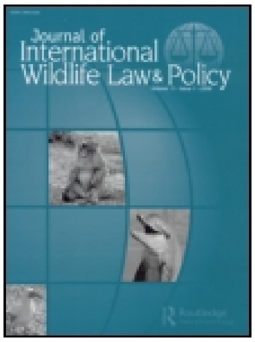

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Mobilizing New Science into Management Practice: The Challenge of Biotelemetry for Fisheries Management, a Case Study of Canada's Fraser River

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1. INTRODUCTION

Natural resources that are "commons" or held in public trust are notoriously difficult to govern.[1] In the absence of exclusive property rights, authorities face the twin challenges of setting limits on the amount that may be harvested (a sustainability challenge) and determining how the harvest should be distributed (an equity challenge). These decisions, which are often controversial on their own, are particularly difficult in fisheries management, where

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[1] E. Ostrom et al., *Revisiting the Commons: Local Lessons, Global Challenges*, 284 SCIENCE 278–282 (1999).

significant gaps in scientific knowledge still exist. Despite recent advances, our understanding of aquatic environments remains strikingly limited, which means that big decisions must be made using incomplete information. Under these circumstances, one might assume that any new knowledge would be cheerfully welcomed by decision-makers and promptly integrated into management plans as a way of filling in gaps and reducing uncertainty. The reality, however, is far more complex. Research in the sociology of science shows that real barriers exist to the uptake of new knowledge by potential users.[2] We will argue that these barriers are paradoxically high in fields such as resource management, where decision-makers are publicly scrutinized and questioned by stakeholder groups and media outlets. This, we suggest, spurs them to be conservative in their practices, preferring tried-and-true knowledge and techniques over newer and potentially very useful ones.[3]

This article examines the case of a rapidly advancing technology—biotelemetry—and its potential impact on the management of Pacific salmon species in Canada's vast Fraser River watershed. Biotelemetry technologies have been around for several decades, but recent innovations and infrastructure investments have made them a powerful knowledge- and data-generating tool.[4] Biotelemetry involves the attachment or implantation of a "tag" on or in an animal that then relays information remotely to a receiver. Importantly, these tags have become smaller, less intrusive, and longer-lasting, while international research groups such as the Pacific Ocean Shelf Tracking Project (POST) and Ocean Tracking Network (OTN) have invested in the laying of data-gathering "listening lines" on ocean- and river-beds worldwide, including the Fraser River system and the Pacific coast of North America.[5] These new technologies are providing unprecedented information on the movements, health, habits, and vulnerabilities of aquatic species.[6] As such, biotelemetry has tremendous potential to aid in conservation, allowing for nuanced management of both fisheries and habitat.[7] This data boon, however, has not yet had a substantial impact on decision-making about the resource. We use concepts

[2] S. Rynes, J. Bartunek, & R. Daft, *Across the Great Divide: Knowledge Creation and Transfer between Practitioners and Academics*, 44 ACAD. MANAGE. J. 340–355 (2001); HARRY COLLINS, EXPLICIT AND TACIT KNOWLEDGE (2010).

[3] A. S. Pullin et al., *Do Conservation Managers Use Scientific Evidence to Support Their Decision-making?*, 119 BIOL. CONS. 245–252 (2004).

[4] S. Cooke et al., *Biotelemetry: A Mechanistic Approach to Ecology*, 19 TRENDS ECOL. EVOL. 334–343 (2004).

[5] D. W. Welch, G. W. Boehlert, & B. R. Ward, *POST—the Pacific Ocean Shelf Tracking Project*, 25 OCEANOL. ACTA 243–253 (2002); S. J. Cooke et al., *Ocean Tracking Network Canada: A Network Approach to Addressing Critical Issues in Fisheries and Resource Management with Implications for Ocean Governance*, 36 FISHERIES 583–592 (2011).

[6] M. J. W. Stokesbury et al., *Tracking Diadromous Fishes at Sea: The Electronic Future Using Hybrid Acoustic and Archival Tags*, 69 AM. FISH. SOC. SYMP. 1–10 (2009).

[7] S. J. Cooke, *Biotelemetry and Biologging in Endangered Species Research and Animal Conservation*, 4 ENDANGER. SPECIES RES. 165–185 (2008).

from the sociology of science and the literature on knowledge mobilization, alongside our own multidisciplinary experience as researchers and practitioners in this region, to examine why this is and to suggest ways forward in this and similar cases where new knowledge meets longstanding resource management challenges.

2. MANAGING PACIFIC SALMON IN THE FRASER RIVER SYSTEM

The Fraser River watershed is one of the most socially and ecologically complex regions in Canada. Located in the southern half of the province of British Columbia, the River and its tributaries drain an area of approximately 220,000 square kilometres. The Fraser itself runs 1,375 kilometres, through both the Rocky and Coast Mountain Ranges, beginning near the Alberta border and meeting the Pacific Ocean at the city of Vancouver (with a metropolitan population of 2.3 million). The Fraser River also has profound economic and cultural importance for First Nation (Indigenous) groups. The traditional territories of 94 distinct First Nations are located within the Fraser system, and anthropological evidence shows that bounty from the river historically sustained some of the highest pre-modern population densities in the world.[8]

The Fraser River is one of the world's most productive salmon habitats. The river hosts five species of 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*. All are anadromous species, meaning that they spawn in fresh water but spend much of their adult lives feeding and growing in coastal waters and the open ocean. Salmon species return to their spawning grounds only once, while steelhead may do so multiple times. Salmon migrations are cyclical, but some estimates suggest that Fraser populations are down as much as 50 per cent from historic levels.[9] There is controversy about the cause of these declines[10], but the fact that there are fewer fish to go around is ratcheting up pressure on officials to better conserve and equitably distribute the resource.

The main body responsible for governing Pacific salmon fisheries in the Fraser River is the federal Department of Fisheries and Oceans (DFO). A

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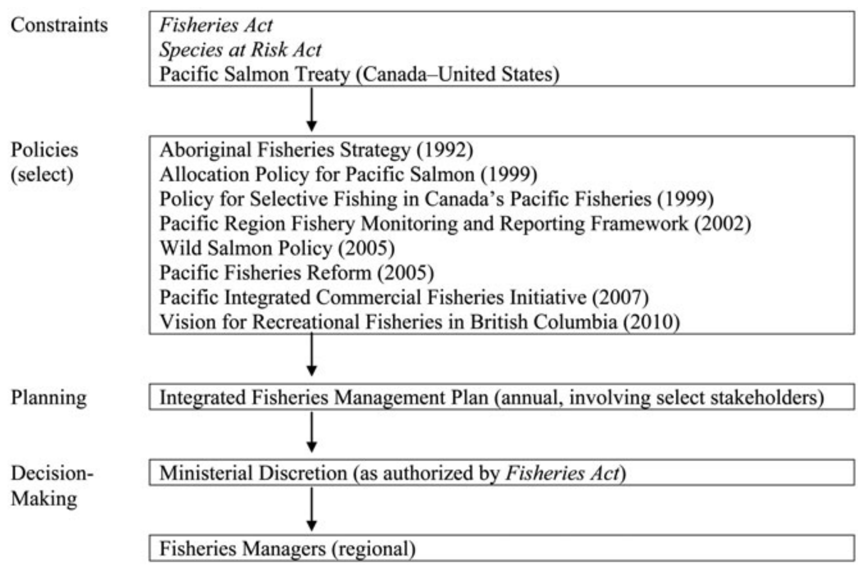
[8] Douglas Ubelaker, *North American Indian Population Size, A. D. 1500 to 1985*, 77 AM. J. PHYS. ANTHROPOL. 289–294 (1988).

[9] Ted Gresh, Jim Lichatowich, & Peter Schoonmaker, *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*, 25 FISHERIES 15–21 (2000); Michael C. Healey, *Resilient Salmon, Resilient Fisheries for British Columbia, Canada*, 14 ECOL. SOC. (2009), *at* http://www.ecologyandsociety.org/vol14/iss1/art2/ (visited 7 June 2013).

[10] BRUCE I. COHEN, THE UNCERTAIN FUTURE OF FRASER RIVER SOCKEYE: VOLUME 2, CAUSES OF THE DECLINE (2012), *at* http://www.cohencommission.ca/en/FinalReport/ (visited 7 June 2013).

FIGURE 1. DFO's decision-making process regarding the pacific salmon fishery in the Fraser River.



rough schematic of DFO's decision-making process is provided in Figure 1. DFO's actions are guided and constrained by several pieces of legislation, notably the *Fisheries Act* (FA) and the *Species at Risk Act* (SARA), as well as international agreements such as the *Pacific Salmon Treaty* (PST) with the United States. Both the FA and SARA are based on strong conservationist principles, although recent changes to the FA limit the protection afforded to some species.[11] The PST mandates that Canada and the United States share information and coordinate planning through the Pacific Salmon Commission (PSC), which has equal representation from both countries. Numerous non-legislated policies are also in force on the Fraser River, including those that provide guidelines for the allocation of quotas, protect First Nation fisheries, and support sport fishery development. Each year DFO undertakes active planning through Integrated Fisheries Management Plans (IFMP), which are drafted in consultation with select stakeholders (First Nations, representatives of commercial and recreational fisheries, and environmental groups) and guided by the principles of DFO's Wild Salmon Policy.[12] Final decision-making

[11] Bill C-38 (2012), *at* http://www.parl.gc.ca/HousePublications/Publication.aspx?DocId=5524772 (visited 30 November 2012).

[12] BRUCE I. COHEN, THE UNCERTAIN FUTURE OF FRASER RIVER SOCKEYE: VOLUME 1, THE SOCKEYE FISHERY (2012), *at* http://www.cohencommission.ca/en/FinalReport/ (visited 7 June 2013).

authority over in-river harvesting rests with the Minister of Fisheries and Oceans.[13]

Regional fisheries managers, however, also have significant decision-making responsibilities and authority.[14] They have a complex role in fisheries governance as they are tasked with participating in IFMP planning, forecasting the status of different species and stocks, implementing Ministerial directives, integrating new scientific knowledge, relating to stakeholders, and adjusting guidelines and regulations in-season.[15] In other words, fisheries managers are important "knowledge synthesizers" who are expected to translate multiple (and sometimes conflicting) claims and information into on-the-ground decisions. As such, fisheries managers are immediate potential users of biotelemetry knowledge, and represent an important site of entry for new science into DFO's overall decision-making process.[16] In the remainder of this article we will focus on the challenges of moving biotelemetry knowledge into fisheries managers' decision-making practices.

3. WHAT BIOTELEMETRY COULD DO FOR FISHERIES MANAGEMENT

The world's oceans, lakes, and rivers are big places with complex ecosystems. While great strides have been made in marine and aquatic sciences, what we do not know still overwhelms what we do. Biotelemetry helps to fill in these knowledge gaps by following animals as they move, eat, reproduce, live, and die. As such, biotelemetry generates rich spatio-temporal data, not only on the animals themselves but their interactions with other species, the habitats they frequent, and human activities such as fisheries. In the Fraser River, biotelemetry provides information on fish behaviours on the long trek to and from spawning grounds—where they rest, what obstacles give them difficulty, and where they die (often prematurely).[17] The Fraser River is home to hundreds of distinct salmon populations, some of which are in danger of extirpation, and each of which have adapted differently to their particular migration route.[18]

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[13] The bilateral Fraser River Panel of the PSC is responsible for the in-season management of the "Fraser River Panel Area" that encompasses the southwest coast of Vancouver Island, the Strait of Juan de Fuca, and Puget Sound, through which many Fraser River-bound salmon pass.

[14] FISHERIES AND OCEANS CANADA (DFO), INTEGRATED FISHERIES MANAGEMENT PLAN—SALMON, SOUTHERN B.C. (2011).

[15] COHEN, *supra* note 12, at 77–83.

[16] Scott Hinch, Vivian Nguyen, & David Patterson, *Integrating Biological and Social Sciences into Management Actions: Success and Future Challenges with Adult Pacific Salmon*, *in* PROCEEDINGS OF OCEAN TRACKING NETWORK ANNUAL GENERAL MEETING (2012).

[17] Scott Hinch et al., *Dead Fish Swimming: A Review of Research on the Early Migration and High Premature Mortality in Adult Fraser River Sockeye Salmon Oncorhynchus nerka*, 81 J. FISH BIOL. 576–599 (2012).

[18] Sayre Hodgson & Thomas P. Quinn, *The Timing of Adult Sockeye Salmon Migration into Fresh Water: Adaptations by Populations to Prevailing Thermal Regimes*, 80 CAN. J. ZOOL. 542–555 (2002).

Biotelemetry research has helped identify particular vulnerabilities of these populations in rivers and coastal waters.[19] It has provided new information on how climate change, catch-and-release sport fisheries, and bycatch affect salmon survival and resilience in the Fraser River.[20]

More immediately, biotelemetry has the potential to assist managers in their pre-, post- and in-season decision-making. Accurate pre-season estimates of run sizes remains a major challenge for DFO,[21] and the year-over-year accumulation of biotelemetry data on the survival rates of outbound smolts compared to (later) adult returns would undoubtedly enhance prediction models. Post-season, biotelemetry data could be used to evaluate pre-season assumptions about in-river mortality on a stock-specific basis, and to reconcile inconsistencies in models estimated from coarser sources of data (such as visual in-river or spawning bed counts). Finally, the fact that biotelemetry data are collected digitally means that they could *potentially* be used to make real time in-season decisions concerning quotas and closings. Communication-enabled receivers exist that immediately relay data to computers. Fisheries managers already use real-time information about water temperature and rate of flow on the Fraser to make in-season decisions,[22] and biotelemetry data could conceivably be integrated into this system to provide real-time information on fish behaviours and survival rates.

Despite this broad utility, biotelemetry has yet to be fully integrated into fisheries management on the Fraser (we will discuss specific cases of success and failure below). First, however, we review what is known about the complex process called knowledge mobilization, or the movement of scientific information from the laboratory to the "real world."

4. KNOWLEDGE MOBILIZATION: CHALLENGES AND OPPORTUNITIES

In recent years, social scientists have begun to empirically investigate how scientific knowledge is (and is not) used, adapted, transformed, and otherwise applied by actors outside the traditional scientific community, particularly

[19] Hinch et al., *supra* note 17.

[20] M. R. Donaldson et al., *The Consequences of Angling, Beach Seining, and Confinement on the Physiology, Post-release Behaviour and Survival of Adult Sockeye Salmon during Upriver Migration*, 108 FISH. RES. 133–141 (2011); E. G. Martins et al., *Effects of River Temperature and Climate Warming on Stock-specific Survival of Adult Migrating Fraser River Sockeye Salmon*, 17 GLOBAL CHANGE BIOL. 99–114 (2010).

[21] DFO, PRE-SEASON RUN SIZE FORECASTS FOR FRASER RIVER SOCKEYE SALMON IN 2012 (2012).

[22] J. S. Macdonald et al., *Modeling the Influence of Environmental Factors on Spawning Migration Mortality for Sockeye Salmon Fisheries Management in the Fraser River, British Columbia*, 139 TRANS. AM. FISH. SOC. 768–782 (2010).

professionals, governments, industry, and civil society.[23] This research has been conducted under several labels, including knowledge management, knowledge transfer, and knowledge translation. We prefer the term knowledge mobilization, however, because it implies an open-ended and ongoing process. Specifically, it reflects the fact that knowledge can flow back and forth between generators and users, have multiple direct and indirect uses, and have impacts that are often non-linear, counter-intuitive, and time-delayed.[24] While the field is still young, existing research suggests that knowledge mobilization is strongly influenced by two factors: *channels* and *institutional receptiveness*.

4.1 Channels

Despite all the talk of this being a knowledge society, research tells us that knowledge does not actually travel very well. Part of the problem has to do with volume. The speed and scale of scientific discovery—along with new communications technologies such as the Internet—ironically makes knowledge consumption more difficult. According to the sociologist Sheldon Ungar, the knowledge society is no longer characterized by knowledge scarcity but *overabundance*.[25] The problem is not access, but search: knowing that relevant and trustworthy information is out there and being able to find it when needed. The problem of search is compounded as the volume of information increases while time (that most stubborn of resources) remains limited. In other words, knowledge consumption is no longer constrained by its absence, but by what sociologists call an "economy of attention"—as it gets increasingly difficult to keep abreast of a field, the opportunity and incentive to seek out other sources of knowledge are diminished.[26]

Under these conditions, knowledge—especially new and unfamiliar knowledge—has to "cut through" to be noticed, hence the emphasis on *channels*. One of the most obvious channels is coverage by the mass media, which is why scientists and universities pay so much attention to this type of exposure.[27] Less obvious, but arguably more important, are social connections.

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[23] V. Ward, A. O. House, & S. Hamer, *Developing a Framework for Transferring Knowledge into Action: A Thematic Analysis of the Literature*, 14 J. HEALTH SERV. RES. POLICY 1–156 (2009); Amanda Cooper & Ben Levin, *Some Canadian Contributions to Understanding Knowledge Mobilization*, 6 EVID. POLICY 351–369 (2010); Johanne Provencal, *Extending the Reach of Research as a Public Good: Moving beyond the Paradox of "Zero-sum Language Games,"* 20 PUBLIC UNDERST. SCI. 101–116 (2011).

[24] John Shields & Bryan Evans, *Knowledge Mobilization/Transfer, Research Partnerships, and Policy-making: Some Conceptual and Practical Considerations*, 33 CERIS 1–14 (2008); Cooper and Levin, *supra* note 23; Ben Levin, THINKING ABOUT KNOWLEDGE MOBILIZATION (2008).

[25] Sheldon Ungar, *Ignorance as an Under-identified Social Problem*, 59 BRIT. J. SOCIOL. 301–326 (2008).

[26] RICHARD LANHAM, THE ECONOMICS OF ATTENTION (2006).

[27] Nathan Young & Ralph Matthews, *Experts' Understanding of the Public: Knowledge Control in a Risk Controversy*, 16 PUBLIC UNDERST. SCI. 123–144 (2007).

The knowledge mobilization literature is nearly unanimous that knowledge moves best through interpersonal connections. This is exemplified in the ritual of the academic conference. On the surface, conferences are costly ways of disseminating information given that papers could be shared free of charge over the Internet. But the purpose of conferences is to exchange knowledge through conversation, exchange, and debate.[28] Research has also shown that scholars are far more likely to cite the work of people they know, or have heard speak, than those who are just names on an article header.[29]

Finally, interpersonal connections are important means of building trust, which is essential for the successful movement of knowledge across groups that may have different priorities and interests. Any knowledge mobilization effort that involves people with different backgrounds—be it interdisciplinary research or community outreach—is far more likely to succeed if participants are willing and able to meet face-to-face.[30] While meetings, consultations, and workshops can be tedious, they are proven means of cutting through the noise and establishing long-term channels for knowledge sharing.

4.2 Institutional Receptiveness

The second major factor affecting knowledge mobilization outcomes has to do with institutions. Most people involved in knowledge generation and use are embedded in institutions that have particular cultures, embody certain values, and encourage and discourage different behaviours. For example, most academic science takes place in universities, which grant researchers a great deal of autonomy and have reward systems that reinforce sharing, openness, peer evaluation, and academic freedom.[31] This contrasts with much private sector research, which is typically conducted in an environment of secrecy and proprietariness. Collaboration between these groups is notoriously difficult because each is embedded in different institutional contexts.[32]

More generally, institutions vary in their stance towards new knowledge. This is captured in the term "absorptive capacity," which has been well studied

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[28] JOHN URRY, MOBILITIES (2007).

[29] S. Paavola, L. Lipponen, & K. Hakkarainen, *Models of Innovative and Knowledge Communities and Three Metaphors of Learning*, 74 REV. EDUC. RES. 557–576 (2004); Nicole Klenk, Gordon Hickey, & Ian James MacLellan, *Evaluating the Social Capital Accrued in Large Research Networks: The Case of Sustainable Forest Management Network (1995–2009)*, 40 SOC. STUD. SCI. 931–960 (2010).

[30] ADAPTIVE CO-MANAGEMENT (Derek Armitage, Fikret Berkes, & Nancy Doubleday eds., 2007).

[31] Robert K. Merton, *The Normative Structure of Science*, *in* THE SOCIOLOGY OF SCIENCE 267–278 (Robert K. Merton ed., 1973).

[32] S.D. Cook & J. S. Brown, *Bridging Epistemologies: The Generative Dance between Organizational Knowledge and Organizational Knowing*, 10 ORGAN. SCI. 381–400 (1999); I. Tuomi, *Data Is More than Knowledge: Implications of the Reversed Knowledge Hierarchy for Knowledge Management and Organizational Memory*, 16 J. MANAGE. INFORM. SYST. 103–117 (2000).

in the business management literature.[33] Absorptive capacity refers to whether an institution has people who are able to learn (who have the appropriate education background), whether it recognizes and rewards learning, and has mechanisms for learning to be worked back into the organization—even if it presents risks and disrupts the status quo.[34] Institutions also differ in what *type* of learning they are willing to "absorb." A firm or a government agency may have excellent means of learning from client complaints, for instance, but not from new science or technological innovations. In short, comprehensive absorptive capacity is not easy—it takes work.

4.3 Working Together or Parallel Play?

On the surface, the case we examine here should be an easy one. DFO has the human capital to receive and act on new knowledge, and many Department employees have frequent contact with academic scientists. DFO also has an internal Science Branch that is tasked with performing research to assist management decisions (although its budget is small),[35] as well as personnel dedicated to providing science advice directly to managers. Most importantly, DFO claims to have a high absorptive capacity stance towards external knowledge, explicitly stating that:

> Science is a cornerstone of fisheries management. To regulate size limits, quotas, seasons, and gear, managers require information on the biology of the fish species, their migration, their abundance and other biological and environmental factors . . . We rely on the latest data and the resulting scientific peer-reviewed advice to make important decisions for the sustainable management of Canadian fisheries.[36]

In reality, though, there is broad recognition among both academic scientists and fisheries managers that real barriers continue to exist even in this (theoretically) conducive environment.[37] DFO has recently become more secretive about its internal scientific research and decision-making processes, in line with a government-wide movement by Canada's ruling Conservative Party towards more centralized control of information and communications.[38]

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[33] Wesley Cohen & Daniel Levinthal, *Absorptive Capacity: A New Perspective on Learning and Innovation*, 35 ADMIN. SCI. QUART. 128–152 (1990); Zahra Shaker & George Gerard, *Absorptive Capacity: A Review, Reconceptualization, and Extension*, 27 ACAD. MANAGE. REV. 185–203 (2002).

[34] Cohen and Levinthal, *supra* note 33.

[35] COHEN, *supra* note 12, at 56–58.

[36] DFO, *Science as a Cornerstone of Decision-Making* (2012), *at* http://www.dfo-mpo.gc.ca/fm-gp/sustainable-durable/fisheries-peches/science-eng.htm (visited 1 November 2012).

[37] BRIAN O. MA, DAVID MARMOREK & KATY BRYAN, EVALUATION OF THE PACIFIC OCEAN TELEMETRY PROJECT (POST) (2012).

[38] Nathan Young & Aline Coutinho, *Government, Anti-Reflexivity, and the Construction of Public Ignorance of Climate Change: Australia and Canada Compared*, 13 GLOBAL ENVIRON. POLIT. 89–108 (2013).

Academic scientists and fisheries managers also inhabit their own professional spheres, attending different conferences and events. So while academic scientists and fisheries managers are both concerned about the same things, namely fish health and ecosystem integrity, they often seem to be engaged in what child psychologists call "parallel play"—occupying the same space but absorbed in their own worlds. In the next section, we use concepts from the sociology of science to examine why it is so difficult for these groups to work together, with a particular eye to the case of biotelemetry and the Fraser River.

5. WHY KNOWLEDGE MOBILIZATION ISN'T EASY—LESSONS FROM THE SOCIOLOGY OF SCIENCE

In brief, we argue that the primary barriers to effective knowledge mobilization in this case are (in shorthand): roles, norms, competition, cost, and risk. We address each in turn.

5.1 Scientists and Managers Produce and Use Knowledge Differently (Roles)

One of the most significant barriers to knowledge mobilization is the fact that scientists and managers work in different knowledge environments. Put another way, they produce and use knowledge differently due in large part to different professional demands.

Scientists typically produce knowledge that is intended for their peers, namely other scientists. Elaborate reward structures reinforce this behaviour. Within universities, scarce rewards such as promotions, graduate students, prestigious research chairs, releases from teaching responsibilities, and merit pay are allocated primarily on the basis of "research contributions" that are assessed and evaluated by fellow scientists.[39] The reward system extends beyond universities as well, particularly via the peer review processes that anchor scientific publishing, requests for outside research funding, and access to technology and materials.[40] The importance of reputation and peer review provide strong incentives to produce knowledge that is useful to other scientists. According to Latour, "usefulness" in the scientific community is judged primarily by "portability"—how well a finding, theory, conclusion, or technique applies to related problems or areas.[41] For a finding to become portable, it has to be rendered as *explicit* as possible, which usually means writing

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[39] Margaret Eisenhart, *The Paradox of Peer Review: Admitting Too Much or Allowing Too Little?*, 32 RES. HIGH. EDUC. 241–255 (2002); KerryAnn O'Meara, *Uncovering the Values in Faculty Evaluation of Service as Scholarship*, 26 REV. HIGH. EDUC. 57–80 (2002).

[40] Arie Rip, *The Republic of Science in the 1990s*, 28 HIGH. EDUC. 3–23 (1994).

[41] BRUNO LATOUR, SCIENCE IN ACTION: HOW TO FOLLOW SCIENTISTS AND ENGINEERS THROUGH SOCIETY (1987).

it up in painstaking detail for publication using language that is most often impenetrable to non-specialists.

Historians of science also note that knowledge production in the sciences has become increasingly specialized over time.[42] The days of scientific generalists—individuals who had a comprehensive working grasp of more than one discipline—are long past. New discoveries and technological advances have splintered the scientific community rather than unified it, and entire university departments today work in fields that simply did not exist a few decades ago. Specialization allows scientists to work on extremely precise problems that are predominantly of interest to other specialists.

While scientists are rewarded for working with *explicit* and *specialized* knowledge, managers are tasked with gathering information and evidence from various sources and translating it into concrete decisions that affect multiple groups. According to sociologists Nico Stehr and Reiner Grundmann, the role of managers is best understood as that of an *expert*, which is a fundamentally different role from that of a scientist.[43] Experts are synthesizers, interpreters, and appliers of knowledge. By definition, then, they are less specialized than scientists and more attuned to non-scientific processes, pressures, and alternative sources of knowledge. Taking this further, legal scholars Holly Doremus and Dan Tarlock argue that experts base their decisions more on *judgement* than *science* per se—while scientific information feeds into decision-making, it rarely determines or dominates the process.[44] What really matters is the judgement that managers bring to bear on multiple streams of information, which invariably involves ranking or weighting different claims according to their perceived relevance and utility. The process of "coming to judgement" is difficult to study and is not well understood in the social sciences. What is clear, however, is that it involves the use of "tacit knowledge" far more than the "explicit knowledge" that scientists are good at producing. Tacit knowledge is knowledge that is gained through experience and practice, and is difficult to codify or communicate. Classic examples include riding a bicycle or mastering a game or hobby—cases where "knowing the rules" is only the first step towards competence.[45] What is particularly significant about tacit knowledge is that it is based on extended periods of trial-and-error or "muddling through" as different processes are tested and refined. As such, tacit knowledge is less portable but more contextual and sensitive to the human dimension of a given problem. On the Fraser River, for instance, tacit knowledge of stakeholder preferences, positions, and likely reactions to

[42] PETER J. BLAU, THE ORGANIZATION OF ACADEMIC WORK (1994).

[43] NICO STEHR & REINER GRUNDMANN, EXPERTS: THE KNOWLEDGE AND POWER OF EXPERTISE (2011).

[44] Holly Doremus & A. Dan Tarlock, *Science, Judgment, and Controversy in Natural Resource Regulation*, 26 PUB. LAND & RESOURCES L. REV. 1–38 (2005).

[45] H. Scarbrough, *Knowledge à la Mode: The Rise of Knowledge Management and Its Implications for Views of Knowledge Production*, 15 SOC. EPISTEMOL. 201–213 (2001).

different outcomes is a critical input to decision-making.[46] Finally, despite being difficult to communicate, tacit knowledge can still be shared. Sociologist Harry Collins argues that tacit knowledge can also be held by groups and organizations (what he calls "collective tacit knowledge") who work in close proximity, share experiences, and are exposed to similar demands and pressures.[47] Under these circumstances, managers' decisions are more likely to be influenced by long-accumulated collective tacit knowledge than by new and outside information.

5.2 Knowledge Producers and Users are Conservative in Different Ways (Norms)

Scientists and managers are also embedded in different normative environments. Norms refer to formal and informal expectations that are affixed to different roles and activities and are enforced by peers, clients, and superiors.[48] Scientific norms have been studied for decades. In the 1940s, sociologist Robert K. Merton wrote that the key norms governing science were openness, universalism, disinterestedness, and scepticism.[49] More recent studies have looked specifically at how scientists communicate, and conclude that scientific norms discourage researchers from claiming to have definitive answers or speculating too broadly about the potential impact of their work.[50] As argued by Thomas Kuhn, most science proceeds incrementally, and individual scientists have little tolerance for colleagues who self-aggrandize, overstate their findings, or break too radically with convention.[51] These so-called "norms of humility" encourage scientists to use cautious language in their writing and speaking, to emphasize probability and uncertainty, and to avoid direct claims about cause-and-effect. The enforcers of such norms are scientists themselves, through both informal means (e.g., reputation) and formal processes (e.g., peer review of papers, funding, and career rewards).

Managers are also subject to normative pressures, but notably different ones. Stehr and Grundmann argue that managers, as users and synthesizers of knowledge (as "experts" in the terms described earlier), are far more exposed to the demands of others than are scientists.[52] These "others" are a varied group, including supervisors, stakeholders, and interested groups such as the media, and their primary mechanism is not peer review but public scrutiny. According

[46] DFO, *supra* note 14.
[47] COLLINS, *supra* note 2.
[48] MICHAEL HECHTER & KARL-DIETER OPP, SOCIAL NORMS (2001).
[49] Merton, *supra* note 31.
[50] KARIN KNORR CETINA, EPISTEMIC CULTURES (1999); Don Fisher, Janet Atkinson-Grosjean, & Dawn House, *Changes in Academy/Industry/State Relations in Canada: The Creation and Development of the NCE*, 39 MINERVA 299–325 (2001).
[51] THOMAS S. KUHN, THE STRUCTURE OF SCIENTIFIC REVOLUTIONS (3rd ed. 1962).
[52] STEHR AND GRUNDMANN, *supra* note 43 at 39–40.

to Helga Nowotny, public scrutiny pressures managers (experts) to evaluate scientific claims based on their "social robustness" rather than their accuracy *per se*.[53] Socially robust knowledge is knowledge that has gained legitimacy in the eyes of clients and stakeholders.[54] For instance, if stakeholders agree that the best way to assess the size of a salmon run is to visually count the fish that reach the spawning ground, then this method has *political value* to the expert/manager even if a more accurate scientific method exists. Given that trust and legitimacy are built slowly, managers have a normative incentive to stick with "tried and true" methods and ignore new science that may disrupt or change how the task is performed.

5.3 There's No Such Thing as "Science" (Competition)

One of the most common misconceptions about science is that it is monolithic. There is no one "scientific community" but many, divided by discipline, specialty, region, method, and emphasis.[55] The reality is that each competes for funding, recognition, and legitimacy.[56] This is part of the essential vitality of science, but it is also problematic for funders and users of knowledge.[57] In the health field, for instance, it is not uncommon for different research groups to approach the study of a disease from completely different directions—all of them claiming to have special insight into the problem. Who is right? More importantly, how can non-specialists tell? In a way, fisheries managers confront exactly this dilemma. Biotelemetry is not the only way to learn about fish populations and their habitats, and when science leads in multiple directions, experts will frequently follow the path that leads to the more convenient social and political outcome (see Case #3 discussed below).

5.4 Knowledge Ain't Free (Cost)

Ideally, scientific claims would be judged on their own merits, with the best ideas and techniques gaining ready access to funding and a receptive ear in industry and government. Unfortunately, this is often the exception rather than the rule. Researchers in a field known as "the political sociology of science" have extensively studied how decisions to support or adopt science are made, and their general conclusion is that "successful science"—science that is taken seriously and has a broad impact on policy or markets—usually has a

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[53] Helga Nowotny, *Democratising Expertise and Socially Robust Knowledge*, 30 SCI. PUBL. POLICY 151–156, 151 (2003).
[54] *Id*. at 155.
[55] KNORR CETINA, *supra* note 50.
[56] Scott Frickel & Neil Gross, *A General Theory of Scientific/Intellectual Movements*, 70 AM. SOCIOL. REV. 204–232 (2005).
[57] Rip, *supra* note 40.

strong foundation of tangible political and economic support.[58] This support, however, is scarce. Government funding for research is limited, and what does exist is often steered into certain disciplines and areas via targeted funding calls, priority-setting, and ideological preference.[59] These scholars therefore conclude that the field of "undone science"—topics, questions, and techniques that are scientifically valid but financially unsupported—is just as significant (and likely larger) than the field of "done science."[60] Put another way, plenty of science that is *potentially useful* is left undone or under-explored because it is not *immediately expedient* for a powerful client group.

Biotelemetry is a reasonably well-funded field at the moment, but it is also very expensive. At present, biotelemetry researchers are able to track only a limited number of animals and environmental variables in specific geographic locations. It would take substantial investment for biotelemetry to become fully integrated into day-to-day management decision-making, particularly to fulfil its potential for real time data access and analysis. The issue of cost is especially sensitive at the current moment, given that the Canadian Government is downsizing the public service and reducing research and monitoring budgets at DFO.[61] Biotelemetry is a technology that is likely yield dividends down the road, but its "immediate expediency gap" is a significant barrier to ensuring the full development of the field. Unfortunately, the costs of inaction are rarely considered in this type of calculus.

5.5 Disincentives to Bridging the Gap (Risk)

One of the oldest distinctions in the sociology of science is between basic (or pure) science and applied science. Basic science is generally seen as being exploratory, curiosity-driven, and aiming for explanation, while applied science is goal-oriented, problem-specific, and immediately usable.[62] While some scholars question how real the basic-applied divide really is in scientific practice,[63] the distinction is relevant for knowledge mobilization. Since the 1940s, the predominant assumption in North America has been that generous funding of basic science would naturally (and inevitably) lead to better

[58] THE NEW POLITICAL SOCIOLOGY OF SCIENCE (Scott Frickel & Kelly Moore eds., 2006); David Hess, *The Potentials and Limitations of Civil Society Research: Getting Undone Science Done*, 79 SOCIOL. INQ. 306–327 (2009); Joanna Kempner, Jon Merz, & Charles Bosk, *Forbidden Knowledge: Public Controversy and the Production of Nonknowledge*, 26 SOCIOL. FORUM 475–500 (2011).

[59] Fisher, Atkinson-Grosjean, & House, *supra* note 50.

[60] Scott Frickel et al., *Undone Science: Charting Social Movement and Civil Society Challenges to Research Agenda Setting*, 35 SCI. TECHNOL. HUM. VAL. 444–473 (2010).

[61] COHEN, *supra* note 47, at 53.

[62] Michael Polanyi, *The Republic of Science: Its Political and Economic Theory*, 1 MINERVA 54–73 (1962).

[63] Terry Shinn, *Change or Mutation? Reflections on the Foundations of Contemporary Science*, 38 SOC. SCI. INFORM. 149–176 (1999); Philip Mirowski & Esther-Mirjam Sent, *The Commercialization of Science and the Response of STS*, *in* THE HANDBOOK OF SCIENCE AND TECHNOLOGY STUDIES 635–689 (Edward J. Hackett et al. eds., 3rd ed. 2008).

applied outcomes. Some of the most important scientific figures of mid-century, including Michael Polanyi and Vannevar Bush, vigorously defended this view, arguing that the collective efforts of a free and curiosity-driven scientific community would produce the raw materials for wondrous applications.[64] This perspective, which has since been termed "the pipeline model," assumes that "fundamental discoveries can be fed into one end of the pipe and move through various stages of development until they emerge [as applications] at the far end."[65]

Research has shown, however, that the pipeline model simply takes too much for granted.[66] In too many cases, neither basic scientists nor "appliers" (be they applied scientists, private companies, or government agencies) are willing to go into the pipe in order to *push* knowledge further toward potential applications nor *pull* it towards specific uses. Entering the pipe means going beyond the norms and rewards that govern each group's behaviours. Basic scientists are rewarded for achieving *explanation* and *description*, while managers require applied knowledge that will assist with *prediction* (observation [x] means that outcome [y] is more likely than outcome [z]) and *prescription* (if [a] is observed, initiate management plan [b]). The gap between these two positions is wide, but not unbridgeable (see the cases below). The main problem is that bridging it, from either side, involves risk. Basic scientists put their credibility on the line when they engage in prediction, which can be seen as violating norms of humility and caution. On the other side, managers risk professional and public embarrassment by choosing new science over more "socially robust" practices. The problem with the pipeline model is that it assumes that knowledge travels on its own based on its merit—something that in fact rarely happens. Knowledge mobilization takes effort and risk, but risk without appropriate incentives, rewards, and protections is a hard sell.

6. BIOTELEMETRY MEETS MANAGEMENT: THREE CASES

Biotelemetry scientists and fisheries managers have had varying levels of success overcoming these barriers. We briefly outline three cases of knowledge mobilization—one successful, one unsuccessful, and one partially successful—to see if any specific lessons can be drawn. We then conclude the article with a series of recommendations.

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[64] VANNEVAR BUSH, SCIENCE: THE ENDLESS FRONTIER (Reprinted 1990 ed. 1945); Polanyi, *supra* note 62.

[65] JANET ATKINSON-GROSJEAN, PUBLIC SCIENCE, PRIVATE INTERESTS: CULTURE AND COMMERCE IN CANADA'S NCES 19 (2006).

[66] Harvey Brooks, *The Relationship between Science and Technology*, 23 RES. POLICY 477–486 (1994).

6.1 Case 1: Climate Change and the Fraser River (Successful)

For the last decade or so, scientists have speculated that higher water temperatures in the Fraser River are one of the main causes of salmon population decline. Laboratory tests found that many salmon populations experienced difficulty at higher temperatures,[67] but animal behaviours are difficult to measure in the lab. For instance, laboratory work does not tell us if fish adapt by seeking out thermal refuges (e.g., in deep lakes along their migration route) or adjust the speed and timing of their migration. In this case, biotelemetry was critical to filling in the blanks. Among other things, it was discovered that temperature-related mortality is high when populations encounter river conditions above their historic norms.[68] This pattern has been observed in multiple years and confirmed experimentally by using holding studies where temperature is manipulated and then releasing tagged salmon to track their migration to spawning grounds.[69] Biotelemetry revealed that salmon are able to seek out cool temperatures when thermal refuges exist, but also that these opportunities are limited in the lower Fraser River.[70]

Collectively, this body of work revealed the mechanisms underlying migration failure associated with warm river conditions. Such data were then used to predict future impacts of climate change.[71] In this case, biotelemetry findings (explicit knowledge) were immediately relevant to fisheries managers concerned about higher water temperatures but lacking tools to work this into existing models (tacit knowledge). Scientists and managers collaborated in developing a prescriptive approach to adjust harvest based on predicted water temperatures.[72]

6.2 Case 2: High Female Mortality (Unsuccessful)

One of the more unexpected findings from biotelemetry research is that upriver migrating female sockeye salmon are extremely susceptible to stress (including high temperatures), perishing at nearly twice the rate of males in

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[67] Erika J. Eliason et al., *Differences in Thermal Tolerance among Sockeye Salmon Populations*, 332 SCIENCE 109–112 (2011).

[68] A. P. Farrell et al., *Pacific Salmon in Hot Water: Applying Aerobic Scope Models and Biotelemetry to Predict the Success of Spawning Migrations*, 81 PHYSIOL. BIOCHEM. ZOOL. 697–709 (2008); Martins et al., *supra* note 20.

[69] G. T. Crossin et al., *Exposure to High Temperature Influences the Behaviour, Physiology, and Survival of Sockeye Salmon during Spawning Migration*, 86 CAN. J. ZOOL. 127–140 (2008).

[70] M. T. Mathes et al., *Effect of Water Temperature, Timing, Physiological Condition, and Lake Thermal Refugia on Migrating Adult Weaver Creek Sockeye Salmon*, 67 CAN. J. FISH. AQUAT. SCI. 70–84 (2009); M. R. Donaldson et al., *Limited Behavioural Thermoregulation by Adult Upriver-migrating Sockeye Salmon in the Lower Fraser River, British Columbia*, 87 CAN. J. ZOOL. 480–490 (2009).

[71] M. J. Hague et al., *Modelling the Future Hydroclimatology of the Lower Fraser River and Its Impacts on the Spawning Migration Survival of Sockeye Salmon*, 17 GLOBAL CHANGE BIOL. 87–98 (2010).

[72] Macdonald et al., *supra* note 22.

difficult environmental conditions.[73] These findings are clearly troubling given the role of females in reproduction. However, there is limited information available to assess the population-level consequences of this phenomenon. Little is known about the sex composition of adults prior to reaching the Fraser, and spawning ground assessments are often not comprehensive enough or can be inconclusive—sometimes confirming a skewed sex ratio and sometimes not. Moreover, at the moment, DFO does not have a process for including this novel finding into their management scheme. DFO does not consider sex ratios when setting escapement targets (the number of fish expected to reach spawning grounds), nor do the fisheries regulators in most other countries.[74] Little is being done at this time to address or apply this finding. This is therefore a case where new knowledge is "stuck in the pipe" awaiting further work on how best to include this novel information in the current management approach.

6.3 Case 3: Catch and Release Mortality (Partially Successful)

The recreational fishery on the Fraser River depends on the practice of "catch and release." Anglers are required to release salmon when they are fishing outside of designated "retention windows," when an endangered species is landed (coho and steelhead), or when the fish is hooked other than in the mouth or lip. Some anglers also release fish voluntarily due to a personal conservation ethic. In all cases, the assumption is that these fish will survive to continue their migration. Riverside tests, which involve the transfer of landed fish to a net pen for an observation period of 24 hours, generally find a mortality rate of about three per cent.[75] Biotelemetry tests, however, suggest that mortality is much higher later on, as high as 40 per cent after 96 hours and up to 65 per cent before reaching spawning beds.[76] This suggests that a 24-hour observation period is insufficient to gauge the actual levels of mortality experienced by fish after they have been caught and released. This is likely due to the fact that brief net pen retention fails to incorporate realism associated with predators, disease development, natural senescence, warm temperatures, and other issues associated with migration in a large and dynamic river.

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[73] E. G. Martins et al., *High River Temperature Reduces Survival of Sockeye Salmon Approaching Spawning Grounds and Exacerbates Female Mortality*, 69 CAN. J. FISH. AQUAT. SCI. 330–342 (2012).

[74] K. C. Hanson et al., *Sexual Variation in Fisheries Research and Management: When Does Sex Matter?*, 16 REV. FISH. SCI. 421–436 (2008).

[75] J. O. THOMAS & B. CAHUSAC, FINAL INVESTIGATIONS INTO SHORT-TERM (0 TO 24 H) HOOKING MORTALITY OF SOCKEYE (*ONCORHYNCHUS NERKA*) CAUGHT AND RELEASED AT GRASSY BAR, FRASER RIVER, BRITISH COLUMBIA (2012), *at* http://www.thinksalmon.com/reports/2011_Fraser_River_Sockeye_CR_Study_(Final_copy).pdf (visited 7 June 2013).

[76] Donaldson et al., *supra* note 20.

While the biotelemetry data are compelling, there is still a great deal of uncertainty around the numbers. Not all mortality can be attributed to catch-and-release, given that some level of "background mortality" is inevitable due to disease and increasingly warm river conditions (see Case #1 above). Teasing out the influence of a catch-and-release event relative to other stressors has proved difficult given that control fish must also be captured and handled (e.g., using a beach seine).[77] There is also the possibility that the tagging methods themselves are responsible for mortality. Researchers have sought to address this by tagging control fish in the ocean and comparing their in-river mortality to that of fish tagged by angling in-river, thus accounting for handling-related mortality.[78] Overall, this has led biotelemetry researchers to estimate that the real delayed mortality rate from catch-and-release at 20–30 per cent,[79] which is lower than the uncorrected 65 per cent figure but substantially higher than the three per cent assumed by DFO.

In this case, DFO evaluated the biotelemetry findings, but chose not to adjust its mortality estimates. Confronted with two sources of information, managers were uncomfortable with the uncertainty associated with the biotelemetry findings, choosing to adhere to the three per cent mortality rate which is also widely accepted by influential recreational fisher stakeholders (and is thus "socially robust"). The new knowledge, while suggesting that harm is far greater than assumed, has been acknowledged but largely ignored to date.

7. RECOMMENDATIONS AND CONCLUSIONS

The Fraser River is a unique case with respect to knowledge mobilization, but also one from which general lessons can be drawn. The river and its fisheries are high profile and diverse, which means that managers are in frequent contact with various stakeholders. Moreover, the complexity of the resource suggests that managers have incentive to seek out scientific information, much of which is generated at universities in the region. As we suggested earlier, in theory this is a case conducive to high knowledge mobilization, but is instead a mixed story of both success and failure. In this final section, we draw on both the theoretical literature and our own experiences to suggest ways to encourage closer collaboration among scientists and managers and further the "uptake" of biotelemetry knowledge into management practice.

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77 M. R. Donaldson et al., *Enhancing Catch-and-Release Science with Biotelemetry*, 9 FISH AND FISHERIES. 79–105 (2008).

78 Donaldson et al., *supra* note 20.

79 *Id.*

7.1 Abandon the Pipeline Model and Pursue Long-Term Mechanisms for Two-Way Exchange

As mentioned at the outset, it is not uncommon for fisheries managers to have occasional contact with academic scientists. These encounters need to be routinized into regular exchanges that deal with the *entire* spectrum of knowledge generation and use, not just the "delivery" of scientific findings to managers tasked with applying it. The current state of affairs is characterized by a double frustration: scientists wonder why managers do not put their findings into practice, and managers do not always know how to fit new findings into established practices. We need to abandon the assumption of the pipeline model that knowledge moves on its own, and replace it with a more long-term collaborative one that brings the tasks associated with basic and applied science closer together. For this to work, there need to be better opportunities for scientists and managers to influence one another directly over the long term. On the one hand, managers need to have input on the drafting of scientific research questions, methodological decisions, and data analysis. On the other hand, scientists need to have a hand in applying their findings. Fisheries managers have indicated that they would be more willing to consider biotelemetry knowledge in their decision-making if scientists could provide clear explanations of the relevance of their findings.[80] This would be a good first step, but does not go far enough. Scientists ought to have access to the "coming to judgement" process that anchors management decision-making. At the moment, the only way scientists can participate in this process is by producing "portable and explicit" knowledge (see the quotation from DFO above about consulting peer-reviewed science). In other words, DFO itself implicitly endorses the dysfunctional pipeline model by conceptualizing "peer-reviewed science" as a collection of facts, divorced from their producers, to be consulted on an as-needed basis. Promoting closer collaboration among scientists and managers would enhance the legitimacy of both groups' work, but bringing them closer together would involve significant investments of effort and time. In our view the most efficient way of doing this would be to establish regular forums for these exchanges and integrate them into already-established consultation and planning activities. It is logical that these activities be coordinated by DFO but run by managers and scientists themselves.

7.2 Provide Support Systems for Risk-Taking and Norm-Breaking

As discussed earlier, scientists and managers have strong incentives to be conservative, and few if any incentives exist to take risks or push back against dominant professional norms. There is a larger discussion to be had about the academic rewards system that privileges the development of *explanation*

[80] MA, MARMOREK, & BRYAN, *supra* note 37.

and *description* over *prediction* and *prescription*. Universities need to recognize that the current narrow definition of "research contributions" promotes disengagement with potential users of scientific knowledge.[81] To compensate, DFO needs to acknowledge the contributions that individual scientists make using the currency of public recognition. A minority of academics achieve in their career the role of a "public intellectual"—a scholar who is broadly recognized as contributing important ideas and findings that enhance the public good. The public intellectual role is high-status (as it enhances the visibility of the scholar's home university), but it depends on public acknowledgement of contributions by the institutions that use them.

As for managers, the public scrutiny that accompanies their role is a major disincentive for deviating from established practices and experimenting with new knowledge and methods. DFO needs to provide a "support system" for such risk-taking. This could include the endorsement of small-scale pilot projects such as, for instance, testing biotelemetry methods on a healthy subpopulation or tributary to see if the findings described in Cases #2 and #3 can indeed be addressed by management. Other actions might include giving new technologies a more prominent place in publications and websites, and committing to publicly defending management decisions based on new science even if they are politically unpopular. These are "institutional receptiveness" issues that can only be addressed internally. DFO has excellent human capital resources, but needs to reform its overall stance to learning and experimentation to maximize the potential of promising new science and technologies.

7.3 Enhance Transparency at DFO

Knowledge mobilization is difficult even in ideal circumstances, and it is hard to see how the current move to greater secrecy at DFO makes it any easier. Organizations typically keep secrets as a method of self-defence. This often makes sense in the private sector, where research and innovation are kept proprietary so that they retain their market value.[82] Secrecy makes less sense in public resource management, particularly in high profile cases such as the Fraser River that involve multiple vocal stakeholder groups. Greater transparency would allow stakeholders and the general public to see precisely how DFO and fisheries managers make their decisions. In our view, this could be achieved by publishing the science advice provided to managers prominently

[81] O'Meara, *supra* note 39; David Weerts & Lorilee Sandmann, *Building a Two-Way Street: Challenges and Opportunities for Community Engagement at Research Universities*, 32 REV. HIGH. EDUC. 73–106 (2008).

[82] James A. Evans, *Industry Collaboration, Scientific Sharing, and the Dissemination of Knowledge*, 40 SOC. STUD. SCI. 757–791 (2010).

on the DFO website along with plain-language descriptions of how decisions were reached in a given season. This would in turn partially counter managers' tendency to act conservatively—favouring "socially robust" practices over new knowledge. In an environment of secrecy, changes in management direction are inevitably viewed with suspicion because stakeholders do not know where they are coming from. Greater transparency would not only help DFO to build trust with stakeholders and the general public,[83] but it would allow managers greater latitude to justify using new knowledge. Transparency involves risk, as it grants public access to the imperfect internal workings of an organization. The benefits for resource management organizations, however, would likely outweigh the costs if it were to lessen the barriers to knowledge mobilization.

[83] Lynn J. Frewer, *Trust, Transparency, and Social Context: Implications for Social Amplification of Risk*, *in* THE SOCIAL AMPLIFICATION OF RISK 123–137 (Nick Pidgeon, Roger E. Kasperson, & Paul Slovic eds., 2003).