• Primary research • Citizen science • Adaptive co-management • Syntheses	• Technological innovations • Systematic reviews • Other knowledge claims and production	Berkes 2009; Jasanoff 2010; Hegger et al. 2012
2. Knowledge mediation sphere	A sphere that mediates the knowledge created and its fate, which may include the formation of boundary objects. The spherical shape emphasizes the non-linearity and dynamic processes of knowledge flow and movement.			
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.	• Social ties (e.g., direct vs indirect, weak vs strong) • Network connectivity • Network position (i.e. individual's social proximity to others in the network • Social cohesion (i.e., length and strength of paths that connect individuals)	• Ego network structure (patterns of ties within a focal individual's immediate set of contacts) • Whole network structure (patterns of ties among all individuals in a bounded population) • Social capital • Homogeneity/heterogeneity of network • Level of conflict	Bodin et al. 2006; Mitton et al. 2007; Fliaser and Spiess 2008, Bodin and Crona 2009; Phelps et al. 2012; Inkpen and Tsang 2005
a. Knowledge actors	The individual/players that are involved in the exchange and mobilization of knowledge	• Who, what and how many stakeholders involved • Facilitator	• Change agent • Champions • Knowledge broker • Boundary organization	Phelps et al. 2012; Argote et al. 2003; Jasanoff 2010; Hegger et al. 2012 ; Young et al. 2016a

b. Characteristics and perceptions of actors	Who and where do the actors come from, their character, and how they are perceived may influence how knowledge is exchanged or mobilized.	• Personality • Skills (communication, leadership) • Social status • Role • Willingness to receive or facilitate knowledge exchange/mobilization • Individual motivations • Values, attitudes, and beliefs	• Background (e.g., education, experience expertise) • Person's power and authority • Absorptive capacity • Knowledge transfer capacity • Diversity of network contacts • Credibility of actor • Knowledge ownership	Argote et al. 2003; Mitton et al. 2007; Gibbons et al. 2008; Wang and Noe 2010 ; Phelps et al. 2012;
c. Relational dimension	The relationship and ties between knowledge actors	• Tie strength • Interpersonal trust • Reciprocity norms between individuals	• Mutual respect • Collaborations and partnerships • Social costs and benefits • Engagement with other actors	Argote et al. 2003; Mitton et al. 2007; Phelps et al. 2012; Hilary 2016; Reed et al. 2014; Cvitanovic et al. 2015
d. Characteristics of the knowledge	The type and attributes of knowledge that is entering the knowledge network can have influence on how it is perceived and mobilized.	• Tacitness and complexity • Explicitness (simple and codified knowledge) • Traditional knowledge • Local knowledge • Scientific knowledge • Experiential knowledge • Perceived benefits and costs of knowledge	• Socially robust • Politicized • Relevance, fit and applicability of knowledge • Uncertainties • Reliability, legitimacy and credibility • Multi-, inter-, transdisciplinary • Accessibility • Political knowledge • Perceived usefulness	Gibbons 1999; Argote et al. 2003; Cash et al. 2003; Hessels et al. 2009; Phelps et al. 2012; Young et al. in review
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.	• Culture/climate • Institutional norms • Economic context • Governance • Political context • Geographic location	• Institutional/organizational structure and support • Rewards/incentives • Human and financial resources (capacity)	Wang and Noe 2010; Pullin and Knight 2005; Mitton et al. 2007; Artlettaz et al. 2010; Driscoll et al. 2011; Cvitanovic et al. 2015

3. Knowledge action outcomes	The outcome of the knowledge which may or may not be measured, as some may be less tangible such as perception change or lack of action/lag in action.	Knowledge actions may be conceptual (raising awareness and changing beliefs, perceptions or thinking), instrumental (direct changes to policy or practice, use of boundary objects), or symbolic (justifying existing policy or practice). Successful knowledge actions are context dependent and vary with conservation objectives. Knowledge action may also not be the primary objective in some circumstances depending on the conservation or management goals.	Armana et al. 2004; Rudd 2011; Reed et al. 2014 ; Star 2010

1.6 Model for Applying the Knowledge-Action Framework: Fisheries Management and Telemetry Technology

Fisheries and aquatic systems are inherently diverse, complex, and dynamic. Fisheries managers are thus confronted with problems that are "wicked". A wicked problem is a problem with no one solution, that is complex and tricky, and cannot be solved with one particular tool but rather poses a constant challenge (Jentoft & Chuenpagdee 2009). Without a doubt, the future sustainable use of fishery resources will require management regimes based on sound scientific evidence, up-to-date knowledge of varied forms (including traditional, local, and experiential), and knowledge from across disciplines (Braunisch et al. 2012).

Fishery resources are also among the most complex to study (Cochrane 1999). Given that fish are found underwater and can travel great distances crossing international borders and traversing multiple jurisdictions, scientists are constrained in their ability to study fish. Many nations frequently share natural resources, resulting in an increased complexity for sustainable management. Traditionally, human use and exploitation has been regulated in the context of serious knowledge gaps. Hence, understanding aspects of the life history and ecology of fish, such as how they are distributed in space and time and move among different habitat patches, can offer insights on population and community processes, which in turn aid in predicting consequences of human exploitation and development, and improve the protection and sustainable management of resources (Nathan et al. 2008). Knowledge regarding the spatiotemporal behaviour of fishes is key to understanding basic biological and ecological questions, and when studied in the context of response to human activities, provides resource managers and practitioners with relevant knowledge to make informed decisions (Lucas and

Baras 2000). Therefore, examining fisheries management problems and the challenges of integrating ecological knowledge to inform fisheries management make an interesting case to explore the movement of knowledge in this system.

1.6.1 Telemetry technology: linking scientific knowledge and fisheries management

Studies of fish movement and animal-environment relationships have been limited by the sheer size and depth of our freshwater bodies and vast oceans, as well as the extreme seasonal environmental variations in some regions such as current speed, ice cover, or turbidity. Some species are cryptic and highly mobile adding to the challenges of studying aquatic species. These limitations and knowledge gaps create challenges for fisheries managers to identify full habitat ranges, understand connectivity, identify corridors for movement, and how population and stocks are structured relative to management jurisdictions – prerequisites for conservation. The strides made in animal tracking technologies (Lucas and Baras 2000, Cooke et al. 2004, Hussey et al. 2015), and advances in analysis, application, and interpretation of large and complex datasets (Rutz and Hays 2009) have contributed to tools that study animal behaviour over great distances in terrestrial and aquatic environments where previously not feasible. Such innovations have created opportunities for research, and revealed novel information and knowledge that was impossible to achieve using traditional methods a few decades ago. In just the past 10 years, innovations have included tools such as three-dimensional positioning systems (O'Dor et al. 1998, Espinoza et al. 2011), large scale listening arrays (Welch et al. 2002, Donaldson et al. 2014), independent gliders (Webb et al. 2001), animal-borne oceanographic sensors (e.g. Biuw et al. 2007), and interactive animal-animal tags (e.g. Holland et al. 2009).

Telemetry technology is the autonomous tracking of animals whereby an electronic tag emits attached to an individual emits a signal to a receiver. Improvements in battery and reductions in tag size enable tracking of smaller taxa and life stages that could not be studied previously (Cooke et al. 2013). Additionally, telemetry can be combined with other research methods (e.g., physiological status studies, genetic tests, stable isotope analysis, local ecological knowledge), which can open doors to address more complex research questions (Cooke et al. 2013). Within a 10-year period (1997-2007) publications in fish radio telemetry studies alone increased almost five-fold (Cooke and Thorstad 2011). The last decade experienced a six-fold increase in aquatic telemetry studies, and the use of telemetry technology to study local to global scale movements and survival of aquatic animals is growing worldwide (Hussey et al. 2015). The establishment of peer-reviewed scientific journals dedicated to telemetry tracking and understanding animal movement, specifically the "*Journal of Animal Biotelemetry*" and the journal "*Movement Ecology*", demonstrate recognition of the importance and potential of electronic tagging. All to say, information on the movement of aquatic species and the use of telemetry as a tool to access this knowledge is growing at an unprecedented rate. As information and databases grow and improve, they will be essential for informed decision-making and a go-to source for end-users. Data generated by telemetry technology have the potential to provide knowledge needed to address key management and conservation problems, and thus make an additional interesting case to evaluate and understand its uptake and application in fisheries management (Cooke et al. 2011, Young et al. in review). In this thesis, I make the assumption that "scientific" knowledge generated from telemetry technology should be mobilized based on the increasing calls for evidence-based decision making and policies.

1.7 Research Questions and Objectives

In an era of rapid environmental change and increasing anthropogenic threats to ecosystems and biodiversity, scientific evidence and, more broadly, relevant knowledge is sorely needed to inform decision makers and public policy. Evidence-based decision making in conservation and environmental management is imperative to ensure sustainable resource management and to maintain or restore biodiversity. As such, the overall objective of my Ph.D. dissertation is to investigate the movement of knowledge, more specifically, scientific knowledge, into fisheries management actions (e.g., practices and policies). My overarching research question for this thesis is what components of the knowledge-action framework presented (environmental and contextual factors, characteristics of knowledge actors, the relational dimension, and the characteristics of the focal knowledge), plays a role in influencing the uptake of knowledge? I explore this research question using a sociological approach and applying a mixed-method strategy of evaluating case-studies using both qualitative and quantitative study designs in three studies.

First, I explore my overarching research question and framework by examining a case-study that is the epitome of a wicked problem – the case of the Fraser River salmon fishery (Chapter 2). Briefly, the Fraser River salmon fishery in British Columbia is one of the most socio-ecologically complex systems, and one of the most managed fisheries in the world (as described in Chapter 2). In this Chapter, I explored the perceived and reported barriers by knowledge users (fisheries government employees and stakeholders) to integrating new knowledge into fisheries management practices. I offer recommendations on how to overcome the identified barriers based on my findings and the literature.

Second, I explored my framework and research question by examining the integration and movement of ecological data derived by fish telemetry as a model in Chapters 3 and 4. In Chapter 3, I designed a quantitative study to explore factors reported by researchers, which influence the mobilization of fish telemetry study findings into actions, such as formal uptake into management policies and practices, as well as social uptake of the study findings by stakeholders and the public. In Chapter 4, I complemented my aforementioned quantitative study with a qualitative study exploring the perceived barriers by fish telemetry researchers to incorporating telemetry study findings into fisheries management. I offer recommendations on how to overcome the identified barriers based on my findings and the literature.

For my qualitative studies (Chapter 2 and 4), I used two approaches that link "grounded theory" (Maxwell 2012), which is the construction of hypotheses from the data collected, with the application of my knowledge-action framework on the data. I chose to do so because my research is exploratory, especially in the field of conservation and natural resource management. Therefore, using grounded theory, I allow emerging themes and hypotheses to be developed, while applying the knowledge-action framework to structure and organize the themes and placing them in a broader context.

Chapters 2-4 have a logical flow as they test and apply my theoretical knowledge-action framework. I further explored the mobilization of telemetry-derived knowledge and data by examining the perspectives of fish telemetry researchers regarding data sharing in Chapter 5. Data sharing is an important aspect of information flow and knowledge mobilization. It is also an avenue to overcome certain barriers that may impede the use of telemetry-derived knowledge. I also explored other aspects of science communication and knowledge mobilization in additional studies that are outside the scope of my thesis (Appendix A).

Chapter 2. What is 'usable' knowledge? Perceived barriers for integrating new knowledge into fisheries management of an iconic Canadian fishery

2.1 Abstract

In fisheries management, new knowledge is often scrutinized for its credibility, legitimacy and saliency (i.e. usability) by a wide variety of knowledge users. Knowledge must be perceived as usable by the knowledge users to facilitate its integration in fisheries management. Thus, understanding the perspectives of knowledge users and their decision-making environment would assist researchers in crafting more usable knowledge. In this chapter, I explore the Fraser River Pacific salmon fishery as a case study to describe the perceived barriers, of 49 government employees and stakeholders, to incorporating new knowledge into fisheries management using qualitative analyses and applying a knowledge-action framework. The framework revealed that 90% of respondents perceived the *environmental and contextual dimension* (e.g., institutional structures and norms) as a barrier for incorporating new knowledge, followed by factors under the *characteristics of knowledge actors* (52% of respondents); *characteristics of the knowledge* (27%); *time* (27%), *knowledge transfer* (17%), *relational dimension* (8%), and *mismatches* (6% of respondents). Informal relationships and network building appears to enable conditions whereby knowledge users can interact with new knowledge. I discuss lessons learned from the Fraser River case study, which I believe can be applied more broadly in the conservation and natural resource management context.

2.2 Introduction

Effective management and conservation of natural resources requires effective use of up-to-date knowledge of all kinds – scientific, traditional, local, and experiential. Scientific evidence, in theory, underpins many of the decisions made by managers; however, decisions in resource management are complex, and must consider multiple scientific disciplines, multiple perspectives and constituencies, have multiple objectives and respect economic and political realities (Jacob and Pulwary 2003, Eden 2011). Despite continuous scientific advances, the question of how science can best support decision making in conservation and environmental management remains unanswered (Cash et al. 2003, Liu et al. 2008).

While scientists routinely express frustration that their research is largely ignored by policy makers, the latter group also express dissatisfaction that the information and scientific evidence needed for decision making are often not readily available, accessible, or applicable (Cash et al. 2003, Young et al. 2016b). For example, results of scientific research may not always be in a form that is 'usable' to decision makers or resource managers (Dilling & Lemos 2011) or knowledge gaps required cannot be filled within the required management or policy making time frame (Soomai et al. 2017a). In other cases, uncertainties about methods, findings, and application can hinder uptake into decision-making or management (Refsgaard et al. 2007, Lansing 2009, Nguyen et al. in review). Discussions on bridging the gap between scientific knowledge and action have emphasized that usable information must be *credible* (dependable and quality information perceived by its users); *legitimate* (information that is transparent and understandable by its users), and; *salient* (relevant information in the context of which the decision making occurs) (Cash et al. 2003, Cook et al. 2010, 2013). Scientists and decision makers have different roles and goals, and studies have suggested that this contributes to a lack of mutual understanding of each other's values, priorities, and knowledge systems (Roux et al. 2006; Gibbons et al. 2008). In the science-policy literature, issues related to the paradoxical relationship between science and politics as well as the influence of governance structures are additional challenges to using science in decision-making (Soomai et al. 2017a). These factors widen the gap between science and action, which undermines the effective flow of information across knowledge and practice (Liu et al. 2008).

In fisheries management and conservation, scientific evidence is embedded in a complex social web and is scrutinized for its credibility, legitimacy and saliency by a wide variety of actors and groups (Cash et al. 2003, Young et al. 2013, 2016c). The fact that fisheries are tied to economies, cultures, and livelihoods, makes fisheries management and conservation a difficult and complex endeavor (Cochrane 1999). Producing usable information and knowledge is, therefore, not an easy task. Often, the usability of information is defined by the *perception* of its utility by fisheries managers and stakeholders as well as the actual capacity (e.g., human and financial resources, institutional and organizational support, political and economic opportunity) to use the information and knowledge (Dilling and Lemos 2011, Nguyen et al. 2016). Scientists often do not completely understand or know potential users' decision-making processes and contexts, which may cause their research to remain 'on the shelf' (Lemos et al. 2012). Uptake of fisheries scientific information into management advice by governmental agencies is often influenced by government models, political regimes, the geographic region, the organizational culture on information management, and personal and institutional interests and values of different stakeholders (Cochrane 2002, Cossarini et al. 2014, Soomai et al. 2011, Soomai et al. 2017a,b). As such, the challenge for fisheries scientists is to understand the perceptions of the knowledge users (e.g., fisheries managers, decision makers, and stakeholders) and the capacity to which it can be used – in other words – the environment in which potential knowledge users interact with new knowledge.

This chapter aims to identify the perceived barriers of integrating new knowledge into fisheries management practices and policies from the perspective of the potential knowledge users to identify what may constitute useable knowledge and to help bridge the gap between knowledge and action. I focus my evaluations on a case in which emerging scientific techniques have produced novel information for the management of a contested fishery, the Pacific salmon fishery in the Fraser River, British Columbia, Canada.

2.3 The case: Fraser River Pacific salmon fishery

The history, economy and culture of the west coast of Canada and northwestern United States have been linked to Pacific salmon for thousands of years. Historically, salmon were the staple of many First Nation (indigenous) people inhabiting the region for food, social and ceremonial purposes. Today, salmon continue to be of significant cultural and economic importance for Canadians, with important ecological roles (Groot & Margolis 1991, Cederholm et al. 1999). The Fraser River watershed is one of the most productive salmon rivers in the world and is thus one of the most socially and ecologically complex regions in Canada. The river is home to five species of anadromous Pacific salmon: Chinook *Oncorhynchus tshawytscha*, chum *O. keta*, coho *O. kisutch*, pink *O. gorbuscha*, and sockeye *O. nerka*, as well as steelhead trout *O. mykiss*; and, hosts three major fishing sectors: The First Nation, commercial and recreational fisheries. Not surprisingly, the Pacific salmon fishery in the Fraser River is among the most intensively managed fisheries in the world, making it an interesting case-study to examine for understanding the movement of knowledge into fisheries management.

Some research suggests that populations of Pacific salmon in the Fraser River have declined by as much as 50% from historic levels (Gresh et al. 2009). There are controversies about the cause(s) of these declines, and contradicting scientific evidence related to the declines (Cohen 2012). The Cohen Commission judicial inquiry was a two-year process that involved hundreds of witnesses and thousands of submitted statements and evidence related to the decline of Fraser sockeye salmon in 2009 (Cohen 2012). The inquiry is an example of the mounted pressure on officials to better manage and conserve salmon resources. The Cohen Inquiry made 75 recommendations, and even so, the government has been slow to implement them (Cohen 2012), and there is significant pressure on fisheries managers and officials to demonstrate positive impacts from public investments as documented in the Office of the Auditor General petition catalogue (e.g., http://www.oag-bvg.gc.ca/internet/English/pet_353_e_39110.html).

2.4 Managing Pacific Salmon in the Fraser River

The management of Fraser salmon is extremely complex (see Cohen 2012), involving the federal Department of Fisheries and Oceans Canada (DFO), the Pacific Region DFO, and the Canada-US bi-national Pacific Salmon Commission (PSC). The mandate for DFO is multifaceted and includes promoting economic growth, ensuring sustainable harvests and ecosystems, conducting research, and consulting stakeholders. In the last few decades, DFO has focused on the co-management of key fisheries. For the Fraser salmon fishery, this is applied under PSC and the Fraser River Panel, which consists of stakeholder representatives including First Nation groups. DFO also consults other advisory boards such as the Commercial Salmon Advisory Board, the Sport Fish Advisory Board, and the Marine Conservation Caucus (representation from ENGOs). As such, stakeholders and resource user groups have a key role in the management of Pacific salmon in the Fraser River. DFO regional managers, in particular, are often expected to synthesize and translate multiple (often contradicting) knowledge claims and information into on-the-ground decisions (Young et al. 2013).

From the scientific perspective, there were 55 scientists (circa 2012) employed in the Pacific region conducting research on a variety of topics such as fish physiology, genomics, oceanography, aquaculture and ecosystem dynamics (Cohen 2012: 53). Collaborative research also exists with external academic institutions including research using biotelemetry tracking, genomics, population modeling, and physiological techniques (Patterson et al. 2016). Research conducted range from questions related to climate change, juvenile outmigration, adult upriver migration, fisheries interactions, and diseases, among others. Annual investments related to Pacific salmon alone by the Government of Canada reached $65M in 2013 (http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/sockeye-smonrouge/index-eng.html). Of this amount, $20M was directly related to Fraser River sockeye, which include fisheries science. The science-policy interface of DFO has been documented as an internal linear model whereby advice is provided by DFO Science in response to management questions, which lead to other information sources and issues to be overlooked, such as local knowledge or academic knowledge (Soomai et al. 2017b). Furthermore, DFO also has an internal review process, entitled the Canadian Science Advice Secretariat[1] (CSAS). It exists for evaluating scientific claims on

[1] The Canadian Science Advisory Secretariat (CSAS) coordinates the peer review of scientific issues for the Department of Fisheries and Oceans. The different Regions of Canada conduct resource assessments independently that is specific to the regional characteristics and stakeholder needs. CSAS facilitates these regional processes, fostering national standards of excellence, and exchange and innovation in methodology, interpretation, and insight. CSAS works with the Regions to develop integrated overviews of issues in fish stock dynamics, ocean ecology and use of living aquatic resources, and to identify emergent issues quickly

issues of concern to fisheries managers and includes stakeholder representatives (see Cooke et al. 2016 for description of evidence assimilation by DFO, Soomai et al. 2017b). Despite these resources and processes, scholars have critiqued and discussed DFO's slow uptake of new scientific tools and findings, particularly findings derived externally (Hutchings et al. 1997, Young et al. 2013b, Patterson et al. 2016).

Regional fisheries managers possess significant decision making responsibilities and authority. With DFO's legislated co-management boards (including representatives from the commercial, recreational and First Nation fishing sectors), consultation with stakeholders, and the substantial investments in internal and external scientific research on Fraser River salmon, managers have a complex role in fisheries governance that includes forecasting the status of different salmon species and stocks, consulting stakeholders, adjusting and regulating fisheries "in-season" and implementing Ministerial directives. They are also expected by stakeholders and the public to make use of new science and knowledge generated by the public funds (i.e. investments by Canadians). Fisheries managers are thus important potential users of new science and represent an important interface for science and action (Young et al. 2013). It is therefore important to understand the perspectives of potential knowledge users and understand the challenges that may impede the movement of new knowledge into action.

This chapter is part of a broader study entitled "Mobilizing new knowledge for fisheries management in the Fraser River" that investigates the role of academic science in the decision making of government regulators and stakeholders involved in the co-management of Fraser River salmon fisheries (see Young et al. 2016a, b). This chapter differs from Young et al. (2016 a, b), as it focuses on the environment (e.g., socio-political context) of the potential knowledge users, and the barriers that they perceive and experience when faced with new knowledge. The interview instrument for the broader study was developed in three stages and uses a mixed-methods approach with exploratory questions that are both closed- and open-ended (see Young et al. 2016a, b for more details). This article evaluates responses that pertain to barriers that may impede the integration of new science into fisheries management, and in particular it evaluates the following open-ended question from the interview schedule: "*In your experience, what barriers do you believe exist in incorporating new knowledge into actual fisheries management practices?"*.

2.5 Methods

I performed qualitative analyses using NVivo 10 software in a three step-process. First, responses were read and coded using the Framework Method (Ritchie & Lewis 2003, Gale et al. 2013) to structure and organize the responses according to themes from the 'knowledge-action framework' (Nguyen et al. 2016; see Table 2.1 for framework components).I illustrated what areas of the knowledge-action gap were most prevalent in acting as barriers to the integration of new knowledge into practice. Responses, now under a framework theme, were read a second time to inductively identify key subthemes (Thomas 2006), which subsequently provided a list of potential codes in order to give more nuances to the framework themes. Lastly, responses were sorted under these subthemes (inductive codes; see Table 2.1) to provide a measure of their prevalence. A response may have multiple thematic codes if warranted.

Table 2.1: Components of the knowledge-action framework used to help code and structure the qualitative data analysis (adapted from Nguyen et al. 2016, Chapter 1)

Element	Description
1. Knowledge production	Generation of 'new' knowledge either in isolation by research institutions or co-created through participation and engagement with knowledge users.
2. Knowledge mediation sphere	The mediation is essentially the "gap" between knowledge and action. It emphasizes the non-linearity and dynamic processes of knowledge movement. Further, it is broken down into two broad components: he knowledge network and the environmental and contextual dimension which lie outside of this network.
3. 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.
3a. Knowledge actors	The individual/players that are involved in the exchange and mobilization of knowledge
3b. Characteristics and perceptions of actors	Who and where do the actors come from, their character, and how they are perceived may influence how knowledge is exchanged or mobilized.
3c. Relational dimension	The relationship and ties between knowledge actors .
3d. Characteristics of the knowledge	The type and attributes of knowledge that is entering the knowledge network can have influence on how it is perceived and mobilized.
4. 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.
5. Knowledge action outcomes	The outcome of the knowledge which may or may not be measured, as some may be less tangible such as perception change or lack of action/lag in action.

The sample population was broadly divided into two groups: government employees and non-governmental stakeholders, and was developed in consultation with senior managers at DFO and experts who have worked on Fraser River salmon fisheries for > 20 years. This was to ensure that key members of the sample population were identified. I used snowball sampling to supplement the original population when respondents voluntarily referred us to others. As per the breakdown shown in Table 2.2, the government employees respondents consisted primarily of fisheries managers. These are individuals who were most directly involved in daily decision-making, and collaborations with stakeholders, as well as individuals who advise and provide data for decision-making (Table 2.2). It also included employees in the DFO Science Branch who were identified by the organization as working closely with fisheries managers and stakeholder groups. Several senior managers were also interviewed, and individuals from the PSC were also included in this group and were primarily fisheries stock assessment scientists. The stakeholder groups were more diverse and included representatives of commercial and recreational fisheries, First Nations communities and fishery, non-governmental organizations, and private consultants (mainly scientists) who were hired by stakeholders and play a role in the co-management processes (see Young et al. 2016 a, b). I recognize that the term stakeholder does not comprehensively describe the diversity and nuances of all individuals involved shown in Table 2. Each of them has distinct interests, values, identities and perspectives. This group is, however, distinct from government employees, and has similar roles in that they are all involved in the co-management of Fraser River salmon but external to government (see Nguyen et al. 2016, Young et al. 2016a, b). Therefore, I present the findings from the two perspectives of government employees and of non-governmental stakeholders. In this article, I illustrate the prevalence of the emergent themes as *number of respondents* who mentioned the coded passage, and elaborate the themes with illustrative quotes.

A total of 49 interviews relevant to this analysis (out of a total of 67) were completed between November 2013 and September 2014; 27 with government employees and 22 with non-governmental stakeholders. About three-quarters of the interviews were conducted face-to-face, while the rest were conducted over the telephone. Some of the requests for interviews were communicated internally by DFO; therefore, response rates were estimated (approximately 66% for government employees and 63% for stakeholders). Interviews lasted between 40 minutes and 3 hours depending on the level of detail provided by respondents. The study was conducted in accordance to the University of Ottawa Research Ethics Board (06-13-10).

Table 2.2: Affiliations of the 49 respondents grouped government employees and stakeholders.

Government employees	N	Stakeholders	N
Fisheries management branch (DFO)	15	Commercial fishery	3
Science branch (DFO)	2	Recreational fishery	5
Senior management (DFO)	2	First Nation fishery	3
Pacific Salmon Commission	6	NGO	8
Other	2	Private consultants	2
		Other	1
Total	27		22

2.6 Results and Discussion

The knowledge-action framework provided structure and organization for coding the open-ended responses. The framework themes revealed that 90% of the 49 respondents believed that factors under the *environmental and contextual dimension* (e.g., the capacity to use new knowledge) were among the greatest barriers to integrating new science into fisheries management, followed by factors under *characteristics of knowledge actors* (52% of respondents); *characteristics of the knowledge* (27%); *time* (27%), *knowledge transfer* (17%), *relational dimension* (8%), and *mismatches* (6% of respondents) (Fig. 2.1; Table 2.3). I present the findings based on the knowledge-action framework and expand on the nuances of each theme by providing illustrative quotes.

Figure 2.1: Distribution of the number of respondents that identified barriers for incorporating new knowledge into fisheries management practices based on the knowledge-action framework themes.

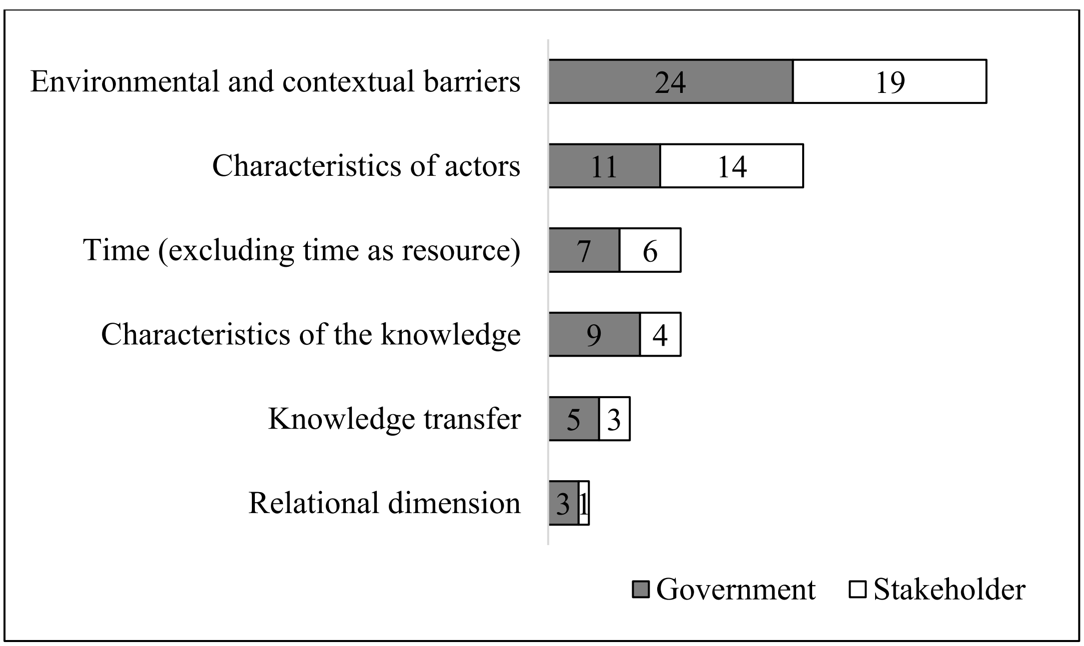


Table 2.3: Coded themes that emerged using a knowledge-action framework (Nguyen et al. 2016) with sub-themes that provide more nuance and description related the framework categories. Numbers reflect respondents who mentioned each theme.

Barriers coded	Government	Stakeholder	Total respondents
1. Environmental and contextual barriers	**24**	**19**	**43**
Government and institutional structures	21	16	37
The 'process' (e.g., bureaucracy, consultations, review, approvals)	10	7	17
Constraints on human and financial resources (including time)	9	8	17
Decision making tools (e.g., forecasts and models)	5	6	11
Lack of process	4	1	5
Management change and changes in management in environment (no continuity and relationship maintenance)	2	2	4
Political and economic factors	4	6	10
Cultural differences between knowledge users and producers	5	2	7
Social impacts (e.g. on livelihoods)	2	2	4
2. Characteristics of actors	**11**	**14**	**25**
Motivations and constrained rationalities (i.e., maintenance of status quo, lack of political will)	6	10	16
Social acceptance and buy-in of new knowledge by users	5	8	13
Understanding of science or undervaluing of science	2	4	6
Compatibility with existing attitude, perceptions and worldviews	1	4	5
Perceived lack of accountability by managers to act on new knowledge	0	2	2
3. Characteristics of the knowledge	**9**	**4**	**13**
Applicability/usability (relevance, compatibility)	6	0	6
Complexity (variability, uncertainties)	0	3	3
Reliability/credibility	2	1	3
Contradictory evidence	2	1	3
4. Relational dimension	**3**	**1**	**4**
5. Time (excluding time as a resource)	**7**	**6**	**13**
6. Flaws and disconnect in knowledge transfer	**5**	**3**	**8**

2.6.1. Environmental and contextual barriers

Environmental and contextual barriers that Fraser River government employees and stakeholders report include governmental and institutional barriers, political and economic barriers, cultural differences between knowledge users and producers, and potential social implications of integrating new knowledge (Table 2.3).

Government and institutional systems, structures, norms, and cultures: Institutional barriers were the dominant theme identified by both stakeholders (16) and government employees (21), such as its rigid management frameworks; lack of organizational support for new initiatives; bureaucracy; cost of new implementations; the government structure and culture; and funding issues. Several respondents felt that it was challenging enough to keep everything afloat and keep up with administrative tasks, that there is little to no time to engage with new science or knowledge:

> *Well, I guess to be brutally honest about it, we are so busy with day-to-day management, and day-to-day operations, and running the projects we are funded to run. We don't spend much time paying much attention to research. We kind of have to wait until research has been vetted through all the processes and it becomes accepted. I guess we learn through other people that we're liaising with and when the government have accepted this research and they are incorporating in what they are doing and then we start using it.* (Interview #34; First Nation stakeholder)

> *We have a process in the region for prioritizing our science requests, and then whether or not they get addressed, and how they get addressed, in what timeframe, depends upon resources available and competing interests for the use of people's time and money.* (Interview #15; Senior fisheries management)

There was extensive discussion by both groups about the constraints of human and financial resources, particularly due to the budget cuts in science and personnel during the tenure of Canada's Conservative government (2006-2015), which includes the study period (Peyton &

Franks 2015). Consequently, this was reported to have led to challenges for fisheries management to engage and incorporate new knowledge. The quotations below illustrate the challenges with declining budgets and the realities of costs for new initiatives:

> *If we continue to see reductions in budgets, we can't even keep doing what we're doing now into the future. Are there other ways that we can do business that is more cost-effective while still meeting our goals in the context of reduced information? The current government [Conservative] here is pretty clear that they're looking to reduce the deficit and are looking at ways to save money* (Interview #21; fisheries management)

It is worth noting that eleven respondents (5 government and 6 stakeholders) identified the established decision-making and management tools to be a barrier to incorporating new knowledge into fisheries management practices. This is also known as path dependence (Munck af Rosenschöld et al. 2014). For instance, quantitative modelling and forecasts are primarily used in the management of Fraser River salmon fisheries (especially for sockeye and pink), and fitting new data or new knowledge (particularly externally-derived) into such existing tools can be perceived as a barrier because of the lack of compatibility. Some respondents critiqued the rigidity of the current management tools, and the dependency of managers' decision-making on these models. For example:

> *There is a contract of managers and others out there who were completely intoxicated with the thought that they can solve everything by modeling. Modeling is only as strong as the weakest information within it. The term assumption is the biggest problem because 'assume' is when you make an ass out of you and me.* (Interview #10; DFO Science Branch)

Another noteworthy theme related to institutional barriers was something respondents referred to as 'the process' (Table 2.3). The process here may refer to the peer-review and CSAS process, the bureaucracy, the Fraser River Panel Process; overall, an "internal approval process" by which there is also a lot of "external consultation process" with stakeholders. Government employees in particular discussed the extensive process of stakeholder consultations:

> *We consult beyond humanly possible and it still comes up short. The requirements are pretty onerous and costly and at times not humanly possible, because we're meeting with individual or group of First Nations, we're meeting with groups of commercial, environmental, these are just the harvesting sectors, and then there's all the internal politics and the salmon commission*. (Interview #15; senior fisheries management)

Interestingly, the "process" that many respondents refer to (especially government employees) appears to be linked with the process of acquiring social acceptance and consensus. Management decisions appear to struggle between democratic and technocratic processes, where managers rely on models for objectivity, but also require social acceptance by stakeholders, as described here:

> *There's usually a process behind it [implementing change], but I wouldn't say there are barriers. We always try to work with the best information that is available. Sometimes process can feel like a barrier. The objective is to make sure that we're doing the right thing and that it's been looked at from multiple angles and that in fact, we will be making the best possible decisions* (Interview #15; senior fisheries management)

Political and economic factors as barriers: A number of respondents associated the use of new knowledge with change that would affect certain groups. Therefore, knowledge may become or be perceived to become "politicized" because it can be used to advance certain agendas or used to maintain status quo. Stakeholders view political agendas and biases (e.g., Conservative government priorities and mandates) to dictate how knowledge is used (or not used), whereas, government employees tended to view the politics of knowledge as political pressures by different stakeholder groups to leverage their stance. The quotation below illustrates the struggle from fisheries managers to apply new knowledge because it may mean implementing change:

> *Usually, new scientific information is going to result in change and that change is going to affect - invariably going to affect - somebody. And that somebody is usually a harvester…and politically harvest groups are pretty powerful. A change may be good for the resource which in theory should sustain fisheries, but in order to implement that you would have to do something with the fishery…it might be sustained and not at same level but it will cause political issues and therefore change does not occur* (Interview #18, male, fisheries management).

2.6.2 Knowledge actors and their characteristics as barriers

Barriers associated with characteristics of the knowledge actors included motivations and constrained rationalities (i.e., maintenance of status quo, lack of political will); the need for social acceptance and buy-in from knowledge users; the lack of understanding science and undervaluing the use of science; the compatibility of the new knowledge with existing attitude perceptions and worldviews of knowledge actors, and; perceived lack of accountability by managers to act on new knowledge.

Motivational factors and constrained decision-making: The motivation of individuals and institutions appear to be an important barrier to integrating new knowledge, and described by respondents as “lack of political will”, “inertia”, “established patterns in big organizations”, or not being able to “teach old dogs new tricks”. Many fisheries practices are historical and established, which makes it difficult to change or incorporate new knowledge or knowledge claims (i.e. path dependence). Stakeholders, in particular, mentioned inertia and lack of political will more often than government employees, suggesting potential criticism of the governing body and structure (Table 2.3). This is consistent with many contested areas of science-policy, such as climate change policy, in which there is lack of motivation to use new knowledge at the institutional level (Munck af Rosenschöld et al. 2014, Stål 2015). Decisions in environmental planning and policy inherently have characteristics that tend to have controversial options that are considered. Often, existing management solutions and strategies are familiar to decision makers and viewed as an investment that has been legitimized; therefore, decisions makers are motivated to restrict their set of options, and keep financial and political cost of decision-making low (Gezelius & Refsgaard 2007). Decision making has also been found to be influenced by path dependence (i.e., choices based on historical and established patterns), previous decisions, incentives or other social situations that are often defined by the role of the knowledge user and thus lead to a narrow decision space or bounded rationalities (Feldman & Ingram 2009, Lodge & Wegrich 2016). For example:

> *I find that it is institutional complacency, calcification, it's hard to penetrate and disrupt the status quo. There are more benefits to maintain [the] status quo than to bring new science. There is no incentive to bring in new science, because it is troublesome and too much work and difficult to bring new science. The political and interest, and economic interest, it is calcified around status quo. Those make it difficult to penetrate.* (Interview #46; private scientist)

It has been documented that DFO uses a linear science-policy model where requests for advice are initiated "in-house" instead of a more active adaptive management framework, which has potential trade-offs such as the cause of new knowledge and issues from other sources to be overlooked and discounted (Soomai et al. 2017b). A recent study by Soomai (2017b) revealed that DFO Maritimes Region preferred using their own fisheries scientific production and grey literature over peer-reviewed scholarly journals or individual authored publications because they are timely and reports are produced in an annual cycle that is relevant and in direct response to fisheries management questions. These government structures and processes create barriers for the utilization of externally-derived scientific knowledge, and could potentially be the culprit for the maintenance of the status quo.

Science literacy and undervaluing science: The lack of understanding of science and how some scientific findings can enhance management practices were described as delaying its incorporation. Gaps may exist in the accessibility of science and its translation in how it can be meaningful to fisheries managers and decision makers (Eden 2011, Bayliss et al. 2012, Crossin et al. In Press). Further, the lack of communication of science in lay language can prevent potential knowledge users from interacting with the knowledge (Hulme 2014). Some stakeholders felt that the undervaluing or underuse of science in fisheries management can cause delay in its incorporation, as illustrated here:

> *I am not absolutely sure how valuable people [fisheries managers and DFO] consider research to be. They probably could take the time to read all the latest papers and really mull it over, but I don't think there is that many people within the government who can do that…I have heard DFO management being described as a big super tanker. If you want to make a change in direction, you got to make a just a little alteration and then it's going to take a while before everything starts to turn.* (Interview #34; First Nation stakeholder)

Social acceptance and buy-in of new knowledge: In such a contested fishery, it is not surprising that new knowledge and knowledge claims are scrutinized by the potential knowledge users. Young et al. (2016a) found that potential knowledge users judge reliable knowledge based on multiple criteria (including judgements about the knowledge claimant/source). Therefore, for new knowledge to be used it has to go through socio-political judgement and be socially accepted, or as others have coined, 'socially robust' (e.g., Gibbons 1999, Nowotny et al. 2013, Young *et al.* 2013b), as described by this respondent:

> *[People] want it to be proven among peer group…. like a democratic acceptance that could also be a hindrance [to using new knowledge]. People can get hung up on that. Someone will say "Hey I did this study and this stock is being exploited too much". Then they will tell the managers to adapt the fishery, and in between people will say let's make sure you are right and that delays things. People just want a "perfect study" and it will slow down the process. Can't have top notch golden data, there is no money for that. There needs to be acceptance of some unknown. If there is disagreement on the model, let's say, that would take months to get proper people [experts] chosen, to get them together, etc. to talk about the "disagreement". For example, the CSAS critique. It's a long process, and is frustrating, but it's just the way it is* (Interview #16; fisheries management)

Scholars have termed this type of knowledge production as Mode 2 or context-sensitive science in which the knowledge produced is both reliable inside the laboratory and outside (Gibbons 2000, Hessels & van Lente 2008). The quote below illustrates the complexity of the socio-political context in which new knowledge enters:

> *Now you've got a large number of ENGOs, First Nations communities, sports fishing groups as well as commercial fishing groups, all vying for a say in how these fish are managed. And many of them have now hired their own biologists, which, I mean, is both good and bad...certainly more eyes are better, but as I said, some groups have different objectives and so you can always sort of shape the information to try and satisfy the end you are interested in, so it certainly can generate a lot of debate. So instead of having a single scientific authority that provides the best guess of the data, and provides the range of uncertainty we now have a number of different groups presenting "the science" or the biological information from their perspective, favouring their view of the objectives and outcomes they want to see, which makes... certainly as I said, makes for an informed debate, but also just adds to the difficulty and the complexity of the process. Whether or not you actually get better decisions is unclear to me* (Interview #36; stakeholder)

2.6.3. Characteristics of the knowledge as barriers

Barriers that relate to the characteristics of the new knowledge include its perceived applicability/usability (relevance to manager needs or compatibility with existing knowledge); the complexity of the new knowledge (associated with variability, uncertainties and challenges for interpretation); its reliability and credibility, and; existing contradictory evidence.

Applicability and usability (relevance, compatibility, representativeness) of the new knowledge: The applicability and relevance of the new knowledge was very important to government employees (Table 2.3), and is a major question among scholars: how to produce "readily usable" information for decision making? Unlike, the social dimension of knowledge, government employees described the more technical aspect of useable knowledge, which should reflect objectivity that is stripped of biases and socio-political influences. This is consistent with Cash et al. (2003)'s framework of credible, legitimate and salient knowledge, and strengthens the findings from Young et al. (2016a), which show that government employees judge the reliability of knowledge more closely to how it fits in their role and rely heavily on internal review processes (more technocratic approach). Stakeholders, on the other hand, judge new knowledge claims from a more social lens and looking at "who" is influencing and interpreting the data, and how credible that person is based on their "on-the-ground" experience and funders, for example. In this study, government employees were concerned about the *compatibility* of the new findings with their current management tools and frameworks, as well as how comparable the new findings are to currently used data. Second, it appeared that an applicability challenge is how *representative* the new knowledge is of the environment in which it is being implemented. Lastly, the applicability also refers to whether the new knowledge *answers the question* that fisheries managers need.

Within the stock assessment process, one major concern was whether descriptive scientific studies could be turned into a quantitative prediction. The quotations below illustrate the challenges that fisheries managers perceive when presented with new knowledge:

> *How can we apply that knowledge to what we have and what we do? From what I can see, we have to be able to model it somehow, so it could be incorporated into our knowledge.* (Interview #24; PSC)

One of the main ones [barriers] would be applicability. The study has to be useable in the management environment. That could be due to a number of things. For example, for post release mortality rates. If you have 3 studies that is design A and a 4th study that is design B, if they are not comparable it is challenging to incorporate into management. (Interview #25; fisheries management)

Complexity of the knowledge (variability, uncertainties): The complexity of new knowledge can also undermine its application as it carries uncertainties as well as variability. This can also lead to potential reliability issues that may delay its incorporation into fisheries management practices (Chapter 4). Furthermore, the new knowledge can also have counter contradictory evidence, which presents a challenge for incorporation as "reconciling the conflicting science is difficult", as stated by a government employee (Table 2.3):

> *In my career working with so many people in stock assessment, complexity and data is simply used as an excuse in many cases. It's easy to say we don't have the science so we don't respond. That's what led to precautionary principle. We can't use data as an excuse or lack of data as an excuse. But there isn't any question that people did that throughout the 80s when we were really modifying how we did things out here. They were quite prepared to blame the next guy and not themselves.* (Interview #39, male stakeholder, ENGO)

2.6.4. Time and Timing

Various perspectives of time were discussed as barriers to using new knowledge such as: 1) the timing of when the new knowledge is brought forth; 2) the time needed to implement something; 3) the time for both scientists and managers to genuinely and meaningfully engage, and; 4) the time for the process to take place (i.e., time for the knowledge to be produced, for everyone to understand it, come to terms with it, and for it to come into practice). Specific decisions and planning occur during specific time frames and cycles for salmon management, and understanding the decision calendar may enhance the incorporation of new knowledge. Sometimes, the failure to provide information at the right time can lead to the information losing virtually of all of its value to the decision maker (Jacobs et al. 2005a). This is consistent with findings from DFO Maritimes Region, in which the author reported DFO management's preference for DFO Science as it is matched with their annual cycle and have direct answers to fisheries management questions (Soomai et al. 2017b)

2.6.5. Barriers Associated with the Relational Dimension

Building trusting and meaningful relationships is a core concept in the literature that suggest people rely on their social network for gathering information as well as judge the legitimacy and credibility of knowledge based on trust (e.g., Bayliss et al. 2012, Young et al. 2016a). The quotation below suggests that building knowledge producer-user relationships can create an informal avenue for knowledge exchange and enhance the use of new knowledge:

> *There are gaps in the "team" of scientists, management and fishers. All this money is going into these great studies and data, and the products are good and ground-breaking. But, there is no procedure in place to get to them. We are sort of relying on communication, working and consultation groups and would hope that any significant findings do make it down the pipe.* (Interview #18; fisheries management)

Another respondent explained the importance of developing trust not only among actors, but also trust in the instruments that are used to produce new knowledge. For example,

> *Human nature is averse to change. There is a tendency to conform to what is familiar. How the new information is presented and communicated is important – compare the new to now— and it's important to do it in a pragmatic way. There was a transition in the 90s to*

move [from fish scale analysis for identifying populations] to genetic based stock discrimination. Even though you can describe in basic detail inheritance of genetic traits and adaptations, how do fishermen know how reliable this new technique is? A lot of comparisons and validations. Compare scale-based vs genetic results, always compare with what they know. It's important to communicate in the currency or the way the audience can relate to. Develop the trust in your expertise. Show them where it can screw up and clearly describe when it will fail. They are always suspicious of you, it's like a sliced bread… they will trust it if you show the weaknesses (Interview #25; PSC)

2.6.7. Facilitators and Potential Solutions

Although not asked specifically, facilitators and potential solutions were offered by 15 respondents (8 government and 7 stakeholders). Solutions varied from those that can be controlled within the knowledge network such as collaborative solutions and knowledge brokering; as well as solutions that lie outside of the control of actors, such as shifting management decision making frameworks and changing institutional structures to streamline new knowledge into practice. These solutions are discussed in Table 2.4, and provide lessons learned.

Table 2.4: Five solutions and facilitators discussed by knowledge users in the Fraser River salmon fisheries with illustrative quotations.

1) Collaborative solutions: iterative dialogue, interactions and knowledge exchange between producers and users An apparent theme was iteration – iterative dialogue, interaction, and knowledge exchange. This is widespread in the literature suggesting that two-way dialogue, long-term relationships with knowledge users and feedback is integral to successful knowledge exchange (e.g., Gibbons et al. 2008, Groffman et al. 2010, Reed et al. 2014, Young et al. 2014). These activities can increase interpersonal trust, and promote the co-production of knowledge as well as solution-oriented agendas, which have been documented to facilitate and promote knowledge mobilization (Fazey et al. 2014, Cvitanovic et al. 2015, 2016b)
2) **Holding workshops and increasing frequency of face-to-face interactions for feedback and development solution-oriented agendas** Respondents positively commented on a model used by a research group from University of British Columbia and Carleton University, which consist of researchers being "very proactive in making their projects relevant and useful". Reasons why their model was preferred is illustrated below: *I think that the model that [university professor names] have in terms of outward reporting, which is kind of a one-day in the Spring everybody comes and takes a look and see what's been going on [research-wise]. But we've also had meetings with them [university researchers] in the Fall, to say well here are some of the questions we have that are outstanding and do you think that some of the project types that they're looking at might be useful. So, there's the pre-planning of projects, as well as the follow-up in terms of these are the results, which then leads to potentially more questions* (Interview #13; fisheries management).
3) Involve a third party: knowledge brokering and boundary organizations Boundary organizations or other bridging organizations and knowledge brokers are often individuals, teams, or organizations perceived as neutral and are trusted by the relevant parties (Berkes 2009). They play an intermediary role and skilled in providing two-way communication among multiple sectors through translating and communicating information into more useful and usable forms. Furthermore, they can assist in producing boundary objects such as agreement on a common list of key resource management questions (Cash et al. 2006, Feldman & Ingram 2009, Clark et al. 2011, Lemos et al. 2012, Nel et al. 2016). In the case of the Fraser River salmon management, the use of a third party was viewed to also help alleviate burden with shrinking capacity. NGOs, in particular, have pivotal roles in actively engaging with knowledge and making change in environmental policy (Jasanoff 2010). These sentiments are illustrated below:

T*o get them to engage with it [new science, disruptive science], it takes people, an organization, willing to take that science and ram it down their throats. Academics can't do that because they have to maintain their integration. It takes organizations, conservation, First Nation and other organizations to ram it down their throats until they are finally breached, but it is very difficult* (Interview #46; private scientist).

4) The role of researchers: being transparent, include broad and multiple lines evidence, and use tailored communication

There are certain solutions and facilitating factors that knowledge producers have autonomy over. For instance, demonstrating transparency of the science (disclosing uncertainties and limitations) and providing multiple lines of evidence to support knowledge claims (e.g., including local knowledge). Multiple lines of evidence is helpful to knowledge users, particularly decision makers, for adapting to the continually changing management context (Cook et al. 2012), especially because managing Pacific salmon is highly unpredictable. Knowledge users that have authority in management of salmon are more often concerned on direct applications of research to known problems, while stakeholders focus on the implications of this new knowledge in a socio-political context (Young et al. 2016b). As such, communicating in the same currency as the audience – in a way that the audience can relate to—can promote effective communication. Knowledge producers tailor their communications and engagement to align with the preferences, roles, understanding and expectations of potential user groups (Groffman et al. 2010, Young et al. 2016b).

5) Formalize review process for integration of external and broader knowledge

Formalizing the process for the use of "external" science (e.g., academia, traditional knowledge, local ecological knowledge) can be a solution to streamline and harness research more broadly and in a more coordinated way. For example, developing a formal process to streamline external science into the CSAS peer review process would give greater weight to the research, as illustrated below:

We're having discussions right now [about new knowledge of 30% bycatch mortality rates], and one of the questions that keeps coming up is "well, has it been peer-reviewed"? So, I think that if this work was channeled through the CSAS process or some similar process [with] same level of standard of review from people outside of that particular area, then we are in a much better position to use that data. [If the new knowledge were reviewed through CSAS] The Department is then in a position that it can hold it up and say hey we have a real credible study here that is suggesting that the impacts of this fishery are not the 70% [bycatch mortality] that was identified in that previous study that had some problems (Interview #21; fisheries management)

The administrative burden that some respondents describe in their roles can undermine the use of new knowledge and evidence-based decision-making for the sustainable management of Fraser River salmon. By streamlining and formalizing a process that brings in external science, it may alleviate some problems with shrinking capacity (human and financial resources):

I don't think that to date we've done a good job of using academia, and I think that's where *there may be an opportunity going forward. I think that's due to the declining resources within DFO in terms of people and budget. ... We ought to try to formalize this process, either within CSAS or separate from it, to allow academics to formally provide advice to the Department to address some of the inadequacies within our organization to get some help on the things we can't do on a yearly basis* (Interview #21; fisheries management)

2.7. Synthesis

In light of my objectives, the next logical question is how can we (knowledge producers and users) narrow the gap between knowledge and action, to produce more useable knowledge and promote more evidence-based policies and practices? I contend that my findings shed light for knowledge producers to better understand the environment in which knowledge users interact with new knowledge given realities of individual and institutional constraints and capacities with the Canadian context of the Fraser River salmon fishery.

Broadly, the results show that there are areas where knowledge producers may have little autonomy for facilitating knowledge integration (environmental and contextual dimension), areas where they may have some influence (characteristics and perceptions of actors), and areas where they may have nearly total control in enhancing knowledge use (characteristics of the knowledge). Furthermore, it is possible that there are potential associations or interactions among the themes identified. For example, I may speculate that a number of institutional processes, such as consultation processes, are linked to increasing social acceptance of new knowledge. Or, I may speculate that inertia and lack of political will is linked to institutional structures and political factors such as government priorities. However, these relationships were not possible to test and are beyond the scope of this study. From a mechanistic view, further research into these interrelationships and links is warranted to improve our understanding of the knowledge-action gap and effective knowledge exchange/mobilization.

I discuss lessons learned from the findings to better understand and develop more effective knowledge exchange and mobilization. These lessons are not only directly applicable to the Canadian Fraser River fisheries, but also more broadly in other natural resource management cases.

2.7.1. Understand that the knowledge users' decision-making environment is complex and their decision-making space is constrained and defined by their roles and institutional capacity

It is clear from the findings that the decision to incorporate or use new knowledge among potential knowledge users is multi-faceted and is influenced by a number of factors that knowledge producers may or may not control. Even "perfect" data or predictions of events may not sway decision makers because there is little room for movement in their decision space. Thus, improved information does not always provide managers with new options, because they are institutionally constrained in ways that impede using it (Jacobs et al. 2005). Soomai (2017)'s work helps shed light on these constraints by highlighting DFO's preference and reliance on internal science, which lead to missed opportunities and overlooked issues captured by external sources, such as academia.

Consistent with results from other studies, I found that 'usable' knowledge needs to be: 1) applicable to management needs and scales (relevant and compatible), 2) socially robust (trusted and accepted by knowledge users), and 3) congruent with the capacity of the knowledge users' decision space (e.g., align with institutional and rational constraints) (Cash et al. 2003, Buizer et al. 2012, Cvitanovic et al. 2016). This may prove to be a challenging task if no relationship or conversation exist between the knowledge producer and user.

In the case of the Fraser River salmon fisheries, most potential knowledge users perceived formal and informal institutional barriers, including bureaucratic processes to undermine the movement and application of new knowledge in fisheries management practices. This is not surprising as policy developments and decision making processes tend to be shaped by wider social and political contexts (Shaxson 2005, Bayliss et al. 2012). Thus, it is critical for knowledge producers looking to make impact to immerse themselves in understanding the decision-making and managerial environment, to make their work accessible and noticeable to decision makers, and to produce more useable and relevant knowledge (as shown in Chapter 4).

2.7.2. Produce knowledge that is applicable and relevant to fisheries management yet socially robust by co-producing knowledge through iterative exchanges, feedback, collaborations, and relationship developments

Fisheries management decisions tend to be complex and there is a need to consider multiple scientific disciplines, involve multiple constituencies, which have multiple (sometimes conflicting) objectives, and consider economic and political realities (Eden 2011, Cook et al. 2012). New models of knowledge production have evolved to better integrate science, scientists, the public, and policy (coined Mode 2 knowledge by Gibbons 2000) (Kirchhoff 2013, Dick et al. 2016). Scholars propose that new knowledge produced, particularly scientific knowledge, should go beyond providing neutral, credible and legitimate support for decision-making. There should be flexibility in the knowledge produced where there is more iterations and interactions among knowledge producers and users leading to co-production of knowledge and social learning (e.g., Schusler 2003, Kirchhoff et al. 2013, Nguyen et al. 2016). Co-production of knowledge has been repeated numerous times in the literature and in the findings as a core principle in producing relevant and usable science (Lemos & Morehouse 2005). Furthermore, another form of co-production can be through *transdisciplinary teams and projects,* which can assist in overcoming the multifaceted and complex nature of resource management by including scientists and non-scientists of various disciplines who work towards a solution-oriented agenda (Hadorn et al. 2006, Stokols 2006, Pohl 2008, Dick et al. 2016).

Researchers or knowledge producers who seek to produce usable and relevant information need to be mindful of the multi-faceted environment that knowledge users engage with daily. For example, Eden (2011) used the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) as a case-study to assess the decision support activities and observed that the insights gained by researchers about the real-world nature of decisions allowed them to think about their research differently, to look for opportunities, and communicate their findings more effectively to knowledge users. On the other hand, knowledge users should also understand the nature of research and its environment to comprehend what different research can provide, and improve their communications of research needs.

2.8. Lessons Learned

The research team associated with this study is part a broader interdisciplinary team of researchers from universities and DFO science who have been investigating the fundamental and applied (e.g., climate change, hydropower, disease, fisheries interactions) migration biology of anadromous Pacific salmon for over 15 yrs. Over the past 7 years, much of the research activity has focused on the fate of fish released after capture by different fisheries sectors. I use the experiential knowledge from our team, and the examples highlighted in the study findings to discuss lessons learned. I present two examples derived from the Fraser River Pacific salmon fishery that were beneficial in mobilizing knowledge into fisheries management strategies: an annual stakeholder symposium as a communication and knowledge exchange model, and; a formal commissioned review process by the Canadian Science Advice Secretariat.

2.8.1. A Communication and Knowledge Exchange Model: Strategic Annual Stakeholder Workshops and Symposium

Scientific advice does not occur in a vacuum and requires iterative processes and exchange between knowledge producers and users (Rice 2011, Patterson et al. 2016). In this study, respondents positively commented about an annual full-day workshop and symposium held at the University of British Columbia (UBC), led and organized Dr. Scott Hinch's Pacific Salmon Ecology and Conservation Lab (PSEC), to be a working model for communication and knowledge exchange. What began 20 years ago, as an informal and modest gathering of researchers at UBC has grown into a highly sought-after symposium with over 70 attendees in 2016. The workshop and symposium occurs in early February, and provides a forum for collaborative research groups (consisting of university primary investigators, graduate students, and government research collaborators across Canada and northwestern US) to update stakeholders on the ongoing relevant individual projects and connecting results strategically with critical management issues. The audience consists of nearly every interest group ranging from DFO, PSC, private scientists, representatives from the First Nation, commercial and recreational fishing sectors, fish processors, and ENGOs. It is an excellent model that fosters relationship-building between scientists, fisheries managers, and stakeholder groups, and demonstrates successful creation of a social network in which trust, credibility, legitimacy and saliency of the research can be developed and built upon – a critical element for successful knowledge transfer (Young et al. 2013). The success of this model is maintained by the researchers' proactivity (Box 1), and also largely on the willingness of the managers to participate and engage. Ideally, the communication should occur at the initial development of research questions and study design (i.e., co-creation of the research agenda) which the group has achieved through smaller, more targeted meetings with key stakeholders and managers. Researchers should also be cognizant about the interpretation of their research by other groups outside of the management environment (Patterson et al. 2016, Young et al. 2016a).

2.8.2. Canadian Science Advisory Secretariat Commissioning: The Formal Request from DFO Fisheries Management Sector to the Science Sector to Develop Scientific Advice on catch-and release mortality

In 2016, the PSEC lab and its collaborators were commissioned by CSAS to create a research document that comprehensively reviewed the mechanistic (i.e., physiological) basis for how different factors (e.g., fish injury, temperature, physiological stress, gear types, population variations, and other) affect fishing-related mortality and a review of the mortality rates (described in Patterson et al. 2016). The CSAS process provides a direct link and mechanism for science from the PSEC lab to be integrated into institutional guidelines for Pacific salmon management. This formal document will be shared with all stakeholder groups. Management changes will not occur until all groups have been consulted. Although it appears to be a tedious process, fisheries managers maintain that this formal process is an effective way to bring in external knowledge and broader lines of evidence that would satisfy the contentious and political arena that surrounds the management of Fraser River salmon.

2.9 Conclusion

It is apparent that, in the case of the Fraser River salmon fisheries management, institutional structures and government processes play a large role in undermining the use of new knowledge, particularly knowledge external to DFO. This highlights the importance for scientists outside of DFO to build their social networks and build relationships with potential knowledge users as demonstrated by the positive feedback from the respondents regarding the UBC annual stakeholder workshop and symposium, and the resulting CSAS review commissioned to develop institutional guidelines based on the external science produced by the PSEC lab. What started as informal relationship building and gatherings became fruitful and led to the integration of the new scientific knowledge. Although the process was slow (approximately 20 years), the proactivity and persistence of the research team led to the incorporation of their findings, and greater evidence-based policies that include multiple lines of evidence.

Chapter 3: Science action starts with collaboration and engagement: an empirical exploration of factors influencing knowledge uptake from fish tracking studies around the globe

3.1 Abstract

Aquatic telemetry technology has generated new knowledge on the underwater world that can inform decision-making processes and presumably improve conservation and natural resource management. However, there is still lack of evidence and understanding of how telemetry-derived knowledge can or has informed management, and what factors facilitate or deter its use. Here I present one of the first quantitative studies on the science-action gap where I evaluate factors that influence the uptake of fish telemetry findings into policies and practices, as well as social acceptance of the findings. I queried 212 fish telemetry researchers from across the globe regarding the successful or unsuccessful knowledge uptake of an applied fish telemetry research project of their choice, resulting in an evaluation of 212 case studies. Respondents' attributes and their project attributes were used as predictor variables and analyzed to identify important factors that influence the uptake of the findings. Researchers with high collaborative behaviours and who spent greater time engaging in public outreach experienced greater uptake of their findings. Respondents who had greater telemetry commitment (e.g., greater telemetry publications, higher proportion of research is fish telemetry, involved in more telemetry projects) and experience also tended to achieve more social acceptance of their findings. Projects led by researchers who were highly involved and familiar with the fisheries management process and where greater effort was devoted to dissemination (to various audiences) tended to experience greater uptake. Lastly, the complexity and controversy of the issue the project addresses had positive influence on uptake of findings. The results support the insistent calls in the literature for greater collaboration and public engagement/communication by researchers to facilitate the use

of evidence in decision making and policies, and demonstrate that institutional rewards need to shift to reward researchers who engage outside of the traditional scientific/academic framework.

3.2 Introduction

Sound scientific evidence and up-to-date knowledge should ideally inform environmental management policies and practices (Pullin & Knight 2003, Sutherland et al. 2004). Yet, research has consistently found that management practices rely heavily on experiential or tacit knowledge that is grounded in managers social networks (Cook et al. 2012, Pullin et al. 2004,Young et al. 2013). As such, discussions of how to better integrate science into practice are increasingly featured in the conservation and natural resource management literature (Fazey et al. 2012, Cook et al. 2013, Cvitanovic et al. 2015, 2016a). To date, much of the accumulating research on the science-action gap and use of evidence in conservation and resource management is qualitative (Raymond et al. 2010, Young et al. 2016a), case-study based (Thakadu et al. 2013, Saarela & Rinne 2016), context-specific (Bayliss et al. 2012, Young et al. 2016a), or conceptual (Gibbons et al. 2008, Reed et al. 2014a, Nguyen et al. 2016). Quantitative and comparative work is now needed to round out the field, particularly research that involves the evaluation of multiple case studies to empirically identify common factors that influence the movement of science into action (Posner et al. 2016). This would offer a more comprehensive understanding of the science-action gap. To this end, I conducted a quantitative study that compares multiple case studies from around the globe related to the use of fish telemetry science to inform fisheries management and conservation practices.

3.2.1. Context: Telemetry Science and Fisheries Management

Telemetry is the tracking of animals using electronic devices attached to an individual that autonomously emit a signal to a receiver (Cooke et al. 2004). It is considered an innovation that has allowed ecologists to understand animal movement, spatial ecology, habitat usage, and other animal-environmental interactions. In the aquatic world, telemetry has opened a window to underwater wonders and has informed conservation and management decisions such as delineation of marine protected areas, understanding post-release survival of bycatch species, informing stock assessments, and more (Hussey et al. 2015, Cooke et al. 2016, Crossin et al. 2017). The growing catalogue of telemetry-derived data throughout the oceans and inland waters has led to novel insights into the ecology of many aquatic species of interest. Indeed, a recent review (Hussey et al. 2015) indicated that there were thousands of published aquatic telemetry studies using acoustic and satellite telemetry alone spanning the globe with apparent exponential growth over the last decade. Effectively using this information is thus critical for improving conservation and sustainable practices in a complex and rapidly changing world (Cooke 2008, Hussey et al. 2015, McGowan et al. 2016). Such an endeavour, however, is not an easy task.

There is a lack of documentation and assessment of the conservation impact of telemetry research (Jeffers & Godley 2016, Mcgowan et al. 2016). Also, hesitation and delay in applying telemetry-derived data to fisheries management have been reported for reasons such as uncertainties associated with telemetry studies, limitations of the technology, unknown effects on tagged animals, distrust of telemetry (reliability and credibility issues), mismatches between management needs and design of telemetry studies (e.g., compatibility, representativeness, timeliness), or lack of awareness and access to new findings (Cooke et al. 2013, Young et al.

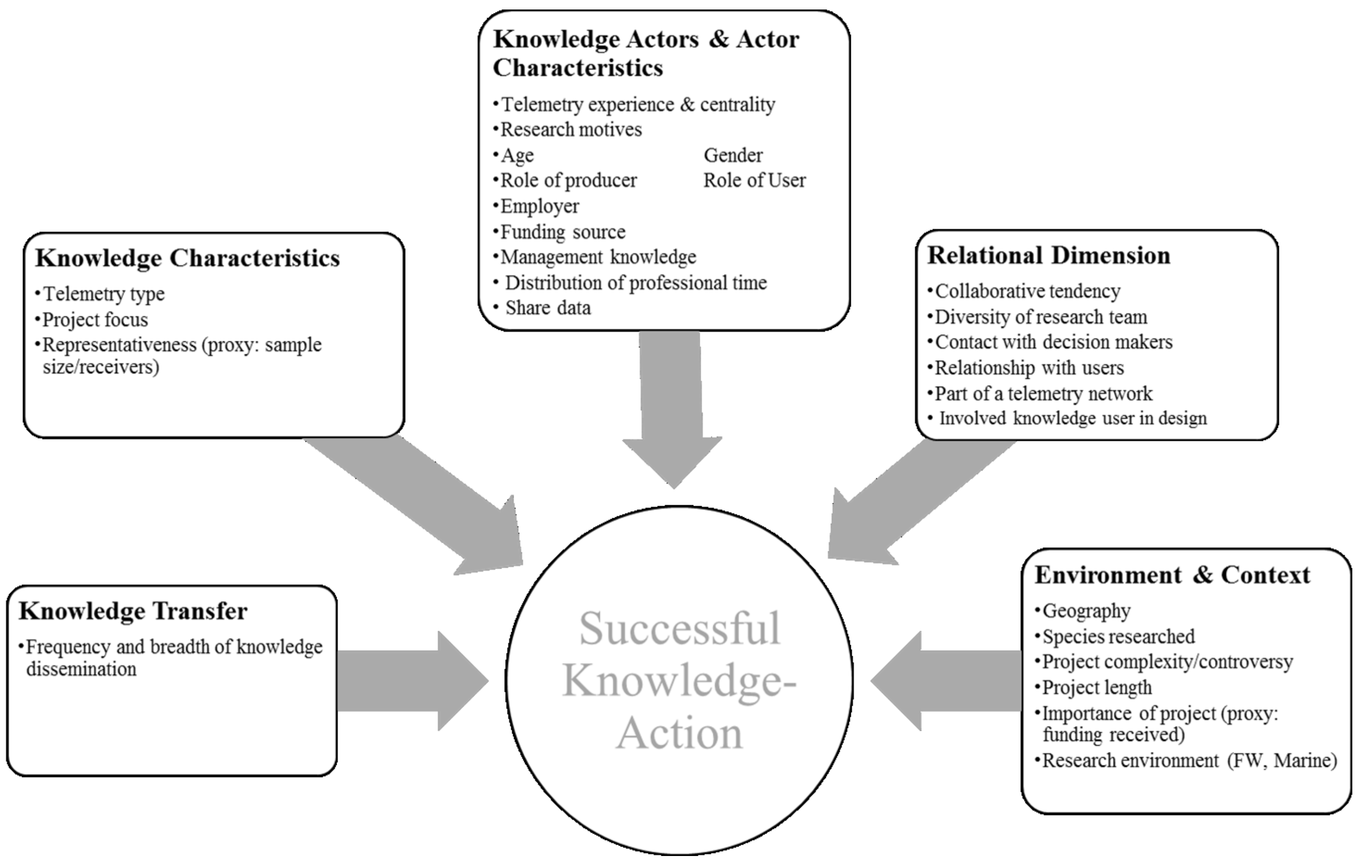
2013, Crossin et al. 2017, Young et al. in review, Nguyen et al. submitted). It has also been suggested that publications focus on research results rather than on conservation and management implications, and that the recommendations put forth lack context and are not useable by decision makers (Roux et al. 2006). Furthermore, McGowan et al. (2016) highlighted the missing link between many telemetry studies and direct conservation actions. As such, understanding the integration of telemetry findings into fisheries management practices makes an ideal case for identifying conditions and factors that better link science to conservation actions.

3.2.2. Conceptual framework

Research on understanding the movement of knowledge is scattered across several disciplines and fields of study, and the development of a knowledge-action framework was needed to synthesize this research (Nguyen et al. 2016). Nguyen et al.'s knowledge-action framework was developed to guide future research on knowledge-action, and provide a stage to develop and organize hypotheses that inform the community of practice and theory on the knowledge-action gap. The framework is based on the theories of knowledge mobilization and knowledge exchange, which both emphasize the social dimension of knowledge movement, particularly the non-linear, iterative, and dynamic way that knowledge moves and is interpreted within and across social groups (van Kerkhoff & Lebel 2006, Fazey et al. 2012, Gainforth et al. 2014). Factors that mediate knowledge flow take place in a "knowledge mediation sphere", which is composed of: 1) the knowledge network (composed of knowledge actors, characteristics of the actors, relationships among actors, and characteristics of the knowledge), and 2) the environmental and contextual dimension. Factors involved in the knowledge production (such as engaging with knowledge users) and the desired knowledge action outcomes are also considered to influence knowledge movement (see Nguyen et al. 2016/Chapter 1 for full details). I hypothesize that the components of the knowledge-action framework – the knowledge transfer, knowledge characteristics, knowledge actors and characteristics, relational dimension, and environmental and contextual dimension – have an influence on the successful uptake of knowledge (Fig. 3.1).

In this chapter, I apply this framework by building exploratory models that examine various factors that have been suggested to influence knowledge outcomes, including Cash et al. (2003)'s framework on the salience, credibility and legitimacy of knowledge as important conditions linking knowledge and sustainability action. I seek to identify factors that are important for achieving a "successful knowledge outcome", which in this study, is defined as the perceived success of knowledge utilization and acceptance from two standpoints: ii) formal uptake of telemetry study findings (e.g., knowledge transfer, integration into policy), and iii) social uptake of telemetry study findings (e.g., stakeholder acceptance, trust, and media interest). I use fish telemetry science and management as a model for exploration. In doing so, I address the question, "What explains the formal uptake and social uptake of fish telemetry findings?" I submit that this work also has broader implications for the conservation and natural resource management communities. This study is one of the first attempts to quantitatively compare multiple case studies and empirically test knowledge-action hypotheses that are widespread in the literature (but see Posner et al. 2016).

Figure 3.1: Conceptual model of a knowledge-action framework that guides the development of the quantitative models built to test the predictions (Supplementary Information S3.1) associated with the hypothesis suggesting that areas of knowledge transfer, knowledge characteristics, knowledge actors and actor characteristics, relational dimension, and environmental and contextual dimension have influence over the uptake of knowledge (successful knowledge outcome). Descriptions of variables can be found in Supplementary Information S3.2.



3.3. Methods

3.3.1. Instrument development and data collection

I surveyed fish telemetry researchers working around the globe in marine and inland waters as part of a broader study on mobilization of fish telemetry-based knowledge, which included both online questionnaires and semi-structured interviews (see Nguyen et al. 2017; **Appendix A).** The interviews provided opportunity to capture in-depth responses and follow-up queries, while the questionnaire allowed us to reach a broader population, to access international respondents, and increase the sample. The survey instruments were developed based on hypotheses synthesized in a knowledge-action framework (Nguyen et al. 2016) as well as the authors' experience and anecdotal information in the field of knowledge mobilization and fisheries.

The survey instrument consisted of three parts: 1) measurements of the researchers' attributes, which included fish telemetry experience, socio-demographics, underlying constructs measuring beliefs, values and motivations, as well as assessment of their professional network and sharing/collaborative tendencies; 2) attributes and characteristics of a chosen "fish telemetry project" of their choice in order to assess factors that may influence the "successful" use of telemetry findings, and 3) assessment of researchers' behaviour and attitudes towards data sharing (which was not analyzed in this study).

In this study, I restricted "telemetry" to acoustic, radio, or satellite tracking only, as these telemetry techniques are used to address similar research questions and management issues. The online questionnaire was pre-tested with 11 individuals who have worked with fish telemetry.

The interview was pre-tested with the first five interviewees and minor adjustments were made. The Carleton University Ethics Board approved the study with anonymity of respondents being maintained (102887).

3.3.2. Data Collection

The initial sample population was built 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 me to others. I conducted 25 face-to-face interviews with fish telemetry experts at the International Conference on Fish Telemetry (Halifax, Nova Scotia), from 13-17 July, 2015. The sample was supplemented with 12 interviews at the meeting of the American Fisheries Society, (Portland, Oregon), from 16-20 August, 2015. Nine phone/Skype interviews were also conducted, totaling 46 interviews (including responses from the pre-tests).

The population for the online questionnaire was determined by extracting the e-mail addresses of authors who have published about fish telemetry as determined by citation records from the Web of Science online database. A search was conducted for articles between 2011-2015 using the following string, (*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), to identify relevant authors in fish telemetry research. The search was undertaken 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 that contained 2605 valid e-mail addresses. I identified 1908 unique e-mail addresses after removing duplicate e-mails and irrelevant records.

Invitations were sent via email on 7 October, 2015. There were 112 bounce-backs and 110 respondents notified us that they did not meet the criteria of a “fish telemetry researcher”, resulting in a final population of 1686. This number likely includes non-target populations as I was aiming to reach the whole population of fish telemetry researchers and used broader search strings. Reminders were sent on the 4th and 14th of November, 2015. I gathered contact information for an additional 155 individuals using a snowball approach, and sent invitations and reminders on Feb 4th and 14th, 2016, for a total sample pool of 1841. The survey closed on 19 February, 2016.

3.3.3 Data Analysis

3.3.3.1 Dependent variables

The dependent variables were developed from six 3-item Likert-type questions that measured various aspects of what could be considered as a “*successful” knowledge outcome*. Respondents were asked to rank on a 3-point scale whether the knowledge outcome was “Not at all successful” (received a score of zero for construct purposes), “Somewhat successful” (score of 1), and “Very successful” (score of 2). A “Not applicable” option was provided to capture the reality that not all projects have the same knowledge outcome objectives. I asked respondents, “In your opinion, how successful were your telemetry findings with respect to the following?”: Making scientific advancements; Knowledge transfer (i.e., findings being used by knowledge users such as stakeholders, managers, etc.); Changing, developing or affirming a policy/practice;

Integration into policy or management framework; Adoption/buy-in/uptake by stakeholders; Trusted by stakeholders; Generating media interest. I opted to drop the "making scientific advancements" statement from the analyses because it was highly biased towards "very successful" and suspected to have high confirmatory bias. A factor analysis with principal component analysis (PCA) was conducted to reduce the number of items to create constructs using the mean scores and verified with Cronbach's alpha test (Supplementary Information S3.3).

In addition to using a Likert-type question to assess the "successful knowledge outcome", I also directly asked the question, "Have findings from this particular telemetry project been used in management or policy decision?" to obtain a binary response. This binary response makes up the third outcome variable (herein called "findings used") assessed in this study. This third outcome variable provides additional information about the reliability and validity for the *formal uptake* outcome variable, and is not the focus of the study (Supplementary Information S3.4).

3.3.3.2 Explanatory variables

A total of 27 variables were measured to explore and understand factors that may influence the uptake of knowledge (i.e., fish telemetry findings). The variables measured were based on literature review and suggested factors reviewed in the knowledge-action framework (Nguyen et al. 2016), experts' knowledge and authors' anecdotal/experiential knowledge (see Fig 3.1; Supplementary Information S3.2). Some variables were constructs that were measured by several items and summed into a scale (Supplementary Information S3.3). The explanatory variables were subsequently grouped into "researcher attributes" and "project attributes" for the purpose of model input. Categorical variables were dummy coded, and scales for underlying constructs were developed. Cronbach's alpha and assessment of correlation matrices with additional bivariate correlation analyses were examined for internal consistency and reliability of the scales (S3.3).

3.3.3.3 Factor Selection

A Random Forest (RF) regression was conducted to identify important variables using R Version 3.3.3 (Breiman 2001, Gromping 2009). RF is a nonparametric technique derived from classification and regression trees (CART), which are modern statistical techniques ideally suited for both exploring and modeling complex data that may contain missing values. A tree is constructed by repeatedly splitting the data, defined by a simple rule based on a single explanatory variable with the objective to split the data into to mutually exclusive groups (each group being as homogeneous as possible) (De'ath and Fabricius, 2000). The splitting continues until an oversized tree is grown, which is then pruned back to the desired size – the final tree size is the number of final groups built. A random forest, however, consists of a combination of many trees, where each tree is generated by bootstrap samples, leaving about a third of the overall sample for validation (the out-of-bag predictions – OOB). Each split of the tree is determined using a randomized subset of the predictors at each node. The overall prediction of a random forest is an average of what an individual tree (from CART) would be (Breiman 2001, Cutler et al. 2007).

This method has been widely applied in ecological studies (e.g., Gislason et al. 2006, Prasad et al. 2006), life sciences (Touw et al. 2013), bioinformatics (Wu et al. 2009), and remote sensing (Chan & Paelinckx 2008). It has shown high accuracy and ability to model complex interactions between variables without being constrained by any assumptions. The RF algorithm can estimate and measure variable importance by looking at how much prediction error increases when the OOB data for that variable is permuted while all others are left unchanged. Because of the exploratory nature of this study, this technique was used to explore all variables and to select important variables for input into a Multiple Regression and General Linear Models (GLMs) (Grömping & Römping 2017). The advantage of using an RF is that it can handle large numbers of variables with a relatively small sample size, in addition to providing an assessment of variable importance (Breiman 2001, Grömping & Römping 2017). The random forest classifier uses the Gini Index (Breiman et al. 1984) as a measure of variable importance by measuring the homogeneity of subgroups for the data (Breiman 2001). The Gini importance measures the decrease in the Gini impurity criterion of each variable over all trees in the forest. Models with 1000 trees were used to calculate the importance of the contribution of each independent variables (Breiman 2001).Variables that contribute more to the RF model have a higher Gini index. I chose variables for model input based on a Gini index of 2 or higher.

3.3.3.4 Models

I conducted exploratory analysis by performing bivariate correlations, t-tests, chi-square and simple regressions between the explanatory variables and each dependent variable. This was done to explore and understand the significant associations that exist between the predictors and outcome variables. I applied univariate Multiple Linear Regressions and verified the models with GLMs Type I and III to each outcome variable to explore potentially important and significant influential factors (Fig 3.2). The models were fitted to three groups of explanatory variables with sub-variables falling into researchers' attributes and into project attributes. This resulted in 6 regression models (Fig 3.2). I used a stepwise backward model selection to select the final model. Multicollinearity was assessed using correlation matrices and VIF scores. Linearity, homoscedasticity, and normality were assessed visually. Durbin-Watson tests were used to assess autocorrelations in the residuals of the regression models. Similar analyses were repeated for *findings used* dependent variable, for reliability and validity evaluations (Fig 3.2).

Figure 3.2: Flow chart of statistical analyses undertaken using R and SPSS statistical packages. First, a random forest (RF) classifier derived from classification and regression tree analyses was used to identify important explanatory variables from 27 variables. The Gini Index was used to select independent variables for model input (cut off at ≥ 2). Second, both General Linear Model fitting and Multiple linear regression models were used to explore the significance of variables grouped under researcher attributes and project attributes against dependent variables “formal uptake” (of telemetry study findings) and “social uptake” (of telemetry study findings). “Findings used” was used a reliability and validity measure. A total of six models were fitted. Bivariate correlations using both Pearson and Kendal Tau correlation coefficients were conducted to further understand the relationships of independent and dependent variables.

Random Forest Classifier (derived from CART) to identify important explanatory variables using GINI importance measures with cut off of ≥ 2 in R

Explored significance and importance of identified variables using GLMs Type I and III SS, and Multiple Regression models (backward selection) in SPSS 20

Formal uptake of knowledge		**Social uptake of knowledge**		**Findings Used**	
M1: Researcher attributes	M2: Project attributes	M3: Researcher attributes	M4: Project attributes	M5: Researcher attributes	M6: Project attributes
Input variables: time_ outreach, time_research, time_dissem, collab_index, telem_exp	Input variables: mgmt_famil, proj_complexity	Input variables: collab_ind, telem_exp, time_outreach	Input variables: dissemination_ ind	Input variables: Telem_exp, Collab_ind time_research, time_engage_stak e, age	Input variables: Mgmt_famil, Proj_complexity

Bivariate correlations (Pearson and Kendall Tau) used to understand the underlying story of the models.

3.4. Results

For this study, a total of 212 (166 online + 46 interviews) responses were used in my analysis. Although I received 348 responses from a sample pool of 1841 potentially relevant participants to my questionnaire, only 212 completed the questionnaire in its entirety of which between 196-208 responded to the focal questions making up the response variables. The overall response rate for my online survey was 19%, which falls within the typical range for expected responses rates for online surveys (Deutskens et al. 2004).

3.4.1 Characteristics of the sample

The sample was confirmed to be "experts" in fish telemetry with 74% of the sample being principal investigator of at least one fish telemetry project. The average researcher in the sample spent 49% (range: <10% to 100%) of their research time on fish telemetry with 10.4 ±7.8 (Mean ± SD) years of fish telemetry experience, and 56% were part of a telemetry network. Most of the respondents fell between the ages of 30-49 years. The majority of the respondents were from North America (66%) and 83% were male. The sample was largely comprised of those affiliated with academic institutions (50%) or government science staff (47%). There was a relatively even number of researchers conducting research in inland and marine systems (Table 3.1).

3.4.2. Principal Component Analysis

A PCA was conducted to reduce the number of outcome variables measuring the "successful" uptake of knowledge (from each case study reported by each respondent). Component 1 described "formal" uptake of knowledge, composed of three items: knowledge transfer; change, affirmation, and development of policy, and; integration into policy. Component 2 described a more "social" uptake of knowledge with greater and positive loadings on the following items: trusted by stakeholder, uptake by stakeholders and generate media interest (Table 3.2).

The suitability of PCA was assessed prior to analysis. Inspection of the correlation matrix determined that all variables had at least one correlation coefficient > 0.3. The overall Kaiser-Meyer-Olkin was 0.8 with individual KMO measures all greater than 0.7, classifications according to Kaiser (1974). Bartlett's test of sphericity was statistically significant ($p<0.01$), indicating that the data was likely factorizable. Visual inspection of the scree plot, however, indicated that potentially 2 components should be retained, which would explain 74% of total variance. A forced factor of 2 PCA was re-run, and I used a varimax orthogonal rotation to help with interpretation of each component. Component 1 described "formal" uptake of telemetry study findings (knowledge transfer; change, affirmation or development of policy; and integration into policy), while Component 2 described more "social" uptake of telemetry findings (Table 3.2).

Table 3.1: Demographics and other relevant covariates describing the sample population of fish telemetry researchers. *Denotes categories that are not mutually exclusive.

Demographics & Covariates		
Age (N=213)	**Freq**	**%**
20-29 years	16	8%
30-39 years	79	37%
40-49 years	61	29%
50-59 years	38	18%
60 + years	19	9%
Gender (N=213)		
Male	175	82%
Female	38	18%
Geographic Location (N=219)		
North America	140	64%
Europe	39	18%
Other	40	18%
Employer*		
Academia	106	44%
National government	57	24%
Regional government	43	18%
Industry	3	1%
NGO	16	7%
Private	15	6%

Telemetry Research Characteristics		
Refereed articles published (N=206)	**Freq**	**%**
None	13	6%
1-4 articles	105	51%
5-9 articles	39	19%
10-14 articles	16	8%
15-20 articles	12	6%
>20 articles	21	10%
Non-refereed articles published (N=207)		
None	38	18%
1-4 articles	85	41%
5-9 articles	39	19%
10-14 articles	16	8%
15-20 articles	12	6%
> 20 articles	17	8%
Number of telemetry projects involved in (N=194)		
None	34	18%
10-14 projects	10	5%
1-4 projects	92	47%
15+ projects	19	10%
5-9 projects	39	20%
Telemetry technology used *		
Radio	103	28%
Acoustic	191	52%
Satellite	72	20%

Engagement behaviours and activities		
Average % (± SD) of professional time spent on:		
Research	47 ±	20%
Engaging stakeholders	13 ±	12%
Disseminating research	17 ±	13%
Outreach	6 ±	5%
Mentoring students	12 ±	11%
Average (± SD) project dissemination activities score (scale 0 = none to 4= 10+ times)		
Presented at a conference	2 ±	1.1
Published a refereed article	1.3 ±	0.9
Published a non-refereed article	1.3 ±	1.1
Attended a stakeholder workshop/consultation meeting	1.6 ±	1.3
Organized a stakeholder workshop/consultation meeting	0.7 ±	1.1
Attended a manager's meeting	1.3 ±	1.2
Made media appearances or comments	1.4 ±	1.3
Wrote a press release	0.7 ±	0.9
Engaged in new media/social media	0.85 ±	1.2
Engaged in public outreach activities	1.4 ±	1.4

Table 3.2: Rotated Structure Matrix for PCA with Varimax Rotation of Two Component Questionnaire. Component 1 describes "formal uptake" of telemetry study findings, while Component 2 describes the "social uptake" of telemetry study findings. The 3-point Likert items are listed with the variable label in parentheses. The scale consisted of 0=not successful, 1=somewhat successful, 2=very successful for each item listed.

Items	**Rotated Components Coefficients**	
	Component 1 (Formal uptake)	**Component 2 (Social uptake)**
Integration into policy or management framework	0.859	-0.300
Changing, developing, or affirming a policy/practice	0.857	-0.320
Adoption/buy-in/uptake by stakeholders	0.830	0.163
Knowledge transfer (i.e. findings being used by knowledge users such as stakeholders, managers, etc.	0.754	-0.313
Trusted by stakeholders	0.740	0.390
Generating media interest	0.513	0.671

3.4.3. Random Forest Classifier

RF analyses identified the most important variables in explaining the response variables: formal and social uptake of knowledge (Fig. 3.3). Based on the Gini index (≥2), I identified a total of 5 different researcher attributes and 4 different project attributes for input into the six regression models: time_outreach, time_research, time_dissem, collab_index, telem_exp, age_cat, mgmt_famil, proj_complexity, dissemination_ind (Fig 3.2, 3.3).

3.4.4. Researcher attributes explaining formal and social uptake of telemetry study findings

Backward stepwise regression models and GLMs indicated that the collaborative extent (collab_ind), telemetry experience/centrality (telem_exp), and proportion of researchers' time spent on outreach (time_outreach) significantly explained both formal and social uptake of knowledge, respectively, $F(3,199)=12.483$, $p<0.001$ and $F(2, 190)=16.990$, $p<0.001$ (Table 3.3). The reliability and validity assessment using the variable "findings used", show similar results to the other models, but indicate that a researcher' time spent on stakeholder engagement (time_engag) was more important than outreach (Table 3.3). Descriptive statistics of significant variables are found in Table 3.4.

3.4.5. Project attributes explaining formal and social uptake of telemetry study findings

The final backward stepwise regression model and GLMs indicated that the researcher's familiarity with management processes relevant to the project (mgmt_famil), and project issue complexity/controversy (proj_complexity) were significant positive predictors of formal uptake of telemetry study findings, $F\ (1, 168)= 16.161$, $p<0.001$ and $F\ (3,191)=17.963$, $p<0.001$, respectively (Table 3.3). These findings were confirmed with the reliability and validity evaluations against the outcome variable "findings used" (Table S3.2). Furthermore, the familiarity and involvement of the focal researcher with management processes of the project (mgmt_famil) and breadth of dissemination activities related to the project (dissemination_ind) were found to be significant positive predictors of social uptake of telemetry findings, F (2, 189), p <0.001 (Table 3.3). Descriptive statistics of significant variables are found in Table 3.4.

3.4.6. Insights from bivariate associations and correlation analyses

Simple bivariate analyses were conducted to explore and gain further insights into the results from the regression models (Table 3.5; Table S3.3). Similar trends to the regression models emerged indicating that the collaborative extent and engagement tendencies of researchers show positive associations with both formal and social uptake of telemetry study findings. The negative association between researchers who spent more time on research activities and the uptake of telemetry study findings strengthen the results that indicate collaboration and engagement as important influential factors. It also appears freshwater research and using radio telemetry (only compatible in freshwater) have positive associations with the uptake of telemetry findings, while saltwater or marine research attributes appear negatively associated with telemetry study findings. Furthermore, the associations test confirmed that researcher familiarity and involvement with fisheries management and the complexity/controversy of issues addressed by the project were important variables, along with the composition of the research team (indicator of collaboration extent of project).

Figure 3.3: Top ten variables based on Gini measure of importance (shown as Increase in Node Purity) in the random forest analyses. More important variables achieve higher increase in Node Purities, that is, to find a split in the classification trees which has a high inter-node variance and small intra-node variance. Numbers to right of bars indicate increase in node purity score.

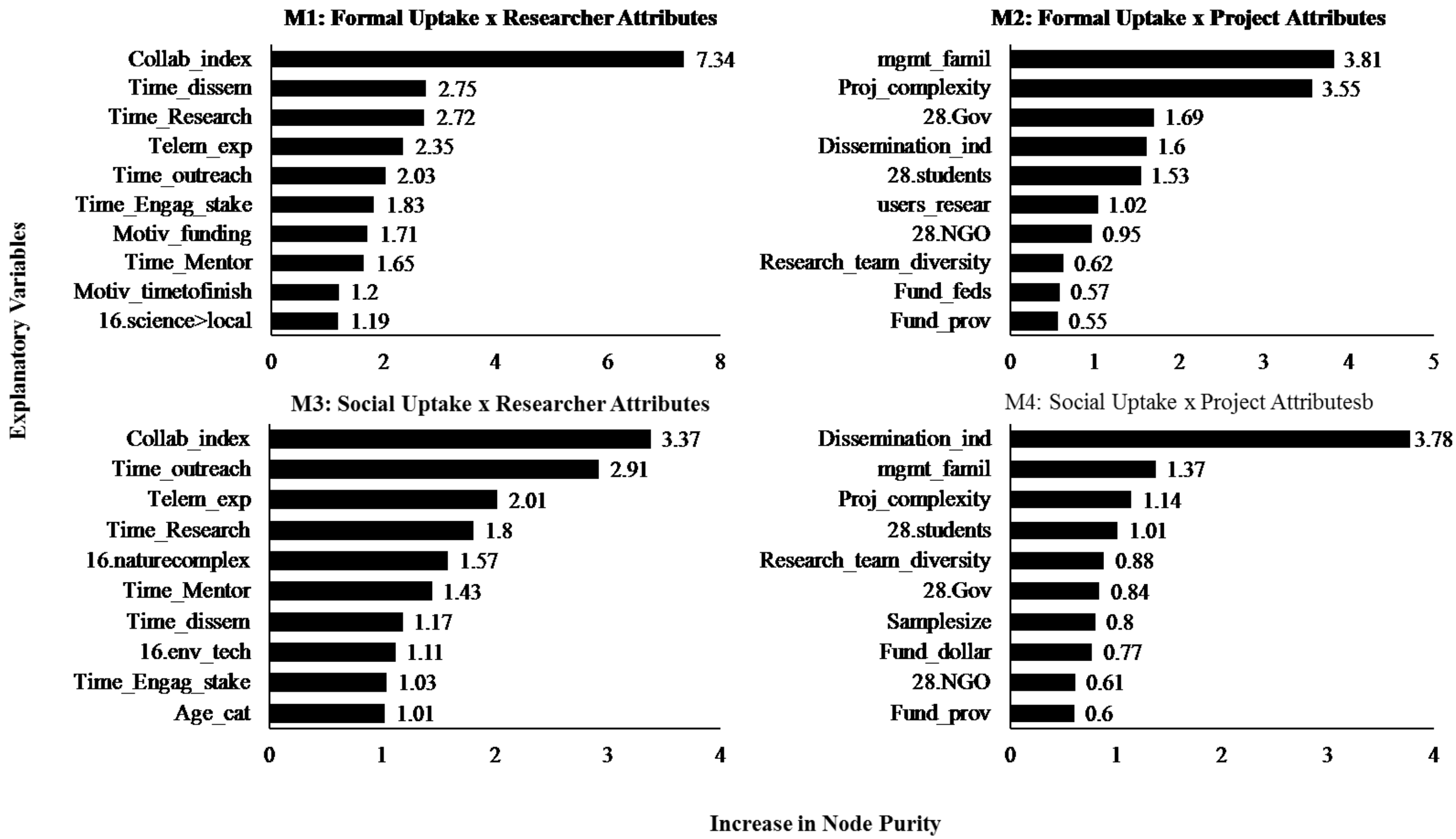


Table 3.3: Correlation coefficients from the final four multiple linear regression models (researcher attributes x formal uptake; researcher attributes x social uptake; project attributes x formal uptake; project attributes x social uptake). Significant variables explaining formal and social uptake of fish telemetry study findings include collaborative extent and tendency (collab_index); professional time spent on outreach (time_outreach); telemetry experience and commitment (telem_exp), fisheries management familiarity and involvement (mgmt_famil); complexity and controversy of issue addressed by project (proj_complexity); breadth and frequency of dissemination activities for project (dissemination_ind).

Researcher attributes										
Independent variables	**Formal uptake**				**Social uptake**					
	B	SE	*B*	Sig.	IV	B	SE	*B*	*t*	Sig.
Intercept	0.28	0.159		0.022	Intercept	0.322	.141		1.812	.072
Collab_index	0.04	0.008	0.322	<0.001	Collab_index	0.03	.008	.272	3.927	<0.001
Time_outreach	0.196	0.088	0.148	0.028	Telem_exp	0.026	.008	.177	3.190	.002
					Time_outreach	0.218	.081	.217	2.701	.008
R^2=0.142	Durbin-Watson=1.888				R^2= 0.212	Durbin-Watson= 1.913				
Project attributes										
Intercept	0.337		0.184	0.069	Intercept	.633	.094		6.739	.000
Mgmt_famil	0.186	0.275	0.048	0	Dissemination_ind	.028	.005	.404	5.888	.000
Proj_complexity	0.041	0.255	0.011	0	Mgmt_famil	.136	.040	.231	3.363	.001
R^2= 0.162	Durbin-Watson = 1.786				R^2= 0.339	Durbin-Watson=2.034				

B: standardized coefficient, alpha <0.01, SE= Standard Error, B= unstandardized coefficient, IV= independent variables

Table 3.4: Descriptive statistics for significant explanatory variables for regression models: Researcher attributes x formal uptake; Project attributes x Formal uptake; Researcher attributes x Social uptake, and; Project Attributes x Formal Uptake. Formal and social uptake scores were binned into scores <1 and ≥ 1 to facilitate interpretation of descriptive statistics. Continuous explanatory variables are presented as the Mean ± SD, while categorical variables are presented as frequencies and % of total number of respondents in brackets.

Researcher attributes x Formal uptake			**Project Attributes x Formal Uptake**		
	Score <1	**Score ≥1**		**Score <1**	**Score ≥1**
Collab_index	15.2 ± 5.0	18.4 ± 4.9	**Mgmt_famil:**		
Telem_exp	9.3 ± 4.0	10.8 ± 4.9	*Not familiar*	4	10
			Somewhat familiar	21	25
Time_outreach:			*Familiar*	8	47
0%	10 (5%)	17 (8%)	*Very familiar*	9	54
1-20%	36 (17%)	124 (59%)	**Proj_complexity**	12.7 ± 4.3	15.0 ± 4.0
21-30%	16 (8%)	7 (3%)			
Mean % outreach	4.60%	6.90%			

Researcher Attributes x Social Uptake			**Project Attributes x Social Uptake**		
	Score <1	**Score ≥1**		**Score <1**	**Score ≥1**
Collab_ind	14.1 ± 4.1	18.7 ± 4.9	**Mgmt_famil:**		
Telem_exp	8.7 ± 3.8	11.1 ± 4.9	*Not familiar*	6	7
Time_outreach			*Somewhat familiar*	15	30
0%	8 (4%)	17 (9%)	*Familiar*	8	44
1-20%	32 (16%)	122 (63%)	*Very familiar*	8	54
21-30%	2 (1%)	14 (7%)	**Mean dissem_ index**	7.7 ± 4.3	14.7 ± 8.6
Mean % outreach	5.4% ± 4.8	6.8% ± 5.3			

Table 3.5: Statistically significant ($p<0.05$) bivariate associations and correlations between outcome and independent variables using simple t-tests, chi square and regression analyses. Results grouped into researcher and project attributes. The bivariate tests were examined as part of the exploratory analysis.

Researcher Attributes			**Project Attributes**		
Formal Uptake					
Significant predictor variable	***Coefficient***	***P***	**Significant predictor variable**	***Coefficient***	***P***
Collaborative extent	0.275	<0.01	Researcher familiarity with fisheries management	0.285	<0.01
Telemetry experience and centrality to research	0.171	<0.01	Complexity and controversy of issue addressed by project	0.239	<0.01
Radio telemetry	0.167	<0.01	Location: coastal	-0.143	0.024
Freshwater research	0.166	0.008	Study species: saltwater	-0.145	0.021
Research priority: importance to society	0.163	<0.01			
North America	0.144	0.023			
Role: Government scientist	0.138	0.027			
Time spent on stakeholder engagement	0.135	0.014			
Dissemination frequency and extent	0.133	0.01			
Research priority: policy implications	0.123	0.044			
Time spent on research	-0.115	0.029			
Social Uptake					
Collaborative extent	0.267	<0.01	Team with high % of local, industry, user groups	0.185	0.003
Telemetry experience and centrality to research	0.212	<0.01	Complexity and controversy of issue addressed by project	0.162	0.002
Freshwater research	0.186	0.003	Diversity of research team	0.152	0.009
Telemetry network member	0.179	<0.01	Team with high % of NGO	0.152	0.009
Time spent on outreach	0.169	0.003	Study focus: catch and release	0.127	0.045
Radio telemetry	0.162	0.01	Study species: saltwater	-0.136	0.033
Age	0.161	0.006	Location: coastal	-0.152	0.017
Gender	0.154	0.015	Knowledge users of project: other researchers	-0.154	0.016
Time spent on mentoring students	0.132	0.016			
Professional time spent on research	-0.112	0.035			

3.5 Discussion

This study presents one of the first attempts in the conservation and environmental literature to empirically and quantitatively examine the conditions and factors under which scientific findings has influenced practiced or social acceptance. Here I focused on fish telemetry studies to examine the extent to which those that conducted the research felt that their findings influenced management practices as well as the perceived influence on stakeholder acceptance of the findings. In addition, I designed the first quantitative study that attempts to apply the knowledge-action framework for conservation and natural resource management (Nguyen et al. 2016). My results have important implications for fish telemetrists looking to make conservation impact, as well as implication for the broader scientific community for improving the link between science and action.

3.5.1 Getting your hands dirty: collaboration, engagement and co-production

The results of this study show that altruistic, collaborative, and pro-engagement behaviours and activities are significant factors that positively influence the successful uptake of telemetry study findings. Posner et al. (2016) also quantitatively demonstrated that the legitimacy (e.g., production of information and technology was respectful of stakeholders' values and beliefs, fair, and unbiased) of ecosystem services knowledge is a strong predictor of impact, which results in an emphasis for researchers to participate in greater stakeholder engagement and collaboration with decision-makers. The authors also suggested that the science-policy or knowledge-action processes are important for successful knowledge uptake because they influence the perceptions of knowledge as legitimate. Regular interactions between scientists are essential for building support and trust. These iterative exchanges aid with crafting perceptions that the study findings are salient because the knowledge users helped frame, and inspire the research (Cash et al. 2003, Posner et al. 2016).

Scientists often shy away from public outreach, or advocacy to either maintain their autonomy and objectivity, or because there is a lack of reward or incentives to engage and participate with the public or mass media (Pace et al. 2010, Lalor & Hickey 2013). However, with human societies facing major environmental crises and human-accelerated environmental changes, there is a need for evidence-based information to guide policy. Scientists are now expected to be more proactive in communicating and engaging with the public and with policy (Lubchenco & Nin n.d., Gibbons 1999, Excellence 2009, Likens 2010). My results provide empirical support for the ever-increasing promotion of collaboration and engagement for successful integration of science and action that are found throughout the literature (e.g., Pohl 2005, Pita et al. 2010, Schuttenberg and Guth 2015). In climate science, for example, collaboration leads to coproduction of knowledge and co-creation of research agendas, which have been shown to lead to more readily 'useable' knowledge (Meadow et al. 2015). In the health sciences, collaboration and multi-professional relationships are also strong themes for implementation of evidence into practice (Rycroft-Malone et al. 2004). The literature is covered with examples of how and why researchers should collaborate, engage, co-produce and co-create knowledge and research agendas with knowledge users (e.g., Bousquet 2008, Eden 2011, Reed et al. 2014, Cvitanovic et al. 2016, Jeffers and Godley 2016, Nel et al. 2016); as such, I do not go into further detail on this topic. However, it is important to note that not all researchers will or should be working collaboratively or engaging stakeholders. Pure science is fundamental in uncovering new insights into conservation research. However, conservation scientists who work on applied objectives have the ethical and practical responsibility for linking their research to management decisions in order to maximize the conservation return-on-investment (Murdoch et al. 2007, Mcgowan et al. 2016).

Additionally, my analysis reveals that researchers who tend to engage in outreach and stakeholder interactions have greater successful knowledge outcomes; yet, my survey results also show that fish telemetrists only spend, on average, 6% of their professional time on public outreach activities, and only 12% on engaging and consulting with managers and stakeholders (Table 3.1). However, at this point in time, there is no evidence on what is an appropriate amount of time one should spend on engagement and outreach. This evidence supports that greater incentives and reward structures are needed to encourage researchers to focus efforts on engagement and relationship-building, such as career promotions that include public outreach activities as productivity metrics rather than publications only (Excellence 2009, Lam 2011). Furthermore, researchers who put the time into being involved and familiarizing themselves with the management processes relevant to their project have experienced more successful knowledge outcomes. An excellent example of "getting your hands dirty" is from conservation scientists who helped implement the corrective measure they proposed, and witnessed a rapid recovery of an endangered hoopoe (*Upupa epops*) population in the Swiss Alps (Arlettaz et al. 2010). Therefore, the commitments and efforts to bridge the gap between a researcher's work and management appear to go a long way. This is positive and hopeful for individuals who invest the time into science and policy.

3.5.2. Experienced and committed fish telemetrists have greater social uptake of telemetry study findings

Fish telemetrists who were highly experienced and involved in fish telemetry research (e.g., greater research time spent on telemetry or sitting on telemetry committees and networks) appear to be characteristic of collaborators. My findings show that these researchers had high success in the social uptake and use of their study findings. There are several possible explanations for this observation. First, it is possible that the core fish telemetry community is composed of highly collaborative individuals because telemetry science demands it (Campbell et al. 2015, Hussey et al. 2015). For example, the cost of acoustic telemetry infrastructure requires collaborations among telemetry scientists and telemetry networks to leverage their return-on-investments. Fish tagged can be found on other researchers' receiver arrays, and therefore cooperation and collaborations are needed (Nguyen et al. 2016). Second, it is possible that individuals engaged in telemetry, an expensive technology, are rather successful in receiving grants because of their collaborative and broad thinking propensities. Telemetry technology is currently viewed by some as unjustifiably expensive (Young et al. in review). Without demonstrating the benefits of tracking, or investing effort into linking telemetry-derived information to management actions, the use of telemetry for conservation is not justified. It is therefore important for these researchers, who have been successful in making impact, to share their lessons learned and experiences so that the telemetry community can improve the conservation return-on-investment highlighted by McGowan and colleagues (2016).

3.5.3. Context matters: complexity and controversy surrounding issue addressed by projects

Lastly, I expected that the greater the complexity and controversy that surrounds a particular project, the less likely it was to be used or integrated into practice; however, to my surprise, complexity and controversy of the project issue was shown to be a positive significant factor in explaining successful integration of telemetry study findings. It is possible that a higher score on project issue complexity and controversy reflects higher societal importance of the project, greater funding and exposure, where findings of the project are essential to decision makers, and could have direct impact (as described by McGowan et al. 2016). There may also be measurement errors as rankings of the items that make up the complexity and controversy of project issue scale are self-ranked and likely to be relative to the respondents' experiences.

3.5.4. Sector doesn't matter

I expected that the public and private sectors would have a much higher rate of successful knowledge outcomes than academia, largely because of their roles and the context of their research. Private scientists are often hired to answer specific questions, and government scientists are publicly funded and should theoretically be answering questions that serve the public. The lack of difference in the application of telemetry findings among all groups was surprising. First, it may be an indication that fish telemetry technology is still novel and has not penetrated the traditional fisheries management frameworks (Chapter 4). Second, it may indicate that research studies in fish telemetry lack explicit quantitative objectives and clear links between the research and actions (as stated by McGowan et al., 2016). Lastly, it may show that even some work of government scientists (even though employed in mission-oriented agencies), or that of private sectors whose client is often government, is not directly being used by management and stakeholders. This may mean that the type of data (i.e., new telemetry findings) is as important as who generates that data.

3.5.5. Evaluating the application of the knowledge-action framework

The knowledge-action framework was useful in assisting with generation of hypotheses and determining what predictor variables to measure. The framework was helpful to place the findings in a broader context (Fig. 3.1), and was flexible enough to adapt to my fish telemetry model. However, the flexibility of the framework comes at a cost, in which the framework does not offer clear pathways to measure spatial temporal scales at which some of the processes of knowledge movement occur. In this study, I used "funding received" as a proxy for assessing the economic value and scale of the project, as well as "project complexity" to capture the importance of the cases. As for time, I measured length of the project from beginning to completion but found recall bias and interpretation of "beginning" and "ending" to be inconsistent. Therefore, this study did not include time as a factor due to the inconsistencies of the data but I acknowledge that it may be important. Improvements on how to measure these attributes should be considered in future research.

Furthermore, grouping and distinguishing variables between researcher and project attributes was helpful with the application of the framework. This is because one cannot assume that a researcher is consistent with their behaviour and attitudes/beliefs through time. For example, a researcher who is highly collaborative, may not have been collaborative for the particular case-study; as such, it was imperative to measure both the researcher attribute (e.g. general collaborative tendency) and the project attributes (collaborative extent of the project). Overall, the framework potentially lacks methods to evaluate interactions among the different components of the framework, which I believe is an important area for future research.

3.5.6. Study limitations

This study is exploratory, and therefore, I cannot claim the findings to be predictive of successful knowledge outcomes.. Nonetheless, certain caveats do exist. First, the use of a survey approach introduces respondent bias with regards to self-reporting and confirmatory bias. The outcome variables are not "true" measures of success but rather "perceived" success by the researcher respondent. Second, this study is also biased towards North American and male fish telemetry scientists.. Nonetheless, I did survey people from 31 countries and 20% of respondents were female. Third, there is also potential for recall bias when respondents were asked to discuss "a completed fish telemetry project with applied objectives". It is likely that respondents chose the most recent project for which they have the most recollection, leading to a sample of case-studies that may or may not have fit the criteria. Lastly, I do not have information on respondents who did not participate in the study, therefore, there are potentially non-response biases. Despite these caveats, my findings revealed strong correlations and associations among similar themes, and reveal interesting trends which I believe have broader implications.

3.5.7 Recommendations and future research

Fish telemetry is an advancement in technology that offers novel insights on fish ecology and animal-environment interactions that is invaluable to understanding the natural world. This kind of new information is critical for updating and informing policies. The world is rapidly changing, and the rate at which it is changing does not allow for traditional fisheries management practices to keep up, unless there is a change in the way we do business. If collaboration and engagement are strong indications of successful use of telemetry findings, we, as the conservation community (academia, public, private), need to foster these behaviours. For example, academic institutions and funding agencies need to promote and offer incentives for individuals to engage in collaborations and get their hands dirty with management (Baas & Hjelm 2015, Dick et al. 2016). The 'publish or perish' system is arcane, and greater emphasis needs to be put on research that has societal and conservation impact, which from the present findings should be measured through engagement and collaborative activities. Public/governmental agencies should look at formally building multi-sector partnerships and leverage the limited human and financial resources (Sorensen & Torfing 2011). Collaboration with other sectors has the potential to leverage the return-on-investments and telemetry is a unique tool that thrives off of collaborative research and designs for it to reach its potential.

An essential next-step is to capture and compare the perspective and success measures from the management and policy perspectives. Comparing case-studies between both management and researchers' perspectives can likely only be limited to a handful of case-studies (similar to Posner et al. 2016). Networks are, thus, an essential stepping stone to obtaining the required information and data needed to evaluate measures of success and research impact, because these networks often include both scientists and practitioners. For example, the Great Lakes Fishery Commission and its associated Great Lakes Acoustic Telemetry Observation System (network of telemetry researchers) make up a community of both science and practice. Evaluating the various cases that have derived from Great Lakes fisheries research using telemetry could be a viable method to get to a truer measure of "successful" knowledge outcomes. Telemetry networks, such as Ocean Tracking Network (OTN) and Australian Animal Tracking and Monitoring System (AATAMS), will play key roles in facilitating knowledge exchanges and linking telemetry findings into actions and public policy (Nguyen et al. 2016).

In conclusion, this work supports the increasing calls in the literature for more transdisciplinary, collaborative and solution-oriented research agendas to ensure that science is informing resource management and conservation practitioners. Researchers looking to make an impact need to step outside of the traditional scientific framework, and familiarize and engage themselves with fisheries management processes, as well as collaborate beyond the scientific boundaries to include non-scientists. Institutions need to be innovative and create collaborative arenas to build support for evidence-based decision making. Context of the research also matters. Building support, and investments of stakeholders into the project will help ensure that the findings do not sit on the shelf. Processes of building relationships, trust, and engaging end-users have shown to have positive impacts on linking telemetry science to action, which is needed now more than ever with the increasing complexity of environmental problems and conservation crises.

3.6 Supplementary Information

S3.1. List of predictions derived from the hypothesis of Nguyen et al.'s knowledge-action framework, which suggests that areas of knowledge transfer, knowledge characteristics, knowledge actors and actor characteristics, relational dimension, and environmental and contextual dimension have an influence on the uptake of knowledge (successful knowledge outcome):

1. Greater frequency and breadth of knowledge dissemination should positively influence knowledge uptake
2. Projects with an applied focus should positively influence knowledge uptake
3. Larger sample size in a project should positively influence knowledge uptake
4. Altruistic research motives should positively influence knowledge uptake; self-driven and pro-growth motivations should negatively influence knowledge uptake
5. Older and more experienced researcher should have more knowledge and experience with knowledge transfer, therefore older and experienced researcher should have greater success in knowledge uptake
6. Roles of producers that are tied to decision-making agencies should have positive influence on uptake (i.e. government agencies should have greater uptake than universities and other institutions)
7. Academia should have lower uptake of knowledge than other institutions because it is not always driven by applied research questions
8. Funding source that are for profit should have a negative influence on uptake /should have lower uptake than public funding sources
9. Researchers that are familiar with management should have greater uptake of their work
10. Time spent on dissemination and outreach should have greater uptake than time spent on mentoring and research/ should have positive influence on uptake
11. Researchers who share data should have higher success in research uptake
12. Greater collaborative tendencies should have a positive influence on uptake
13. Greater diversity of research team should have a positive influence on uptake
14. Direct contact with decision makers should have a positive influence on uptake

15. Positive and collaborative relationship with users should have a positive influence on uptake
16. Being part of a telemetry network should have a positive influence on uptake
17. Involving knowledge users in design should have a positive influence on uptake
18. There is an effect of species' characteristics on uptake of knowledge
19. Greater complexity and controversy surrounding the issue addressed by the project should have lower uptake of knowledge
20. Greater importance of the project, therefore greater funding for project, should have greater knowledge uptake
21. There is an effect of research environment on knowledge uptake
22. There is an effect of geography of research on knowledge uptake

S3.2: List of explanatory variables tested grouped by categories based on the knowledge-action framework with description of the variable type, the coded name for analysis or the construct used for analysis, and the associated question number from the interview/questionnaire found in Appendix B.

Knowledge Transfer			
Variable	**Variable Type**	**Construct or code for analysis**	**Question**
Frequency of dissemination	dissemination_ind	Dissemination_ind	Q34. How often of the following activities have you and your research team done related to the chosen project (conference, publication, stakeholder workshop, manager's meeting, engage in new media, public outreach etc.)
Knowledge Characteristics			
Variable	**Type**	**Construct or code for analysis**	**Question**
Telemetry type (project specific)	Dummy coded	Equip_acous; equip_radio; equip_sat	Q21 What type of telemetry equipment did you use (radio, acoustic, satellite)
Telemetry type (project specific)	Binary	Excluded from analysis	Q21a Passive or Active
Project focus	Categorized and dummy coded	focus_energy; focus_behaviour; focus_habitat; focus_MPA; focus_survival; focus_bycatch; focus_CnR; focus_movement; focus_overwintering; focus_disease; focus_spatemporal; focus_vul_hydro; focus_fisheries; focus_climate; focus_predator; focus_social; focus other	Q24 Indicate the focus of the project (16 items). Check all that apply.
Sample size	Categorized (ordinal)	sample_size_cat (proxy for representativeness of study)	Q38 What is average number of fish tagged per year
Actor characteristics			

Variable	Type	Construct or code for analysis	Question
Telemetry Experience (years)	Continuous	Telem_exp	Q1. Number of years doing field telemetry
Telemetry Experience (number of projects)	Cat/ratio		Q3. Number of different fish telemetry projects led
Telemetry Experience (Principal Investigator)	Binary		Q2. Have you been a PI for a fish telemetry project
Telemetry Experience (number of peer-reviewed publications)	Ratio/interval		Q4. Number of refereed publications related to fish telemetry
Telemetry Experience (number of non-refereed publications)	Ratio/interval		Q5. Non-refereed publication related to fish telemetry
Motivation and behaviour	Categorized (ordinal)	time_ research; time_mentor; time_outreach; time_stake_eng; time_other	Q9 What % of your professional time over the past 5 yrs have you spent on each of the following: Research, engaging stakeholders, disseminating research, public outreach, mentoring, other
Age	Continuous (categorized)	Age_cat	
Gender	Binary	Gender_Bin	
Employer	Categorical	Employer_Cat	Q13 Which category best describes your employer
Researcher role	Categorical	Role_field; role_lab; role educ; role_consult; role_mngr; role_gov; role_ass	Q14 My role is best described as (field researcher, lab researcher, educator, consultant, manager, government, assistant, etc.)
Research motivation	Ordinal		Q15 Over the past five years, how important were the following criteria in your choice of research agenda/questions? 15 items (see Appendix A)
Values and beliefs	Ordinal/index?		Q16 Please indicate your level of agreement with each of following statements (see Appendix A)

Number **of** end users/knowledge users		users_hydro; users_feds; user_prov; users_region; users_Fishers_suers_indig; users_community; users_resear; users_others	Q27a Who are the end users of findings produced by project? Check all that apply (10 items)
Funding source	Binary	fund_feds; fund_prov; fund_region;fud_industry; fund_envorg; fund_fishass; fund_uni; fund_network	Q29 What type of research funding have you received for this particular project? Check all that apply. (8 items)
Familiarity with management	Ordinal	mgmt_famil	Q36 Please select the statement below most applicable to your familiarity and involvement with the fisheries management process (not familiar, somewhat, familiar, very)
Relational dimension			
Variable	**Type**	**Construct or code for analysis**	**Question**
Telemetry network	Binary	Telem_net	Q6 Are you currently part of a telemetry research network?
Collaborative frequency	Ordinal	Collab_ind	Q17 Freq of collaboration with the following groups related to your fish telemetry research (uni, government, managers, industry, etc.) - 7 items
Collaborative extent	Dummy/count		Q18 In the past 5 years, I have (shared data, co-authored and collaborated with uni, industry, go, ENGO, local community). Check all that apply.
Diversity of research team	%	28.students; 28.gov; 28.industry; 28.ngo; 28.other_uni	Q28 Approx what % of the research team were: students, gov, industry, NGO, other uni
Diversity of research team	Summed the number of different players involved	Research_team_diversity	Q30 Who was involved in grant proposal? (grad student, uni research, gov research, gov managers, private, industry, NGO)
Local institution	Binary		Q32 Is your affiliated institution a LOCAL institution relative to project location?
Local institution (collaborate with)	Binary		Q32a If no, do you have any collaborations or affiliations with local institution or organization?
Direct contact with regulatory body	Binary	Dir_gov_cont	Q33 Does your team have any direct contact with governing body of fish studied in project?

Direct contact with regulatory body (describe)	Categorized		IF YES, describe (categorized as negative, neutral, positive, administrative, collaborative, advisory or employed by government)
Environmental and contextual dimension			
Variable	**Type**	**Construct or code for analysis**	**Question**
Country of project	Categorized	North America, Europe, Other	Q23 Where did the chosen project occur?
Species category	Categorical	Sp_multi; sp_migr; sp_econ; sp_endang; sp_cultural; sp_shark; so_inv; sp_FW; sp_SW	Q22 What was the focal species of project? (categorized into multispecies, migratory, economic, cultural, protected, invasive, FW, SW, shark)
Size of study site	Categorized (ordinal)		Q23a Can oud escribe size of study site (categorized)
Project issue complexity and controversy	Summed into construct	proj_complexity	Q25 Please rank the following items as low, moderate or high in relation to this particular project and its context (stakeholder conflict, controversy, media, etc.) - 8 items
Project length	Continuous		Q26 What year did this project begin and complete?
Country of researcher	Categorical		
Funding received for project (e.g., scale of project)	Continuous (categorized)	fund_dollar	$US dollar amount received for project as proxy for scale of project.

S3.3: Details on construct variables and Cronbach's alpha test for reliability

Construct	Items	Score type	Cronbach's alpha
"Formal" uptake of fish telemetry study findings (DV_formal)	In your opinion, how successful was your telemetry findings with respect to (not at all successful =0, somewhat successful=1, very successful=2, not applicable): 1. Knowledge transfer (i.e. findings being used by knowledge users such as stakeholders, managers, etc.) 2. Changing, developing or affirming a policy/practice 3. Integration into policy or management framework	Mean score	0.863
"Social" uptake of fish telemetry study findings (DV_social)	In your opinion, how successful was your telemetry findings with respect to (not at all successful =0, somewhat successful=1, very successful=2, not applicable): 1. Adoption/buy-in/uptake by stakeholders 2. Trusted by stakeholders 3. Generating media interest	Mean score	0.734
Project issue complexity and controversy (proj_complexity)	Please rank following items as low (0), moderate (1) or high (3): 1. Level of stakeholder conflict 2. Number of different stakeholder groups 3. Level of controversy surrounding issue of project or study species 4. Level of media attention 5. Level of management attention 6. Number of jurisdictions involved 7. Complexity of regulator, legal or governance context for the work 8. Level of data scrutiny by end users (i.e., skepticism of data, questioning of data)	Summated	0.806
Telemetry experience and centrality to research (Telem_exp)	1. Years of experiencing with telemetry research 2. Have you been a principal investigator in a fish telemetry project?	Summated	0.779

	3. Number of fish telemetry project involved in 4. Number of refereed publications for fish telemetry 5. Number of non-refereed publications for fish telemetry 6. Percentage if research time spent on fish telemetry		
Collaboration tendency (Collab_index)	Have you (Yes=1, No=0): 1. Shared data with: 2. Co-authored a publication or presentation with: 3. Collaborated in other was with: a. colleagues in universities or college; b. b) colleagues in industry; colleagues in government; c. colleagues in environmental groups; d. colleagues employed by local and community or indigenous groups Frequency of collaborations related to fish telemetry research (Never=0. Rarely=1, Occasionally=2, Often = 3): 1. University-employed researchers 2. Government-employed researchers 3. Fisheries managers/policy makers 4. Industry representatives 5. Local people and stakeholders 6. Environmental/conservation-related non-profit organizations 7. Other	Summated	0.768
Frequency of dissemination activities (dissemination_ind)	Approximately, how often of the following activities have you and your research team done related to the chosen project (in total)? (None =0, 1-3 times=1, 4-6 times=2, 7-9 times =3, 10+times=4) 1. Presented at a conference 2. Published a refereed article 3. Published a non-refereed article 4. Attended a stakeholder workshop/consultation meeting 5. Lead (i.e. organized) a stakeholder/consultation meeting 6. Attended a manager's meeting	Summated	0.877

	7. Made media appearances/comments 8. Wrote a press release 9. Engage in new media/social media 10. Engaged in public outreach activities		
Diversity of proposal/grant writing team (research_team_diversity)	Who was involved in the grant proposal? 1. Graduate students/and or post-doctoral fellows 2. Other university researchers/scientists 3. Government researchers/scientists 4. Government managers/policy makers 5. Industry representatives 6. Environmental/conservation related non-governmental organizations (including fisheries associations)	Summated	N/A

S3.4: Analysis and findings for models and bivariate tests for dependent variable, “findings used”. Tests were used as a reliability and validity measure, to compare with findings for “formal uptake”.

Table S3.1: Top ten variables based on Gini measure of importance (shown as Increase in Node Purity) in the random forest analyses. More important variables achieve higher increase in Node Purities, that is, to find a split in the classification trees which has a high inter-node variance and small intra-node variance. Numbers to right of bars indicate increase in node purity score.

M5: Findings used x researcher attributes		**M6: Findings used x project attributes**	
Variable	**Mean Decrease Gini**	**Variable**	**Mean Decrease Gini**
Telem_exp	3.46	Mgmt_famil	2.83
Collab_ind	3.40	Proj_complexity	2.79
Time_research	2.28	28.students	1.70
Time_engag_stake	2.07	Dissemination_ind	1.68
Age_cat	2.03	Samplesize_cat	1.63
Time_dissem	1.65	28.Gov	1.55
Time_mentor	1.44	28.Uni	1.18
Time_outreach	1.35	Research_team_diversity	0.94
Radio	1.31	28.NGO	0.82
16.naturecomplex	1.23	Sitesize	0.72

M= Model

Table S3.2: Correlation coefficients from the multiple linear regression models (researcher attributes x findings used; project attributes x findings used). Significant variables explaining "findings used" including telemetry commitment and experience (telem_exp); collaborative extent (collab_ind); professional time a researcher spends on consulting and engaging managers and stakeholders (time_engag_stake); fisheries management familiarity and involvement (mgmt_famil); and complexity/controversy of the issue the project addresses (proj_complexity).

	Researcher Attributes				
IV	**B**	**SE**	***Wald***	***Sig***	**Odds Ratio**
Constant	-2.508	0.639	15.418	<0.001	0.081
Telem_exp	0.095	0.036	6.905	0.009	1.1
Collab_index	0.072	0.033	4.737	0.03	1.075
Time_engag_stake	0.457	0.197	5.382	0.02	1.579
Cox & Snell R^2 = 0.129					
Intercept	-3.675	0.755	23.695	p<0.001	0.025
mgmt_famil	0.597	0.18	11.004	p<0.001	1.816
Proj_complexity	0.202	0.047	18.8	p<0.001	1.224

Table S3.3: Significant bivariate correlation ($p<0.05$) and association tests between dependent variable, "findings used" and the explanatory variables grouped under researcher and project attributes.

Researcher Attributes	X^2/t-stat[t]	***P***	**Project Attributes**	X^2	***P***
Radio telemetry	13.294	<0.001	Equipment: Radio telemetry	13.294	0.011
Collaborative extent	3.693t	<0.001	Direct contact with governing body	13.221	p<0.001
Freshwater research	7.5	0.006	Funding: regional/provincial/state	9.943	0.002
Telemetry commitment and experience	3.968[t]	<0.001	Project focus: movement pattern/ behaviour	6.829	0.009
Time spent on research	3.282[t]	0.001	Project focus: hydropower vulnerabilities	6.55	0.01
Time spent on stakeholder engagement	3.471[t]	0.001	Freshwater project	6.062	0.014
Time spent on public outreach	2.564[t]	0.011	Knowledge users: federal government	5.798	0.022
Research priority: importance to society	3.506[t]	0.001			
Research priority: policy implications	2.955[t]	0.003			
Belief that S&T will solve environmental problems	-2.272	0.024			

Chapter 4: Applying a knowledge-action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study

4.1 Abstract

Telemetry technology and the associated tagging and tracking of aquatic animals is an innovation that has changed how we view and understand the underwater world. Telemetry studies have produced new knowledge about animal movement, habitat use, and survival over various temporal and spatial scales and in areas that are inaccessible or inhospitable to humans. This fundamental knowledge on animal biology and ecology has the potential to improve management of aquatic resources such as fisheries. However, the use and integration of telemetry-derived knowledge into conservation and management practices remain tenuous. Therefore, I surveyed 212 fish telemetry experts to describe the barriers to incorporating telemetry-derived knowledge into fisheries management practices. I apply a knowledge-action framework to structure the findings and reveal four primary challenges to integrating telemetry findings into management: the perceived uncertainties and unclear relevance of telemetry findings; the underlying motivations and constrained rationalities of actors (individual and institutional levels) involved that lead to inaction or suboptimal decisions; the constraints of formal institutions, governance structures and lack of organizational support, and; the concept of time and mismatches in scale, culture and worldviews. On a more positive note, the relational dimension (collaboration and quality of relationship building) appears to be important for overcoming and avoiding barriers. Identifying the key barriers influencing the movement of telemetry-derived knowledge may direct where efforts should be placed to facilitate knowledge mobilization and exchange. I provide recommendations to navigate these barriers, and argue that

these lessons also apply to other fields of applied ecology, conservation and resource management.

4.2 Introduction

Innovation and investments in telemetry technology have opened a window to understanding the underwater world in ways that were previously 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 the natural environment (Cooke et al. 2004, Kays et al. 2015, Hussey 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 in 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. With that being said, the impacts and integration of telemetry-derived information and knowledge remain tenuous (McGowan et al. 2016), and understanding the barriers to mobilizing telemetry-derived knowledge into management or conservation action would be useful in improving conservation of aquatic ecosystems.

Telemetry makes an interesting case study in that it has rapidly become a widely-used technology in scientific research, but is still relatively new in the world of fisheries and aquatic resources management (Crossin et al. 2017). Potential applications include delineating critical fish habitats for designation of protected areas, informing species/population threat assessments, generating mortality estimates, 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 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 (2016) offer a framework to integrate telemetry-derived data into decision-making and actions, but still, there is a lack of empirical evidence on the barriers to this integration. Here, I offer empirical data on perspectives of international researchers to supplement this literature. The cost of conducting telemetry studies is relatively high and much investment has gone into aquatic telemetry research; therefore, being able to effectively use telemetry-derived knowledge in fisheries management is important for improvement on the conservation return-on-investment (McGowan et al. 2016). Although I focus on fish telemetry, I submit that my findings have relevance to other fields involving the tagging and tracking of wildlife. The data come from interviews and surveys with 212 experts in fish telemetry (mostly academic and government researchers) that aimed to uncover their views on the barriers to incorporating telemetry-based knowledge into fisheries management and conservation practices.

4.3 Methods

An international survey was conducted of fish telemetry researchers, as part of a broader study on mobilization of fish telemetry-derived knowledge that included both online questionnaires and semi-structured interviews. Interviews were conducted with a subsample of respondents, with the questionnaire administered to the balance (see next section). 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?*)

In addition, I complemented these responses by asking respondents to talk about 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 socio-demographic 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, I restricted "telemetry" to acoustic, radio, or satellites tracking only, as these telemetry techniques are used to address similar research questions and management issues. The online questionnaire was pre-tested with 11 individuals who have worked with fish telemetry. The interview was pre-tested with the first five interviewees and minor adjustments were made. The Carleton University Ethics Board approved the study with anonymity of respondents being maintained (102887).

4.3.1 Sampling

The initial sample population was built 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. I opportunistically conducted 25 face-to-face interviews with fish telemetry experts at the International Conference on Fish Telemetry in Halifax, Nova Scotia, from 13-17 July, 2015. I supplemented this sample with 12 interviews at the meeting of the American Fisheries Society, Portland Oregon, from 16-20 August, 2015. Phone/Skype interviews were also scheduled with nine individuals, totaling 46 interviews (including responses from the pre-tests).

The population for the online questionnaire was determined by extracting the e-mail addresses of authors who have published fish telemetry as determined by citation records from the Web of Science online database. A search for articles between 2011-2015 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 undertaken 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 that contained

2605 valid e-mail addresses. I identified 1908 unique e-mail addresses after removing duplicate e-mails and irrelevant records.

I sent e-mail invitations on 7 October, 2015. There were 112 bounce backs and 110 respondents notified us that they did not meet the criteria of a "fish telemetry researcher", resulting in a final population of 1686. I recognize that this number is an overrepresentation of the target population as I aimed to reach the whole population of fish telemetry researchers. Reminders were sent on the 4^{th} and 14^{th} of November, 2015. I gathered contact information for an additional 155 individuals using a snowball approach, and sent invitation and reminders on Feb 4^{th} and 14^{th}, 2016, for a total sample pool of 1841. The online survey closed on 19 February, 2016.

For this study, a total of 212 (166 online + 46 interviews) responses were used in the data analysis. Although I received 348 responses from a sample pool of 1841 potentially relevant participants to my 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 responses rates for online surveys (Deutskens et al. 2004).

4.3.2 Data analysis

Qualitative analyses were performed using NVivo 10 software. Responses were read and coded using the framework method (Ritchie & Lewis 2003, Gale et al. 2013), namely the conceptual knowledge-action framework that enables comparison of case-study based findings (Nguyen et al. 2016), and to organize information about the mobilization of telemetry-derived knowledge. This framework is comprised of three elements: knowledge production, the knowledge mediation sphere, and knowledge action. The mediation sphere is the interface of knowledge and action in which factors exist that mediate or influence the knowledge outcomes (see Chapter 1 for description). The framework was used to structure and organize the qualitative analysis of this study. As such, I characterized the barriers and facilitators experienced and perceived by the respondents based on the components of the framework (Chapter 1).

Responses, now under a framework theme, were read a second time to inductively identify key subthemes (Thomas 2006), which subsequently provided a list of potential codes in order to give more nuances to the framework themes. Lastly, responses were sorted under these subthemes (inductive codes) to provide a measure of their prevalence. A response may have multiple thematic codes if warranted and are presented in both quantitative (the prevalence of the codes) and qualitative (by illustration of quotes) styles.

4.4 Results

4.4.1 Characteristics of the sample

The respondents from this study were, overall, highly experienced fish telemetry researchers with most (75% of 209) having been principal investigator of at least one telemetry project, and 33% have engaged in more than five fish telemetry projects as principal investigator. For almost 40% of the respondents, >25% of their research is related to fish telemetry. The majority (82% of 208) of respondents had at least five years of experience in fish telemetry (Table 4.1). The sample population, however, is highly skewed toward respondents from high income regions, particularly from North America (mainly the USA), followed by Europe and

Australia/South Pacific. Responses are primarily from a male-centric perspective as 80% of respondents are male and between the ages of 30-59 years (Table 4.1). The study respondents were also mainly affiliated with academia (51% of 210 respondents) or a government and government-related organization (40%), with the rest of the respondents being from non-governmental organizations (4%), industry, and private companies (5%). As such, findings presented reflect the biases of the demographics from the sample population and should be kept in mind.

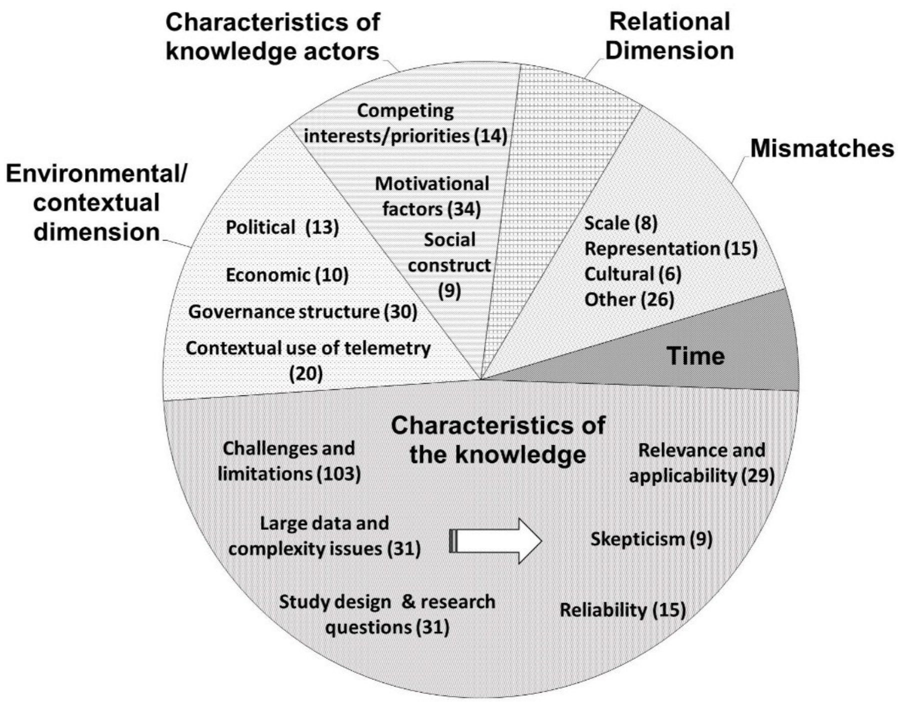
Table 4.1: Socio-demographic and other characterizing variables of the sample population

Socio-demographic	%	*N*	Telemetry Experience and Research	%	*N*
Age (n= 204)			**Work environment (n=205)**		
20-29 years	8%	16	Freshwater	22%	46
30-39 years	38%	79	Marine	40%	83
40-49 years	30%	62	Both	37%	76
50-59 years	16%	34			
60-69 years	6%	13	**Telemetry technique used (non-mutually exclusive)**		
70-79 years	2%	4	Radio	N/A	106
			Acoustic	N/A	183
Gender (n=209)			Satellite	N/A	74
Female	19%	40			
Male	80%	168	**Years of telemetry experience (n=208)**		
Prefer not to say	1%	1	1-4 years	18%	37
			5-9 years	34%	71
Location (n=193)			10-20 years	37%	76
North America	64%	124	20+ years	12%	24
Europe	19%	36			
South Pacific (mainly Australia)	8%	15	**Number of projects as principal investigator (n=195)**		
Great Britain	4%	7	1-4 projects	44%	85
South and Central America	3%	6	5-9 projects	18%	35
Asia	2%	3	10-14 projects	6%	11
South Africa	1%	2	15+ projects	10%	19
			None	23%	45
Employer (n=210)					
Academia	106	51%	**Percentage of telemetry-related research (n=202)**		
Government	84	40%	<10%	27%	55
Industry	1	0%	10-25%	19%	38
NGO	9	4%	26-75%	38%	76
					33
Private	10	5%	76-100%	16%	

4.4.2 Coding based on the knowledge-action framework

Overall, this study reveals that, 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 overall responses coded, Fig 4.1). This was followed by factors within the *environmental and contextual dimension* (16% of overall responses coded); *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) and "time" (5%). These latter broad concepts may also be linked with some of the barriers that fall within the abovementioned themes.

Figure 4.1: Overview of application of knowledge-action framework (adapted from Nguyen et al. 2016) 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.



4.4.3. The characteristics of telemetry-derived knowledge: limitations, study biases, uncertainties, and complex datasets

Many researchers felt that the limitations and challenges of conducting fish telemetry research (e.g., costs, small sample size, tag effects, limited spatial/temporal coverage, poor detection efficiencies of receivers) are also carried through to the uptake and integration stage of these findings as uncertainties and biases. Telemetry research also generates large datasets that are complex to interpret, and can create incompatibilities with software and scales at which the knowledge producers and potential knowledge users work. The reliability, relevance, and applicability of telemetry findings have also been questioned, 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 to dismiss findings by resource managers (Table 4.2). Interestingly, researchers were not only critical about the knowledge users, but were also critical 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)

Table 4.2: Summary of barriers identified using a knowledge-action framework (Nguyen et al. 2016). See Supplementary Information Table S4.1 full descriptive table, including illustrative quotes.

Broader barrier	# of coded responses	Specific barriers	# 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 datasets	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
Char acter istics of know	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/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/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 vs. 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 impedes the integration of telemetry-derived knowledge (i.e., process time, time to learn, time to invest in dissemination, etc.)

4.4.4 Environmental and contextual dimensions

4.4.4.1 Inflexible and outdated governance structures and tools

Inflexible, non-adaptive and stagnant *governance and institutional culture and structures* were one of the main themes identified undermining the integration of telemetry-derived knowledge (Table 4.2). 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 the 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)

Fourth, the traditional and outdated systems that governments use to manage natural resources may impede the integration of new information. Lastly, the system of which stock assessment is built on is too rigid to incorporate new results and improve the ecological complexity of the models where “*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).

4.4.4.2 Context in which fish telemetry methods are used

Respondents highlighted that sometimes the context in which telemetry techniques were used may facilitate or impede the uptake of findings (Table 4.2). For instance, if fish telemetry was used to research a critically endangered species, there is greater likelihood for the findings to be used as specific legislations 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, telemetry used in a highly politically charged and controversial areas such as hydropower development or marine protected areas that may affect large numbers of stakeholders were thought to face greater challenges in integrating telemetry findings.

4.4.4.3 Socio-political and economic contexts

The socio-political context received less attention among the participants but was still regarded as an important factor in the incorporation of telemetry data in management practices (Table 4.2). Managers may be influenced by political reasons in their decision-making, and priorities of the current government can also influence allocated resources and priorities to certain issues. Furthermore, the notion that "money makes the world go around" was identified by respondents where economic factors may drive the way scientific knowledge is used and mobilized, however, this was only mentioned by only 10 respondents.

4.4.5 The knowledge actors: motivations, incentives and competing interests

The greatest perceived barriers in the category of knowledge actors were related to motivations of actors involved, particularly the "lack of political will" of individuals and the "institutional inertia" that exists at the organizational level (Table 4.2). 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 which support the *status quo* or support an existing belief were reported to be rapidly accepted and integrated than knowledge that appears to be an "inconvenient truth" or "socially and politically unpalatable". Knowledge that does not fit into current social constructs such as status quo, norms, values and beliefs are 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 stated that sometimes telemetry is glorified. One respondent described that new technology in their culture is like a "shiny new gadget", and findings from telemetry research are often overhyped where managers jump 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).

4.4.6 Relationships among players in the knowledge network

The lack of relationships among players and lack of collaborations in the knowledge network were identified as barriers for integrating telemetry-derived findings (Fig 4.1). The collaboration between managers in the early stages of a project was identified to be important. One government scientist explained that:

> *Many times, when 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)

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

Mismatches associated with scales and culture was an overarching and encompassing theme that was linked to some of the other barriers identified. The first scale mismatch explicitly discussed was between individually-tracked fish and its representation of the population. The second scale mismatch was the representation of the geographic scale from a localized project (e.g., array size) to a more representative scale (e.g., stock area) at which fish are managed. Third, the mismatch in time scale between studies and management requirement, which are often dictated by battery life and tag retention.

4.4.8 Time

There were various aspects of time discussed in the responses including the time it takes for the entire 'process' to occur, such as the scientific process, the peer-review, the decision-making process, and implementing the change (Table 4.2). Secondly, from the researchers' perspective was the time to translate and package the telemetry-derived findings in a comprehensible manner for policy makers. Lastly, time from the management point-of-view related to learning technical aspects of incorporating telemetry into management and understanding the nuances and complexities of telemetry data.

4.4.9 Facilitators and solutions

Some of the open-ended responses also included facilitators or suggested solutions to mobilizing telemetry findings into fisheries management and some respondents offered potential solutions and approaches to overcome the barriers (Table 4.3).

The most cited reason for successful uptake of telemetry-derived knowledge into fisheries management practices was attributed to researchers building relationships and engaging with stakeholders and 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 facilitated some abovementioned barriers such as the design of relevant research questions that are useful to managers, and improved the *transparency* of the research. The compatibility of the findings with existing approaches, values and perceptions made the integration easier. In other words, relationships and collaborations promote the saliency, legitimacy and credibility of telemetry study findings, which result in facilitating their utilization (Cash et al. 2003). Another respondent claimed 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 buy into the findings (Table 4.3).

Solutions were offered such as improving and expanding the analytical toolbox for understanding telemetry data, and improving how to model behaviour. Furthermore, a few respondents suggested that sharing data would increase sample size and provide greater weight of evidence as well as developing a standardized metric that fisheries managers recognize and value. 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. Lastly, some respondents emphasized for the need to have more flexibility in management systems and structure, such as appropriately implementing adaptive management frameworks (Table 4.3).

Table 4.3. Summary of identified facilitators and solutions for the incorporation of telemetry-derived knowledge into fisheries management using inductive coding. For full descriptive table with illustrative quotes, please see Supplementary Information Table S4.2.

Reported Facilitators	**#of coded responses**
Relationship and engagement with stakeholders and managers from the onset and throughout the research	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 the perceived simplicity and explicit knowledge that telemetry research can produce	2
Suggested Solutions	**# of coded responses**
Improve analytical toolbox	4
Data sharing/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

4.5 Discussion

Our findings reveal four major barriers for incorporating telemetry-derived knowledge and information into fisheries management practices. The first, and the most cited barrier relates to the fact that telemetry is a relatively new tool in fisheries management. Researchers believe that many of the characteristics of the telemetry-derived information, such as representativeness (scaling from individual to population level or site-specific study to generality), study biases (tagging effects, unaccounted detections, species and site-specific questions), and complexity or difficulty interpreting telemetry data delay or prevent its use in fisheries management.

Second, researchers perceived the underlying motivations, dissonance between existing beliefs and new information, and rational constraints of knowledge users (e.g., fisheries managers, decision makers, stakeholders) as challenges to overcome (Bradshaw & Borchers 2000, Gezelius & Refsgaard 2007). For instance, fisheries managers are often constrained by path dependence, a concept that describe how choices in the past have impact on choices in the present (Hegland & Raakjaer 2008). They may also be constrained by incentives or other social situations (e.g., stakeholder demands) (Lodge & Wegrich 2016), and cannot or do not make the most optimal choice (from the researcher's perspective). Policy makers are usually motivated by research that is relevant for a contemporary issue acceptable to current government, that identifies practical solutions, can be used to identify policy options, is demonstrated to work, does not attract controversy, and is effectively communicated. Researchers must thus navigate these priorities to make telemetry noticeable and acceptable to policy makers.

Third, fish telemetrists appear frustrated by the formal institutions, the government and institutional structures, and lack of organizational support to include telemetry science into fisheries management. In other words, institutional inertia and hierarchical structure of bureaucracies. The use of information and knowledge can vary at different government levels. The formal hierarchical structure of bureaucracies creates a disconnect in how knowledge is used or prioritized, and a disconnect between managers on the ground and senior managers who set priorities (Yang & Maxwell 2011). The idea of institutional inertia on its own is complex and beyond the scope of this study. However, I 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 Roseschöld et al. 2014). Understanding these mechanisms can help focus efforts toward breaking down barriers and perhaps leverage changes.

Fourth, there appears to be an overarching mismatch in scale (spatio-temporal scale of study does not meet scale at which managers work), perceptions, beliefs, and values between scientists and managers or policy makers. In addition, the concept of time presents a barrier to the use of fish telemetry research. Such mismatches can often delay or completely impede the utilization of fish telemetry if it is not reconciled because fish telemetrists and managers cannot work together towards a common goal, or telemetry study findings are not useful because they do not meet managers' needs.

These identified barriers have also been highlighted in other areas of natural resource and environmental management, and have been discussed at length in the literature (Vlek & Steg 2007, Cook et al. 2010, Dilling & Lemos 2011, Eden 2011, Clark et al. 2016, Soomai 2017). The barriers that relate to the characteristics of telemetry-derived knowledge, in my opinion, are the most relevant to telemetrists, and the area in which they may have the most control. As such, I focus the remaining of the discussion on addressing barriers that relate to telemetry-derived information and knowledge.

McGowan et al. (2016) argue and challenge telemetrists to develop explicit management objectives in their study designs (along with other respondents in this study), because the investments that have been put into telemetry science for conservation, and the growing potential 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 the study also felt that the links to management actions were not clear when telemetry studies are designed, thus the findings highlight what McGowan and colleagues considered to hinder the impacts of telemetry, and that is through the telemetry-derived knowledge itself.

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

From a researcher's perspective, it may seem daunting to penetrate the policy making and management environment. The fisheries and resource management decision interface is extremely complex and multifaceted (Chapter 2), and organizational structures and cultures have been identified as hurdles for implementing new information and approaches to management (Dilling & Lemos 2011, Yang & Maxwell 2011, Soomai 2017). Often, scientific evidence only make a small part of the "decision space" of managers or policy makers, and other factors including values, judgment, pragmatics, competing interests and path dependency will 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 it out in an organization (Damodaran & Olphert 2000, Soomai 2017). There is thus an urgent need to recognize that organizational structures and cultures can either enable or disable communication at the science-policy interface, and greater collaborative model (not linear model) is required to use new and up-to-date information (Soomai 2017). However, there has been documented success by researchers that have accounted for the various factors in decision making, and have also been proactive in building relationships and gaining peer acceptance of not only their scientific findings, but their research program (Patterson et al. 2016, Chapter 2). As such, I discuss ways in which researchers can act on to improve their conservation return-on-investment, while navigating the multifaceted decision environment of knowledge users.

4.5.2 Improve 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, and potentially address some present concerns of reliability and relevance to fisheries managers (Lennox et al. in review). New modeling and statistical techniques have been developed to identify behaviours and environmental correlates of behaviours and habitat use (e.g., Gurarie et al. 2015, Jacoby and Freeman 2016, Jønsson et al. 2016**),** which will be invaluable for fisheries management. Furthermore, one respondent suggested a 'common telemetry or movement model' that could be applied in a consistent way to demonstrate the value of telemetry to fisheries managers (Table 3). Fish telemetrists can partner and collaborate with experts developing new analytical tools and approaches to enhance the legitimacy and credibility of their work. Such collaborations are also needed to find pragmatic solutions to the current conservation crisis that demands for new tools and frameworks that can help link the growing telemetry-derived data of the aquatic world to conservation and management (McGowan et al. 2016).

4.5.3 Share and standardize data and metrics

Sharing telemetry data can maximize its impact through development of global collaborative efforts and facilitating data sharing infrastructure. By sharing data, sample sizes are increased, data is extended beyond the reach of a given study, which can lead to opportunity for asking 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. 2016). To help realize the potential that aquatic telemetry can have with informing 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 across spatio-temporal scales (Crossin et al. 2016). The lack of standardization across telemetry studies can make it challenging for managers to work at various scales, but as previously mentioned, new analytical and statistical techniques (e.g., state-space models, network analysis) will become a go-to source and help make useful population-level predictions from relatively small numbers of tagged animals (Crossin et al. 2016).

Standardizing metrics for data and metadata, as well as study designs can help improve data quality for reuse and assimilation or synthesis to answer complex questions or provide more relevant evidence (Koslow 2000, Nguyen et al. 2016). However, the nuances of field data are often not easily represented. Furthermore, there are inherent challenges in telemetry research with respect to standards given with the proprietary coding schemes of competing manufacturers, not to mention different telemetry platforms (e.g., radio vs acoustic). The broader community (including scientists, managers, and telemetry manufacturers) need to engage in dialogue regarding this difficult topic if telemetry is to reach its full applied potential.

4.5.4 Informal Relationships and Collaborations: making telemetry relevant, and linking where telemetry fits into management

A number of challenges can potentially be overcome through informal relationships between the researcher and the management staff and stakeholders. Having personal interactions and building trust through genuine relations and conversation over time have been suggested to be important in fostering meaningful exchange of knowledge and information that can result in some form of action (Jacobs et al. 2005b, Mitton et al. 2007, Gibbons et al. 2008, Groffman et al. 2010, Young et al. 2014, Patterson et al. 2016). Young et al. (2016a) reported that knowledge viewed as credible and reliable is often trusted and used by knowledge users. The perception of reliable knowledge was associated with the perceived character and motivation of the knowledge claimant, which reinforces the value of relationship building among knowledge actors. 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 (Chapter 2, Patterson et al. 2017, Young et al. 2016b). Here, relationships with individuals "on the ground" who address science priorities and management issues is essential to define how fish telemetry can be useful. 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 – management want to reach a policy or decision while scientists want to reach general principles and understanding of a question (Patterson et al. 2017). These patterns lead to barriers for integration unless there is communication and coordination between managers and researchers to better link management activities with science activities and advice. The pairing of scientists and managers through communication and coordination allow for managers to articulate the problems, and allow scientists to develop ideas, and hypotheses that relate to the problems as well as matching performance metrics with management objectives and constraints (Patterson et al. 2016). An excellent example can be drawn from researchers, managers, and stakeholders of the Fraser River Pacific salmon fishery who proactively maintained informal relationships through symposiums and targeted solution-oriented meetings, which have led to successful use of telemetry-derived and physiological information (Young et al. 2013b, Patterson et al. 2016).

Collaborations and relationship building with stakeholders and grassroots community organizations can also put pressure on governing bodies using bottom-up pressure. Ostrom (1992) stated better institutions can be 'crafted' by resource users and policy makers. As such, targeting, educating and empowering the wider user group such as fishers and non-governmental organizations may prove to be an effective means of integrating fish telemetry-based knowledge into management practices, whether though bottom-up pressure by stakeholders or through voluntary institutions and collective action (Granek et al. 2008, Danylchuk and Cooke 2011, Cooke et a. 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.

Building these interpersonal relationships and understandings can address many of the mismatches in language and culture, and disparities in what information telemetry science can offer with what managers need. A byproduct of these interactions is social learning. Social learning can facilitate coproduction of knowledge and adaptive co-management of fisheries because it leads to more legitimate management measures through establishing common goals and purpose, open communication, as well as functional collaborative relationships (Schusler et al. 2003, Reed et al. 2010).

4.5.5 Formal relationships and collaborations: greater science-management interface within organizations or 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 that can address many of the identified barriers of this study and help with designing management objectives in studies (Pohl 2005, Hessels & 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 scale, 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 that is responsible for the management of the Great Lakes fisheries. GLATOS provides a formal platform and interface for telemetry researchers to share data and resources, as well as interact and collaborate with the management community. Such interfaces can facilitate joint study design and co-production of knowledge that may be more socially robust and viewed as legitimate, credible and salience by the knowledge users. Thus, a concerted effort to create interfaces for regular interactions and exchanges between science and management may go a long way in reconciling mismatches and create sustainable fisheries. In addition, GLFC offers a model that values relationships. Their budget provides an interface for researchers and managers to come together at social events, and annual workshops to maintain the relationships built (Gaden et al. 2008).

4.5.6 Evaluation of the application of the knowledge-action framework

We applied the knowledge-action framework described by Nguyen et al. 2016 in this study. The framework was very useful for the qualitative analysis as it provided a structured guide for coding. The framework also offered a platform for quantitatively comparing qualitative data, and providing context for the findings. The flexibility of the framework also allowed for the use grounded theory to identify subthemes and gather more nuance information from the data. However, there are also costs to using a framework. Researcher bias and interpretation will play a large role in how the framework components are interpreted and the fit of the data in each. Furthermore, I found that there was a lack of strategy 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, I believe it is important that findings can accumulate in a manner that facilitate comparisons and synthesis to bridge the gap between knowledge and action.

4.6 Conclusion

This study revealed that fish telemetrists perceived characteristics and attributes of telemetry data, such as uncertainties, incompatibilities, complexity of telemetry data, and lack of relevance to management needs to undermine the used of telemetry-derived information. This supports McGowan et al. (2016)'s 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. With that said, it is also naïve of me to assume that my entire sample have the desire to make an impact. Co-production of knowledge, and co-designing telemetry studies with managers and other users is an important concept that is widespread throughout the literature for addressing the barriers identified. Evidence have shown that the coordination and communication in the scientist-manager pairing model works, and thus can be an avenue for fish telemetrists to explore in order 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 those on the ground to address. Based on my findings, changes and innovations in institutional structures are apparently needed for effective use of new knowledge, such as telemetry-derived knowledge.

Facilitating the mobilization of telemetry-derived knowledge is essential for informed decision making and effective policy implementations because of the variety of updated knowledge and insights it can offer about the animals and their interactions with the environment (Hussey et al. 2015, Crossin et al. 2016, McGowan et al. 2016). Telemetry-derived data is growing exponentially, and globally. Effectively using the knowledge derived from this growing catalogue of fish telemetry data is needed in an era of major environmental crises and human-accelerated environmental change worldwide. I hope that my findings can help the fish telemetry community better link their work to conservation outcomes, and I anticipate that these lessons are relevant to those tagging and tracking other taxa beyond fish, as well as providing greater empirical evidence towards understanding knowledge mobilization in the context of natural resource management and conservation.

4.7 Supplementary Information

Table S4.1 Detailed descriptions with illustrative quotes of identified barriers to the incorporation of telemetry-based knowledge into fisheries management using the knowledge-action framework (Chapter 1)

Broader barrier	# of mentions	Specific barriers	# of mentions	Description	Illustrative responses
Characteristics of the knowledge	199	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-based knowledge	Quote 1: It is the ability to get large enough sample sizes to actually and adequately represent the population and also the constraints of the technology. For example, I work with lamprey…having an active transmitter that can be tagged without having tag effects in an entire size range of fish is a limitation. If fish manager need to know about lamprey across all size range that's a limitation (Interview #261, female, 50-55 years, government, N America) Quote 2: The sparsity, applicability, and lack of replication in telemetry data tends to limit its incorporation into fisheries management practices. Although the cost of telemetry has come down substantially, it plays a major factor in how much data can be collected. We are able to get a LOT of data from a few animals, but this doesn't necessarily reflect what all of the animals in a population are doing. Managers have a hard time making population level decisions based the behaviour of a few individuals. The problem is having too much data, yet not enough, all at the same time (Survey #58, male, 35-40 years, government, N America).
		Study design and research questions	37	The study design and research questions are not applicable to or do not align with management needs	The lack of hypothesis-driven research questions, or the failure to clearly communicate hypothesis-testing when presenting the data, makes many efforts appear descriptive vs. inferential. There is a history of workers becoming emoted with the technology and deploying it without careful construction of research questions and hypotheses. This has also, at times, imposed spatially-explicit structuring of research questions that are often less informative (e.g., asking "Does species X go into bay Y?" instead of asking "Where does species X go, and under what conditions?"). (Survey #144, male, 45-50 years, academia, N America)
		Large and complex datasets	31	The complexity of the data analysis, the nuances and	The biggest barrier are people's [researchers] lack of understanding of the limitations of the technology. Their inability to interpret the data safely…they don't understand the mistake that

				variability of telemetry data can lead to challenges in interpreting and understanding what the data reveals, if anything at all.	they are making, the conclusions that they are coming to and how erroneous it could be. To see that incorporated into management is frightening. Papers that I review, there is inadequate calibration. Even if there is, they don't include it in their papers so the readers have no ability to evaluate what their concluding is actually supported or valid...readers need to see that in publications to get beyond just here is my biological conclusions. Need to convince that what you are doing is valid. (Interview #239, male, 50-55 years, academia, N America)
		Relevance and applicability	29	The perceived lack of relevance and applicability of telemetry findings into fisheries management	Telemetry projects are often "one-off" projects, often species or life stage specific. The original science question may not be testing fishery-based management questions. Telemetry outputs are therefore not well integrated into a common fishery management practices (Survey #32, male, government, 40-50 years old, North America)
		Reliability	15	The perceived lack of reliability of the telemetry findings	Because of low sample sizes, managers are often unwilling to make decisions based on telemetry because of the potential variation, and even if there is compelling evidence irrespective of the sample size, affecting the inertia within government (which seemingly strives to maintain the status quo) is a daunting/demoralizing task in many cases. (Survey #184, male, 35-40 years, government, N America)
		Skepticism	9	The overall skepticism from potential knowledge users of telemetry-based knowledge due to the characteristics (mainly limitations and uncertainties) of telemetry	I think the most significant barrier to complete adoption of results obtained through telemetry is that there is always a theory as to why results might not be valid. For example, in our research we have estimated survival rates for steelhead populations as they migrate through the nearshore and coastal zone. There are always detractors who claim that we don't know what the effect of the tag is on the survival of the fish, or more recently, that predators may be able to hear the signal put out by the acoustic tag, making our calculated survival rates invalid or biased. Perhaps the reality that we can't directly observe what is going on is the most significant barrier for people to completely buy into telemetry results. (Survey #37, female, 30-40 years old, government, North America)

Environmental and contextual dimension	74	Governance and institutional structures	30	The established structural dimension can be a disincentive to change, to break norms and to take risks (path dependence)	Quote 1: The government of fisheries managers have 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, 60-65 years, private, N America) Quote 2: Commercial fisheries managers really don't see the point of the [telemetry] research…they fail to see population connectivity will benefit what they have to do. They fail to see that telemetry derived mortality estimates are useful for them. That discrimination against acoustic telemetry research isn't just against telemetry…they are very traditional in their views, they like otolith cuts, growth curves, catch curves, commercial catch statistics… that's what they want us to do. (Interview #275, male, age unknown, government, Australia)
		Context of use of telemetry	20	Some questions and issues that telemetry can address appear to provide clearer answers than others	The majority of telemetry work I have been involved with has been to estimate rates of mortality given an anthropogenic stressor. I would say, of all the data I typically collect in a single research project, the telemetry results are the easiest to disseminate once they have been analyzed. Telemetry provides easy numbers: X% of fish survived capture or X% of fish were able to pass a barrier. The challenge I have run into is having policy makers and managers see the entire picture and understand the caveats that are attached to the resulting numbers. For example, X% of fish may have passed the barrier, but we were only able to detect movements to a point that is just a short distance from the barrier and looking beyond this point would change the estimate of the number of fish successfully passing the barrier (Survey #84, female, 30-35 years, academia, N America)
		Economic parameter	10	Economic priorities can supersede what telemetry-based knowledge recommends	Economic costs/societal priorities often outweigh telemetry findings (e.g., dams provide huge economic benefits to society and any modifications are so expensive (>$tens of millions), they outweigh their role as a barrier to a population's life history expression, even if it jeopardizes that population (Survey #145,

					male, 40-50 years old, government, N America)
		Political context	13	Political agenda can supersede what telemetry-based knowledge recommends	The current strong interest in promoting renewable energy sources, especially in coastal waters has caused these [natural resources] agencies, and the renewable energy companies, to be reluctant to investigate fish movements and the effects of their renewable energy devices upon these movements (Survey #8, male, 70-80 years old, private, Europe)
Characteristics of knowledge actors	63	Motivational factors	34	The motivation of individual and institutional level actors to mobilize telemetry-based knowledge (e.g., lack of political will, institutional inertia, maintenance of status quo, rewards and incentives)	Quote 1: There is often just too much at stake, and we don't have the political will to make things happen because in the end, industry and the mighty dollar win out…Political will is the largest barrier, our law makers and enforcers cave too often for fear of not getting re-elected (Survey #184, male, 35-40 years, government, N America) Quote 2: It's difficult for a single scientist [to push uptake of findings]. They [fish farming organization or hydropower] might personally attack you, degrade your personal integrity... people working with this issue, it's difficult because they fight [against] this [scientific results]. Sometimes it might easier for scientists to keep your mouth shut and publish internationally and not fight in the media or community. (Interview #247, female, 40-50 years old, government-related, Europe)
		Social constructs	9	Social constructs other than motivation such as values, norms, and beliefs	Quote 1: Depends on what you found out reinforces what management agencies already think or whether they are at odds with management agencies. If you give them confirmation, it conforms and makes it easier to enforce policy then the uptake can be quite quick. If findings against perceived previous knowledge then you're up for a long haul. (Interview #257, male, 60-65 years, academia, N America) Quote 2: People are actually true believers of telemetry results. They are more confident in accepting result that came from telemetry then if you provide them with conventional studies (Interview #264, male, 50-55 years, academia, Europe)
		Competing interests/priorities	14	Conflicting priorities, agendas and interests of	Policy makers try to establish a balance between competing interests. e.g. for research on a river system, input is required by land owners, fisheries management organizations,

				different knowledge actors	conservation groups, and hydropower plant owners. If telemetry studies are suggesting a specific management approach (e.g. increase flows downstream of a hydropower station), competing interests might not be amenable to these suggestions because it will incur a cost for them (Survey #75, male, 40-50 years old, NGO, Europe)
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/other potential knowledge users.	Quote 1: Lack of integration/communication among governmental biologists/administrators/policy makers with academia. I have and continue to experience a significant disconnect between academia and these entities. Many folks don't know about, don't care to know about, or know about and disregard the results because they think that the telemetry tags cause undue stress on the fishes harboring the tags, therefore impacting their survival and behavior in non-natural ways. These same professionals seem to be fairly single-minded about this. (Survey #41, gender and age unknown, government, N America) Quote 2: It's because framework science to management is not working…that [aligning research with management needs] involves a lot of interplay between management and scientists, and it's intensive. For the most part, we are not doing it. (Interview #266, male, 50-55 years, academia, Australia)
Mismatches	55	Scale	8	The spatial, temporal and institutional scale mismatches	Quote 1: The telemetry results are not necessarily easily scaled up into region or country wide management policies. Also, the results only tell us fish movement patterns on small spatial or temporal scales, and this can only translate to fisheries management practices such as involving implementation of protected areas or reserves. Management of a species quite often also needs biological and demographic information as well, and a range of management tools (size/catch limits etc.). (Survey #54, female, 35-40 years, academia, Australia) Quote 2: Spatial scales for adequate protection of mobile organisms are rarely in line with those accepted by communities or government. Stakeholders are rarely in agreement in the need for area protection, particularly favoured fishing areas. The timelines for showing positive benefits of MPAs are often in excess of what stakeholders expect. (Survey #209, gender unknown, 55-60 years, private, N America)

		Representation	15	The mismatch of telemetry studies tagging individual fish and their representation of the overall population	Quote 1: Lack of powerful data, as often coastal (coral reef) telemetry studies are limited to only one or two sites and 10 - 30 fish. Quite often there are differences in movement patterns within sex and sizes of fishes, so small sample numbers are not giving enough information to make informed and robust management decisions. (Survey #54, female, 35-40 years, academia, Australia) Quote 2: Telemetry studies usually involve far fewer subjects (individual fishes) than other sources of information relating to movements (e.g., long-term fisheries-independent sampling programs). Many decision-makers appear wary of extending detailed information regarding individual fishes into inferences about population ecology (as do some scientists). Thus, the scale of the analyses in fish telemetry work is often different than the scale of the decision. (Survey #144, male, 45-50 years, academia, N America)
		Cultural	6	The cultural mismatch between different knowledge actors (e.g., researchers vs. managers)	The adaptive management framework has been adopted and prompted for over 25 years and it almost always never works. Because needs for researchers and managers are not the same. The funding framework and all of the drivers are very different. If you really want to change the real-world applicability of and money spent on telemetry, then you need to change what the drivers are…the drivers for sciences and managers have no bearing on each other. Even with the best data in world we got to publish papers. Paper publications have nothing to do with what management does. It could be used by them, but not an effective mechanism (Interview #266, male, 50-55 years, academia, Australia)
		Other		Mismatches described by respondents that did not fit into any other categories.	Mismatches between timing of decision making and funding research. In terms of conservation and spatial management (MPAs) in particular, decisions on zoning are usually made first and funding comes later to rationalize or justify decisions. Where the data does not support decisions made based on political imperatives, science rarely triumphs over inertia associated with existing decisions. Things would have to get really bad for zoning to be changed, for example. (Survey #64, male, 55-60 years, government, Australia)

Time	24	NA	NA	The various aspects of time that impedes the integration of telemetry-based knowledge (i.e., process time, time to learn, time to invest in dissemination, etc.)	Resource managers don't (and often cannot) change policies based upon every new study that gets published. There is a long process where results must be replicated, and/or reconciled with contradictory results, and this information must be synthesized with other knowledge. Sometimes this happens quickly, and sometimes it never happens due to external factors (political and/or socio-economic). Perhaps you might think of the process as a barrier, but on the other hand, you might consider that in time all research findings (telemetry included) are incorporated into fisheries management practices. (Survey #1, age and gender unknown, government, N America)

Table S4.2 Detailed descriptions and quotes illustrating identified facilitators and solutions to the incorporation of telemetry-based knowledge into fisheries management through qualitative inductive coding.

Facilitators	#of mentions	Illustrative quotes
Relationship and engagement with stakeholders and managers from the onset and throughout the research	14	We have a very tight relationship with the management group. In our office, we are together…same office, not compartmentalize…we eat lunch together, go to coffee together, people know each other, we share a common goal. The second part [of success] is when the science started, the managers were involved in beginning. They may not understand all nuances of model, but they get it and they trust that's what it's doing is getting information that they need (Interview #253, male, 50-60 years old, government, North America)
Addressing management questions and ensuring research design will generate knowledge that is useful to managers	11	Scientists have to be able to understand the type of questions that managers are interested in. Managers are not going to go to data and figure out data. Scientists have to frame their analyses after those issues that managers are interested in. Obviously, they need to speak in language that would be comparable to what managers can understanding. Knowing the question, knowing what messages should be and coding those messages in some way …that they can be decoded in way that someone can use it. Packaging issue in a non-offensive way…can you do it in conversational manner (Interview #243, male, 60-65 years, academia-government, N America)
Transparency of study (e.g., being transparent about limitations and validation of studies)	1	People don't understand how the data is (are) collected, if it's reliable, what happens to the fish you don't detect, effects of the tags on the animals, how representative the data from a tag fish are to the rest of population. If you design those things in the work that you do and be transparent about that, it usually turns out pretty good (Male, 50-60 years old, government, North America)
Simple visualization and dissemination of results and the perceived simplicity and explicit knowledge that telemetry research can produce	2	It's [telemetry data] immediately available. You track a fish, you know where it's gone…it's something that people can people relate to…it's about the individual. (Interview #254, male, 30-35 years, private, UK)
Solutions	**# of mentions**	**Illustrative quotes**
Improve analytical toolbox	4	Most practitioners are unaware of appropriate statistical methods for quantifying telemetry data. This is true even of experts who are well respected in the field. The technology has greatly exceeded our ability to use it effectively and objectively and there is a profound need for improved quantification and data management methods in the user community (Survey #229, male, 50-55 years, government, N America) The rate at which data is collected far exceeds the rate at which analytical expertise is developing within the research community. There is a clear divide between the 'data generators' and the 'data analyzers'. This can

		generate significant barriers to publication, or limits on publishing in influential outlets, when the analysis experts are the gate-keepers. This can be problematic as publication helps to establish the validity of conclusions and provides a sound basis for scientists that are leery of contentious public debates to advocate on behalf of their findings. (Survey #144, male, 45-50 years, academia, N America)
Data sharing/standardization of data; compatibility of tag and receivers (codes and frequencies)	4	Part of the problem is that there are few telemetry expectations from resource managers, although I think this is changing. A common "telemetry" or "movement" model that could be applied in a consistent way, such that the majority of fishery managers can recognize and see its value would be useful. For example, 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, N America)
Adaptive management framework/structural flexibility/organizational support	4	We need a really good framework to incorporate science data into managements…that involves a lot of interplay between management and scientists, and it's a really intensive mode. For the most part, we are not doing that. We need a good adaptive management framework where telemetry is used to provide critical information but also flexible enough that you can alter data collection to account for the fact that we get new information arising that may or may not answer questions so you can alter research design to actually provide what management needs have feedback loops where management and researchers can continue to refine the questions and set way data collected and we don't do that at all. (Interview #266, male, 50-55 years, academia, Australia)
Bottom up pressure	1	Where I have been very successful to push pressure on management is through user groups, the recreational sector. We've attended competition and got them actively involved in our tagging studies and through the fishery surveys. We informed them and not just obtain information but actually have a feedback process where we go to comps and give public talks. Through the information we got from telemetry studies, in particular, we transformed a lot of tournaments to catch-and-release only. The user groups themselves are implementing the strategies that are making a difference, without any intervention of management organizations. (Interview #263, gender and age unknown, academia, South Africa).
Compatibility with existing approaches, values and perceptions of knowledge user	1	In-part, managers are not asking for telemetry input, therefore when telemetry data is provided it's not always clear what to do with it or how to weight it along with other types of data. External tagging for example is a mainstay of the fishery assessment biologist, and although its more limited than telemetry, managers and resource harvesters have come to look for and accept the results. "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. (Survey #32, male, 40-45 years, government, N America)

Chapter 5: To share or not to share in the emerging era of big data: Perspectives from fish telemetry researchers on data sharing

5.1 Abstract

The potential for telemetry data to answer complex questions about aquatic animals and their interactions with the environment is limited by the capacity to store, manage, and access data across the research community. Large telemetry networks and databases exist, but are limited by the actions of researchers to share their telemetry data. Promoting data sharing and understanding researchers' views on open practices is a significant step toward enhancing the role of big data in ecology and natural resources management. I surveyed 307 fish telemetry researchers to understand their perspectives and experiences on data sharing. A logistic regression revealed that data sharing was positively related to researchers with collaborative tendencies, who belong to a telemetry network, who are prolific publishers, and who express altruistic motives for their research. Researchers were less likely to have shared telemetry data if they engage in radio and/or acoustic telemetry, work for regional government, and value the time it takes to complete a research project. I identify and provide examples of both benefits and concerns that respondents have about sharing telemetry data.

5.2 Introduction

Telemetry is an extraordinary tool for monitoring animal movement in the wild, with applications in the aquatic, aerial and terrestrial realms (Cooke et al. 2004, Hussey et al. 2015, Kays et al. 2015). The miniaturisation of electronic tags, the development of safe and efficient tagging methods, and the manufacture of long-lasting batteries has facilitated the rapid global increase in telemetry studies of animal spatial ecology and survival. In the few decades since electronic tagging systems have become widely available, scientists have collected a vast amount of data on animal movement (Donaldson et al. 2014). Today, electronic tracking systems permit researchers to follow tagged animals over multiple years, and monitor animals in challenging environments (Urbano et al. 2010). Telemetry data, both current and historic, can inform managers and policy, and may provide critical knowledge that can help prevent extinctions, assist with conserving biodiversity, and facilitate the implementation of ecosystem-based management (Cooke 2008, Donaldson et al. 2014, Block et al. 2016).

Telemetry has unique benefits in aquatic environments by exposing the otherwise unseen. It enables researchers to track and characterize the behaviour and movements of individuals and populations over diverse temporal and spatial scales, ranging from time frames of seconds to years, and from distances of meters to tens of thousands of kilometers. These electronic devices may also be equipped with sensors that measure multiple physical parameters (e.g. depth, temperature, conductivity, fluorescence), that provide information about the animals' environment (Hussey et al. 2016). There is great potential for telemetry to answer complex questions about animals and their interactions with the environment across large scales. However, this potential is limited by the capacity to store, manage, access and share the enormous amount of data generated across the research community (Howe et al. 2008, Hussey et al. 2016). Telemetry data is moving into the realm of 'big data' and accordingly the approach to its management must also evolve. Networks and centralized databases, such as MoveBank (Kranstrauber et al. 2011), the Ocean Tracking Network (OTN; Cooke et al. 2011), the Australian Integrated Marine Observing System -Animal Tracking (IMOS AT), the United States' Animal Telemetry Network (ATN), Ocean Biogeographic Information System–Spatial Ecological Analysis of Megavertebrate Populations (SEAMAP), and the Global Tagging of Pelagic Predators (TOPP; Block et al. 2016), provide mechanisms for archiving and potentially sharing animal movement data. While these regional and global networks can leverage individual telemetry studies, they may be limited by the willingness of the research community to share their data (Hussey et al. 2015). Establishing data sharing standards and protocols is therefore the next necessary step to take advantage of big telemetry data in ecology (Campbell et al. 2015).

Data sharing involves providing access to privately stored data. Data producers have a range of options for data sharing, from making data fully open access (i.e. public) to limiting its distribution to individual investigators upon request**.** For the purpose of this article, data sharing is defined as the release of research data to public databases for use by others (i.e. making the data fully open access). Although scientists frequently share data, sharing is often limited to small-scale, established networks of close collaborators or colleagues rather than the broader community (Cragin et al. 2010). Generally, there are four rationales for sharing data: i) to verify and/or reproduce research; ii) to make results of publicly-funded research available to the public; iii) to allow other researchers to ask new and different questions using the data; and, iv) to advance the state of research and innovation, through providing new knowledge and understanding (Thomas 2009, Tenopir et al. 2011, Borgman 2012, Poisot et al. 2013). These rationales are being reinforced by an unfolding discussion within the science community at large regarding whether all publicly-funded research data should be openly available (Arzberger et al., 2004, Tenopir et al., 2011), and by requirements by both research funding agencies and journals that data be made publicly available and/or published along with the research. Personal benefits have been reported for those who have shared data, including increased visibility and relevance of research output, opportunities for additional publications through collaborations, and increased citation rates of primary publications (e.g., Piwowar et al. 2008, Poisot et al. 2013).

In the context of telemetry, sharing data involves providing access to both raw data and metadata about animal positions, characteristics, and movements to an array of researchers and potentially other stakeholders. This in turn enhances the geographic and zoological scale of movement and habitat-use studies by providing information about detections of tagged individuals in array systems that may be distant from the original tagging locations. Data sharing may contribute to novel approaches in disciplines that do not generally tag animals. For example, animal-borne environmental sensors can benefit oceanographic or atmospheric sciences as well as informing trackers about environmental factors that are important to animals (e.g., Roquet et al. 2013). Additionally, analysts may be able to answer broader ecological questions that are beyond the scope of a single researcher or research group by using information from shared datasets. Collectively, data sharing can maximize the efficiency and utility of funding for ecological research and accelerate the advancement of the science.

Despite acknowledgment of the potential benefits of data sharing (see Parra and Cummings 2005, Enke et al. 2012, Campbell et al. 2015, Hussey et al. 2015), ecologists are often reluctant to let others in on their own data on animal movements (Nelson 2009). This is not unique to ecology but is also found in other research communities like neuroscience and medicine (e.g., Koslow 2000, Reidpath & Allotey 2002), and likely arises because data sharing poses a conundrum. Data can take multiple forms, be viewed and handled in many ways, may originally be collected in specially designed experiments for specific purposes, and for all of these reasons are often difficult to interpret when taken out of their initial context (Borgman 2012). Data sharing also varies among different research fields. Some disciplines such as astronomy and genomics have established highly successful, open, data sharing conventions (e.g. Sloan Digital Sky Survey for astronomy, GenBank for genetics, Benson et al. 2000). In ecology and environmental engineering, researchers have reported that data sharing is very costly in time and effort, due in part to a lack of metadata standards and data preparation procedures, which make data sharing expensive and time consuming (Kim and Stanton 2011). Other reasons for reluctance in sharing data include the potential violation of intellectual property rights of the data owner, fear of loss of control over unpublished data, fear of being scooped by others, and lack of incentives and rewards to share data (e.g., Campbell & Bendavid 2003, Evans 2010, Janssen et al. 2011, Enke et al. 2012).

Kim and Stanton (2012) divide the factors that may influence an individual's choice about whether to share data into four major categories: 1) institutional (e.g., journal or funding agency requirements, normative pressures by colleagues or culture of their field); 2) individual (i.e., perceived costs, risks and benefits to sharing); 3) IT capability (e.g., IT support, data repositories, data standards), and 4) altruistic motivations such as the desire to contribute to advancing knowledge or to help colleagues save time and effort.

For aquatic telemetry to have maximum impact and realize its full scientific potential, the development of a global collaborative effort to facilitate data sharing infrastructure and management over scales not previously realized is sorely needed (Hussey et al. 2015). If we accept this tenet, and given that data sharing already occurs, albeit generally on a regional basis, it is important to investigate what personal and social factors are currently associated with sharing telemetry data. In so doing it may be possible to determine why some researchers share their data and others do not.

Given the availability of existing telemetry databases for archiving and sharing data, most researchers are not likely limited by lack of access to the necessary infrastructure. Therefore, an investigation of the perceived barriers in (e.g., costs and risks) in this community to participate in data sharing could identify drivers of individual reluctance, facilitate efforts to encourage data sharing, and advance the science of telemetry, ecology, and conservation in the way that other disciplines have benefited from data archiving and sharing standards (Nelson 2009). Moreover, such information could be used to establish or refine guidelines for data sharing (e.g., embargo policies) that would facilitate future sharing. In this study, I examine the data sharing experiences of active fish telemetry researchers using acoustic, radio, or satellite telemetry. Our focus on fish is due to the fact that many opportunities for data sharing already exist, because researchers use cross-compatible technology (see Donaldson et al. 2014) with the common objective of tracking animal movement.

In this article, I i) explore the characteristics of individuals who have shared fish telemetry data in public databases relative to those who have not, ii) quantify perceived barriers to sharing fish telemetry data, and iii) document reported examples of positive and negative experiences that have materialized from sharing telemetry data. I anticipate that the results from this study will assist in providing recommendations for guidelines on data sharing, and offer insights to current barriers that may induce reluctance among some researchers to engage in sharing data.

5.3 Methods

We conducted an international survey, as part of a broader study of fish telemetry researchers, to identify their perceptions and experiences regarding barriers or enablers to the use of their telemetry research in fisheries management. The study employed both online questionnaires and face-to-face interviews. The Carleton University Ethics Board approved this study and the anonymity of respondents is being maintained (102887). I asked standard socio-demographic questions and collected information on potential variables that may influence the likelihood of a participant to share or to not share data. I followed up with more open-ended questions to understand current sharing practices, concerns and benefits of our sample population of fish telemetry researchers:

- *Do you share your telemetry research data in publicly available databases?*

- *Do you have concerns with sharing research data in publicly available databases? If yes, please describe those concerns.*
- *Have any of those concerns actually materialized? (e.g., did your concerns come to reality?) Please describe.*
- *Have you benefited from publicly sharing your data (i.e. has anything grown or developed out of sharing your data)? If yes, how?*
- *Have you used shared data for your own research related to fish telemetry? If yes, please describe how it was used?*

For the purpose of this study, 'telemetry' was restricted to acoustic, radio or satellite tracking only, as these telemetry techniques address research questions. The questions were optional (allowing respondents to skip) and open-ended. As such, sample size varied across questions. The online questionnaire was pre-tested with 11 individuals who have worked with fish telemetry.

5.3.1 Semi-structured interviews

I conducted 24 face-to-face semi-structured interviews with fish telemetry experts at the International Conference of Fish Telemetry in Halifax, Nova Scotia, from 13-17 July, 2015. I further supplemented this sample with 11 interviews at the American Fisheries Society 146th Annual Meeting in Portland, Oregon, from 16-20 August, 2015. I scheduled phone interviews with nine individuals with whom I was unable to meet at the conferences, totalling 44 interviews (including the data gathered by our interview pre-test). Results from semi-structured interviews were used to provide in-depth qualitative information and complement the online questionnaire results.

5.3.2 Online questionnaire

Our target audience for the online questionnaire was researchers who have engaged in fish telemetry projects. I extracted e-mail addresses of authors who have published "fish telemetry" science from citation records within the Web of Science online database. A search was undertaken 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). I restricted the search to articles published between 2011 and 2015, and used the following search string to identify relevant research 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 resulted in a set of records that contained 2605 valid e-mail addresses. After screening and removing duplicate e-mails as well as clearly irrelevant records, I identified 1908 unique e-mail addresses.

Invitations were sent by email to potential participants on 7 October, 2015. There were 112 bounce backs and 110 respondents who notified us that they did not meet the criteria of a "fish telemetry scientist," leaving 1686 e-mail addresses for potential respondents. It is important to note that this number is an overrepresentation of our potential target population since the search string may have returned some e-mail addresses that lie outside our target population. Two reminders were sent on the 4th and 17th of November, 2015. In addition to the search described above, I also used a snowball approach to ensure I contacted as many participants as possible. On February 4 and 14th, 2016 we contacted an additional 155 contacts that our survey respondents had suggested. Online access for the last wave of respondents was closed on 19 February, 2016.

We received 348 responses from the pool of potentially relevant participants (N=1841), of which 213 completed the questionnaire in its entirety and 49 completed approximately 75% of the survey (excluding optional section). Thus, I used 306 responses (262 survey responses + 44 interview responses) in our analyses. The remainder of the participants partially completed the questionnaire, thus the number of responses varied by question. The overall response rate was 19%, which is within the expected range of response rates for online surveys (Deutskens et al. 2004) even though the total number of invites sent out was an overestimation of the target population. I do not attempt to generalize from respondents' perspectives as a representative sample of the broader research community, but rather provide insights and identify future research directions on the issue of sharing telemetry data.

5.3.3 Quantitative data analysis

Binary logistic regression was used to explore the effects of several independent variables on the odds of a researcher sharing or not sharing telemetry data (IBM Statistic SPSS 20). The goal of the analysis was exploratory rather than to build a predictive model. A number of independent variables hypothesized to influence the likelihood of an individual to publicly share or not share data were tested: age (continuous), gender (dummy coded), geographic location by continent (dummy coded), number of refereed publications (range categories), number of non-refereed publications (range categories), telemetry involvement (index), telemetry technology used (dummy coded: acoustic, radio, satellite), research environment (dummy codded: freshwater vs saltwater), employer(s) (dummy coded: academia, federal government, state/provincial government, private, non-governmental), collaborative extent (index), collaborative frequency (index), belonging to a telemetry network (dummy coded), and employment role(s) (dummy coded: lab-based researcher, field-based research, educator/instructor/professor, tenured/untenured faculty, consultant, manager/administrator, government scientist, graduate student or post-doc fellow, research assistant/technician). Separate binary logistic regressions were used to analyze the relationship of researchers who have participated in sharing data vs. those who have not on a set of 15 research motives (Table 3), as well as on a set of views about the limitations and authority of scientific knowledge (Appendix 1), respectively. *Research motivation* of participants was assessed using Likert scale questions, with respondents asked to indicate the importance of each item as "not important" (0), "somewhat important" (1), "important" (2) and "very important" (3). The views of scientific knowledge were evaluated using a Likert scale (scoring in brackets), with respondents asked to indicate their agreement with each item: "strongly disagree" (0); "disagree" (1); "neutral" (2); "agree" (3); and, "strongly agree" (4).

Chi-square, independent t-tests, and series of simple binary logistic regressions were utilized to examine individual factors and their bivariate relationship between data sharing groups (Abu-Bader 2010). Factor selection tests showed significant relationships among data sharing and all factors tested except for collaborative frequency, gender, geographic location, employment role, non-refereed publications and general beliefs, thus these factors were excluded from the logistic regression tests I conducted an intercorrelation matrix to explore the correlations of the factors, and provide further information for the exploratory logistic regression analyses.

5.3.4 Index variables

The *collaborative extent* (collaboration_score) was measured by evaluating whether participants: i) shared data/telemetry infrastructure (i.e. shared receiver and data picked up from other receivers); ii) co-authored a publication or presentation; iii) collaborated in other ways. Each of the three activities were broken down to what group the participant engaged with, such as with a) colleagues in universities or colleges, b) with colleagues in industry, c) with colleagues in government, d) with colleagues employed by environmental groups and, d) with colleagues employed by local community and/or indigenous groups (Young and Matthews 2010). For each group the respondent participated with, they received a score of 1. The *collaborative extent* index was thus created by summing the total score ranging from 0, for someone who has never collaborated in any activity with any of the groups, to 15, for someone who collaborated in all three activities with all five groups.

The *collaborative frequency* differs from the *collaborative extent* in that it demonstrates how often an individual collaborated rather than how broadly they collaborated. This index, was calculated using the frequency of collaboration with: university-employed researchers/scientists, government-employed researchers/scientists, fisheries managers/policy makers, industry representatives (i.e. commercial fishing sector fish buyers, etc.), local people and stakeholders (including indigenous people, those directly impacted by fish research), environmental/conservation-related non-profits/ other organizations, and other. The frequency was measured on a scale of never (0), rarely (1), occasionally (2), and often (3). The scores for each collaboration were summed to make up the collaborative frequency index. The index thus ranged from 0 for someone who never collaborated up to 15 if they collaborated often with all groups.

Lastly, the *telemetry involvement* factor (telemetry_score) describes how involved an individual is with fish telemetry research and networks. This was measured using three indicators that included: i) the percentage of their research that involves fish telemetry research with scores of 1 for <10%, 2 for 10-25%, 3 for 26-50%, 4 for 51-75% and 5 for >75% ; ii) the number of fish telemetry projects they have been involved in as a principal investigator, where a score of 0 was given for none, 1 for 1-4 projects, 2 for 5-9 projects, 3 for 10-15 projects, and 4 for >15 projects; and, the number of years the individual has been involved in telemetry research where score of 1 was given to 1-4 years, 2 for 5-9 years, 3 for 10-20 years, and 4 for > 20 years. All scores were summed to provide an index for telemetry involvement ranging from 2 (indicating very low involvement in fish telemetry) to 13 (for someone highly involved in fish telemetry).

5.3.5 Qualitative data analysis

Responses to the semi-structured interviews were categorized and coded using qualitative analysis software, NVivo 10. The transcript of each interview was coded by the number of times a particular theme was mentioned (i.e. number of mentions), that made up the metrics of our results. The reported results are therefore not mutually exclusive, because individual respondents may have mentioned multiple themes in one response. Anonymous direct quotes from interviews and questionnaires were used to illustrate themes emerging from our qualitative analysis.

5.4 Results and Discussion

5.4.1 Characteristics of respondents in the study

The majority of respondents from our study are male (82% of 222), with an average age of 42 years, with most participants between 30-59 years old (84%) (Table 5.1). Most of the researchers work in North America (67% of 212), followed by 20% from Europe and the rest elsewhere (Table 5.1). Most respondents worked with acoustic telemetry technology (N=200), followed by radio telemetry (n=107) and satellite (n=70). These categories were not mutually exclusive. Thirty-nine percent of respondents conducted research in the marine environment, 24% did research in exclusively in freshwater environments, and 37% worked in both environments including estuaries.

We sought to target researchers with “expertise” in fish telemetry and of our respondents, 79% had five years or more of telemetry experience (Table 5.1). Seventy percent of our sample population had been a principal investigator on a fish telemetry project. Nearly half of our sample population had been involved in 1-4 telemetry projects as a principal investigator, and the average respondent spent about 38% of their research time on fish telemetry research (Table 5.1). The number of peer reviewed publications by individual respondents ranged from one to > 26 publications. About half of the respondents published less than five peer reviewed articles (non-telemetry work included), and just under half (43%) published less than five non-refereed articles, while 20 respondents (8%) published in excess of 26 peer reviewed publications. More than half the respondents are members of a telemetry network (55%), the remainder are not (45%).

Most of our respondents are employed by academic institutions (44% of 334 responses), followed by government (26% national, 16% regional), with less than 10% employed by NGO/NPOs, private organizations or industry.

5.4.2 Current data sharing in fish telemetry

We found that slightly less than half (44%) of surveyed researchers had participated in data sharing on public databases (Fig. 5.1). This was slightly lower than that reported by Tenopir and colleagues where in a relatively recent cross disciplinary survey of scientists found that 54% of respondents made their data available electronically to others (Tenopir et al. 2011). That same study also revealed that less than 6% of scientists actually make “all” of their data available. Given the latter, it appears that data sharing among fish telemetry scientists is relatively high; however, almost a third of respondents chose not to answer our questions with regards to data sharing, which might suggest an inflated return.

Of the researchers who participated in sharing telemetry data, 40% still had concerns with sharing (Fig. 5.1) suggesting that existing data sharing protocols and/or standards may not adequately address all the concerns of our participants. Interestingly, 60% of those who had not shared data reported they had no reservations about doing so, indicating that there were other reasons for the lack of participation beyond concerns that I explore below. The lack of familiarity/opportunity or lack of culture (normative pressure) of sharing data in ecology or, specifically, in aquatic telemetry, may be a limiting factor as it is still a relatively novel concept. This may also be related to a perceived lack of incentives or rewards for ecologists generally to share data (Kim and Stanton 2011).

Overall, 32% of the 209 respondents who answered data sharing-related questions have used shared data related to fish telemetry. Interestingly, of those who have *not* participated in sharing data, 79% reported that they have *used* shared data (Fig. 5.1), suggesting that our sample may comprise of a number of data analysts or secondary data users.

5.4.3 Characteristics of individuals more likely to share data: logistic regression

The intercorrelation matrix (Supplementary Information Table S5.1) indicates that data sharing is associated with the following variables: individuals engaged in *satellite telemetry* research; *saltwater research*; members of a *telemetry network*; *older researchers*; having a *track record of collaborating*, and; having a *high number of publications* (except for the highest category, 20+ articles). I further explore this using a logistic regression analysis that compares the attributes of researchers who share telemetry data and those who do not (Table 5.2). When considered together, model variables accounted for approximately 32% of observed variance (based on Pseudo R^2). Several attributes stand out as being particularly significant.

First, researchers who are *frequent publishers* (published between 5-9 and 10-20 articles) are significantly more likely to have shared data (Table 5.2). In fact, those who have published between 5-9 articles were about 9 times more likely to have shared data than those who do not publish, and those who have published 10-20 articles were 13 times more likely to have shared telemetry data. Second, the *collaborative extent* of an individual has a positive association with sharing. A one-point increase on the collaboration index is associated with a 30% increase (1.3 times) in the odds of having shared data. Similarly, researchers who are *part of a telemetry network* are 2.8 times more likely to have shared their telemetry data than those who are not members of a network. Third, the technology used by researchers appears to be important.

Researchers who use *radio and/or acoustic telemetry technology*, and researchers who work for a *regional government agency* are less likely to have engaged in sharing data than those who are not in these categories (Table 5.2).

The findings above highlight the gap in data sharing among the fish telemetry community. Regional government agencies do not often have the capacity and resources to share data and are usually focused on local issues with less priority for broader scale issues. More importantly, there are potential disincentives to share data as a manager because of government security concerns, and the potential for being challenged by others who are reusing the data such as concerns of being challenged for mismanaging a resource if their data was revisited, or perceived risk of being accused of poor science in management by others reanalysing the data. As such, data sharing may not be a priority for regional governments and they may not perceive a benefit from networking.

Overall, it appears that individuals who are highly productive (high number of publications) are also highly collaborative and engage in telemetry networks, which suggests that individual traits may be a significant factor driving participation in data sharing. Discussions around individual personalities and traits are beyond the scope of this study but nevertheless may play an important role in understanding collaborative tendencies and motives to share data. Those who are highly productive also have tendencies to work with satellite telemetry in the ocean environment. Satellite telemetry researchers often collaborate with oceanographers to understand animal behaviour and response to oceanographic variables. Data sharing in oceanography is an accepted norm (e.g., International Oceanographic Data and Information Exchange; National Oceanographic Data Centres; World Ocean Database, Reed et al. 2010, Levitus et al. 2013), thus the exposure of respondents to this culture may be reflected in our findings, where satellite telemetry researchers tend have a stronger track record and participation in sharing their telemetry data than those involved in radio and/or acoustic telemetry.

We also compared responses on research motivation to data sharing (Table 5.3). Two motivations for researcher choice of research questions/agenda were significantly associated with data sharing: i) “Importance to society”, and ii) “Length of time required to complete the research". Each one-point increase on the Likert scale was associated with a 2.7 time increase in the odds that a researcher had shared data. Conversely, researchers who agreed that "length of time required to complete the research" is important in their research agenda were less likely to have shared (each one-point increase on this item is associated with a 46% decrease in the odds of having shared data 1.0-0.545 = 0.455; Table 3). In our view, these are significant findings that suggest a way for funders, universities, and governments to encourage data sharing. Prior research has shown that scientists who are motivated primarily by time considerations are typically under pressure to meet productivity requirements for tenure, promotion, or otherwise (Anderson et al. 2007, Cooper 2009). Such pressures are clearly not conducive to data sharing, whereas the more altruistic "importance to society" motivation is. Productivity measures should be rethought to include data sharing as a research productivity measure for academic activity. For example, the potential to include data sharing or open practices in productivity indices found on scholar's profiles such as Google scholar, ResearchGate or Academia could incentivize open practices.

5.4.4 Concerns with sharing telemetry data

Overall, 39% of respondents expressed concerns about sharing their telemetry data (Fig. 5.2). When respondents were asked if these concerns had ever materialized (not necessarily with fish telemetry data), only 11 of 39 individuals reported yes. Of those who reported that their concerns materialized, 4 had participated in data sharing and 7 had not (Fig. 5.1) suggesting that some of the concerns reported by fish telemetry researchers are based on negative experiences outside of fish telemetry research. Seven themes related to concerns regarding sharing fish telemetry data emerged from open-ended responses and dialogue (Fig. 5.2). It appears that most fish telemetry researchers' concerns fall within the "individual motivational factors" category reported by Stanton and Kim 2012. These concerns included *perceived risks* of misinterpretation, data usage before publishing, ownership, lack of recognition, exploitation of information, non-reciprocal sharing of data, and *perceived costs* of sharing (time and effort). I further grouped these perceived risks and costs into three broader categories: i) concerns pertaining to the *misuse of data*; ii) concerns related *to lost opportunity and ownership*; and, iii) *technical and logistical* concerns (Fig. 5.2).

Table 5.1: Socio-demographics and characteristics of the respondents in frequencies and percentages. Asterix (*) denotes categories that are not mutually exclusive

Variables	N	%	Variables	N	%	Variables	N	%
Gender (n = 222)			***# projects as principal investigator***			***Refereed articles*** (n=253)		
Female	40	18	(n = 280)			1-4 articles	140	55
Male	182	82	None	68	24	5-9 articles	60	24
			1-4	131	47	10-14 articles	18	7
Employer*			5-9	45	16	15-20 articles	13	5
Academia	146		10-14	12	4	21-25 articles	2	<1
Federal government	86		>15	24	9	26+ articles	20	8
Provincial or state government	54							
Industry	8		***Location*** (n = 212)			***Non-refereed articles***		
NGO/NPO	21		N America	141	67	**(**n=209)		
Private	19		Europe	36	17	1-4 articles	118	56
			S Pacific	16	7.5	5-9 articles	44	21
Telemetry experience (n= 220)			United Kingdom	6	3	10-14 articles	18	9
1-4 years	47	21	Asia	5	2	15-20 articles	13	6
5-9 years	74	34	Central and S America	5	2	21-25 articles	2	<1
10-20 years	71	32	South Africa	2	1	26+ articles	14	7
>20 years	28	13	Middle East	1	0.5			
						Telemetry portion of		
Age **(n=222)**			***Research Environment*** (n =224)			***research*** (n=220)		
20-29 years	20	9	Marine	87	39	<10%	58	26
30-39 years	88	40	Freshwater	53	24	10-25%	42	19
40-49 years	58	27	Both	84	37	26-50%	54	25
50-59 years	38	17				51-75%	26	12
60-69 years	14	6	***Telemetry Method****			>75%	40	18
70 + years	3	1	Radio	107				
			Acoustic	200		***Telemetry Network*** (n=302)		
			Satellite	70		Yes	123	55
						No	99	45

Table 5.2: Results of the binary logistic regression (degrees of freedom=19) to test for significant effects of independent variables that were included in the model exploring relationships between individuals who shared vs. have not shared their fish telemetry data. The odds ratios are the change in odds for a one-unit increase in continuous variables and for a change in factor levels for categorical variables.

Variables included in final model	Coefficient	S.E.	Wald	Significance	Odds ratio
Demographic					
Age	0.027	0.019	1.41	0.159	1.027
Fish Telemetry Research characteristics					
Freshwater	0.153	0.487	0.31	0.754	1.165
Saltwater	-0.066	0.553	-0.12	0.905	0.936
Radio telemetry	-1.366	0.511	-2.67	**0.008***	0.255
Acoustic telemetry	-2.707	0.748	-3.62	**< 0.001****	0.067
Satellite telemetry	0.531	0.434	1.22	0.221	1.701
Employer or affiliation					
University	-0.866	0.633	-1.37	0.171	0.420
Federal Government	-0.67	0.651	-1.03	0.303	0.511
State/Provincial Government	-2.01	0.798	-2.52	**0.012***	0.134
NGO/NPO	-1.41	0.899	-1.57	0.117	0.244
Private	0.066	0.859	0.08	0.939	1.07
Industry	-2.113	1.32	-1.59	0.111	0.121
Research activity					
Telemetry involvement (index)	0.158	0.091	1.73	0.084	1.172
Number of refereed publications					
1-4 articles	1.488	0.796	1.87	0.062	4.427
5-9 articles	2.236	0.899	2.49	**0.013***	9.359
10-20 articles	2.570	0.988	2.6	**0.009****	13.06
20+ articles	1.374	1.081	1.27	0.204	3.952
Collaboration extent (index)	0.286	0.073	3.9	**<0.001****	1.331
Belong to telemetry network	1.013	0.424	2.39	**0.017***	2.754

*Denotes significance at α=0.05 ** significance at α=0.01

Table 5.3: Results of the binary logistic regression to test for significant effects of 15 criteria for respondent choice of research questions/agendas on the whether respondents have shared or have not shared fish telemetry data.

Research motive variable	Coefficient	S.E.	Wald	P value	Odds ratio
1. Create research environment suitable for graduate training	-0.059	0.177	0.112	0.738	0.942
2. Scientific curiosity	-0.51	0.315	1.728	0.189	0.661
3. Importance to society	0.989	0.315	9.858	**0.002***	2.689
4. Desire to protect fish and improve sustainability of fisheries	0.149	0.335	0.197	0.657	1.16
5. Availability of funding	0.246	0.243	1.028	0.311	1.27
6. Length of time required to complete the research	-0.607	0.228	7.114	**0.008***	0.545
7. Potential contribution to scientific theory	-0.05	0.256	0.038	0.846	0.952
8. Recognition from your peers and the scientific community	-0.067	0.261	0.066	0.797	1.069
9. Potential contribution to conservation and management policies	-0.439	0.339	1.673	0.196	0.645
10. Industry consulting opportunities	-0.231	0.301	0.592	0.442	0.793
11. Priorities of your employer	-0.254	0.208	1.493	0.222	0.776
12. Probability of publications in major professional journals	0.152	0.236	0.417	0.519	1.165
13. Personal or professional interest	0.404	0.326	1.535	0.215	1.498
14. Potential to generate income for my lab/employer	-0.041	0.24	0.03	0.863	0.959
15. Potential to generate personal income	0.062	0.253	0.06	0.806	1.064

*Denotes significance at $\alpha=0.05$

Figure 5.1: Flow chart breaking down the responses of respondents who have participated in data sharing relative to those who have not.

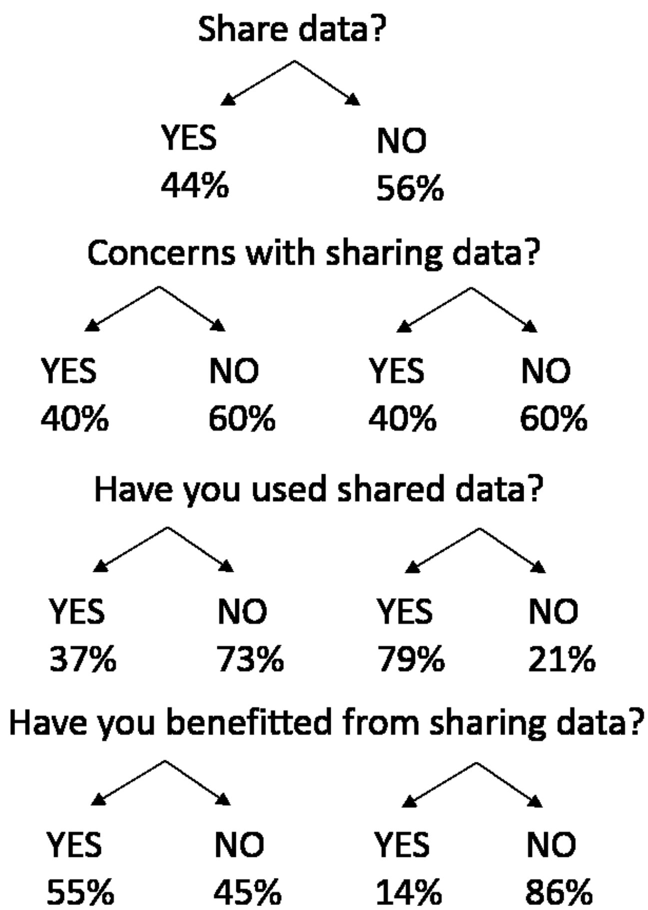
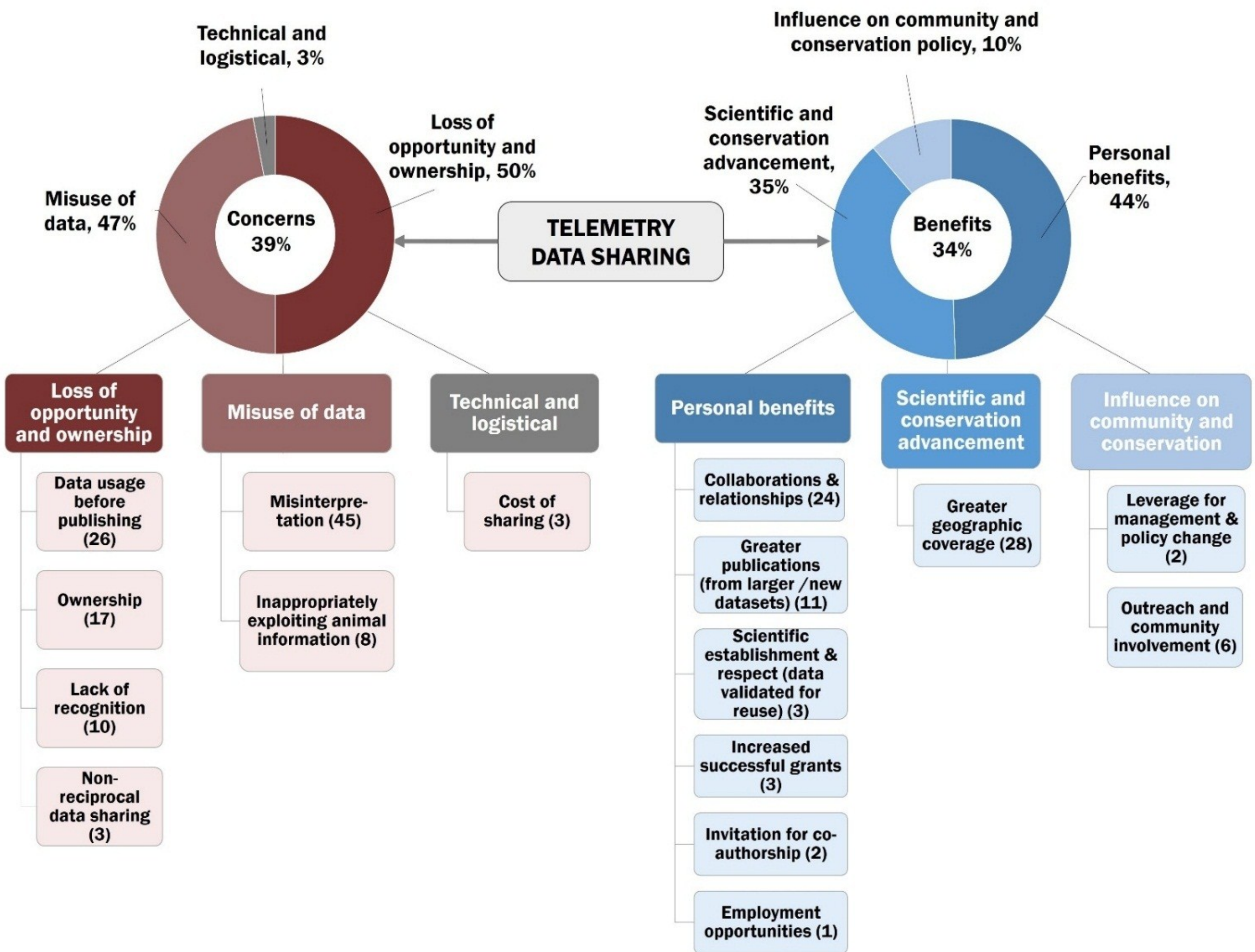


Figure 5.2: Infographic illustrating the reported **concerns** with, and **benefits** of sharing telemetry data. The overall percent of respondents with concerns and experienced benefits are shown in the centre of the donuts. The broad emerging themes for concerns and benefits are depicted in the donut chart, while the breakdown into subtopics of each broad theme are found below the concerns and benefits donut chart. Numbers in parentheses represent the "number of responses coded".



5.4.4.1 Concerns pertaining to the misuse of data

Misinterpretation

The most reported concern was the potential for *misinterpretation* of the data (45 mentions), such as data being analyzed without a full understanding of the design, nuances, caveats, and complexity of the study (Fig. 5.2). The nuances and caveats of telemetry data are critical for its interpretation, particularly understanding the condition of the animal, the tag and/or handling effects, the capture method, environmental conditions and other important variables that may influence the animal's behaviour and tracking data. Investigators reported to us nine specific instances in which they felt shared data has resulted in misinterpretations. One example shared is illustrated below:

> *One of the guys used my data as advertisement for sharing. I went to a meeting and he presented my data wrongly…. To me it emphasized that it was dangerous to have data out there that anyone can pull off the web and do what they want*. (Female, 20-29 years, North America)

It is not surprising that concerns about misinterpretation of shared telemetry data was the most frequently reported. Many of the available telemetry studies have been exploratory, marking the first-time detailed movement patterns have been documented for individual animals of valued species facing conservation or management problems (Cooke 2008, Hussey et al. 2015). Frequently, these studies were also conducted over relatively short time frames, with small sample sizes due to costs and other challenges. All of this could lead to potential biases in the data that are known to the data collector but potentially less so by those who re-use the data. Telemetry data can be complex and challenging to interpret due to variation in detection range and efficiency, how telemetry arrays are designed, availability of satellite coverage, or what it means when an animal is not detected. Failure to understand the limits of detection ranges of receivers can cause biases and misinterpretations of data (Kessel et al. 2013). Also, there are concerns that interpretations made based on restricted datasets and are supportive of particular ideas or hypothesis, can have alternate conclusions, or more nuanced and different interpretations when the analysis includes larger datasets.

Potential for inappropriately exploiting shared information

Data producers also expressed concerns about not knowing how shared information could be used. Although only a handful of participants raised issues about inappropriately *exploiting information* (8 mentions), it is still a factor to consider by large networks, which act as central databases (Fig. 5.2). As an example, one study participant raised the potential issue of “large companies (e.g., resource extraction, shipping, hydropower) discovering data about sensitive species that might be impeding that company’s progress and removing that species”. Many of the species that are the subject of tracking studies are either economically valuable or imperiled (Hussey et al. 2015). Those interested in exploiting (including poaching) such organisms could use tracking data to focus their harvest efforts. For imperiled species, any level of fishing mortality may be problematic and make it difficult or impossible to achieve recovery targets. For commercially exploited species, tracking data could be used to make harvest so efficient that it pushes fisheries to collapse (Dewar 1998). This issue has arisen in freshwater where anglers attempted to argue that tracking studies on gamefish conducted using “tax dollars” should be made public under the premise that it would show the anglers where fish are distributed in space and time (see Grover 2001). It may also create opportunities for those with interests in culling species (e.g., sharks or other predators that could be regarded as threats to humans) to pursue unauthorized efforts (see Meeuwig et al. 2015).

It is thus not surprising that the tracking community has concerns about how the data that they generate could ultimately be used. It would be counterproductive if a study was initially conducted by a researcher in an effort to identify critical habitat for an endangered species to only find that information exploited by those that use the information to harvest that species (Cooke et al. 2013). To alleviate this concern, it would seem appropriate that some tracking data, especially for endangered species, not be put in a fully public database but rather have access given only to those individuals/projects for which the goals are consistent with existing legal requirements and whose objectives are enhancing conservation and resource management.

5.4.4.2 Concerns related to loss of opportunity and ownership

The next most frequent concern is the issue of *ownership* (17 mentions) and of *data being used before the authors could publish it*, which is similar to being "scooped" (someone appropriating and publishing an idea before the originator has a chance) (26 mentions, Fig. 5.2). One respondent expressed this concern as particularly relevant for long-term studies. The concern of data ownership is particularly acute with regards to the efforts and expense of field work. These sentiments are illustrated below:

> *Someone might use the data before I get the chance to publish all my papers. It was expensive to collect and took a lot of effort! Nonetheless once I have published all my papers I would be happy to publicly archive the data- in fact I probably should.* (Male, 30-39 years old, North America)

Five respondents mentioned incidences where their data was published or presented without recognition:

> *I had one project where we collected a fair bit of telemetry data on juvenile [species], it was actually a really challenging project, a huge design phase with the telemetry company to build tag for little [species], involved needing to recapture individuals to remove the transmitter etc., we shared some of that information with another researcher and then ultimately a publication came out of it without any acknowledgement.* (Male, 40-49 years old, North America)

There were also reported concerns that there would be *lack of recognition* (10 mentions) or *non-reciprocal sharing of data* (3 mentions; Fig. 5.2). One respondent said they had "*lots of experiences where I have given data to people and some of them I handed over the data. I never heard a word and the paper was published. They never asked a single question*". (Male, 30-39 years old, North America)

Data are extremely valuable, and their value as long-term baseline continues to increase. Telemetry data, in particular, are large data sets, expensive to collect, curate, and often to analyze, requiring significant investments of both time and money to capture, tag, and track the animals. A key question is whether tagging an animal assigns ownership over that animal's movement data and whether it is ethical to withhold such data. In the medical realm, Vickers (2006) argued that a patient providing data on their personal condition does so for the advancement of the science rather than the individual researcher's agenda, raising ethical quandaries about the right to withhold any such data from other researchers who may use it to advance the field. In fish telemetry, arguments have been made that over-sharing of animal movement data can lead to increased exploitation of a species and be detrimental to its survival (Cooke et al. 2013, Margenau 1987) as mentioned above.

Sharing data has the potential to be used as part of a new idea or study or even simply be reimagined by a different analyst to become completely novel. Ecological data are particularly applicable to synthesis and meta-analysis to identify long-term or global trends in animal movement or behaviour that transcends the scope of individual studies (Porter 2010, Stewart 2010). This type of use of shared data could be construed as ignoring the contributions of the original scientists who went to great lengths to tag, record, filter, and compile the data (Moles et al. 2013). Scientists who share their data may thereby feel exposed to being scooped, having their own study overshadowed by a more comprehensive meta-analysis, or to criticism of their data collection or analysis. However, such concerns are generally counterproductive to science (Vickers 2006) and were found to rarely materialized among telemetry scientists in our survey, with only 11 of 39 respondents who expressed concerns, indicating negative experiences with data sharing. With better sharing conventions and standards for recognizing those who share data, such concerns should become less common.

5.4.4.3 Technical and Logistical concerns

The cost to sharing data was only mentioned three times (Fig. 5.2) although this seemed to be a significant concern in the literature (e.g., Tenopin et al. 2011, Stanton and Kim 2012, Borgman 2012). This concern is illustrated by one of the respondents below:

> *Yes, it is a lot of work to share data. Some of my funding agencies are beginning to require sharing of data, but are not giving us the upfront tools or funding to make this a reality. I think it is easier to do if you understand, from the beginning of a project, that you will be sharing the data. Then you can organize it such that it is easier to share later*

on. Also, I sometimes work with very large telemetry datasets (some in the petabytes) and there is no such data sharing service available that can handle this large of a dataset. (Male, 30-39 years old, North America)

The requirement on the part of funding agencies that investigators store and make available the data they acquire with public funding is rapidly becoming the norm internationally, and as noted the obligation has in many circumstances preceded the ability for individual investigators to accommodate the requirement. National authorities have recognized the benefit of archiving the long-term data for monitoring purposes, and have moved or are moving to incorporate animal telemetry data within national ocean data registries. Australia's Integrated Marine Observing System has a national aquatic animal telemetry data system for its centralized Animal Tracking database (http://imos.org.au/animaltracking.html). In the USA, the US Integrated Ocean Observing System (US IOOS) is currently developing a national telemetry data system (Block et al. 2016), and Canada's Ocean Tracking Network and has been heavily involved internationally in developing new data nodes that are mutually compatible in order to facilitate data exchanges (http://members.oceantrack.org/data/discovery/GLOBAL.htm). These resources will hopefully address many of the archiving and cost issues currently of concern to the scientific community.

5.4.5 Benefits to sharing telemetry data

Perceived benefits to sharing data may increase the likelihood of adopting data sharing (Stanton and Kim 2012). In our study, about a third of individuals (34% of 182) reported actual benefits from publicly sharing their research data (Fig. 5.1). Of those who have benefitted, 49 respondents already participate in data sharing, whereas 13 had not shared telemetry data but still benefitted (presumably from sharing other types of research data). The fact that only about one third of the respondents reported benefits also suggests the lack of rewards and incentives that currently exist for sharing telemetry data. Nine categories emerged based on reported benefits of sharing fish telemetry data were described by respondents (Fig. 5.2, Table S3). These categories were further grouped under three broader themes of benefits to sharing data such as: i) scientific and conservation advancement; ii) personal benefits; and, iii) influence on community and policy (Fig. 5.2).

5.4.5.1 Scientific and conservation advancement: tackle more questions and complex problems

The most frequent described benefit is the increased geographic coverage of receiver/detection in a study area (Fig. 5.2). For example, one respondent mentioned that "*with the growth of ACT and FACT Network, we now have the ability to monitor individuals over a much greater spatial (and temporal) range. This was something that was unanticipated (at the start of our project) but has allowed our project to grow extensively*." (Male, 30-39 years, North America)

Other common benefits that have materialized by sharing telemetry data are collaborations and opportunities for co-authorship. One respondent said, *"my students have benefitted directly with the number of manuscripts published with information provided from others. There is absolutely no way we are going to answer the questions unless we get cooperation*." (Male, 50-59 years, North America)

Big science costs big dollars. However, if big telemetry science can be accomplished by using a distributed model where many partners participate (e.g. funding agencies, journals), big science becomes affordable and realistic (Poisot et al. 2013). This is the opportunity that has arisen with the deployment of acoustic telemetry receiving infrastructure around the globe. Provided that researchers use compatible technology, animals tagged in one location can be detected elsewhere. At times, telemetry arrays are purposefully built over large spatial scales (e.g., Welch et al. 2002, Cooke et al. 2011) while in other cases it is purely serendipitous that a tagged animal is detected on a receiver deployed in a far-off locale by a different research team (see Welch et al. 2006 for example of a white sturgeon that was tagged in California but detected in the lower Fraser River of British Columbia). As the use of the technology expands, such examples are becoming routine. A recent synthesis on the big questions in the movement ecology of marine megafauna identified a number of fundamental and applied questions that are best addressed through the use of large-scale telemetry arrays (on the continental and/or ocean basin scales) that will only be possible if data are shared (Hays et al. 2016). Additionally, sharing telemetry data and increasing the detection range can allow for more complex and larger scale questions to be asked. As a result, telemetry findings are more likely to be relevant to management and conservation questions, which not only can help advance our scientific knowledge of fish ecology but also contribute to improving management practice and conservation strategies (Crossin et al. 2017, McGowan et al. 2016).

5.4.5.2 Personal benefits: increased recognition, productivity and career advances

Data sharing can directly benefit one's career and recognition in the scientific community. One of the most cited benefits of data sharing is the number of collaborations, publications and co-authorship that result from sharing activities (Fig. 5.2). For example, sharing data has provided greater numbers of detections and expansion of telemetry arrays, which led to more data and therefore more publications. One respondent mentioned that sharing their data resulted in direct *employment opportunities*, while other respondents have reported that sharing telemetry data has helped them gain more respect and become more *established in the scientific community* (3 mentions):

> *So far, mostly just respect of other researchers that you are willing to share. I haven't realized specific benefits yet, but I expect them to happen as time goes on and data sharing becomes more socially acceptable. There is a very old paradigm of not sharing scientific information in this world, and I look forward to this changing so that we can learn even more from each other.* (Male, 30-39 years old, North America)

Similar to other fields like medicine, sharing data has led to higher citation rates and recognition (Piwowar et al. 2007); however, these benefits extend beyond the publication metrics. The reuse of data can be taken as a strong indicator that the original study was well performed and influential to the field (Costello 2009, Spires-Jones et al. 2016) and are given more credit by the scientific community in ways that can lead to greater career success (Whitlock 2011). The increase in citation rates and research credibility of individual projects would not only benefit the individual, but also the field of telemetry itself. Furthermore, sharing data can also result in more *successful grants and funding* (3 mentions). However, telemetry is a slow process, and for acoustic telemetry, data may only be downloaded once or twice a year, which may lead to a potential lag time in benefits reported. The telemetry networks that do exist are relatively young and it may be too early to fully understand the potential benefits. Still, highlighting these tangible rewards and benefits could help shift the culture towards a more sharing one.

5.4.5.3 Sharing data to influence community and policy

There were six mentions of instances where sharing data acted as means of *public outreach and community engagement*, and three mentions of *influencing management and policy*. Most were examples provided by respondents from the satellite tracking of sharks where information was placed on websites to increase public awareness. This may be a useful model for others to explore avenues of engaging the public using telemetry data.

One respondent describes their experience with sharing data and using it publicly:

> *[Sharing data] allows people to see the results very quickly whereas with a scientific model, we study for 2 years then analyze data then publish in [a] journal. May take 3.5 years from when you started, it is inaccessible to people, how many members of the public will pick a journal and fight their way through it. With real time capabilities, people have the instant gratification that people expect now, primarily funded by tax payers. I felt it was appropriate that stakeholders could see their investment, even though it was not a requirement. Also, it reduced the shock element of the results. People are looking and learning as they go along, outreach benefits of doing that, the reach at local levels, we would get emails from teachers in Europe with all pupils following shark tracks, we would be at in a little tiny boat harbour with our boat with tagging dirty stuff and people encouraging and allowed public access to see the track. This connected them, and led to level of grassroots support in the community.* (Male, 40-49 years old, North America)

Sharing animal tracks on websites and social media has led to increased interest by the public. Examples include the telemetry tracking of “sea turtle races” across the Atlantic, and white sharks that have their own Twitter accounts. One satellite tracking website (Satellite Tracking and Analysis Tool) that facilitates data sharing and visualization, enables the public to follow various species of animals in almost real-time track leading to articles in national and international television, radio, print and online. One sea turtle website had over 2 million visits in two years of operation (Coyne and Godley 2005) and has provided subsets of tracking data to teachers for educational activities in the classroom. Sharing data publicly has been shown to raise awareness and increase public education about tagged animals, as shown by numerous articles in national and international television, radio, print and online news outlet (Coyne and Godley 2005).

Furthermore, the sharing of environmental and fish capture data in Western Canada by government agencies and community-based experts has allowed competing, and often disagreeing, parties to agree on management strategies for British Columbia salmon fisheries (Pinkerton 1999). In this instance, data was available equally to the aboriginal fishing groups and state agencies, to university analysts, and to the public. A neutral, third party, the University of Washington, analyzed these data and validated the tribes and state management agencies' catch records. The arrangement has enabled these co-managing parties to resolve some of their disagreements about management actions, because they can at least agree on the core data (Pinkerton 1999).

5.5 Conclusion

Unlike big science such as genomics and physics, many ecologists tend to undertake so-called 'small science' conducting hypothesis-driven research led by a single principal investigator (Knorr Cetina 1999). Telemetry is one of the new technologies driving a move to more collaborative, large scale, and big science; but, this requires structures that support project coordination, resource sharing and standardized information flow (Lynch 2008, Cragin et al. 2010, Reichman et al. 2011). As researchers use common technology, there are new opportunities to share data that can extend the reach of a given study. Moreover, data sharing can provide the broader research community with the opportunity to ask questions or test hypotheses on new scales, often not envisioned by the research team that tagged the animals in the first place. Currently, some researchers share data, but others remain reluctant to do so. In the realm of animal tracking, this is the first study of its kind to explore concepts of data sharing among fish telemetry researchers. As revealed by a recent synthesis (Hussey et al. 2015), aquatic telemetry continues to grow exponentially. To fully realize the benefits of this growth it is necessary to understand the perspectives of fish telemetry researchers on data sharing.

We believe that it is necessary to promote the shift of data sharing as a culture within the fish telemetry community in order to achieve the potential that aquatic telemetry has for future sustainability of aquatic resources. However, achieving this remains a challenge with some members of the telemetry community expressing continuing concerns such as: i) misuse of the data, particularly misinterpreting data that has been taken out of context; ii) motivational concerns such as loss of opportunity and ownership, and; iii) technical and logistical barriers that will arise if data sharing is to be part of the fish telemetry science culture. To counter these concerns, I suggest that the tangible benefits identified in this study need be promulgated to the community in an effective manner. These benefits include i) scientific advancement, an enhanced ability to tackle complex problems and answer more detailed questions cost effectively over greater temporal and spatial scales, ii) personal benefits including advancements in careers and productivity, iii) benefits to the wider community and for conservation.

The findings from survey will assist the leadership of telemetry networks as well as those engaged in funding telemetry research on developing data sharing mechanisms that address researcher concern re sharing. In addition, the examples emerging from this survey provide the research community with tangible examples of both the benefits of sharing as well as the potential pitfalls with doing so. From my perspective, it is not about sharing or not sharing – rather, how to parameterize the rules and mechanics of sharing to protect the interests of the researchers as well as to ensure that doing so does not compromise the conservation of aquatic resources (e.g., by identifying the spatial ecology of an endangered species for conservation and then using that information to target them for harvest). Based on the findings, I provide recommendations for fostering the shift towards a data sharing culture among the fish telemetry community (Box 5.1).

Box 5.1: Recommendations for moving towards data sharing as a norm in fish telemetry science

1. *Raising awareness of the benefits and value of sharing fish telemetry data*:

A number of personal benefits were reported in this study as well as benefits to the wider community. Highlighting and promoting the benefits resulting from sharing data and the value of sharing data may encourage fish telemetry researchers to participate. The fact that a number of researchers do not share data and did not have concerns with sharing data suggests that lack of familiarity and awareness could be a reason for lack of data sharing. Furthermore, most ecologists and those engaged in conservation research such as fish telemetry researchers do so to inform management and conservation practices. We show that individuals whose research agenda is dictated by the importance to society are likely to share data, and we believe that many fish telemetry researchers have altruistic motives to make an impact on society and conservation (Costello 2009). As such, the motivation already exists, but there is a need to address concerns and raise awareness on the importance of sharing telemetry data and potential benefits to do so. We see a role for existing database networks to act as stewards in raising awareness and promoting the benefits of sharing telemetry data.

2. *Appropriate rules, protocols, enforcement and norms need to be established by telemetry database networks*:

In spite of good intentions, guidelines or suggestions tend to be ineffective for encouraging data sharing, indicating that rules and requirements must be established to surmount inaction among researchers (Eysenbach and Sa 2001). Reichman (2011) reported in *Science* that "the concern is that if data are made openly available in the interim they may be used by other investigators, effectively scooping the data originators. Properly curated data alleviates this concern, as the use of data without permission or attribution would be recognizable to other scientists and condemned by colleagues and funding sources. Proper curation requires time and money and is inadequately supported in research funding". In this study, we found that fish telemetry researchers were relatively less concerned with the proprietorship of data or being scooped. Respondents also reported direct benefits to the data producer such as greater number of detections for their projects, new collaborations, and publication opportunities. Creating appropriate sharing policies, and norms or etiquettes that foster collaborations, co-authorship, and transparency between the data producers and users can promote the benefits of data sharing while addressing the concerns of misuse of the data.

3. *Funding agencies, institutions and institutional repositories as stewards for data sharing through restructuring rewards and incentives:*

Institutions, repositories (publishers), and funding agencies can act as stewards for the mobilization of scientific research data and data sharing (Cragin et al. 2010). Funding agencies are moving towards requiring data sharing plans in research proposals (Vickers 2006; Hampton et al. 2013), but it is journals that will act as gate-keepers, if they begin a coordinated effort to require open data it will rapidly become the norm. This is already standard in genetic research (Ball et al. 2004) and has engendered a convention of data sharing in which data are published in public archives after publications even when not required (Hampton et al. 2013). Tenopir et al (2011) reported that most scientists they surveyed reported insufficient time and lack of funding as reasons why they do not share data. Funding agencies and institutions thus have a role in creating incentives for data sharing rather than high productivity as we have shown that researchers concerned with the turnaround time of their research projects are less likely to share data. Incentives and recognition for sharing data may go a long way. In 2014, the journal Psychological Science adopted three Center for Open Science badges, which are badges rewarded to papers that use transparent practices. Following this adoption, there was an increase in data sharing in psychological science from less than 3% to over 20% (Kidwell et al. 2016). Costello (2009) also suggested that data sharing motivation should follow similar structures as publication motivation whereby published datasets should be cited in publications.

4. *Standardizing data and fostering data management skills as a prerequisite for data sharing*:

Although very few respondents reported concerns related to the logistics or technological barriers of sharing their telemetry data, this may be an issue in the future if telemetry data evolves to big science and data sharing is to become a norm (as increasingly recognized with ecological and environmental data, Borgman et al. 2007). Past studies have shown technological and logistical challenges with transfers of large data files, data preparation costs, and unrewarded time and lack of resources dedicated to standardizing and preparing data (e.g., Cragin et al. 2010, Poline et al. 2012). To mitigate this, identifying sharable and appropriate data standardization before the end of a project would potentially reduce cost; providing appropriate IT support and structure to make data sharing easy; having embargo services that are flexible and controlled by the researcher; investments in data management consultation and planning to fish telemetry researchers prior to project starts can improve the data quality for synthesis, preservation, sharing and reuse (Lynch 2008, Cragin et al. 2010, Kolb et al. 2013). Promoting data management skills among the fish telemetry research community can also prevent misinterpretation of the data and improve data quality for reuse.

In this study, fish telemetry researchers were primarily concerned with data being misrepresented or misinterpreted, which may be complex to address (Cragin et al. 2010). In neuroscience, Koslow

(2000) suggested that the misinterpretation of the data could be overcome by including the relevant experimental conditions and variables in the database, however, the nuances of data collected in the field cannot be as easily represented. Nonetheless, identifying standardization of data and ensuring essential metadata is included in that standardization (e.g., handling time, capture gear, environmental conditions, injury indices, etc.) can help with better interpretation of telemetry data and provide researchers reusing the data with appropriate context (Lynch 2008, Kowalczyk and Shankar 2011).

5.6 Supplementary Information

Table S5.1 Intercorrelations matrix for logistic regression analysis

	Share telemetry data	Radio	Acoustic	Satellite	Freshwater	Saltwater	Age	TelemetryNetwork	University	Federal Government	State Government	Industry	NGO/NPO	Private	Collab_score	Telemetry_score
Share telemetry data	1															
Radio	-0.0421	1														
Acoustic	-0.1342*	-0.1079	1													
Satellite	0.3291**	-0.1415*	-0.1379*	1												
Freshwater	-0.055	0.5627**	0.0083	-0.2273**	1											
Saltwater	0.1682*	-0.2973**	0.2956**	0.3005**	-0.4127**	1										
Age	0.2255**	0.1918**	-0.0442	0.0731	0.1319*	-0.0032	1									
TelemetryNetwork	0.3364**	-0.0521	0.1790**	0.2110**	-0.0104	0.2686**	0.0747	1								
University	0.0111	-0.0633	0.021	0.0934	-0.0649	0.0756	-0.1600**	0.1290*	1							
Federal Government	0.0844	0.0456	-0.0611	0.0571	-0.0235	0.0509	0.1055	-0.0005	-0.4080**	1						
State Government	-0.1611*	-0.0526	0.0027	-0.1966**	0.0389	-0.1923**	-0.0205	-0.0798	-0.3735**	-0.2704**	1					
Industry	-0.0903	-0.0293	0.064	-0.0728	0.0122	-0.104	-0.1156*	-0.0512	-0.0335	-0.1024	-0.0758	1				
NGO/NPO	-0.0003	0.0588	-0.0091	0.0551	-0.0093	0.0573	-0.0582	0.0375	-0.1558**	-0.1697**	-0.1257*	-0.0445	1			
Private	0.0117	0.0324	0.0603	-0.0385	0.0502	0.0452	0.1714**	-0.0838	-0.1644**	-0.1609**	-0.0836	-0.0422	-0.0163	1		
Collaboration_score	0.3566**	0.1181*	0.0828	0.1242*	0.0965	0.1451*	0.087	0.3401**	-0.0795	0.0671	-0.0239	0.0627	0.0705	-0.0085	1	
Telemetry_score	0.3251**	0.2984**	0.2208**	0.1744**	0.2272**	0.1757**	0.3833**	0.4010**	-0.0415	0.0548	-0.0556	-0.1227*	-0.0499	0.104	0.3249**	1
No publications	-0.128	-0.0277	-0.2469**	-0.0259	0.0218	-0.1852**	-0.1675**	0.0315	-0.011	-0.0201	-0.0075	0.0284	0.1131*	-0.0751	-0.0218	-0.2393**
1-4 publications	-0.2275**	-0.2379**	-0.022	-0.1867**	-0.2102**	-0.0614	-0.1767**	-0.1990**	-0.0529	-0.0209	0.1089	0.0431	-0.0611	-0.0102	-0.2364**	-0.3586**
5-9 publications	0.129	0.0452	0.1270*	0.0058	0.0976	0.031	0.0834	0.0265	-0.0495	0.0592	0.0399	0.0179	-0.0103	-0.0305	0.1043	0.0703
10-20 publications	0.1972**	0.1192*	-0.012	0.1825**	0.0788	0.0806	0.1251*	0.1418*	0.098	-0.0252	-0.1158*	-0.0598	-0.0189	0.0321	0.1568**	0.2745**
20+ publications	0.0711	0.2109**	0.0842	0.1333*	0.1121	0.1675**	0.2087**	0.0999	0.0609	0.0181	-0.1103	-0.0499	0.01	0.1159*	0.107	0.4567**

* p<.05

** p<.01

Table S5.2: Concerns described by respondents with regards to sharing telemetry data in public databases

Concerns (coded)		Brief Description	Number of mentions
Misuse of data	Misinterpretation	Data taken out of context without understanding of the nuances can lead to misinterpretation of the data	45
	Inappropriately exploiting animal information	The potential for abusing and inappropriately exploiting locations of animals	8
Motivational: lost of opportunity and ownership	Data usage before publishing	Data being published before the data producer/collector had time to publish their own research	26
	Ownership	The sense of ownership of the data due to investments in collecting the data	17
	Lack of recognition	Lack of recognition or acknowledgements when sharing data	10
	Non-reciprocal sharing of data	Others not sharing their data in return	3
Technical and logistical	Cost of sharing	Time, effort and other investments in making data publicly available	3

Table S5.3: Benefits described by respondents as a result of sharing telemetry data in public databases.

Benefits (coded)		Brief Description	Number of mentions
Tackle more questions and complex problems	Increased geographic coverage	Greater detection coverage for study sites	28
Personal benefits	Collaborations	New collaborative relationships developed	24
	Publication	Publication as a result of new datasets or larger dataset	11
	Establishment and respect	Establishment and respect within scientific community as shared data have been validated for reuse	3
	Grants	Increased successful grants	3
	Co-authorship	Invitation for co-authorship	2
	Employment	New relationship or collaboration, and increased network which can lead to employment	1
Influence on community and conservation	Management and policy change	Greater leverage for influencing management practices and policy decisions	2
	Outreach and community involvement	Sharing animal movement data can engage public and educate public	6

Chapter 6: General Discussion

6.1 Synthesis and Future Research Directions

This Ph.D. dissertation examined factors that influence the mobilization of new knowledge into fisheries management actions. It is well established that there exists a divide between knowledge and action (Roux et al. 2006, Braunisch et al. 2012, Cook et al. 2013); therefore, I developed a knowledge-action framework and subsequently applied it to my data chapters to evaluate this gap. In particular, I explored the research question that asked what components of the knowledge-action framework have influence on moving knowledge (focusing on scientific knowledge) into practice or action (e.g., instrumental, symbolic, conceptual) (Chapter 1). The various data chapters of my dissertation support different aspects of the framework and have also added new information to help refine it. Chapter 2 provides strong evidence to support that the environmental and contextual dimension plays a large role in influencing knowledge outcomes. Chapter 3 provides support for the influence of relational dimension and knowledge transfer activities on knowledge action. Evidence from Chapter 4 supported the influence of characteristics of the knowledge on the knowledge outcomes. Chapters 2-4 yield support for the influence of characteristics and perceptions of knowledge actors (researchers, managers and stakeholders) on knowledge outcomes. Although Chapter 5 does not explicitly apply the knowledge-action framework, findings from the chapter offer evidence to support that knowledge actors and their perceptions and characteristics can influence actions, and in this case, sharing telemetry data. Furthermore, Chapter 5 illustrate that institutional norms, such as reward structures and sharing policies, can potentially act on individual motivations to engage in sharing data. These findings have important implications for the science-action literature, for improving the exchanges and data sharing between producers and users, and for resource management and conservation. Here, I focus my discussion on broad themes that my chapters reveal within the context of the knowledge-action framework. First, I will discuss the implications of the environmental and contextual dimension of the mediation sphere. Second, I will discuss the dynamics reported within the knowledge network of the mediation sphere (Figure 2.1). Third, I will discuss the implications of my findings regarding my fish telemetry and fisheries management model. Lastly, I will conclude with discussions on benefits, shortcomings and future directions of the knowledge-action framework.

6.1.1 The influence of environmental and contextual dimension on knowledge action outcomes

Chapter 2 revealed the importance and strong influence of the environmental and contextual dimension (EC) in influencing knowledge outcomes (or lack of). In particular, Chapter 2 highlighted the restrictive nature of some of the existing broader socio-political context, and institutional structures and norms on the use of new knowledge (Cvitanovic et al. 2015, Dick et al. 2016) from the point of the Fraser River salmon case study. All chapters revealed, in some form or another, that the environmental and contextual dimension sets the boundary in which the knowledge actors can have “impact”. That is, knowledge actors, those “on the grounds” working directly on the problem, must work within these boundaries**.** Similarly, when dealing with data sharing, institutional norms and structures influence how actors perceive advantages and disadvantages of sharing their research data (Chapter 5). The findings of this dissertation echo the importance and need for institutional innovations that enable conditions for meaningful knowledge exchange, encourage knowledge sharing, and to better align the two worlds of knowledge and practice.

In general, people involved in knowledge generation and use are embedded in institutions that have specific cultures, values, and incentives that can explain different behaviours (Merton 1973, Young et al. 2013). For instance, knowledge producers are often scientists who are embedded in a social system that places strong normative emphasis on particular activities, such as securing research grants and publishing in prestigious peer-reviewed journals (Miller 2005, Mcgrail et al. 2017). Career promotion, recognition, and other rewards associated with these norms provide strong incentive for academic scientists to use their time and communicate their research in particular ways (as shown in Chapter 3). The norms that govern scientists also encourage objectivity, rigorousness, and conservative communication and interpretations of findings (Merton 1957, Mulkay 1976). For example, academic reward systems rarely recognize interdisciplinary work, outreach efforts, collaborative activities (including data sharing) or activities and publication outside of peer-reviewed journals (Jacobs 2003, Macsia et al. 2003, Fox et al. 2006). This is unfortunate, as I found that collaborative work outside the traditional academic and scientific framework significantly explained successful knowledge outcomes (Chapter 3). Scientists, therefore, must often work within these boundaries and constraints that are set by the established institutional norms and culture.

Whilst scientists are judged on the productivity, objectivity and the rigorousness of their scientific endeavors, resource managers and policy makers are judged by their decisions and their outcomes. Rather than producing knowledge, managers are often tasked with gathering and synthesizing evidence from multiple sources, and translating it into tangible decisions and actions that may affect multiple stakeholder groups (Cook et al. 2012, Young et al. 2013). Resource managers also work in an environment that is complex, diverse, and dynamic in its environmental and societal conditions (van Riper et al. 2016). Managers must also accommodate perspectives of multiple groups in their conservation decisions and therefore need multiple lines of evidence for decision-making (Cook et al. 2012). In contrasts to scientists, managers are confined by their agency's missions and available resources that must serve both the mission and designated constituencies (Feldman & Ingram 2009). In addition, the various items they are accountable for result in their worldviews being shaped by their "decision space" – the realistic options available to them given their constraints to resolve particular problems (Jacobs et al. 2005, Feldman & Ingram 2009). From the climate science literature, Feldman & Ingram (2009) suggest three factors that constrain decision makers from using a tool or information. First, the "awareness" of alternative strategies or policies related to a problem is often driven by the demands of elected officials instead of driven by evidence (Kingdon 1995). As such, there is a disconnect in the levels of decision-making. Second, the organizational goals and objectives can restrict knowledge exchange and feedback. Lastly, bureaucracies that have been developed by indirect commands within the organization often is what prescribes appropriate and inappropriate ways of handling and using new information (Stone 1997). The findings from Chapter 2 closely reflect the aforementioned challenges such as resource constraints, disconnects between regional fisheries managers and elected officials, and bureaucratic processes as described by Fraser River salmon fisheries managers. Chapter 5 support the potential effect that institutional norms, culture and policies have on an individual's decision and perception about sharing data to further ecological knowledge.

As discussed, the institutional norms and cultures of each group of knowledge actors shape their motivations, decisions and behaviours. Changing these well-established and embedded institutional norms and culture cannot occur overnight. From my findings, it appears that processes and dynamics within the EC dimension are particularly large-scale, slow and long, much like how one of the respondents from Chapter 4 described it: "*It's like the Titanic. It's not easy to turn when you know the iceberg is coming*". However, from a theoretical and philosophical perspective, how can the environmental and contextual dimension be molded to facilitate knowledge mobilization and exchange? This would require fundamental changes to both institutional templates used by knowledge producers and users. Institutional innovations are required by government and research institutions as well as research funders alike to promote a culture whereby collaborative and knowledge exchange activities are legitimized as a core way of doing business, and recognized and rewarded appropriately (Cvitanovic et al. 2015, Dick et al. 2016). For instance, research questions are often driven by funding agencies or incentives structures. Funding agencies can act as stewards to facilitate this fundamental shift by devising incentives that measure conservation or societal impact rather than research contributions as suggested in Chapter 4. Already, there has been documented changes in granting agencies and their requirement for researchers to have impact. For example, the Natural Environment Research Council (NERC) in the UK distributes "Impact Awards" that recognize NERC-funded researchers whose work has made substantial impact on the economy and society (http://www.nerc.ac.uk/latest/events/impact/). Furthermore, the university reward system can also encourage impact research through redesigning promotions that include public engagement and research impacts (as supported by Chapter 3).

From the institutional side of decision-making agencies, creating policies and norms that foster collaboration and network building among all sectors should be the core of business, which would enhance data, information, and knowledge exchange. The creation of multi-sector partnerships and networks would be conducive toward enhancing access to new and relevant knowledge and information (Dick et al. 2016, (Gibbons et al. 2008, Young et al. 2014). Permanently embedding scientists in the governing organizations (as knowledge brokers) should improve the likelihood that priority knowledge gaps will be answered, and streamlining the information to decision makers (Cook et al. 2013). Furthermore, a number of barriers identified in my thesis stem from a centralized government arrangement, in which procedural hurdles can delay action for effective fisheries management. Centralization can also use up a high proportion of resources to just maintain the status quo because of the increasing complexity of centralized management (Tainter 1996). An alternative approach is polycentric governance or systems, which are characterize by multiple centres of functionally autonomous units (Ostrom 1999, 2010). Polycentric systems can build relationships and trust among local, regional, and national levels of network and facilitate the learning and adaptation of knowledge in different contexts (Clark et al .2011, Paterson et al. 2014**).** Young et al. (2014) suggest promoting inter- and trans-disciplinary research and "multi-domain' working groups that include various sectors such as joint government-university and/or public-private partnerships. Creating transdisciplinary centres or teams can facilitate collaborations and multiple disciplinary work (Dick et al. 2016). Such changes are needed in light of continuing loss of biodiversity and environmental degradation and its consequences for society.

On a positive note, changes have been developing in recent years. Multiple disciplinary research and projects have gained recognition and support (Gewin 2014) through the establishment of dedicated funds (e.g. the US National Science foundation and Research

Councils UK), the emergence of institutes and centres that offer programs linking disciplines and transcending traditional disciplinary boundaries, and an increasing appearance of mission statements in university programs, course curricula and for hiring new faculty members (Klein 2000, Dick et al. 2016). For example, these centres may be part of an academic institution such as "Transdisciplinary Hubs" at Brock University in Canada (https://www.brocku.ca/trans-disciplinary-research or the Transdisciplinary Research Integration Centre embedded within the government in Japan, which was created to improve system resilience after the Tohoku earthquake in 2011 (http://systemsresilience.org/index-e.html). Programs and policies that enable transdisciplinarity, collaboration and co-creation/co-production of agendas and knowledge is essential in the current climate. As the American Academy of Arts and Sciences reported in 2013, a new playing field is developing where the public and private sectors and academia play a new role and need to adapt to new worldwide economic realities and to societal challenges that are global, complex, interconnected, and urgent (www.amacad.org/arise2; Dick et al. 2016).

6.1.2 The influence of dimensions within the knowledge network on knowledge outcomes

The knowledge network appears to have boundaries that are defined by the EC dimension. When knowledge enters the knowledge network (as described in Chapter 1), the knowledge-action framework hypothesizes that the characteristics of that knowledge will influence its destination, the characteristics and perceptions of the knowledge actors, and the relational dimension among the actors should influence knowledge movement (Chapter 1). In this model, it is assumed that new knowledge is accessed.

The influence of knowledge characteristics

Chapter 4 indicated that from a researchers' perspective, the characteristics of telemetry-derived knowledge such as the limitations with the telemetry study design and the complexity of the data limits its application and use in fisheries management. Subsequently, these characteristics led to relevance, applicability and reliability issues. Similarly, Cash and his colleagues (2003) suggested that scientific information is likely to effectively influence social responses to public issues to the extent that the information is perceived by relevant stakeholders to be *credible* (scientific robustness of the arguments and output), *salient* (relevance to users' needs), and *legitimate* (extent to which information is perceived fair, unbiased and respectful of all stakeholders). Although I did not test Cash et al.'s framework directly in my thesis, using grounded theory in my qualitative analyses, I show emerging themes that support Cash's conceptual framework where the characteristics of the knowledge need to be credible, legitimate and salient to be considered and used by fisheries managers. Furthermore, Chapter 5 demonstrate from a "data" perspective, that data producers are concerned with the characteristics of the data (i.e., nuance of the data) being misinterpreted and misrepresented. This is important as it shows that it is not only knowledge characteristics and attributes, but also the characteristics and attributes of the data that can influence the end-product (how it is interpreted, how it is used, what it is used for).

The importance of the relational dimension

Chapter 3 quantitatively identified the importance of factors in the relational dimension for "successful knowledge outcome", which was defined in the chapter to be the "formal uptake of telemetry study findings" (i.e., integration and uptake into policies and practices) and "social uptake of telemetry study findings" (i.e., social acceptance and uptake by stakeholders and the public). Chapters 2 and 4 both qualitatively supported the relational dimension as an area that enables conditions that facilitate the flow of knowledge into action, and also ensures production of salient, credible and legitimate knowledge. Chapter 5 does not explicitly test the influence of relationships in data sharing, but demonstrated that sharing data has developed new relationships and collaborations, and that potential reluctance of sharing data may stem from lack of relationship and trust between the data producers and users as reported by respondents who were frustrated by the lack of communication by data users.

There are recurrent and increasingly insistent calls in the literature to effectively bridge the divide between knowledge and action, particularly for a shift in establishing a new culture of communication, sharing and collaboration among all sectors (Braunisch et al. 2012). My thesis finds strong support for arguments in the growing body of literature that relationship-building and its associated activities such as stakeholder engagement, collaboration, co-production of knowledge, and transdisciplinary work is required to tackle wicked problems, and build resilient social-ecological systems (e.g., Beier et al. 2016, Hadorn et al. 2006, Meadow et al. 2015, Reed 2008, Young et al. 2016b). Here, I demonstrate that improving the relational dimension and enabling an arena for iterative and meaningful knowledge exchange can positively influence knowledge action.

The influence of knowledge actors and their worldviews

The data chapters in my thesis provide evidence to support that the actors, their characteristics and perceptions influence knowledge action. In Chapter 2, the fisheries managers and stakeholders describe that the motivations of actors can significantly drive or hinder the use of new knowledge, and that knowledge must be socially accepted by the actors in the knowledge network to be useful. Similarly, Chapter 4 revealed, from the perspective of fish telemetrists, that motivational factors (e.g., political will, willingness to go against norms), social constructs (e.g., worldviews, beliefs, values), and competing interests and priorities among knowledge actors hinders the application of telemetry-derived knowledge. Chapter 3 provides strong evidence that the collaborative tendencies and willingness of researchers to engage outside of the academic framework, described earlier, has positive impacts on successful knowledge outcomes. Lastly, Chapter 5 highlight that the perspectives of fish telemetrists regarding benefits and concerns for sharing data has the potential to act as barriers or enablers to data sharing and working towards a data sharing culture. These findings provide further empirical support for past research suggesting personal perceptions and biases can undermine effective knowledge exchange between knowledge producers and users (e.g. Cvitanovic et al. 2015, Fazey et al. 2006, Levtison and Walker 2012). This is particularly problematic when dealing with contentious and polarized topics, such as that of the Fraser River Pacific salmon. It is therefore prudent for knowledge producers to recognize that different individuals or user groups may interpret information differently, which may affect the extent to which it impacts decision-making processes (Raymond et al .2010, Young et al. 2016a). However, it is also important to recognize that individual actors may positively influence impact if there is the motivation and willingness to do so. Thus, institutional innovations discussed earlier, are required to create incentives and norms to foster motivations that enhance collaborative research and knowledge exchange.

The knowledge actors' toolbox for knowledge-action

Earlier, I discussed the long and slow dynamics of the environmental and contextual dimension that is challenging to shift. However, processes and dynamics within the knowledge network are likely to be faster and shorter. Therefore, I bring attention to the various components of the knowledge network because individual actors potentially have greater control over the actions and processes that may lead to impact in this dimension. Knowledge exchange and knowledge mobilization are increasingly recognized as a key factor facilitating the social, environmental and economic impacts of research (Fazey et al. 2012, Young et al. 2013b, Reed et al. 2014b) resulting in the sustainable management of natural systems and the goods and services they provide, and in turn ensuring the safety and wellbeing of the people that depend on them. Concepts and strategies to engage in collaboration and knowledge exchange are extensively described in the literature (van Kerkhoff & Lebel 2006, Lang et al. 2012, Cook et al. 2013, Reed et al. 2014b), as such I only briefly discuss a few relevant examples here.

Co-creation and co-production of knowledge is widely discussed in the literature to bridge the gap between knowledge and action. The concerted effort in co-production and co-creation of knowledge have been documented to improve understanding of the political, social, economic and institutional complexities of moving knowledge into actions (Nel et al. 2016). Knowledge co-production is defined as the "collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem" (Armitage et al. 2011). Evidence suggests that close collaborations in knowledge production lead to perceptions of the results as credible, salient and legitimate and more likely to be adopted for implementation (Cash et al. 2003).

Knowledge co-production is also facilitated by boundary work. Boundary work can be mediated by boundary spanners or knowledge brokers, and boundary organizations who are perceived as neutral and trusted relevant parties (Berkes 2009, Crona and Parker 2012). A key product of boundary work are boundary objects, which are co-produced outputs that are adaptable to different viewpoints yet robust enough to maintain identity across them (Star and Griesemer 1989, form Nel et al 2016). For example, a boundary object can include definitions and standards of practice (Clark et al. 2011), models for integrating different viewpoints, and indicators that improve communication between different knowledge domains (Turnhout et al. 2007, Nel et al. 2016). Knowledge users in the Fraser River case study (Chapter 2) echo these approaches and reveal that third parties, such as the use of ENGOs as boundary organization, co-designing research studies, and increasing face-to-face interactions through strategic workshops and meetings enable conditions to create usable knowledge.

Telemetry data can contain a wealth of information about tracked animals and their environment; thus, data sharing is another tool, particularly for fish telemetrists, to engage with to address complex problems and potentially make their findings more relevant to fisheries managers and other knowledge users (Campbell et al. 2015, Chapter 5). It can be expensive to create knowledge because of costs and labour of data collection, and in some ways, implies that there is a responsibility to make the data available to the scientific community – particularly when data is collected from tagged animals that may reduce their survivorship (Campbell et al.

2015, McGowan et al. 2016). Data sharing with the public is also an avenue for fish telemetrists to explore for engaging the public and raise awareness of the utility of telemetry technology in conservation and fisheries management. As such, sharing data can be a tool within the knowledge network for collaboration, relationship building, raising awareness, advancing scientific knowledge and addressing wicked problems.

Generally, there are actions that knowledge producers and users can engage with to bridge that gap between knowledge-action. Most of these actions are found within the knowledge network as discussed above, and have the potential to trickle through to the environmental and contextual dimension – a process that has rarely been explored. I discuss this issue later in the future research directions section.

6.1.3 Scales and Levels

The effects scales and levels may span over the whole framework as various dimensions can be found at various scales and levels (Cash et al. 2006). Chapter 2 and 4 find evidence and support for influences of scales (particularly temporal scales) on knowledge mobilization. Chapter 2 revealed time as an important factor for action, including time needed to implement the new knowledge; time for both knowledge producers and users to engage in meaningful and genuine knowledge exchange; and time for processes to take place such as time for production of knowledge, time for interpretation, and time to accept the new knowledge. In particular, Chapter 4 supports the mismatches and interactions in scales and levels. Fish telemetrists reported challenges incorporating their work due to mismatch in representativeness (scaling individual data into population relevant information); in spatio-temporal scales (study scale does not meet management scales); and mismatch in cultures between knowledge producers and users. Chapter 5, however, show that sharing data can offer benefits that remediate the issue of scale through achieving greater geographic coverage for telemetry studies. Nonetheless, failure to recognize the importance of scale and level interactions, and failure to recognize the diverse perceptions and values of scale by different actors can lead widening the knowledge-action gap (Cash et al. 2006). My data provides empirical evidence to support Cash et al. (2006)'s conceptual argument of mismatch in scales, which may result in production of scientific and technical information that, again, lacks salience, credibility or legitimacy from the perspectives of the players at different levels (Cash et al. 2003). Incorporating interactions of scales and levels in a knowledge-action framework is thus critical producing usable knowledge.

6.2 Assessment of the Application of Knowledge-Action Framework: Lessons Learned and Future Research Directions

The findings from my thesis contributed to understanding the relative importance and the dynamics within and between the environmental and contextual dimension and the knowledge network of the mediation sphere. My data provided information on what areas are restrictive, and which can act as enabling conditions for effective knowledge action outcomes. I found supporting evidence for each of the dimensions of the framework; however, the framework can be improved. First, the framework was developed from readings of academic literature and from an academic researcher's perspective. It is unknown whether a framework built from a knowledge user or other perspective would change its core features. Second, as described in Chapter 1, the knowledge-action framework is a roadmap and is not prescriptive. It is meant to be flexible and to adapt to various contexts. Indeed, its flexibility was useful and appropriate for my fish telemetry and fisheries management model. However, the flexibility of the framework is also costly as it leaves room for unstandardized utilization of the framework.

From a qualitative research perspective, I found that there were more chances for interpreter bias. Some emerging themes from Chapter 2 and 4 were challenging to exclusively categorize and place under the framework. This indicates that the framework lacks a strategy to incorporate and deal with interactions and overlap among the different framework dimensions, and subjective interpretations can lead to different conclusions. However, the framework was particularly useful for placing emergent themes into a broader context and facilitate comparison.

From a quantitative research perspective, the benefits of the framework were its utility in developing hypotheses, predictions, and highlighting the variables that ought to be measured. Still, there was a lack of strategy to measure and assess interactions among the dimensions of the framework. For example, collaborative tendencies of a researcher were significant in explaining the success of knowledge uptake in Chapter 3. The collaborative tendency should be under relational dimension because it involves collaborations among actors, however, it is also a tendency of a researcher and should also be framed under actor characteristics. Although I acknowledge interactions in my development of the framework, it is still an area that lacks information and appropriate methodologies to understand and study these interactions.

As alluded to earlier, the framework lacked strategies to capture the different scales and levels that span various boundaries and dimensions of the framework. Implementing the framework proved to be unclear in such situations. Future research should consider investigations into interactions and provide clearer links into the relationships between the environmental and contextual dimension and the knowledge network. For example, how do knowledge actors interact with political factors, and how does that affect knowledge movement? Understanding these interactions and the movement of knowledge across levels and scales can improve the processes of knowledge exchange and mobilization.

Furthermore, my dissertation provides a one-sided perspective of researchers on the use of telemetry findings. Further research is required to understand the knowledge users' environment, however, access to this population is much more challenging (Posner et al. 2016). Measures of knowledge action outcomes were also self-reported and relative to researchers' experiences. More research is required to develop more accurate measures of knowledge action outcomes and its nuances. As mentioned, further researcher is also needed to understand the interactions of the knowledge components at different scales and levels.

6.3 Way Forward: Guide for knowledge exchange and mobilization research in conservation and natural resource management

The knowledge-action framework developed in my thesis reflects on a body of literature that is emerging to understand the knowledge-action gap. The emergence of this interdisciplinary topic for understanding the movement of knowledge is still disparate and scattered, with little reflection on how to organize, synthesize and move it forward. To that end, we hope that this framework will provide a roadmap to identify and summarize relevant variables and ideas for studying the knowledge-action gap using KE/KMb concepts (see Box 6.1 for implementation scenarios). The knowledge-action framework is a starting point for developing and testing hypotheses, design of data collection methods, and analysis of findings related to conservation knowledge-action research by illuminating the social nature of knowledge, even in the light of an evidence-based decision-making era (*sensu* Sutherland et al. 2004). Future application of the framework by knowledge users would be useful and informative. With a theoretical framework, there is a common map to enable context-specific research to contribute to the wider body of scholarship and build on body of evidence about the mechanisms of knowledge flow and potential knowledge-action outcomes. The proposed framework is presented in broad and generic terms because it must allow for flexibility so that it can be built on further as more empirical evidence and emerging theories are directed towards this young concept. I encourage researchers to start here, and build empirical evidence on what works and what doesn't work when attempting to narrow the gap between knowledge and action so that we can make progress in conserving biodiversity and sustainably manage natural resources.

Box 6.1: Implementation Scenarios – How might the framework be useful for researchers?

1. **Hypothesis and Research Question Design**: The framework provides researchers with a clear conceptualization of the multi-stage nature of knowledge exchange/mobilization practices in the context of the knowledge-action gap. It prompts researchers to look at each of the three dimensions as distinct social arenas that contain their own rituals, processes, and variables, but are nonetheless intertwined in a broader social action (moving knowledge to action). Facilitators and barriers to knowledge movement can exist in any one stage, or across several. Each stage is complex enough to invite hypothesis generation and testing on specific cases. In short, the model allows researchers to deconstruct a complex social phenomenon (going from knowledge to action) into a set of more readily researchable processes.
2. **Organizing and Structuring Empirical Evidence:** The framework provides researchers with a set of potential content codes for analyzing empirical evidence. This is particularly valuable for qualitative analysis, documentary analysis, and the analysis of data from participatory or "action research". Evidence can be classified as belonging in one or several dimensions of the framework as a first content code, with later sorting according to theme.
3. **Comparisons:** The framework provides a basis for comparisons across both similar and dissimilar cases. By providing a more structured means of designing research, developing content codes, and presenting findings, disparate cases become more comparable. This is an important step in making KE/KMb research more cumulative, as trends, patterns, and anomalies are easier to spot in similarly organized research questions, data, and findings.

Appendix A. Abstracts of non-thesis publications during doctoral studies

1. Cooke, S.J., **Nguyen, V.M**., Kessel, S.T., Hussey, N.E., Ford, A.T. (2017) Troubling issues at the frontier of animal tracking for conservation and management. Conservation Biology DOI: 10.1111/cobi.12895

    No abstract available for article.

2. Cooke, S.J., Gallagher, A.J., Sopinka, N.M., **Nguyen, V.M.**, Skubel, R.A., Hammerschlag, N., Boon, S., Young, N., Danylchuk, A.J. (In Press). Considerations for effective science communications. FACETS Journal 00, 00-00.

    It is increasingly common for scientists to engage in sharing science-related knowledge with diverse knowledge users—an activity called science communication. Given that many scientists now seek information on how to communicate effectively, we have generated a list of 16 important considerations for those interested in science communication: (1) Define what science communication means to you and your research; (2) Know—and listen to—your target audience; (3) Consider a diverse but coordinated communication portfolio; (4) Draft skilled players and build a network; (5) Create and seize opportunities; (6) Be creative when you communicate; (7) Focus on the science in science communication; (8) Be an honest broker; (9) Understand the science of science communication; (10) Think like an entrepreneur; (11) Don't let your colleagues stop you; (12) Integrate science communication into your research program; (13) Recognize how science communication enhances your science; (14) Request science communication funds from grants; (15) Strive for bidirectional communication; and (16) Evaluate, reflect, and be prepared to adapt. It is our ambition that the ideas shared here will encourage readers to engage in science communication and increase the effectiveness of those already active in science communication, stimulating them to share their experiences with others.

3. Delle Palme, C.A., **Nguyen, V.M.**, Gutowksy, L.F.G., Cooke, S.J. (2016). Do fishing education programs effectively transfer 'catch-and-release' best practices to youth anglers yielding measurable improvements in fish condition and survival? Knowledge and Management of Aquatic Ecosystems 417, 42.

There is growing interest in educating anglers on catch-and-release (C&R) best practices, yet there is little information on whether angler education programs yield measurable improvements in fish condition and survival. As such, we conducted a study focused on mixed-gender youth groups (aged 8–10) and contrasted three levels of training intervention. Treatment 1 training had no mention of C&R best practices. Treatments 2 and 3 trainings involved visual aids to illustrate best practices, while Treatment 3 added a hands-on demonstration. When caught by the most highly trained participants, fish experienced the least amount of air exposure, but were handled for longer periods, as trained anglers were more careful. Higher levels of training led to a higher likelihood that anglers wet their hands and used a bucket filled with water while handling fish but all treatment groups yielded similar incidences of deep hooking and bleeding. Overall, mortality (initial and after ~12 h) was low across all treatments. Our findings suggest that a short (~20 min) fishing workshop can transfer information on C&R practices, at least in the short-term, that can lead to some improved conditions for angler-caught fish. It is unclear the extent to which this information is retained in the long-term or how different target populations or training strategies might influence knowledge transfer and adoption and thus biological outcomes. With growing interest in sharing C&R best practices with anglers, we suggest that there is need for additional research on outreach strategies to ensure that such efforts are effective and yield meaningful benefits to fish welfare and conservation.

4. Young, N., **Nguyen, V.M.**, Corriveau, M.A., Cooke, S.J., Hinch, S.G. (2016). How do knowledge users perceive and evaluate new claims about a contested resource? The problem of different expectations in knowledge exchange and mobilization. Journal of Environmental Management 184, 380-388.

This article examines how potential users of scientific and local/traditional/experiential knowledge evaluate new claims to knowing, using 67 interviews with government employees and non-governmental stakeholders involved in co-managing salmon fisheries in Canada's Fraser River. Research has consistently shown that there are major obstacles to moving new knowledge into policy, management, and public domains. New concepts such as Knowledge Exchange (KE) and Knowledge Mobilization (KMb) are being used to investigate these obstacles, but the processes by which potential users evaluate (sometimes competing) knowledge claims remain poorly understood. We use concepts from the sociology of science and find that potential users evaluate new knowledge claims based on three broad criteria: (1) the perceived merits of the claim, (2) perceptions of the character and motivation of the claimant, and (3) considerations of the social and political context of the claim. However, government employees and stakeholders have different interpretations of these criteria, leading to different knowledge preferences and normative expectations of scientists and other claimants. We draw both theoretical and practical lessons from these findings. With respect to theory, we argue that the sociology of science provides valuable insights into the political dimensions of knowledge and should be explicitly incorporated into KE/KMb research. With respect to practice, our findings underline the need for scientists and other claimants to make conscious decisions about whose expectations they hope to meet in their communications and engagement activities.

5. Cooke, S.J., Allison, E.H., Beard, T.D., Arlinghaus, R., Arthington, A.H., Bartley, D.M., Cowx, I.G., Fuentevilla, C., Leonard, N.J., Lorenzen, K., Lynch, A.J., **Nguyen, V.M.**, Youn, S.-J., Taylor, W.W., Welcomme, R.L. (2016) On the sustainability of inland fisheries: Finding a future for the forgotten. Ambio 45, 753-764.

At present, inland fisheries are not often a national or regional governance priority and as a result, inland capture fisheries are undervalued and largely overlooked. As such they are threatened in both developing and developed countries. Indeed, due to lack of reliable data, inland fisheries have never been part of any high profile global fisheries assessment and are notably absent from the Sustainable Development Goals. The general public and policy makers are largely ignorant of the plight of freshwater ecosystems and the fish they support, as well as the ecosystem services generated by inland fisheries. This ignorance is particularly salient given that the current emphasis on the food-water-energy nexus often fails to include the important role that inland fish and fisheries play in food security and supporting livelihoods in low-income food deficit countries. Developing countries in Africa and Asia produce about 11 million tonnes of inland fish annually, 90 % of the global total. The role of inland fisheries goes beyond just kilocalories; fish provide important micronutrients and essentially fatty acids. In some regions, inland recreational fisheries are important, generating much wealth and supporting livelihoods. The following three key recommendations are necessary for action if inland fisheries are to become a part of the food-water-energy discussion: invest in improved valuation and assessment methods, build better methods to effectively govern inland fisheries (requires capacity building and incentives), and develop approaches to managing waters across sectors and scales. Moreover, if inland fisheries are recognized as important to food security, livelihoods, and human well-being, they can be more easily incorporated in regional, national, and global policies and agreements on water issues. Through these approaches, inland fisheries can be better evaluated and be more fully recognized in broader water resource and aquatic ecosystem planning and decision-making frameworks, enhancing their value and sustainability for the future.

6. Young, N., **Nguyen, V.M.**, Corriveau, M.A., Cooke, S.J., Hinch, S.G. (2016). Knowledge users' perspectives and advice on how to improve knowledge exchange and mobilization in the case of a contested fishery. Environmental Science & Policy 66, 170-178.

Environmental scientists have long been frustrated by the difficulties involved in transferring their research findings into policy-making, management, and public spheres. Despite increases in scientific knowledge about social-ecological systems, research has consistently shown that regulators and stakeholders draw on tacit, informal, and experiential knowledge far more than scientific knowledge in their decision-making. Social science research in the fields of knowledge exchange (KE) and knowledge mobilization (KMb) suggest that one of the major barriers to moving knowledge into practice is that scientists fail to align their communication strategies with the information-seeking behaviours and preferences of potential knowledge users. This article presents findings from in-depth qualitative research with government employees and stakeholders involved in co-managing Pacific salmon fisheries in Canada's Fraser River. We investigate how members of these groups access, view, and use scientific information, finding both similarities and differences. Members of both groups express a strong interest in academic science, and self-report using scientific information regularly in their work and advocacy. However, the two groups engage in different information-seeking behaviours, and provide notably different advice to academic scientists about how to make research and communication more relevant to potential users. For example, government employees focus on the immediate applications of research to known problems, while stakeholders express greater concern for the political context and implications of scientific findings. We argue that scientists need to "go where the users are" in the behavioural and intellectual sense, and tailor their communications and engagement activities to match the habits, preferences, and expectations of multiple potential user groups. We conclude with recommendations on how this may be done.

7. **Nguyen, V.M**., Lynch, A.J., Young, N., Cowx, I.G., Beard, T.D., William, T.W., Cooke, S.J., (2016). To manage inland fisheries is to manage at the social-ecological watershed scale. Journal of Environmental Management 18, 312-325.

Approaches to managing inland fisheries vary between systems and regions but are often based on large-scale marine fisheries principles and thus limited and outdated. Rarely do they adopt holistic approaches that consider the complex interplay among humans, fish, and the environment. We argue that there is an urgent need for a shift in inland fisheries management towards holistic and transdisciplinary approaches that embrace the principles of social-ecological systems at the watershed scale. The interconnectedness of inland fisheries with their associated watershed (biotic, abiotic, and humans) make them extremely complex and challenging to manage and protect. For this reason, the watershed is a logical management unit. To assist management at this scale, we propose a framework that integrates disparate concepts and management paradigms to facilitate inland fisheries management and sustainability. We contend that inland fisheries need to be managed as social-ecological watershed system (SEWS). The framework supports watershed-scale and transboundary governance to manage inland fisheries, and transdisciplinary projects and teams to ensure relevant and applicable monitoring and research. We discuss concepts of social-ecological feedback and interactions of multiple stressors and factors within/between the social-ecological systems. Moreover, we emphasize that management, monitoring, and research on inland fisheries at the watershed scale are needed to ensure long-term sustainable and resilient fisheries.

8. Dick, M., Rous, A.M., **Nguyen, V.M**., Cooke, S.J. (2016) Necessary but challenging; multiple disciplinary approaches to solving conservation problems. FACETS Journal 1, 67-82.

Contemporary conservation problems are typically positioned at the interface of complex ecological and human systems. Traditional approaches aiming to compartmentalize a phenomenon within the confines of a single discipline and failing to engage non-science partners are outmoded and cannot identify solutions that have traction in the social, economic, and political arenas in which conservation actions must operate. As a result, conservation science teams must adopt multiple disciplinary approaches that bridge not only academic disciplines but also the political and social realms and engage relevant partners. Five reasons are presented that outline why conservation problems demand multiple disciplinary approaches in order to move forward because: (i) socio-ecological systems are complex, (ii) multiple perspectives are better than one, (iii) the results of research must influence practice, (iv) the heterogeneity of scale necessitates it, and (v) conservation involves compromise. Presenting reasons that support multiple disciplinarity demands a review of the barriers that impede this process, as we are far from attaining a model or framework that is applicable in all contexts. Two challenges that impede multiple disciplinarity are discussed, in addition to pragmatic solutions that conservation scientists and practitioners can adopt in their work. Overall, conservation researchers and practitioners are encouraged to explore the multiple disciplinary dimensions of their respective realms to more effectively solve problems in biodiversity and sustainability.

9. **Nguyen, V.M.,** Young, N., Hinch, S.G., Cooke, S.J. (2016) Getting past the blame game: convergence and divergence in perceived threats to salmon resources among anglers and indigenous fishers in Canada's lower Fraser River. AMBIO 10.1007/s13280-016-0769-6

This article examines threat perception as a potential dimension of inter-group conflict over salmon fisheries in Canada's Fraser River watershed. Environmental changes and the entry of new user groups are putting pressure on both the resource and regulators, as well as threatening to exacerbate conflicts, notably between First Nation (indigenous) fishers and non-indigenous recreational anglers. While resource conflicts are often superficially conceptualized as cases of competing interests, we build on recent studies suggesting that conflicts are associated with deeper cognitive and perceptual differences among user groups. We report findings from 422 riverbank interviews with First Nation fishers and recreational anglers focusing on perceptions of threat to the fisheries. Responses reveal both substantial agreement and disagreement in threat perceptions between the two groups. These patterns provide a potential roadmap for consensus building, and suggest possible avenues for policy-makers to defuse the "blame game" that often dominates this type of conflict.

10. Cooke, S.J., **Nguyen, V.M**., Wilson, A.D.M., Donaldson, M.R., Gallagher, A., Hammerschlag, N. Haddaway, N.R. (2016). The need for speed in a crisis discipline: perspectives on peer review duration and implications for conservation science. Endangered Species Research 30, 11-18.

Scholarly peer review relies on rigorous yet fair assessments of articles by qualified referees in a timely manner. We considered the extent to which a prolonged peer-review process can delay the dissemination of results in a conservation context by combining insight from a survey with our own perspectives. A survey of authors who published peer-reviewed articles in biodiversity and conservation in 2012 and 2013 yielded 461 responses from participants in 119 countries. Approximately 44% of respondents thought that slow review times might hamper conservation, while only ~5% provided specific examples of how slow reviews had actually impeded conservation actions or policy formation. When queried about the value of expediting the review process for studies of high policy or conservation relevance, ca. 1/3 of respondents thought it was a worthwhile idea in principle, though mechanics of implementing such practices are unclear. Author self-identification of potentially important papers could lead to requesting a rapid review provided that a paper meets certain criteria—an approach already used by some generalist journals. Given the urgency of many conservation-oriented initiatives, we encourage the entire editorial team (staff, editors, referees, authors) to make a concerted effort towards improving the speed of the peer-review process while maintaining quality. Such efforts would reflect the notion that timeliness is a key component of scientific relevance to practitioners and policy makers in a crisis discipline. We conclude that there is a ‘need for speed’ and advocate that rapid, rigorous and thorough peer review can be accomplished and can provide collective benefits to the scientific community and global biodiversity.

11. Lynch, A. J., Cooke, S.J., Deines, A., Bower, S., Bunnel, D.B., Cowx, I.G., **Nguyen, V.M.**, Nonher, J., Phouthavong, K., Riley, B., Rogers, W.D., Taylor, W.W., Wolemer W.M., Youn, S., Beard, T.D. Jr. (2016) The social, economic, and ecological importance of inland fishes and fisheries. Environmental Reviews 10.1139/er-2015-006

Though reported capture fisheries are dominated by marine production, inland fish and fisheries make substantial contributions to meeting the challenges faced by individuals, society, and the environment in a changing global landscape. Inland capture fisheries and aquaculture contribute over 40% to the world's reported finfish production from less than 0.01% of the total volume of water on earth. These fisheries provide food for billions and livelihoods for millions of people worldwide. Herein, using supporting evidence from the literature, we review 10 reasons why inland fish and fisheries are important to the individual (food security, economic security, empowerment), to society (cultural services, recreational services, human health and well-being, knowledge transfer and capacity building), and to the environment (ecosystem function and biodiversity, as aquatic "canaries", the "green food" movement). However, the current limitations to valuing the services provided by inland fish and fisheries make comparison with other water resource users extremely difficult. This list can serve to demonstrate the importance of inland fish and fisheries, a necessary first step to better incorporating them into agriculture, land-use, and water resource planning, where they are currently often underappreciated or ignored.

12. Nguyen, V.M., Haddaway, N.R., Gutowsky, L.F.G., Wilson, A.D.M., Gallagher, A.J., Donaldson, M.R., Hammerschlag, N., Cooke, S.J. (2015) How long is too long in contemporary peer review? Perspectives from authors publishing in conservation biology journals. PLOS ONE 10(8): e0132557.

Delays in peer reviewed publication may have consequences for both assessment of scientific prowess in academia as well as communication of important information to the knowledge receptor community. We present an analysis on the perspectives of authors publishing in conservation biology journals regarding their opinions on the importance of speed in peer-review as well as how to improve review times. Authors were invited to take part in an online questionnaire, of which the data was subjected to both qualitative (open coding, categorizing) and quantitative analyses (generalized linear models). We received 637 responses to 6,547 e-mail invitations sent. Peer-review speed was generally perceived as slow, with authors experiencing a typical turnaround time of 14 weeks while their perceived optimal review time was six weeks. Male and younger respondents seem to have higher expectations of review speed than females and older respondents. The majority of participants attributed lengthy review times to reviewer and editor fatigue, while editor persistence and journal prestige were believed to speed up the review process. Negative consequences of lengthy review times were perceived to be greater for early career researchers and to have impact on author morale (e.g. motivation or frustration). Competition among colleagues was also of concern to respondents. Incentivizing peer-review was among the top suggested alterations to the system along with training graduate students in peer-review, increased editorial persistence, and changes to the norms of peer-review such as opening the peer-review process to the public. It is clear that authors surveyed in this study viewed the peer-review system as under stress and we encourage scientists and publishers to push the envelope for new peer-review models

13. McClellan Press K., Mandelman J., Burgess E., Cooke S.J., **Nguyen V.M.,** Danylchuk A.J. (2015) Catching sharks: recreational saltwater angler behaviors and attitudes regarding shark encounters and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, DOI: 10.1002/aqc.2581

With the increasing popularity of recreational angling around the world, there is a need to better understand the potential contribution of recreational fishing to reported shark population declines. However, the nature and perception of shark encounters – a fundamental precursor to future research, management and conservation measures aimed to increase shark survival – is not well documented in recreational fisheries. Five hundred and ninety recreational saltwater anglers responded to the survey and reported their experiences targeting or incidentally catching sharks, as well as their attitudes toward sharks, shark fishing techniques, and shark conservation and management. The survey found sharks were caught regularly, with 57% of respondents commonly targeting sharks and 93% of respondents having caught a shark at least once. Eighty-eight percent of the respondents released the last shark that they caught and most respondents often or always practised catch-and-release when catching sharks. The survey revealed that avid anglers have positive attitudes toward sharks and shark conservation and have a desire to handle and release sharks in ways that will increase their likelihood of survival. However, the survey also revealed that there are a variety of situational factors (e.g. target fish, fishing platform) that influence the choices that anglers make while fishing, which may influence adherence to catch-and-release methods. Based on their positive attitudes toward sharks, recreational anglers may be strong allies for the development, dissemination, and adoption of species and situational-specific best practice catch-and-release guidelines for this group of fishes within the wider recreational saltwater angling community

14. Cooke, S.J., **Nguyen, V.M.**, Dettmers, J.M., Arlinghaus, R., Quist, M.C., Tweddle, D., Weyl, O.L.F., Raghavan, R., Portocarrero-Aya, M., Agudeo Cordoba, E, Cowx, I.G. (2016) Sustainable inland fisheries – Perspectives from the recreational, commercial and subsistence sectors from around the globe. Pages 467-505 in G.P. Closs, M. Krkosek and J.D. Olden, Eds. Conservation of Freshwater Fishes. Cambridge University Press, Cambridge.

No abstract available for book chapter.

Appendix B. Online questionnaire used for data collection in Chapters 3-5.

Section A: Your fish telemetry experience

The first part of our questionnaire will ask you about your experience with telemetry tagging technology (limited to radio, acoustic and/or satellite tags) and fish research.

1. Have you done work involving fish using acoustic, radio or satellite tags?
"Work" is defined as research that may include consulting work, academic projects, government programs, etc.
○ Yes
○ No
If yes, please check all that apply:

Radio ☐
Acoustic ☐
Satellite ☐

If yes, during what period were/are you doing research with field telemetry?
Please indicate in years (e.g. 1990-2011 or 1994-current)

[ ]

2. Have you been a principal investigator for a fish telemetry "project"?(Project defined as an applied project with clear objectives associated with a funding cycle)
Principal investigator is one who has led and/or secured funding for a project.
○ Yes
○ No
3. How many different fish telemetry projects have you led? (as principal investigator)
Project defined by the cycle of ONE research grant
○ None
○ 1-4 projects
○ 5-9 projects
○ 10-14 projects
○ 15+ projects

4. How many REFEREED papers have you published (including co-authorship) related to your research with fish telemetry?
○ None
○ 1-4
○ 5-9
○ 10-14
○ 15-20

- ○ 21-25
- ○ Greater than 25

5. How many NON-REFEREED (e.g. technical report, government report, etc.) have you published (including co-authorship) related to your work with fish telemetry?

- ○ None
- ○ 1-4
- ○ 5-9
- ○ 10-14
- ○ 15-20
- ○ 21-25
- ○ Greater than 25

6. Are you CURRENTLY part of a telemetry research "network"?
Network: defined as a formal or informal group of researchers that collaborate in the sharing of telemetry infrastructure, expertise and tag detections

- ○ Yes
- ○ No

If yes, which one (s)?

[ ]

7. Approximately, what percentage of your research time do you CURRENTLY spend engaged with fish telemetry?

- ○ <10%
- ○ 10%
- ○ 20%
- ○ 30%
- ○ 40%
- ○ 50%
- ○ 60%
- ○ 70%
- ○ 80%
- ○ 90%
- ○ 100%

8. Please check the boxes indicating the environments where you conduct telemetry research on fish:
Telemetry: defined as acoustic, ,radio and satellite in this survey

- ☐ Freshwater lakes
- ☐ Freshwater rivers
- ☐ Estuaries
- ☐ Coastal marine waters
- ☐ Open ocean
- ☐ Other, please specify... ______________________

9. What percentage of your professional time over the past five years have you spent on each of the following categories:

RESPONSES SHOULD ADD UP TO 100%

Research activities (e.g. literature review, study design, data collection, etc)	
Engaging and consulting with managers and stakeholders	
Disseminating research to scientific peers (e.g., conferences, meetings, publication)	
Public outreach	
Mentoring/student training	
Other	

Section B: Some demographics and characteristics questions
The second part of this online questionnaire will ask questions about you as a researcher. Remember, you may skip questions you don't feel like answering.

10. In what year were you born?

11. What is your gender?
- ○ Male
- ○ Female
- ○ Other
- ○ Prefer not to say

12. In what country are you currently based?

13. Which categories best describe your current employer (s)?
Please check all that apply.
- ☐ University or College
- ☐ Federal Government/Agency
- ☐ Provincial/State Government/Agency
- ☐ Industry
- ☐ Civil society and advocacy group (ENGO, CNGO, NGO, other)
- ☐ Self-employed, please explain: ______________________
- ☐ Other, please specify... ______________________

14. My role is best described as...
Please check all that apply.
- ☐ Field-based researcher/scientist
- ☐ Laboratory-based researcher/scientist
- ☐ Educator/instructor/professor
- ☐ Tenured/Untenured Faculty
- ☐ Consultant
- ☐ Manager/administrator
- ☐ Government (provincial, state, regional, federal) scientist
- ☐ Graduate student or post-doctoral fellow
- ☐ Social scientist
- ☐ Research assistant/technician

☐ Other, please specify... ______________________

Tell us about your research motives...

Next, we would like to learn about your past and current career goals/motives.

15. Over the past five years, how important were the following criteria in your choice of research agenda/questions?
Please answer in relation to your fish telemetry research.

	Not important	Somewhat important	Important	Very important
Create a research environment suitable for graduate training	○	○	○	○
Scientific curiosity	○	○	○	○
Importance to society	○	○	○	○
Desire to protect fish and improve sustainability of fisheries	○	○	○	○
Availability of funding	○	○	○	○
Length of time required to complete the research	○	○	○	○
Potential contribution to scientific theory	○	○	○	○
Recognition from your peers and the scientific community	○	○	○	○
Potential contribution to conservation and management policies	○	○	○	○
Industry consulting opportunities	○	○	○	○
Priorities of your employer	○	○	○	○
Probability of publications in major professional journals	○	○	○	○
Personal or professional interest	○	○	○	○
Potential to generate income for my lab/employer	○	○	○	○
Potential to generate personal income	○	○	○	○

16. Please indicate your level of agreement with each of the statements below:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Scientists should participate in policy debates	○	○	○	○	○
Scientists have a responsibility to communicate their findings to stakeholders and public	○	○	○	○	○
Scientists should advocate a political or policy position	○	○	○	○	○

Linkages between universities and government agencies should be strengthened	○	○	○	○	○
Policy-makers ought to consult university researchers when formulating conservation policy or strategies	○	○	○	○	○
Collaboration is time consuming and slows down the productivity of researchers	○	○	○	○	○
Most environmental problems will eventually be solved by scientific and technological advancements	○	○	○	○	○
New science and technology often create as many problems as they solve	○	○	○	○	○
Scientific knowledge ought to be given more weight than local knowledge in the formulation of environmental policy and management practices	○	○	○	○	○
Nature is so complex that it is not fully knowable through scientific investigation	○	○	○	○	○

Section C: Professional Networks and Data Sharing

You're about 1/3 of the way through! Thank you again for your participation

17. Please indicate the frequency of collaboration with the following groups related to your fish telemetry research and professional network:

	Never	Rarely	Occasionally	Often
University-employed researchers/scientists	○	○	○	○
Government-employed researchers/scientists	○	○	○	○
Fisheries managers/policy makers	○	○	○	○
Industry representatives (i.e. commercial fishing sector, fish buyers, recreational fishing sector, etc.)	○	○	○	○
Local people and stakeholders (including indigenous people, those directly impacted by fish research)	○	○	○	○
Environmental/conservation-related non-profits/organizations	○	○	○	○
Other, please specify below	○	○	○	○

Please specify "other" here:

[ ]

18. In the past 5 years, I have....
Please check all that apply. Leave BLANK if not relevant.

	With colleagues in universities or colleges	With colleagues in industry	With colleagues in government	With colleagues employed by environmental groups	With colleagues employed by local community and/or indigenous groups

Shared data/telemetry infrastructure (i.e. shared receiver and data picked up from other receivers)	☐	☐	☐	☐	☐
Co-authored a publication or presentation	☐	☐	☐	☐	☐
Collaborated in other ways (please specify below)	☐	☐	☐	☐	☐

Please use this box to specify any other collaborations

In YOUR experience, what are the most significant barriers to incorporating telemetry findings into ACTUAL fisheries management practices?
Please use space provided to respond.If you have not encountered BARRIERS, please tell us why it was easy for your telemetry findings to be used by end users?

Part 2 CASE STUDY: Influences on uptake or integration of fish telemetry science

In this section we want you to focus on ONE CASE STUDY. Please think of one completed fish telemetry project (PROJECT defined as an applied project with clear objectives associated with a funding cycle) that you have beenthe most involved with and/or have the most experience.

Section A: Characteristics of Your Project

Please make sure you refer to the chosen fish telemetry project throughout the remainder of the survey.

19. Please provide the name of the project you have chosen.

20. Were you involved in the "project management" of this project?
Project management includes budgeting, being involved with the project from securing funding, logistical organization, to dissemination of the project data.

○ Yes
○ No

21. What type of telemetry equipment was used in this project?
Please check all that apply.

- ☐ Acoustic
- ☐ Radio
- ☐ Satellite

21a. If you used acoustic or radio tracking, what method of telemetry tracking did you use?
Please check all that apply.

- ☐ Passive
- ☐ Active
- ☐ Both

22. What was/were the focal species of this project?
Please list SCIENTIFIC NAMES of species. Use one box per species.

[ ]
[ ]
[ ]
[ ]
[ ]
[ ]

23. Where did the chosen project occur?
Please indicate the geographical boundaries of the study (i.e. country (ies), water body, cities/villages, etc.)

[ ]

23a. If applicable, can you describe the size (in km) of your study site?
For example, river kilometers, from river mouth to x km mid-reach, surface area of lake covered with detections)

[ ]

24. The following question deals with area (s) of work as it relates to your fish telemetry project. Please indicate the FOCUS of your project:
If the project DID NOT focus on a particular area, please leave BLANK.

- ☐ Energy/extraction sector evaluation (e.g., dams, oil platforms, hydrokinetic turbines)
- ☐ Migratory patterns and behaviour (life history perspective)
- ☐ Habitat use
- ☐ Protected area management/evaluation
- ☐ Fish survival (natural mortality)
- ☐ Bycatch (fishing mortality or sublethal effects)
- ☐ Recreational catch-and-release (fishing mortality or sublethal effects)
- ☐ Movement patterns/behaviour
- ☐ Overwintering behaviour
- ☐ Disease
- ☐ Spatial/temporal ecology
- ☐ Vulnerability to hydropower development
- ☐ Fisheries interaction
- ☐ Climate change impacts
- ☐ Predator vulnerability

☐ Human dimensions/social sciences

If the focus of the chosen project was not found in the list above, please describe below.

25. Please rank the following items as low, moderate or high in relation to this particular project and its context:

	Low	Moderate	High	Don't know
The level of stakeholder conflict	○	○	○	○
The number of different stakeholder groups	○	○	○	○
The level of controversy surrounding issue of project or study species	○	○	○	○
The level of media (e.g. radio, news, etc.) attention	○	○	○	○
Level of management attention	○	○	○	○
Number of jurisdictions involved	○	○	○	○
Complexity of regulatory, legal or governance context for the work	○	○	○	○
The level of data scrutiny by end users (i.e. skepticism of data, questioning of data)	○	○	○	○

25a. Please use this space to provide examples or elaborate on any of the examples listed above (Q.25).

26. In what year did this project begin?
Please indicate the when the study design began.______

In what year did this project complete/terminate?_____
Please indicate the first year data was disseminated____

Section B: Collaborative extent of the project...you are >50% through the survey!

In this section, we will be asking you about collaborations and project teams.

27. How did you FIRST become involved with this project? Please tell us a bit of the background as to how this project was initiated.

27a. Who are the end users and stakeholders of the findings produced by your project?
Please check all that apply.

☐ Fisheries managers
☐ Hydropower company
☐ Federal government
☐ Provincial/state government agencies
☐ Local/regional government agencies
☐ Fishers
☐ Indigenous groups
☐ Local community
☐ Other researchers
☐ Other, please specify... ______________________

28. Approximately what percentage of your research team were:

Students/post-doctoral fellows

Government affiliates

Industry/user group affiliates (example: fishers)

Non-governmental affiliates

Other universities/research group

29. What type of research funding have you received for this particular project?
Please check all that apply.

- ☐ Federal/National
- ☐ Provincial/State
- ☐ Regional/Local
- ☐ Industry funding/partnership
- ☐ Conservation or Environmental related association
- ☐ Fisheries-related association
- ☐ University or College
- ☐ Telemetry network funding

30. Who was involved in the grant proposal?
"Involve" means directly and indirectly (consulting, input, etc.). Please check all that apply.

- ☐ Graduate students and/or post-doctoral fellows
- ☐ Other university researchers/scientists
- ☐ Government researchers/scientists
- ☐ Government managers/policy makers
- ☐ Private sector researchers/scientists
- ☐ Industry representatives (ex: fishers)
- ☐ Environmental/conservation related non-governmental organizations (including fisheries associations)

31. How much total funding was secured for this project?
Please skip if you are not a principal investigator.Project: defined as an applied project with clear objectives associated with a funding cycle.

Please approximate to nearest $10,000 in US dollars

32. Is your affiliated institution a LOCAL institution relative to the project location?

- ○ Yes
- ○ No

If NO, do you have any collaborations or affiliations with a local institution or organization relative to the project location?
If YES, please skip the question.

- ○ Yes
- ○ No

33. Does your research team have any direct contact with the governing/regulatory body of the fish studied in this project?

- ○ Yes
- ○ No

If YES, how would you describe your relationship with this governing/regulatory body?

34. Approximately, how often of the following activities have you and your research team done related to the chosen project (in total)?
Please choose the best category that describes your response.

	None	1-3 times	4-6 times	7-9 times	10-15 times	15 + times
Presented at a conference	○	○	○	○	○	○
Published a refereed article	○	○	○	○	○	○
Published a non-refereed article (e.g. technical report)	○	○	○	○	○	○
Attended a stakeholder workshop/consultation meeting	○	○	○	○	○	○
Lead (i.e. organized) a stakeholder workshop/consultation meeting	○	○	○	○	○	○
Attended a manager's meeting	○	○	○	○	○	○
Made media appearances/comments	○	○	○	○	○	○
Wrote a press release	○	○	○	○	○	○
Engage in new media/social media (twitter, blogs, website, etc.)	○	○	○	○	○	○
Engaged in public outreach activities	○	○	○	○	○	○

Section D: Assessment of Knowledge Transfer

In this section, we would like to evaluate the uptake of your project findings

36. Have findings from this particular telemetry project been used in management or policy decisions?

○ Yes

○ No

Please leave any comments you may have here regarding previous question:

35. In YOUR opinion, how successful was your telemetry findings with respect to the following:

	Not at all successful	Somewhat successful	Very successful	Not applicable
Making scientific advancements	○	○	○	○
Knowledge transfer (i.e. findings being used by knowledge users such as stakeholders, managers, etc.)	○	○	○	○
Changing, developing or affirming a policy/practice	○	○	○	○
Integration into policy or management framework	○	○	○	○
Adoption/buy-in/uptake by stakeholders	○	○	○	○
Trusted by stakeholders	○	○	○	○
Generating media interest	○	○	○	○

Please describe why you believe your findings were utilized. If they were not, please explain why you believe they were not.

Please select the statement below that is most applicable to your familiary and involvement with the management and regulatory process of the species studied.

○ Not familiar (Ex: I have never been involved or interacted with the fisheries management of the species or the end users of the study context)

- ○ Somewhat familiar (Ex: I am aware of regulatory and management process, but still have uncertainties about them)
- ○ Familiar (Ex: I am actively interacting and involved with the fisheries managers and regulatory body)
- ○ Very familiar (Ex: I am regularly consulted, and actively participate in the management process of the study species)

A few more questions regarding your chosen project case study. This is the last section!
Remember! You are still using the same project chosen from Part 3 of the questionnaire.
38. What is the average/range number of fish tagged per year for this project?
Please indicate to the nearest "10" fish

[ ]

38a. If applicable, how many receivers were used in this study?

[ ]

39. Has your group conducted any validation studies for tagging prior or during this project?
- ○ Yes
- ○ No

If YES, please describe the validation/effect study briefly

[ ]

41. What are some of the greatest limitations or uncertainties of your project?
Please describe any internal or external criticism of the project in terms of uncertainties and limitations.

[ ]

41a. What are some of the greatest strengths of your project?
Please describe any aspects of the project that facilitated uptake of your findings.

[ ]

Thank you! You have completed the survey!
Please do not hesitate to contact the researcher, Vivian Nguyen, if you have any questions or comments, vivian.nguyen@carleton.ca
Can we follow-up with you?
If yes, please provide us with your e-mail address

[ ]

Do you know anyone who may significantly contribute to this study? If so, please indicate their name or e-mail below:

[ ]

If you are keen to continue, we have some other interesting questions to ask you...
1. Have you ever run into difficulties in obtaining “support” from the management or stakeholder community for tagging fish?
Support can be logistical, financial, etc.
- ○ Yes
- ○ No

If YES, please describe:

[ ]

2. Have you ever run into difficulties in obtaining “permission” to deploy telemetry receivers on land/water controlled by a given group?

- ○ Yes
- ○ No

if YES, please describe.

3. A disruptive technology is a new tool, technique or way of doing things that disrupts the status quo. Do you believe telemetry technology is a disruptive technology in the world of fish research and fisheries management?

- ○ Yes
- ○ No

Why or why not? Please explain in space provided.

4. Do you share your telemetry research data in publicly available databases?

- ○ Yes
- ○ No

5. Do you have concerns with sharing research data in publicly available databases?

- ○ Yes
- ○ No

If YES, please describe those concerns.
If NO, please leave blank.

6. Have any of those concerns actually materialized? (e.g., did your concerns come to reality?) Please describe.
If NO, please leave blank.

7. Have you benefited from publicly sharing your data?
I.e. has anything grown or developed out of sharing your data?

- ○ Yes
- ○ No

If YES, how?
Here, we are looking for specific examples of collaborations that have developed or papers that emerged from data sharing related to fish telemetry.

8. Have you used shared data for yourown research related to fish telemetry?

- ○ Yes
- ○ No

If YES, please describe how it was used?
If NO, please skip and leave blank.

References

Alavi M, Leidner, DE. 2001. Knowledge management and knowledge management systems: conceptual foundations and research issues. MIS Quarterly **25**: 107-136.

Amara N, Ouimet M, Landry R. 2004. New evidence on instrumental, conceptual, and symbolic utilization of university research in government agencies. Science Communication **26**(1): 75–106.

Argote L, McEvily B, Reagans R. 2003. Managing knowledge in organizations: an integrative framework and review of emerging themes. Management Science **49**: 571-582.

Arlettaz R, Schaub M, Fournier J, Reichlin TS, Sierro A, Watson JEM, Braunisch V. 2010. From Publications to Public Actions: When Conservation Biologists Bridge the Gap between Research and Implementation. BioScience **60**:835–842.

Armitage D, Berkes F, Dale A, Kocho-Schellenberg E, Patton E. 2011. Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. Global Environmental Change **21**(3): 995-1004.

Arzberger P, Schroeder P, Beaulieu A, Bowker G, Casey K, Laaksonen L, Moorman D. 2004. Promoting Access to Public Research Data for Scientific , Economic , and Social Development. Data Science Journal **3**:135–152.

Baas L, Hjelm O. 2015. Support your future today: Enhancing sustainable transitions by experimenting at academic conferences. Journal of Cleaner Production **98**:1–7. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.jclepro.2015.02.059.

Bainbridge I. 2014. How can ecologists make conservation policy more evidence based? Ideas and examples from a devolved perspective. Journal of Applied Ecology **51**: 1153–1158.

Barraza R, Velazquez-Angulo G, Flores-Tavizón E, Romero-González J, Huertas-Cardozo JI. 2016. The role of science in advising the decision making process: A pathway for building effective climate change mitigation policies in Mexico at the local level. International Journal of Environmental Research and Public Health **13**.

Bayliss HR, Wilcox A, Stewart GB, Randall NP. 2012. the Global Management of Invasive Species **8**:37–56.

Beier P, Hansen LJ, Helbrecht L, Behar D. 2016. A How-to Guide for Coproduction of Actionable Science. Conservation Letters **0**:9.

Bennet A, Bennet D, Fafard K, Fonda M, Lomond T, Messier L, Vaugeois N. 2007. Knowledge mobilization in the social sciences and humanities. Frost, WV: MQI Press.

Berkes F. 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. Journal of environmental management **90**(5): 1692-1702.

Biuw M, Boehme L, Guinet C, Hindel M, Costa DP, Charassin JB, Roquet F, Bailleul F, Meredith M, Thorpe S, Tremblay Y, McDonald B, Park YH, Rintoul SR, Bindoff N, Goebel M, Croker DE, Lovell P, Nicholson J, Monks F, Fedak MA. 2007. Variations in behavior and condition of a Southern Ocean top predator in relation to in situ oceanographic conditions. Proceedings of the National Academy of Sciences 104, 13705–13710.

Bodin Ö, Crona B, Ernstson H. 2006. Social networks in natural resource management: what is there to learn from a structural perspective. Ecology and Society: **11**(2): r2.

Bodin Ö, Crona BI. 2009. The role of social networks in natural resource governance: What relational patterns make a difference? Global environmental change: **19**(3): 366-374.

Borgatti SP, Cross R. 2003. A relational view of information seeking and learning in social networks. Management Science **49**: 432–445.

Bousquet G. 2008. A model for interdisciplinary collaboration. Modern Language Journal **92**:304–306.

Braunisch V, Home R, Pellet J, Arlettaz R. 2012. Conservation science relevant to action: A research agenda identified and prioritized by practitioners. Biological Conservation **153**:201–210.

Breiman L. 2001. Random Forests:5–32.

Breiman L, Friedman J, Stone CJ, Olshen RA. 1984. *Classification and regression trees*. CRC press.

Buizer J, Jacobs K, Cash D. 2012. Making short-term climate forecasts useful: Linking science and action. Proceedings of the National Academy of Sciences of the United States of America **113**:6.

Campbell HA et al. 2015. Finding our way: On the sharing and reuse of animal telemetry data in Australasia. Science of the Total Environment **534**:79–84.

Cash DW, Adger WN, Berkes F, Garden P, Lebel L, Olsson P. 2006. Scale and Cross-Scale Dynamics : Governance and Information in a Multilevel World **11**.

Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jäger J, Mitchell RB. 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences of the United States of America **100**:8086–8091.

Cederholm CJ, Kunze MD, Murota T, Sibatani A. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries **24**(10): 6-15.

Chan JC, Paelinckx D. 2008. Remote Sensing of Environment Evaluation of Random Forest and Adaboost tree-based ensemble classi fi cation and spectral band selection for ecotope mapping using airborne hyperspectral imagery **112**:2999–3011.

Chow WS, Chan LS. 2008. Social network, social trust and shared goals in organizational knowledge sharing. Information & Management **45**: 458-465.

Clark WC, van Kerkhoff L, Lebel L, Gallopin GC. 2016. Crafting usable knowledge for sustainable development. Proceedings of the National Academy of Sciences **113**(17): 4570-4578.

Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, McNie E. 2011. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). Proceedings of the National Academy of Sciences of the United States of America **5**:0900231108

Clark WC, van Kerkhoff L, Lebel L, Gallopin GC. 2016. Crafting usable knowledge for sustainable development. Proceedings of the National Academy of Sciences **113**(17): 4570-4578.

Cochrane, K. L. 1999. Complexity in fisheries and limitations in the increasing complexity of fisheries management. ICES Journal of Marine Science: Journal du Conseil, 56(6), 917-926.

Cohen BI. 2012. The Uncertain Future of Fraser River Sockeye. Volume 3: Recommendations - Summary - Process.

Collins H. 2010. Tacit and Explicit Knowledge. Chicago: University of Chicago Press.

Cook CN, Carter RWB, Fuller RA, Hockings M. 2012. Managers consider multiple lines of evidence important for biodiversity management decisions. Journal of Environmental Management **113**:341–346.

Cook CN, Hockings M, Carter RW. 2010. Conservation in the dark? The information used to support management decisions. Frontiers in Ecology and the Environment **8**:181–188.

Cook CN, Mascia MB, Schwartz MW, Possingham HP, Fuller RA. 2013. Achieving conservation science that bridges the knowledge-action boundary. Conservation Biology **27**:669–678.

Cooke SJ, Hinch SG, Wikelski M, Andews RD, Kuchel LJ, Wolcott TG, Butler PJ. 2004.

Biotelemetry: a mechanistic approach to ecology. TRENDS in Ecology and Evolution **19**: 334-343.

Cooke SJ, Rice JC, Prior KA, Bloom R, Jensen O, Browne DR, Donaldson LA, Bennett JR, Vermaire JC, Auld G. 2016. The Canadian context for evidence-based conservation and environmental management. Environmental Evidence. **5**:14

Cooke SJ et al. 2016. A moving target: incorporating knowledge of the spatial ecology of fish into the assessment and management of freshwater fish populations. Environmental Monitoring and Assessment **188**.

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

Cooke SJ, Thorstad EB. 2011. Is radio telemetry getting washed downstream? The changing role of radio telemetry in studies of freshwater fish relative to other tagging and telemetry technology. American Fisheries Society Symposium **76**: 1-22.

Cossarini DM, MacDonald BH, Wells PG. 2014. Communicating marine environmental information to decision makers: Enablers and barriers to use of publications (grey literature) of the Gulf of Maine Council on the Marine Environment. Ocean & Coastal Management **96:** 163-172.

Contandriopoulos D, Lemire M, Denis J-L, Tremblay E. 2010. Knowledge exchange processes in organizations and policy arenas: A narrative systematic review of the literature. Milbank Quarterly **88**(4):444-483.

Cowling R. 2005. Maintaining the research-implementation continuum in conservation. Society for Conservation Biology Newsletter **12**: 1-19.

Crona B, Bodin Ö. 2006. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. Ecology and Society **11**(2): 7.

Crona B, Parker J. 2012. Learning in support of governance: theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance. Ecology and Society **17**(1).

Cutler DR, Edwards TC, Beard KH, Cutler A, Hess KT, Gibson J, Lawler JJ. 2007. Random forests for classification in ecology. Ecology **88**(11): 2783-2792.

Cvitanovic C, Fulton CJ, Wilson SK, van Kerkhoff L, Cripps IL, Muthiga N. 2014. Utility of primary scientific literature to environmental managers: An international case study on coral-dominated marine protected areas. Ocean and Coastal Management **102**:72–78.

Cvitanovic C, Hobday AJ, van Kerkhoff L, Wilson SK, Dobbs K, Marshall NA. 2015. Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs. Ocean and Coastal Management **112**:25–35.

Cvitanovic C, McDonald J, Hobday AJ. 2016. From science to action: Principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making. Journal of Environmental Management:1–11. E

Damodaran L, Olphert W. 2000. Barriers and facilitators to the use of knowledge management systems. Behaviour Information Technology **19**:405–413.

De Young R. 1993. Changing behavior and making it stick the conceptualization and management of conservation behavior. Environment and behavior **25**(3): 485-505.

Dick M, Rous AM, Nguyen VM, Cooke SJ. 2016. Necessary but challenging : Multiple disciplinary approaches to solving conservation problems. Facets **1**:67–82.

Dilling L, Lemos MC. 2011. Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. Global Environmental Change **21**:680–689.

Donaldson MR, Hinch SG, Suksi CD, Fisk AT, Heupel MR Cooke SJ. 2014. Making connections in aquatic ecosystems with acoustic telemetry monitoring. *Frontiers in Ecology and Environment* 12, 565–573.

Driscoll CT, Lambert, KF, Weathers, KC. 2011. Integrating science and policy: a case study of the hubbard brook research foundation science links program. BioScience **61**(10): 791-801.

Eden S. 2011. Lessons on the generation of usable science from an assessment of decision support practices. Environmental Science and Policy **14**:11–19.

Eliot TS. 2004. The Data , Information , Knowledge , Wisdom Chain : The Metaphorical link.

Espinoza M, Farrugia TJ, Webber DM, Smith F, Lowe CG. 2011. Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. Fisheries Research **108**: 364-371.

Estabrooks C a., Thompson DS, Lovely JJE, Hofmeyer A. 2006. A guide to knowledge translation theory. The Journal of continuing education in the health professions **26**:25–36.

Excellence C. 2009. Universities need a new social contract **462**.

Fazey I et al. 2012. Knowledge exchange: a review and research agenda for environmental management. Environmental Conservation **40**:1–18.

Fazey I, Bunse L, Msika J, Pinke M, Preedy K, Evely AC, Lambert E, Hastings E, Morris S, Reed MS. 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Global Environmental Change **25**:204–220. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.gloenvcha.2013.12.012.

Feldman DL, Ingram HM. 2009. Making Science Useful to Decision Makers: Climate Forecasts, Water Management, and Knowledge Networks. Weather, Climate, and Society **1**:9–21.

Fliaster A, Spiess J. 2008. Knowledge mobilization through social ties: The cost-benefit analysis. Schmalenbach Business Review, 60, Available at SSRN: http://ssrn.com/abstract=1101654

Folt CL, Chen CY, Moore MV, Burnaford J. 1999. Synergism and antagonism among multiple stressors. Limnology and Oceanography **44**(3): 864–867.

Francis RA, Goodman MK. 2011. Post-normal science and the art of nature conservation. Journal for Nature Conservation **18**(2): 89–105.

Gale NK, Heath G, Cameron E, Rashid S, Redwood S. 2013. Using the framework method for the analysis of qualitative data in multi-disciplinary health research. BMC medical research methodology, **13**(1): 117.

Gainforth HL, Latimer-Cheung AE, Athanasopoulos P, Moore S, Ginis K a. 2014. The role of interpersonal communication in the process of knowledge mobilization within a community-based organization: a network analysis. Implementation science:59.

Gezelius SS, Refsgaard K. 2007. Barriers to rational decision-making in environmental planning. Land Use Policy **24**:338–348.

Gibbons M. 1999. Science's new social contract with society. Nature **402**:81–84.

Gibbons M. 2000. Mode 2 society and the emergence of context-sensitive science. Science and Public Policy **27**:159–163. A

Gibbons, P., Zammit, C., Youngentob, K., Possingham, H.P., Lindenmayer, D.B., Bekessy, S., Burgman, M., Colyvan, M., Considine, M., Felton, A., Hobbs, R.J., Hurley, K., McAlpine, C., McCarthy, M.A., Moore, J., Robinson, D., Salt, D., and Wintle, B. 2008. Some practical suggestions for improving engagement between researchers and policy-makers in natural resource management. Ecol. Manag. Restor. **9**(3): 182–186.

Gibbons M. 1999. Science's new social contract with society. Nature **402**: 81-84

Gislason PO, Benediktsson JA, Sveinsson JR. 2006. Random Forests for land cover classification **27**:294–300.

Greenhalgh T. 2010. What is this knowledge that we seek to "exchange"? Milbank Quarterly

88:492–499.

Gresh, T., Lichatowich, J., and Schoonmaker, P. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific ecosystem: evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest. Fisheries **25(**1): 15-21.

Groffman PM, Stylinski C, Nisbet MC, Duarte CM, Jordan R, Burgin A, Andrea Previtali M, Cary JC. 2010. Restarting the conversation: Challenges at the interface between ecology and society. Frontiers in Ecology and the Environment **8**:284–291.

Grömping, U. 2009. Variable importance assessment in regression: linear regression versus random forest. The American Statistician **63**(4): 308-319.

Grömping U, Römping UG. 2017. Variable Importance Assessment in Regression : Linear Regression versus Random Forest Variable Importance Assessment in Regression : Linear Regression versus Random Forest **1305**.

Groot C, Margolis L. 1991. *Pacific salmon life histories*. UBC press.

Goh SC. 2002. Managing effective knowledge transfer: an integrative framework and some practice implications. Journal of Knowledge Management **6**: 23-30.

Greenhalgh T, Wieringa S. 2011. Is it time to drop the “knowledge translation” metaphor? A critical literature review. Journal of the Royal Society of Medicine **104**: 501–509.

Hadorn GH, Bradley D, Pohl C, Rist S, Wiesmann U. 2006. Implications of transdisciplinarity for sustainable research. Ecological economics **60**:119–128.

Hegger D, Lamers M, Van Zeijl-Rozema A, Dieperink C. 2012. Conceptualising joint knowledge production in regional climate change adaptation projects: Success conditions and levers for action. Environmental Science and Policy **18**:52–65.

Hegland TJ, Raakjær J. 2008. Recovery plans and the balancing of fishing capacity and fishing possibilities: Path dependence in the common fisheries policy. In *Making Fisheries Management Work* (pp. 131-159). Springer Netherlands.

Hessels LK, van Lente H. 2008. Re-thinking new knowledge production: A literature review and a research agenda. Research Policy **37**:740–760.

Hirsch Hadorn G, Bradley D, Pohl C, Rist S, Wiesmann U. 2006. Implications of transdisciplinarity for sustainability research. Ecological Economics **60**:119–128. A

Hilary E. 2016. Collaborative research partnerships for knowledge mobilisation. Evidence & Policy **12**(2): 199-216.

Holland KN, Meyer CG, Dagorn LC. 2009. Inter-animal telemetry: results from first deployment of acoustic "business card" tags. Endangered Species Research **10**:287–293.

Hulme M. 2010. Problems with making and governing global kinds of knowledge. Global Environmental Change **20**(4): 558-564.

Hulme PE. 2014. EDITORIAL: Bridging the knowing-doing gap: know-who, know-what, know-why, know-how and know-when. Journal of Applied Ecology **51**:1131–1136.

Hussey NE et al. 2015. Aquatic animal telemetry: A panoramic window into the underwater world. Science **348**.

Hutchings JA, Walters C, Haedrich RL. 1997. Is scientific inquiry incompatible with government information control ?1198–1210.

Inkpen AC, Tsang EW. 2005. Social capital, networks, and knowledge transfer. Academy of management review **30**(1): 146-165.

Jacobs K, Garfin G, Lenart M. 2005a. More than Just Talk: Connecting Science and Decisionmaking. Environment: Science and Policy for Sustainable Development **47**:6–21.

Jacobs K, Garfin G, Lenart M. 2005b. More than Just Talk: Connecting Science and Decisionmaking. Environment: Science and Policy for Sustainable Development **47**:6–21.

Jacobson N, Goering P. 2006. Credibility and credibility work in knowledge transfer. Evidence & Policy: A Journal of Research, Debate and Practice **2**(2): 151-165.

Jasanoff S. 2010. NGOs and the environment: From knowledge to action. Third World Quarterly **18**(3): 579-594.

Jeffers VF, Godley BJ. 2016. Satellite tracking in sea turtles: How do we find our way to the conservation dividends? Biological Conservation **199**:172–184.

Jentoft S, Chuenpagdee R. 2009. Fisheries and coastal governance as a wicked problem. Marine Policy **33**: 553-560.

Kingdon J. 1995. Agendas, Alternatives, and Public Policies. 2nd ed. Harper Collins, 254 pp.

Kirchhoff CJ. 2013. Understanding and enhancing climate information use in water management. Climatic Change **119**:495–509.

Kirchhoff CJ, Lemos MC, Dessai S. 2013. Actionable Knowledge for Environmental Decision Making : Broadening the Usability of Climate Science.

Knight AT, Cowling RM, Rouget M, Balmford A, Lombard AT, Campbell BM. 2008. Knowing but not doing: selecting priority conservation areas and the research–implementation gap. Conservation Biology **22**(3): 610-617.

Lalor BM, Hickey GM. 2013. Environmental science and public policy in Executive government : Insights from Australia and Canada **40**:767–778.

Lam A. 2011. What motivates academic scientists to engage in research commercialization: "Gold", "ribbon" or "puzzle"? Research Policy **40**:1354–1368.

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ. 2012. Transdisciplinary research in sustainability science: Practice, principles, and challenges. Sustainability Science **7**:25–43.

Lansing E. 2009. Uncertainty and Fishery Management in the North American Great Lakes : Lessons from Applications of Decision Analysis.

Lemos MC, Kirchhoff CJ, Ramprasad V. 2012. Narrowing the climate information usability gap. Nature Climate Change **2**:789–794. Nature Publishing Group. Available from http://dx.doi.org/10.1038/nclimate1614.

Lemos MC, Morehouse BJ. 2005. The co-production of science and policy in integrated climate assessments. Global Environmental Change **15**:57–68.

Levin B. 2013. To know is not enough: research knowledge and its use. Review of Education **1**: 2-31.

Likens GE. 2010. The role of science in decision making : does evidence-based science drive environmental policy ?

Liu Y, Gupta H, Springer E, Wagener T. 2008. Linking science with environmental decision making: Experiences from an integrated modeling approach to supporting sustainable water resources management. Environmental Modelling & Software **23**:846–858.

Lodge M, Wegrich K. 2016. The Rationality Paradox of Nudge: Rational Tools of Government in a World of Bounded Rationality. Law and Policy **38**:250–267.

Lubchenco J, Nin E. (n.d.). Entering the Century of the Environment : A New Social Contract for Science.

Lucas MC, Baras E. 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. Fish and Fisheries **1:** 283–316.

Maxwell JA. 2012. *Qualitative research design: An interactive approach* (Vol. 41). Sage publications.

McGowan J et al. 2016. Integrating research using animal-borne telemetry with the needs of conservation management. Journal of Applied Ecology.

McGrail MR, Rickard CM, Jones R. 2006. Publish or perish: a systematic review of interventions to increase academic publication rates, Higher Education Research & Development **25**:1, 19-35

Meadow AM, Ferguson DB, Guido Z, Horangic A, Owen G, Wall T. 2015. Moving Toward the Deliberate Co-Production of Climate Science Knowledge. Weather, Climate, and Society:150406095212003.

Meffe GK. 1998. Conservation scientists and the policy process. Conservation Biology **12**(4): 741-742.

Merton RK. 1957. Priorities in scientific discovery: a chapter in the sociology of science. American sociological review **22**(6): 635-659.

Milner-Guland E. 2012. Interactions between human behaviour and ecological systems. Philosophical Transactions Royal Society B **367:** 270-278.

Mitton C, Adair C, Mckenzie E, Patten SB, Perry BW. 2007. Knowledge transfer and exchange: review and synthesis of literature. The Milbank Quarterly **85**: 729-768.

Morris S, Reed MS. 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Global Environmental Change **25**(1): 204–220. Elsevier Ltd. doi:10.1016/j.gloenvcha.2013.12.012.

Mulkay, M. J. (1976). Norms and ideology in science. Social Science Information **15**(4-5): 637-656.

Munck af Rosenschöld J, Rozema JG, Frye-Levine LA. 2014. Institutional inertia and climate change: A review of the new institutionalist literature. Wiley Interdisciplinary Reviews: Climate Change **5**:639–648.

Murdoch W, Polasky S, Wilson KA, Possingham HP, Kareiva P, Shaw R. 2007. Maximizing return on investment in conservation **9**.

Nathan R, Getz WM, Revilla E, Holyoak M, Kadmon R, Saltz D. Smouse PE. 2008. A movement ecology paradigm for unifying organismal movement research. Proceedings of the National Academy of Sciences **105**(49): 19052-19059.

Nel JL, Roux DJ, Driver A, Hill L, Maherry AC, Snaddon K, Petersen CR, Smith-Adao LB, Van Deventer H, Reyers B. 2016. Knowledge co-production and boundary work to promote implementation of conservation plans. Conservation Biology **30**:176–188.

Nguyen VM, Young N, Cooke SJ. 2016. A roadmap for knowledge exchange and mobilization research in conservation and natural resource management. Conservation Biology **0**:n/a-n/a..

Nowotny, H., Scott, P. B., and Gibbons, M. T. 2013. *Re-thinking science: Knowledge and the public in an age of uncertainty*. John Wiley & Sons.

Ntshotsho P, Prozesky HE, Esler KJ, Reyers B. 2015. What drives the use of scientific evidence in decision making? The case of the South African Working for Water program. Biological Conservation **184**: 136–144.

O'Dor RK, Andrade Y, Webber DM, Sauer WHH, Roberts MJ, Smale MJ, Voegeli FM. 1998. Applications and performance of radio-acoustic positioning and telemetry (RAPT) systems. Hydrobiologia **371–372**:1–8.

Ostrom E. 1992. Community and the endogenous solution of commons problems. Journal of Theoretical Politics **4**(3): 343-351.

Ostrom E. 1999. Coping with tragedies of the commons. Annual review of political science **2**(1): 493-535.

Ostrom E. 2009. A general framework for analyzing sustainability of social-ecological systems. Science (New York, N.Y.) **325**:419–422.

Ostrom E. 2010. Polycentric systems for coping with collective action and global environmental change. Global Environmental Change **20**(4): 550-557.

Ostrom E. 2014. Collective action and the evolution of social norms. Journal of Natural Resources Policy Research **6**(4): 235-252.

Pace ML et al. 2010. Communicating with the public : opportunities and rewards for individual ecologists. Frontiers in Ecology and Environment **8** (6): 292-298.

Pahl-Wostl C. 2006. The importance of social learning in restoring the multifunctionality of rivers and floodplains. Ecology and society **11**(1): 10.

Paterson M., Hoffmann M., Betsill M., Bernstein S. 2014. The micro foundations of policy diffusion toward complex global governance: An analysis of the transnational carbon emission trading network. Comparative Political Studies **47**(3): 420-449.

Patterson DA, Cooke SJ, Hinch SG, Robinson KA, Young N, Farrell AP, Miller KM. 2016. A perspective on physiological studies supporting the provision of scienti fi c advice for the management of Fraser River sockeye salmon (Oncorhynchus nerka) **4**:1–15.

Peyton, J., and Franks, A. 2015. The new nature of things? Canada's Conservative Government and the design of the new environmental subject. Antipode, 1–21. https://doi.org/10.1111/anti.12179

Phelps C, Heidl R, Wadhwa A. 2012. Knowledge, networks, and knowledge networks: a review and research agenda. Journal of Management **38***:*1115 DOI: 10.1177/0149206311432640

Phillipson J, Lowe P, Proctor A, Ruto E. 2012. Stakeholder engagement and knowledge exchange in environmental research. Journal of Environmental Management **95**(1): 56-65.

Pinch TJ, Bijker, WE. 1984. The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. Social studies of science **14**(3): 399-441.

Pita C, Pierce GJ, Theodossiou I. 2010. Stakeholders' participation in the fisheries management decision-making process: Fishers' perceptions of participation. Marine Policy **34**:1093–1102.

Pohl C. 2005. Transdisciplinary collaboration in environmental research. Futures **37**:1159–1178.

Pohl C. 2008. From science to policy through transdisciplinary research. Environmental Science & Policy **11**:46–53.

Posner SM, Mckenzie E, Ricketts TH. 2015. Policy impacts of ecosystem services knowledge.

Prasad AM, Iverson LR, Liaw A. 2006. Newer classification and regression tree techniques: Bagging and random forests for ecological prediction. Ecosystems **9**:181–199.

Pullin AS, Knight TM. 2003. Support for decision making in conservation practice: an evidence-based approach. Journal for Nature Conservation **11**:83–90.

Pullin AS, Knight TM, Stone D a., Charman K. 2004. Do conservation managers use scientific evidence to support their decision-making? Biological Conservation **119**:245–252.

Raymond CM, Fazey I, Reed MS, Stringer LC, Robinson GM, Evely AC. 2010. Integrating local and scientific knowledge for environmental management. Journal of Environmental Management **91**:1766–1777.

Rice JC. 2011. Advocacy science and fisheries decision-making. ICES Journal of Marine Science **68**(10): 2007-2012.

Ritchie J, Lewis J, Nicholls CM, Ormston R. (Eds.). 2013. Qualitative research practice: A guide for social science students and researchers. Sage.

Reed M, Evely AC, Cundill G, Fazey IRA, Glass J, Laing A. 2010. What is social learning?

Ecology and Society. andrews.ac.uk/handle/10023/1624.

Reed MS. 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation **141**:2417–2431.

Reed MS, Stringer LC, Fazey I, Evely AC, Kruijsen JHJ. 2014. Five principles for the practice of knowledge exchange in environmental management. Journal of Environmental Management **146**:337–345.

Refsgaard JC, van der Sluijs JP, Højberg AL, Vanrolleghem PA. 2007. Uncertainty in the environmental modelling process – A framework and guidance. Environmental Modelling & Software **22**:1543–1556.

Rose DC. 2015. The case for policy-relevant conservation science. Conservation Biology **29**:748–754.

Roux DJ, Rogers KH, Biggs HC, Ashton PJ, Sergeant A. 2006. Bridging the Science – Management Divide : Moving from Unidirectional Knowledge Transfer to Knowledge Interfacing and Sharing. Ecology and Society **11**(1): 4.

Roux DJ, Stirzaker RJ, Breen CM, Lefroy EC, Cresswell HP. 2010. Framework for participative reflection on the accomplishment of transdisciplinary research programs. Environmental science & policy **13**(8): 733-741.

Rycroft-Malone J, Harvey G, Seers K, Kitson A, McCormack B, Titchen A. 2004. An exploration of the factors that influence the implementation of evidence into practice. J Clin Nurs **13**:913–924.

Rudd MA. 2011. How research-prioritization exercises affect conservation policy. Conservation Biology **25**(5): 860-866.

Rutz C, Hays GC. 2009. New frontiers of biologging science. Biology Letters **5**: 289-292.

Saarela SR, Rinne J. 2016. Knowledge brokering and boundary work for ecosystem service indicators. An urban case study in Finland. Ecological Indicators **61**:49–62.

Schultz P. 2011. Conservation means behavior. Conservation Biology **25**(6): 1080-1083.

Schusler TM. 2003. Social Learning for Collaborative Natural Resource Management. Society & natural resources **16**:309–326.

Schuttenberg HZ, Guth HK. 2015. Seeking our shared wisdom: A framework for understanding knowledge coproduction and coproductive capacities. Ecology and Society **20**.

Shanley P, Lopez C. 2009. Out of the loop: why research rarely reaches policy makers and the public and what can be done. Biotropica. 41(5):535-544.

Shaxson L. 2005. Questions for policy makers and practitioners practice **1**:101–111.

Singh GG, Tam J, Sisk TD, Klain SC, Mach ME, Martone RG, Chan K. 2014. A more social science: barriers and incentives for scientists engaging in policy. Frontiers in Ecology and the Environment **12**(3): 161-166.

Soomai SS. 2017a. The science-policy interface in fisheries management: Insights about the influence of organizational structure and culture on information pathways. Marine Policy **81**:53–63.

Soomai SS. 2017b. Understanding the science-policy interface: Case studies on the role of information in fisheries management. Environmental Science & Policy **72:** 65-75.

Soomai SS, Wells PG, MacDonald BH. 2011. Multi-stakeholder perspectives on the use and influence of "grey" scientific information in fisheries management. Marine Policy **35**(1): 50-62.

Sorensen E, Torfing J. 2011. Enhancing Collaborative Innovation in the Public Sector. Administration & Society **43**:842–868. SAGE Publications.

Stål HI. 2015. Inertia and change related to sustainability - An institutional approach. Journal of Cleaner Production **99**:354–365.

Star SL. 2010. This is not a boundary object: Reflections on the origin of a concept. Science, Technology & Human Values **35**(5): 601-617.

Stokols D. 2006. Toward a science of transdisciplinary action research. American Journal of Community Psychology **38**:63–77.

Stone DA. 1997. Policy Paradox: The Art of Political Decision Making. W.W. Norton, 394 pp

Sutherland WJ, Pullin AS, Dolman PM, Knight TM. 2004. The need for evidence-based conservation. Trends in Ecology and Evolution **19**:305–308.

Tainter JA. 1996. Complexity, problem solving, and sustainable societies. Getting down to earth: practical applications of Ecological Economics, 61-76.

Tenopir C, Allard S, Douglass K, Aydinoglu AU, Wu L, Read E, Manoff M, Frame M. 2011. Data sharing by scientists: practices and perceptions. PloS one **6**:e21101. Available from http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0021101.

Thakadu OT, Irani T a., Telg R. 2013. Predictors of Knowledge-Sharing Behaviors Among Community-Based Natural Resources Organizations in the Okavango Delta, Botswana.

Science Communication **35**:572–602. Available from http://www.scopus.com/inward/record.url?eid=2-s2.0-84884132626&partnerID=tZOtx3y1.

Thomas DR. 2006. A General Inductive Approach for Analyzing Qualitative Evaluation Data **27**:237–246.

Torfing J, Sørensen E, Røiseland A. (n.d.). Transforming the Public Sector Into an Arena for Co-Creation: Barriers, Drivers, Benefits, and Ways Forward.

Touw WG, Bayjanov JR, Overmars L, Backus L, Boekhorst J, Wels M, Sacha van Hijum AFT. 2013. Data mining in the life science swith random forest: A walk in the park or lost in the jungle? Briefings in Bioinformatics **14**:315–326.

van Kerkhoff L, Lebel L. 2006. Linking Knowledge and Action for Sustainable Development. Annual Review of Environment and Resources **31**:445–477.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth's ecosystems. *Science*, *277*(5325), 494-499

Vlek C, Steg L. 2007. Human Behavior and Environmental Sustainability : Problems , Driving Forces , and Research Topics **63**:1–19.

Wagner, C. M., Jones, M. L., Twohey, M. B., & Sorensen, P. W. (2006). A field test verifies that pheromones can be useful for sea lamprey (Petromyzon marinus) control in the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(3), 475-479.

Wang S, Noe RA. (2010). Knowledge sharing: A review and directions for future research. Human Resource Management Review **29**: 115-131.

Webb DC, Simonetti PJ, Jones CP. 2001. SLOCUM: an underwater glider propelled by environmental energy. IEEE Journal of Oceanic Engineering **26**:447–452

Weingart P. 1999. Scientific expertise and political accountability: paradoxes of science in politics. Science and public policy **26**(3): 151-161.

Welch DW, Boehlert G, Ward BR. 2002. POST—the Pacific Ocean Salmon Tracking Project. Oceanologica Acta **25**:243–253.

Wu J, Liu H, Duan X, Ding Y, Wu H, Bai Y. 2009. Prediction of DNA-binding residues in proteins from amino acid sequences using a random forest model with a hybrid feature **25**:30–35.

Yamamoto YT. 2012. Values, objectivity and credibility of scientists in a contentious natural resource debate. Public Understanding of Science **21**(1): 101–125.

Yang T, Maxwell TA. 2011. Information-sharing in public organizations : A literature review of interpersonal , intra-organizational and inter-organizational success factors. Government Information Quarterly **28**:164–175. Elsevier Inc. Available from http://dx.doi.org/10.1016/j.giq.2010.06.008.

Young JC et al. 2014. Improving the science-policy dialogue to meet the challenges of biodiversity conservation: Having conversations rather than talking at one-another. Biodiversity and Conservation **23**:387–404.

Young N, Gingras I, Nguyen VM, Cooke SJ, Hinch SG. 2013. Mobilizing new science into management practiceb : the challenge of biotelemetry for fisheries management, a case study of Canada's fraser river. Journal of International Wildlife Law & Policy **16**:331–351.

Young N, Corriveau M, Nguyen VM, Cooke SJ, Hinch SG. 2016a. How do potential knowledge users evaluate new claims about a contested resource? Problems of power and politics in knowledge exchange and mobilization. Journal of Environmental Management **184**: 380-388.

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