PERSPECTIVE

Embracing Implementation Science to Enhance Fisheries and Aquatic Management and Conservation

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The management and conservation of fisheries and aquatic resources are inherently applied activities. Therefore, when knowledge generated from research and monitoring, or knowledge that is held by practitioners and other actors (e.g., Indigenous elders, fishers), fails to inform those applied decisions, the persistent gap between knowledge and action is reinforced (i.e., the knowledge–action gap). In the healthcare realm, there has been immense growth in implementation science over the past decade or so with a goal of understanding and bridging the gap between knowledge and action and delivering on evidence-based decision making. Yet, within fisheries and aquatic sciences, the concept of implementation science has not received the same level of attention. We posit, therefore, that there is an urgent need to embrace implementation science to enhance fisheries and aquatic management and conservation. In this paper, we seek to describe what implementation science is and what it has to offer to the fisheries and aquatic science and management communities. For our context, we define implementation science as the scientific study of processes and approaches to promote the systematic uptake of research and monitoring findings and other evidence-based practices into routine practice and decision making to improve the effectiveness of fisheries management and aquatic conservation. We explore various frameworks for implementation science and consider them in the context of fisheries and aquatic science. Although there are barriers and challenges to putting implementation science into practice (e.g., lack of capacity for such work, lack of time to engage in reflection, lack of funding), there is also much in the way of opportunity and several examples of where such efforts are already underway. We conclude by highlighting the research needs related to implementation science in the fisheries and aquatic science realm that span methodological approaches, albeit a common theme is the need to involve practitioners (and other relevant actors) in the research. By introducing the concept and discipline of implementation science to the fisheries and aquatic science community, our hope is that we will inspire individuals and organizations to learn more about how implementation science can help deliver on the promise of evidence-based management and decision making and narrow the gap between research and practice.

THE ISSUE

The urgency and scale of the ecological crisis demands that we deploy our best available knowledge to mitigate environmental problems, but significant barriers to knowledge mobilization exist (Cvitanovic et al. 2015; Walsh et al. 2019; Karcher et al. 2024). The knowledge–action gap is a well-known phenomenon in scientific and policymaking communities (e.g., Kadykalo et al. 2021; Roche et al. 2022). Science-based knowledge is expanding rapidly as available data and computational approaches improve and researchers publish increasingly more findings. Diverse knowledge systems (sensu Cornell et al. 2013) and ways of knowing that are based on personal and collective experience and memory, such as traditional knowledge, local knowledge, Indigenous knowledge, and other forms of tacit knowledge (e.g., Fazey et al. 2006; Tengö et al. 2014, 2017; Reid et al. 2021) are appropriately becoming more recognized and prevalent in aquatic sciences. As such, a wealth of available data, information, and knowledge

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currently exists in the world, but its value is unrealized if it is not accessible or applied by decision-makers to guide the management and conservation of biodiversity (see Target 21 of the Kunming-Montreal Global Biodiversity Framework). Managing this knowledge–action gap is, therefore, an important priority for researchers and decision-makers. Research on the knowledge–action gap and strategies to mitigate it have proceeded under several different names across several disciplines (see Table 1).

In this Perspective, we draw attention to the development of implementation science in health research and outline its potential application to aquatic management and conservation efforts, which, in comparison to these other ideas, has received less attention. Specifically, we describe what implementation science is and what it has to offer fisheries management and aquatic conservation. We begin by providing a definition of implementation science and discussing the history and success of implementation science in other domains and disciplines. Next, we outline and summarize frameworks for implementation science and adapt and develop a framework specific to fisheries management and aquatic conservation. We consider opportunities for embracing implementation science and include two brief case studies, while also identifying several strategies to overcome barriers to implementation science. We conclude by presenting and outlining a research agenda for implementation science to enhance aquatic management and conservation. By formally introducing the concept and discipline of implementation science to the fisheries and aquatic science community we hope to inspire individuals and organizations to learn more about how implementation science can help deliver on the promise of evidence-based management and decision making (Sutherland et al. 2004) and narrow the gap between research and practice.

WHAT IS IMPLEMENTATION SCIENCE?

Implementation science emerged in the healthcare sector out of necessity (Colditz and Emmons 2012); evidence that could yield better outcomes for patients was not being embraced by practitioners. This is highlighted by the fact that ~80% of funds invested in medical and health research did not impact healthcare delivery (Chalmers and

Table 1. Key concepts for understanding and addressing the knowledge–action gap and the field of implementation science.

Concept	Description/applications	Key works
Science communication	Identifying best practices for communicating scientific methods and findings to the public and/or specific audiences. Research into specific techniques and audience receptiveness and reactions.	Burns et al. 2003; Cooke et al. 2017b; Borowiec 2023a, 2023b
Technology transfer	The process of transferring technology (does not have to be a physical product) from the person or organization that owns or holds it to another person or organization, in an attempt to transform inventions and scientific outcomes into new products and services (like fisheries management) that benefit society.	Bozeman 2000
Evidence-based decision making	A process for making decisions about a program, practice, or policy that is grounded in the best available evidence (recognizing that evidence comes in different forms and there can be many sources of bias).	Sutherland et al. 2004
Diffusion/adoption	Research into diffusion/adoption of new ideas, techniques, and technologies among and across groups, networks, organizations, and markets.	Norton and Bass 1987; Rogers et al. 2014
K* (knowledge mobilization, knowledge exchange)	Research into processes by which specific and general knowledge moves across social groups and is applied to specific ends/goals.	Fazey et al. 2013; Cvitanovic et al. 2015; Hinderer et al. 2021
Translational research	Research into the direct applications or applied potential of pure science research and discoveries.	Collins 2011
Implementation science	The study of processes and approaches to promote the systematic uptake of research and monitoring findings and other evidence-based practices into routine practice and decision making, to improve the effectiveness of fisheries management and aquatic conservation.	Modified version of Eccles and Mittman (2006) tailored to a fisheries and aquatic sciences context for this paper
Knowledge brokers/ knowledge brokerage	Facilitate the exchange of knowledge between and among researchers and practitioners; the full suite of activities required to link decision-makers with researchers, facilitating or mediating their interaction so that they are better able to exchange knowledge for evidence-informed decisions.	Lomas 2007; Meyer 2010; Fazey et al. 2013; Cvitanovic et al. 2017; Kadykalo et al. 2021; Karcher et al. 2021
Evidence synthesis	Subject-wide evidence syntheses that combine elements of systematic reviewing, mapping, and meta-analysis and interactive Web apps to provide an industrial-scale, cost-effective way to synthesize evidence.	Sutherland and Wordley 2018; Martin et al. 2023
Boundary organizations	Intermediary organizations between science and policy that involve actors from both sides of the boundary and work to link research to decision making by enabling knowledge exchange.	Cash 2001; Guston 2001; Crona and Parker 2012; Bednarek et al. 2018; Song et al. 2020
Knowledge coproduction	An iterative and collaborative process that brings together diverse actors to create integrated, context-specific, and goal-oriented knowledge through mutual learning.	Fazey et al. 2013; Cooke et al. 2020; Norström et al. 2020; Chambers et al. 2021; Muhl et al. 2023
Open science practices	Open access publishing that makes scientific literature available to all; open materials (detailed methods, data, code, and software) that increase the transparency and use of research findings; open education resources that allow researchers and practitioners to acquire the skills needed to use research outputs.	Roche et al. 2022

Glasziou 2009) and that <50% of clinical advances were broadly embraced (Grant et al. 2003). Given that virtually all humans will interact with the healthcare system multiple times throughout their lives, the consequences of the gap between knowledge and action (or clinical improvement) are troubling and cost dollars and lives. As a discipline or scholarly domain, implementation science emerged from early work on diffusion of innovations (from the private sector) while also pulling upon knowledge use and technology transfer scholarship (Dearing et al. 2012). When those concepts were merged with the paradigm of evidence-based healthcare, which espouses in part the need for evidence-based practices to be shared and embraced by evidence users (healthcare practitioners), implementation science became a necessary and nascent discipline to bridge the gap between knowledge and action (Fixsen et al. 2005; Colditz and Emmons 2012; Bauer et al. 2015).

One of the most accepted definitions for implementation science emerges from the inaugural issue of the journal *Implementation Science*. Eccles and Mittman (2006) defined implementation science as:

> The scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice, and, hence, to improve the quality and effectiveness of health services and care.

This same definition can be refined for our purposes as:

> The study of processes and approaches to promote the systematic uptake of research and monitoring findings and other evidence-based practices into routine practice and decision making, to improve the effectiveness of fisheries management and aquatic conservation.

Note that we added the term "monitoring" to recognize that monitoring, assessment, and evaluation are not explicitly research but represent key aspects of an adaptive fisheries management cycle (Walters 1986; Krueger and Decker 1999). Moreover, we explicitly acknowledge that evidence comes in many forms, such that the traditional perspective of implementation science is seeing revisionist thinking about what evidence looks like (Brownson et al. 2022), such as knowledge held by rightsholders, stakeholders (e.g., fishers), and practitioners (see Downey et al. 2022).

It is important to note that the goal of implementation science is not to establish the impact of a given action (albeit that is core to related domains like evidence-based decision making), but, rather, to identify the factors that influence the uptake of a given action and its application (Bauer and Kirchner 2020). This inherently requires a different way of thinking, where the centuries-old philosophy of the independence of knowledge that is foundational to the scientific method is replaced by one where other actors are intimately involved in the process (e.g., coproduction). We understand that for more fundamentally oriented research, this may not be necessary or desirable and acknowledge that implementation science is inherently aligned with applied or mission-oriented research. Bauer and Kirchner (2020) provided a simple summary of the two key goals of implementation science: (1) identify uptake barriers and facilitators across multiple levels of context, and (2) develop and apply implementation strategies that overcome these barriers and enhance the likelihood of facilitating the uptake of evidence-based innovations. Implementation science, unlike other terms, such as technology transfer or knowledge mobilization, is specific to the context of evidence-based decision making. That does not mean that implementation science does not have similar theoretical approaches (and others including behavioral change theory), but, rather, that the end goal with implementation science is more specific. In our context, the goal is to ensure that the best possible fisheries management and aquatic science decisions for the benefit of all are informed by the best available knowledge (Sutherland et al. 2004; Cooke et al. 2017a; Figure 1).

In the healthcare domain, implementation science has become disciplinary—several journals now focus on implementation science and many others publish such content (summarized in Mielke et al. 2021); a number of textbooks are dedicated to the topic (e.g., Nilsen and Birken 2020; Weiner et al. 2022); bespoke courses and other training opportunities have evolved; various symposia/conferences focus on healthcare implementation science, and many scholars and professionals identify as "implementation scientists." We are unaware of similar formal developments in fisheries and aquatic sciences, although that does not mean that some individuals and organizations are not working in this space in some capacity. Bammer (2003) was one of the first to write about implementation science in the context of applied ecology and environmental management. More recently, Hering (2018) acknowledged that the developments seen in healthcare have yet to emerge in the environmental space. Not surprisingly, Bammer (2003) and Hering (2018) serve as calls for just that—something that we have embraced specific to fisheries management and aquatic conservation.

Implementation science involves investigation at a variety of levels. In the context of healthcare, this may involve the individual patient/subject as well as the provider, clinic, facility, organization, community, and even the policy environments (Bauer and Kirchner 2020). In the context of fisheries management and conservation, our "patients" tend to be various elements of ecosystems or social–ecological systems—typically a water body, animal population, and individual actors (or actor communities). However, key are the practitioners themselves, as well as their employers (organization) and broader policy and social environments in which they work. Because fisheries and aquatic ecosystems are most appropriately considered as social–ecological systems (Arlinghaus et al. 2017), there are many inherent interconnections and feedback loops that require consideration across a range of spatiotemporal scales (Cumming et al. 2006). It is also important to note that although implementation science as a discipline tends to center on the "implementation scientist," other actors such as practitioners are critical to such work and must be fully engaged (Bauer and Kirchner 2020), emphasizing the need for an agile knowledge coproduction process (Chambers et al. 2022).

OPPORTUNITIES FOR EMBRACING IMPLEMENTATION SCIENCE IN THE AQUATIC SCIENCES: TWO CASE STUDIES

The opportunity for fisheries and aquatic science to learn from other sectors and embrace the notion of implementation science is clear. To some extent, this is already happening and driven primarily by research funders that explicitly seek to connect knowledge to action (Hinderer et al. 2021; Cvitanovic et al. 2021a), although such programs seldom

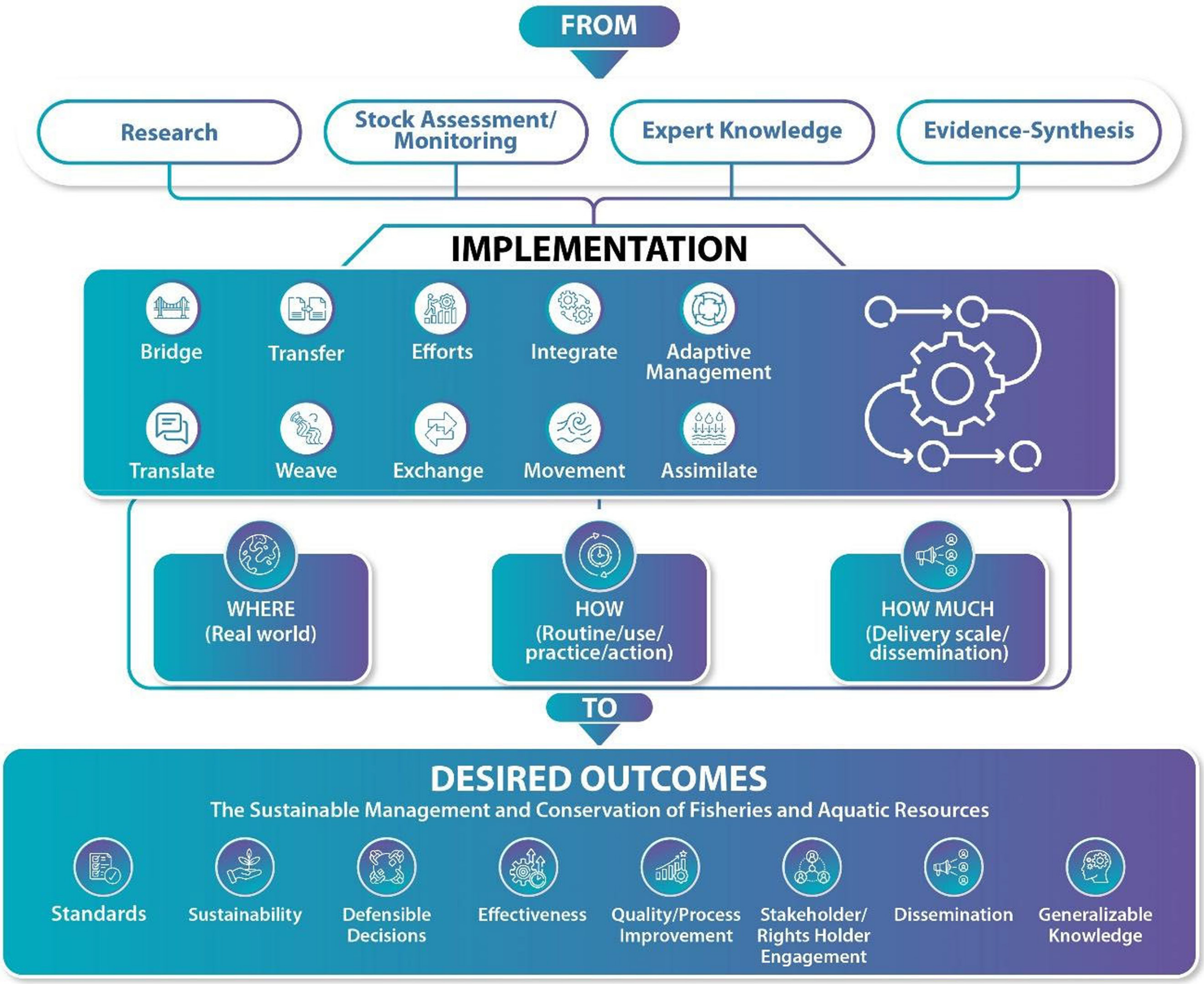

Figure 1. Schematic overview of the goals of implementation science adapted to be specific to the context of fisheries and aquatic science and management. Evidence coming from various streams supports implementation, which itself includes many subcomponents and processes. Implementation varies with context, including where, how, and how much is being done. Implementation ideally supports desired outcomes that contribute to the sustainable management and conservation of fisheries and aquatic resources. Adapted from Villalobos Dintrans et al. 2019.

meet their full suite of objectives due to a range of persistent and systematic barriers (Karcher et al. 2021). We acknowledge that some level of ad hoc implementation science has been happening for decades and is encouraged in some organizations (such as the U.S. Geological Survey Cooperative Fish and Wildlife Research Units). We suspect that those ad hoc efforts often take the form of sober reflection rather than formal study of the management process, highlighting opportunities to formalize such efforts. In this section, we present two such case studies, including lessons learned to help guide and improve the success of implementation science in our field.

Case Study 1: Sea Lamprey Control: Sterile Male Release Technique

The Great Lakes Fishery Commission (GLFC), established by the 1955 Canada–U.S. Convention on Great Lakes Fisheries (U.S. Department of State 1956), implements one of the most successful invasive vertebrate control programs globally (Siefkes et al. 2021). To diversify the portfolio of control techniques targeting invasive Sea Lamprey *Petromyzon marinus*, the GLFC has invested in the development of a broad arsenal of techniques (Siefkes et al. 2021), including a sterile male release technique (SMRT) as part of an integrated pest management approach. The objective of the SMRT was to reduce Sea Lamprey recruitment through a genotoxic effect of lethal mutations that prevent hatching in embryos generated from sterilized males (Bravener and Twohey 2016). In 1988, the chemosterilant Bisazir was approved by the U.S. Food and Drug Administration, a sterilization facility was constructed, and a series of field experiments were implemented in 33 Lake Superior tributaries from 1991 to 1996 (Twohey et al. 2003). Efforts were redirected in 1996 to the St. Marys River, a 120-km hydrologic connection draining Lake Superior into Lake Huron, to combat an increasing Sea Lamprey population in Lake Huron. The SMRT was ultimately terminated in 2011 due to difficulty isolating and measuring its effects in relation to other elements of the integrated pest management approach (i.e., trapping and pesticide; Bravener and Twohey 2016), high variation in the Sea Lamprey stock–recruitment relationship and density-dependent compensation (Jones et al. 2003), and a potentially larger-than-estimated Sea Lamprey population in the target river (Holbrook et al. 2016). Although the SMRT field experiments were well designed to evaluate ecosystem outcomes, several lessons were learned that could have improved implementation, reduced barriers to uptake of the science, and facilitated evidence-based decision making.

In hindsight, the SMRT may have been prematurely terminated and would have benefited from an effectiveness–implementation hybrid approach. Post-termination assessment showed that embryo survival in the St. Marys River was lower when the SMRT was applied (32%) than during the post-SMRT period (67%), even though the target ratio of sterile : normal males was never achieved (Bravener and Twohey 2016). Although a total of 49 research projects related to SMRT were funded by the GLFC between 1970 and 2011, the focus of this research was basic and biological science related to chemosterilants (1971–1985; 16 projects), physiological mechanisms of Bisazir on embryo viability (1982–2005; 13 projects), and demographic effects of SMRT (1992–2010; 20 projects). Although the GLFC invested heavily in development and assessment of the SMRT tool, only two years (1989–1991) were invested by the SMRT Task Force to develop the experimental design for implementation of field experiments aimed at determining the efficacy of the SMRT to reduce Sea Lamprey recruitment. Additionally, a decision analysis model for the St. Marys River was developed to inform early decision making, but, ultimately, was not updated with new data within the required timeframe to inform the decision to terminate the SMRT program. Explicitly copairing ecological outcome and implementation hypotheses, in the experimental design could have reduced the time to implementation of the SMRT as a control tool and the uncertainties associated with decisions to reallocate effort to a different system and ultimately to terminate the program after 20 y of experimental deployment. Understandably, the focus of managers was on killing Sea Lampreys, an implementation strategy that involved decision-makers in identifying management limitations (e.g., field staffing), trade-offs (e.g., cost-per-kill), decision points (e.g., target nest viability), and barriers to implementation (i.e., perceptions of managers regarding SMRT efficacy) could have better positioned the GLFC and its partners to identify practical uses for the SMRT as a supplemental tool in the Sea Lamprey Control Program rather than abandoning it as an alternative to conventional methods (Bauer and Kirchner 2020). A retrospective assessment of the SMRT, along with other supplemental controls for invasive Sea Lamprey in the Laurentian Great Lakes, led to a recent shift in the philosophical approach to Sea Lamprey control (Siefkes et al. 2021). Combined with post-SMRT assessment data (Bravener and Twohey 2016), the philosophical shift towards supplemental controls has revitalized discussions around SMRT and the tool has been redeployed as part of a long-term supplemental control research project. The project includes an adaptive management implementation framework to better position the GLFC to evaluate efficacy of the method and barriers to its implementation in the Sea Lamprey Control Program (Lewandoski et al. 2021).

Case Study 2: The Ningaloo Research Program, Australia

The Ningaloo Region in Western Australia is home to the Ningaloo Marine Park, a global biodiversity hotspot that was inscribed on the World Heritage List in recognition of the "outstanding universal value of the area" in 2011. The region is also a premier tourist destination and a key service point for oil and gas development and exploration, as well as supporting two permanent regional communities. Given multiple and competing uses of the region, its management presents a significant challenge for decision-makers. As a result, in 2006, the Ningaloo Research Program (NRP) was funded—a program of research valued at AU$36 million designed explicitly to generate new knowledge to enable managers and practitioners to make better-informed decisions about the management of the area. The program consisted of 40 research projects in the overarching themes of biodiversity, physical environment, socioeconomics and human use, and management support tools.

An evaluation of the NRP found that it met its aim of generating new knowledge to support evidence-informed decision making in the region (Cvitanovic et al. 2016), with the Marine Protected Area managers interviewed in the study stating that the knowledge generated through the NRP had inherent value for decision-making processes (Cvitanovic et al. 2016). In particular, Marine Protected Area managers noted the importance of the socio-ecological models, which were developed in the NRP to understand and effectively manage human pressures throughout the region. Further, participants of this study also spoke about the considerable efforts and resources (both financial and time) put towards supporting the communication of results to decision-makers. This included traditional linear modes of communication, such as written reports, peer-reviewed papers, and policy briefs, through to multidirectional approaches to knowledge exchange, such as workshops, community forums, and the use of a knowledge broker embedded in the region during the program (Cvitanovic et al. 2016; Chapman et al. 2017).

Despite this, however, participants (both from relevant decision-making agencies and the NRP research community) were unable to provide any evidence of this knowledge being used in decision-making processes, instead talking about a range of persistent barriers to knowledge exchange that contributed towards an implementation gap. These included the following: cultural differences among scientists and decision-makers, a range of institutional barriers such as problems associated with unsupportive leadership, and the inaccessibility of primary science to decision-makers. Drawing on lessons from the NRP, Cvitanovic et al. (2016) recommended a number of steps that could be taken through future research investments aiming to support implementation science, including, but not limited to, utilizing stakeholder mapping processes to identify and include all relevant stakeholders prior to the commencing of research design, implementing participatory research approaches (e.g. coproduction; Norström et al. 2020) and knowledge brokers that remained employed for several years following the completion of the research (sensu Cvitanovic et al. 2019) to enhance knowledge exchange during the implementation of research, and ensuring that appropriate and long-term knowledge management systems are established. Within the marine sciences, a series of other studies have since built on these principles (e.g., Cvitanovic and Hobday 2018; Cvitanovic et al. 2021b; Karcher et al. 2022), further highlighting opportunities to build tailored frameworks for supporting implementation science in the context of fisheries and aquatic marine sciences, as described in the next section.

TOWARDS AN IMPLEMENTATION SCIENCE FRAMEWORK FOR FISHERIES AND AQUATIC SCIENCE

Theories, models, and frameworks used in implementation science are numerous, fragmented, and adapted from diverse disciplines, such as social psychology and organizational theory (Nilsen 2015). A review of theoretical approaches used in implementation science by Nilsen (2015) highlighted three aims for implementation frameworks and theories: (1) describing and/or guiding the process of translating research into practice (i.e., process frameworks), (2) understanding and/or explaining factors influencing implementation outcomes (i.e., determinant frameworks), and (3) evaluating implementation (i.e., evaluating frameworks). Implementation frameworks should ideally be used before and throughout an implementation effort (Moullin et al. 2020), which also helps produce generalizable application of implementation frameworks, models, and theories. In the context of fisheries, this means there are a number of theoretical models and frameworks to choose from, each with varying assumptions, beliefs, and aims. Here, we focus on a framework to describe and guide implementation science in fisheries (Figure 2).

The frameworks and models described above help apply implementation science throughout the implementation process (Figure 2). Varied study designs that support implementation science also exist (summarized in Table 2). It is important to note the distinction between implementation science studies and efficacy or effectiveness studies. While implementation science studies focus on understanding the uptake and sustainability of an innovation or implementation (e.g., studying barriers to uptake), efficacy and effectiveness studies seek to evaluate the innovation and its outcomes (e.g., evaluate increase in fish population or habitat use). However, there are instances where hybrid "implementation–effectiveness" designs are used to study both the strategy of implementation and its outcomes (Table 2).

While many frameworks have been developed for other domains (e.g., see Nilsen 2015, 2020; Villalobos Dintrans et al. 2019; Damschroder et al. 2020; Ridde et al. 2020), here, we focus on the one proposed by Villalobos Dintrans et al. (2019). Implementation science frameworks were summarized by Villalobos Dintrans et al. (2019) into time-based frameworks that investigate *when* and component-based frameworks that investigate *who* (people) and *what* (intervention and environment). Studying the *when* includes understanding the pre-implementation stage, such as assessing characteristics and needs of actors involved (e.g., fisheries managers, decision-makers, fishers, rightsholders) and environmental factors influencing design of implementation (e.g., polarization of fisheries, capacity and resources, comanagement structures). Similarly, the post-implementation process needs to consider these factors (e.g., actors, environment, process). The implementation science framework (Figure 2) highlights that the provider and recipient (e.g., practitioner) are connected via coproduction, comanagement, or two-way knowledge exchange as previous evidence in fisheries has shown the importance of this connection for implementation (e.g., Cooke et al. 2020).

Although classic implementation science tends to consider effectiveness and implementation as being separate (see Table 2), Curran et al. (2012) advocated for embracing hybrid designs that combine effectiveness and implementation. Hybrid designs can be accomplished in three ways: (1) testing effects of a fisheries management intervention on relevant outcomes while observing and gathering information on implementation, (2) dual testing of fisheries/aquatic management and implementation interventions/strategies, and (3) testing of an implementation strategy while observing and gathering information on a fisheries/aquatic management intervention's impact on relevant outcomes. With limited resources and time to assess interventions and what are often long-time scales for management, outcomes to

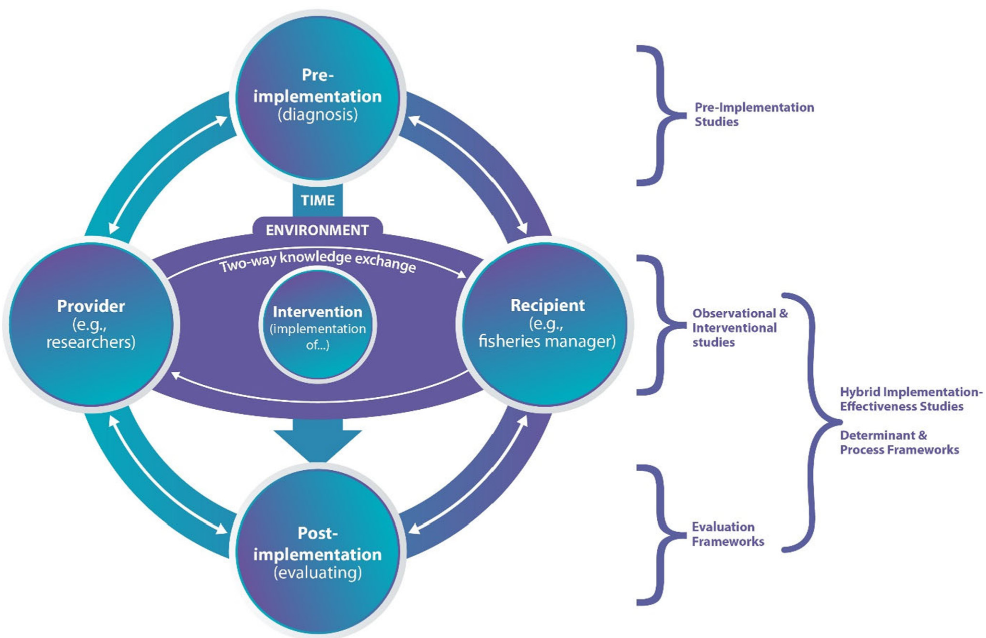

Figure 2. Synthesis of various implementation science frameworks. Details can be found in Table 2, including examples specific to fisheries and aquatic science and management. Informed and adapted from Nilsen 2015; Villalobos Dintrans et al. 2019; Damschroder et al. 2020.

Table 2. Forms of implementation science study relevant to fisheries and aquatic management and conservation. Adapted from Curran et al. 2012.

Modes of study	Description	Fisheries/aquatic example
Pre-implementation	Exploratory or descriptive studies used to identify barriers or facilitators to evidence-based practice and understand gaps in the quality of management and conservation outcomes.	Informal watershed management program conducted on an annual basis to reflect on progress towards achieving goals (Becerra 1995).
Observational	Studies (often qualitative) used to determine the extent to which evidence-based practices are being implemented in practical settings.	Evaluating the extent to which biotelemetry findings were being embraced by fisheries managers in the Great Lakes (Nguyen et al. 2021).
Interventional	Experimental studies used to test how implementation strategies (e.g., hands-on training sessions versus online modules) affect evidence-based practice use.	Evaluating the effectiveness of different training programs for those involved in the delivery of fisheries management training courses in India (Som et al. 2020).
Effectiveness–implementation hybrid	Studies that examine the effectiveness of an evidence-based practice (e.g., a given management intervention) in addition to assessing implementation outcomes (e.g., feasibility, fidelity, sustainability).	Implementation of management strategy evaluations for marine fisheries in Australia that combine evaluation outcomes that span effectiveness of evidence-based practice and implementation (Smith et al. 1999).

become evident (e.g., changes in fish community structure, conservation stocking to re-establish imperiled species), doing such research through a hybrid approach is efficient and also has the potential to "force" implementation scientists and practitioners to work collaboratively towards complementary goals.

OVERCOMING BARRIERS TO DOING IMPLEMENTATION SCIENCE

Barriers to the adoption and application of implementation science include, but are not limited to (1) lack of clarity about the problems (i.e., knowledge–action gap), (2) varied understanding of management decision-making processes, (3) unfamiliarity with implementation science, and (4) lack of capacity or institutional support to undertake or participate in implementation science. Here, we briefly identify opportunities for overcoming each of those barriers.

Lack of Clarity about the Problems

The widely held belief by knowledge generators that their work is already implemented is one of the biggest barriers. On the knowledge generator side, the gap can be largely attributed to the inflated perspective of a "publication" (Piwowar 2013). Research has revealed that knowledge moves in complex ways. Simply acknowledging that such a gap exists and is pervasive is a necessary first step to attempting to overcome that barrier. Taking time to reflect on why that barrier exists in a given context, project, program, or organization is a worthwhile endeavor that is best done jointly by knowledge generators and knowledge users. Indeed, there are challenges on the knowledge user side of the gap, whereby the tendency to rely on the status quo or experience of like-minded colleagues can reinforce the idea that there is not a problem. Humility by all parties and a commitment to doing better (for the benefit of aquatic resources and the peoples that depend on them) would be beneficial.

Varied Understanding of Management Decision-Making Processes

Some researchers may assume that a single empirical paper is the basis for decisions, whereas evidence-based management requires the assembly, evaluation, and synthesis of a body of evidence (Sutherland et al. 2004; Salafsky and Redford 2013). A given piece of knowledge may be just one piece of evidence in a broader, complex suite of considerations (Donnelly et al. 2018). Collaborating widely and deeply (i.e., engaging in coproduction) with those making decisions or that otherwise have rights or stakes in decisions or hold relevant knowledge can reveal opportunities for informal improvements of systems or processes while learning about how they make decisions. Various forces (e.g., political, bureaucratic, public) may be more powerful or prolong decisions.

Unfamiliarity with Implementation Science

Not surprisingly, if one is unfamiliar with the concept of implementation science, one is unlikely to embrace it. Training and a dearth of concrete examples of implementation science in action are missing elements in natural resources and environmental management. Efforts have been made in healthcare to include implementation science training in medical education (see Carney et al. 2016) and similar opportunities exist in fisheries and aquatic sciences (and more broadly in natural resources and environmental management). Doing implementation science means taking a pause and reflecting on processes—a feature of adaptive management, which is a more common concept within the fisheries community. There is a need for sharing more stories about when, where, and how implementation science was incorporated into projects or programs given that the ones described in the case studies above are (in our opinion) quite uncommon. Updating fisheries science curriculum, providing continuing education courses, and potentially revising the American Fisheries Society certification programs to include training in implementation science should be considered.

Lack of Capacity or Institutional Support to Undertake or Participate in Implementation Science

Given that there is often a flawed assumption that the current system "is not broken" or "is the way it is," it is difficult to justify spending time and resources on implementation science. Yet, not doing so means that opportunities for improvement will be missed and implementation will be further hampered. In some institutions or in the minds of some leaders, they simply may not want to be subject to such study or reflection. In other cases, it might be a lack of understanding about what could be learned from such a process or not having the internal capacity to do such work. Fortunately, there are experts in implementation science who can be recruited or contracted to do such work. Nonetheless, such experts, particularly in the environmental field, are still relatively rare. Moreover, we are unaware of any instances in the fisheries or broader environmental space where an implementation team has been formed as is common in other disciplines (e.g., Aijaz et al. 2021). Allocating funds, especially by organizations or funding bodies that support applied fisheries research, needs to be accompanied by a robust assessment of its implementation (or lack thereof), thus, informing future funding investments and training opportunities. In the examples above, the GLFC and the NRP both have invested in implementation science recognizing the need to ensure that investments are as impactful as possible.

A RESEARCH AGENDA FOR IMPLEMENTATION SCIENCE

Implementation science research agendas have been established for the healthcare realm (e.g., Juckett et al. 2019; Estabrooks and Glasgow 2023) and we are aware of one other attempt to develop a broad implementation research agenda (Eccles et al. 2009). Given the novelty of implementation science to the field of fisheries and divergent opinions about the nature of knowledge–action gaps, we envision codeveloping research agendas that account for the state of integration between branches of science and management. A research agenda should be driven by shared objectives, inclusive of diverse perspectives, and span multiple planning horizons and available resources. Below, we discuss elements of a generalized research agenda (Table 3), noting that the agenda should be system-specific as the state of understanding and use of the concepts, data, and resources varies widely among contexts (note, by context, this could be jurisdiction, ecoregion, etc.).

As noted in the above discussion of challenges with embracing implementation science, an essential first step is defining the problem and acknowledging that there is a knowledge–action gap and that implementation science has value in managing it. Identifying the characteristics of the gap is a critical next step, which requires extensive interaction with relevant actors to reflect on current barriers and challenges. Developing implementation science specific to fisheries and aquatic science will require work, and the research needs are great; therefore, resources will be required. The processes leading up to the implementation of a management intervention are rarely documented and when they are, the specific science involved in that decision train may not be cited or easily identifiable, making such work challenging. Given that decisions on, say, how to regulate harvest, are pervasive in fisheries management, and given that context (e.g., system properties, drivers, quality of data, human behavior, etc.) can vary widely within (e.g., over time) and among cases, understanding how drivers of evidence use impact outcomes of interest to managers and publics will always be somewhat challenging. As such, conducting implementation science at relevant scales and including replication where possible will be needed. We recognize that there is no single pathway for implementation in all contexts, but the community can determine some general principles that can be used in training of fisheries and aquatic science professionals. Unlike the healthcare realm, resources for implementation science are likely to remain scarce, so being efficient and searching for generalities will presumably be important. Finally, there is need to establish an evidence base. To that end, we encourage scholarship around understanding what different actors consider to be evidence and evidence-based management, the extent that it is embraced in their activities, and to identify relevant barriers and enablers.

The case studies shared here demonstrate where efforts are being made in the fisheries and aquatic realm to enhance implementation, yet rarely are those actions studied in a meaningful way, such that it is difficult to determine what works and what doesn't. It is also our perception that if time is taken to reflect on those actions, rarely is that work recorded and shared in a way that contributes to the implementation science evidence base. In the healthcare realm, eight implementation outcomes have been proposed by Proctor et al. (2011) and executing empirical studies in the fisheries and aquatics realm that explicitly measure those outcomes (i.e., adoption, acceptability, appropriateness,

Table 3. Research agenda spanning different temporal scales relevant to implementation science to support fisheries and aquatic management and conservation.

Task	Short (<5 yr)	Long (>5 yr)
Define the problem	• Does a knowledge–action gap exist? What does the gap mean and what are its implications?	• Evaluate management decision-making contexts: How are management decisions made? What is the current understanding and use of evidence-based management decision making? Are structured decision-making approaches being used?
Identify the gaps	• Identify gaps: Who is at the table and who is not? What data/knowledges/evidence are available and how is the information summarized or synthesized? Are actions impeded by lack of knowledge? Is knowledge being ignored? What are the perceived and real barriers to implementation?	• Determine variables influencing knowledge use in decision making: What social, political, economic, and scientific factors influence use? Are some forms of knowledge more usable than others?
Develop implementation science	• Assess the state of understanding of implementation science: Does the community understand implementation science? What are the perceptions among decision-makers and practitioners? What resources and expertise are available?	• Define an appropriate framework (see Figure 2 and Table 2) • Codevelop research objectives: What do managers and researchers want to measure/know? • Establish research priorities: Given limited resources, where do we focus attention? • Identify available funding opportunities: How can resources be leveraged?
Establish an evidence base	• Synthesize data on knowledge use in decision making.	• Determine necessary empirical studies to measure adoption, acceptability, appropriateness, costs, feasibility, fidelity, penetration, and sustainability (sensu Proctor et al. 2011).

costs, feasibility, fidelity, penetration, sustainability) is needed. Doing so will reveal if and how a given evidence-based action can be implemented. Given that cost (of action or inaction) is often a major barrier to embracing evidence, cost-effectiveness analyses should be undertaken as has been recently advocated for public health research (Krebs and Nosyk 2021). In fisheries and aquatics, resources for management action (e.g., restoration) are often limited and wicked problems are common (e.g., Jentoft and Chuenpagdee 2009), emphasizing the need to consider trade-offs. When practitioners make decisions there is typically little theoretical or conceptual rationale for their choice of intervention (including in fisheries; e.g., Young et al. 2016). Moreover, when interventions or actions are implemented, rarely are the details of those actions recorded with sufficient detail or contextual information (or data) to enable meaningful analysis. This further emphasizes the need for practitioners to be part of implementation science teams as their work, if done in a reasonably rigorous manner, can help to build the evidence base (Geng et al. 2017). Such engagement has the opportunity to accelerate progress and ensure relevance.

CONCLUSIONS

Our goal is to bring awareness of implementation science to the fisheries and aquatic science and management communities. In doing so, we hope to foster a culture of learning, reflection, and formal study intended to improve applied fisheries and aquatic science. The concept of implementation science is largely unknown, yet it has much to offer. The framework presented is intended to guide those interested in operating in this space and foster coproduction of system-specific approaches to implementation science. We used two case studies (one freshwater and one marine) to highlight where implementation science had been used (to various degrees). Those case studies both required substantial investment, a commitment to impact (institutional culture), and involvement of experts trained in implementation science. Doing so requires acknowledging that the knowledge–action gap is pervasive and that efforts to bridge that gap should be embraced. Fortunately, there are many human dimensions experts working in the fisheries and natural resource management fields and some of them have expertise in implementation science. Opportunities exist for training researchers to conduct implementation science and to build such capacity within funding bodies and natural resource management bodies. The research needs and opportunities are many and if addressed could help to catapult us forward and deliver on the promise of applied science. The "science" of implementing and applying science needs to be mainstreamed in fisheries management and conservation and our hope is that this Perspective helps move the community closer to that goal.

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CONFLICT OF INTEREST STATEMENT

Cooke is Editor-in-Chief of *Fisheries* and Nguyen and Danylchuk are Science Editors for *Fisheries*. As such, the paper was handled by other editorial team members.

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