FACETS
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SCIENCE APPLICATIONS FORUM

Enhancing fisheries education and research through the Canadian Fisheries Research Network: A student perspective on interdisciplinarity, collaboration and inclusivity

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Citation: Turgeon K, Hawkshaw SCF, Dinning KM, Quinn BK, Edwards DN, Wor C, Parlee CE, Debertin A, Hawkshaw M, Nelson BW, Zhang F, Benestan L, Angel E, Morse BL, and Mombourquette D. 2018. Enhancing fisheries education and research through the Canadian Fisheries Research Network: A student perspective on interdisciplinarity, collaboration and inclusivity. FACETS 3: 963–980. doi:10.1139/facets-2017-0038

Handling Editor: Steve J. Alsop

Received: April 18, 2017

Accepted: September 18, 2018

Published: December 13, 2018

Published by: Canadian Science Publishing

Abstract

Fisheries involve complex problems not easily addressed by a single discipline, methodology, or set of stakeholders. In 2010, the Canadian Fisheries Research Network (CFRN) was initiated to increase fisheries research capacity in Canada through interdisciplinary and inclusive research collaborations. As post-graduate students in the network, we reflected on the type of training necessary to tackle fisheries problems and reviewed opportunities available at Canadian universities to receive such training. This paper presents an overview of fisheries education currently available in Canada, reflects on our training within the CFRN, and proposes improvements to fisheries education and research. Our review of the subject revealed few dedicated fisheries programs, limited interdisciplinary programs, few specialized fisheries training programs, and a heavy reliance on academic supervisors to secure research opportunities in fisheries. In contrast, the CFRN enhanced our training by deliberately focusing on tools and techniques to address fisheries issues, providing venues to foster interdisciplinary and inclusive research collaborations, and exposing the realities of stakeholder collaborations. We call for post-graduate-level fisheries education and research that is interdisciplinary, collaborative, and inclusive to produce well-rounded scientists and managers, and we suggest ways that universities, researchers, and funding agencies can incorporate these themes into fisheries education and research.

Key words: academic training, collaboration, education, inclusivity, interdisciplinary, fisheries management, fisheries sciences

Introduction

Fisheries, defined as any activity leading to the harvesting of fish, including the capture of wild fish or the raising of fish through aquaculture (FAO 2014), experience problems related to fish biology and habitat in both marine and freshwater ecosystems, and must also consider issues related to humans that rely on fisheries. The latter aspect includes the cultural significance of fisheries with implications for traditional rights holders, corporate control, reallocation, recreational fishing rights, the economic role of fisheries in regional and national economies, and the governance and management of fisheries by different levels of government.

Fisheries are beset with a myriad of complex challenges, which have been recognized in the literature as wicked problems (Jentoft and Chuenpagdee 2009). Wicked problems are not one-dimensional; they involve more than one conflict type, are difficult to define, have no immediate solution, and best resolutions are not easily definable (Rittel and Webber 1974). As a result, there is potential for multiple and conflicting stakeholder objectives. This complexity is exacerbated by the fact that no single individual, discipline, or area of expertise has all of the resources necessary to adequately address these wicked problems (Rittel and Webber 1974; Jentoft and Chuenpagdee 2009; Haapasaari et al. 2012; Glavovic et al. 2015). The integration of knowledge across disciplinary boundaries (i.e., interdisciplinarity, see definitions below), along with more inclusive and innovative approaches, have been suggested as a stronger and more acceptable approach to managing fisheries (Stephenson and Lane 1995; Feldman and Khademian 2001; Lejano and Ingram 2009; Ludwig 2014).

To address the complex nature of fisheries, several conceptual and methodological frameworks have been developed to facilitate fisheries management (e.g., adaptive co-management (Holling 1978; Walters 1986), integrated management (Stephenson and Lane 1995; Bastien-Daigle et al. 2008), management strategy evaluation (Butterworth 2007; Fulton et al. 2014), and ecosystem-based fishery management (Pikitch et al. 2004; Long et al. 2015)). Despite their independent origins, each of these frameworks recognized the importance of an inclusive approach and suggested means to integrate ecological, economic, social, and institutional dimensions into fisheries management. By inclusive, we mean the active and continuous participation of multiple disciplines combined with the expertise of various sectors (fishermen, processors, and government) to develop research questions and formulate responses in fisheries.

Interdisciplinary approaches to fisheries management and research exist on a spectrum of interactions among and across disciplines. Interdisciplinarity can be distinguished from multidisciplinarity by the degree of interaction between disciplines, and extends beyond collaboration to include the integration of data, methods, theories, concepts, and models (Klein 1990; Huutoniemi et al. 2010; Haapasaari et al. 2012). Transdisciplinarity goes even farther, and involves academic disciplines working jointly with practitioners (Haapasaari et al. 2012; Klein et al. 2012), which is an inclusive and collaborative approach. To be successful as early career fisheries professionals, students should be introduced to the diverse disciplines and contexts relevant to fisheries science and fisheries management (Chapman et al. 2015; Bigford 2016). Moreover, they should incorporate some level of interdisciplinarity into their research through, for example, cross-training in both natural and social sciences (Blickley et al. 2013; Ciannelli et al. 2014; Goring et al. 2014). Students must also be able to communicate across disciplines and sectors (i.e., industry, government, academia, non-governmental organizations, and Indigenous Peoples), which are characterized by different backgrounds, knowledge, interests, values, and objectives (McMullin et al. 2016).

There is a reported disconnect between educational opportunities in fisheries and the needs of students, employers, and society (Science, Technology and Innovation Council 2015; McMullin et al. 2016). This is a long-standing and topical concern, warranting a special issue in the journal

Fisheries in 2016 (vol. 41, No. 8). In this special issue, potential employers of fisheries graduates specifically reported that many skills are lacking in new hires (e.g., strong communication skills, critical thinking, and the ability to work as a team (McMullin et al. 2016)), pointing to deficiencies in fisheries education in the United States. This raises the question as to whether Canada, an important global contributor to fisheries and ocean sciences (Council of Canadian Academies 2013), is adequately laying the groundwork for the next generation of fisheries experts to address the most pressing issues in fisheries, on both national and global scales.

The Canadian Fisheries Research Network (CFRN) (cfrn-rcrp.ca/CFRN-RCRP), launched in 2010, was a 5-year interdisciplinary strategic network initiative of the Natural Sciences and Engineering Research Council (NSERC). A main impetus for the CFRN was the recognition that university and government research programs were not addressing research questions that the fishing industry had identified as a priority. To enhance Canadian fisheries research capacity, the CFRN aimed to further collaboration between academic researchers, government scientists and managers, and the commercial fishing industry. The network included academics and students from research programs ranging from biology to social sciences and interdisciplinary programs, in addition to government and industry stakeholders. Eleven projects emerged from research priorities identified by industry partners and mostly focused on Canadian capture commercial marine and Great Lakes fisheries, with some limited interaction with recreational and First Nations fisheries. Research projects mainly focused on fisheries management sciences (i.e., rigorous application of the scientific method of problem solving in the development of strategic alternatives and their evaluation on the basis of objectives that integrate biological, economic, social, operational, and other relevant factors into decision making, sensu Stephenson and Lane 1995). A second objective of the CFRN, common to all NSERC strategic networks (Hasler et al. 2011), was to train a future generation of researchers and managers capable of addressing complex challenges in an effort to achieve viable and sustainable use of natural resources.

The authors of this paper are a subset of these CFRN students, from diverse backgrounds and disciplines. We started this reflection with an overview of the current state of fisheries education offered across Canada. We reviewed the courses and programs available for prospective students interested in a career in fisheries science and management. We were interested in providing an initial assessment of the state of fisheries education in Canada and to compare it with our own educational experience in fisheries. Given our recent experience as students in Canadian fisheries education programs and as new fisheries professionals, we organized a series of structured discussions from which we extracted a set of lessons learned. In these lessons learned, we (1) reflect on how our participation in the CFRN complemented and enhanced our university programs, (2) comment on the importance of inclusive and interdisciplinary collaborations in fisheries education and research, and (3) report some of the challenges in undertaking this collaborative approach to fisheries. Finally, based on our lessons learned and the current state of fisheries education in Canada, we developed a series of recommendations on how to improve fisheries education and research, both in Canada and globally.

An overview of the current state of fisheries education in Canada

The quality, scope, and general approach to fisheries education in Canada will have implications for students seeking educational opportunities, for employers hiring, and, most importantly, for the capacity to address complex fisheries management problems in Canada. To evaluate the current state of fisheries education in Canada, we reviewed the availability and scope of university-level fisheries education opportunities.

In May and June of 2016, we systematically searched all Canadian university websites to find fisheries-related undergraduate programs (bachelor), graduate programs (master's and doctoral), and university-level fisheries courses. We excluded colleges, technical institutes, and institutions granting non-academic degrees, as well as aquaculture-specific programs and courses. Each program and course was independently scored by six assessors as having a weak, moderate, or strong link to fisheries science/management based on descriptions available on the university websites (see Table 1 for the scoring criteria). Assessors overwhelmingly agreed on the rankings of programs and courses. Where rare disagreements occurred, a seventh assessor identified the majority consensus. The results may under-represent the number of programs and courses available, especially those with a weak link to fisheries, because of the paucity of course information available online for some universities, as well as the poor search functionality of some university and department websites.

Of the 101 educational institutes across Canada that grant academic degrees, 60 (59%) had programs or courses with links to fisheries (Table 2 and Fig. 1). This included 121 graduate programs, predominantly located in Ontario (27 graduate programs), Québec (21), and British Columbia (19) (Fig. 1a and Table S1). The geographic distributions of the 122 fisheries-related undergraduate programs (Fig. 1b and Table S2) and the 328 fisheries-related courses (Fig. 1c and Table S3) across Canada are similar to the distribution of graduate programs. Only four provinces had graduate programs that were strongly related to fisheries (British Columbia, Ontario, Québec, and Newfoundland and Labrador (Fig. 1a)), and five provinces had undergraduate programs related to fisheries (British Columbia, Manitoba, Ontario, Québec, and Newfoundland and Labrador (Fig. 1b)). Of the fisheries-related programs in Canada, most are only weakly related to fisheries, with only two provinces (Newfoundland and Labrador and British Columbia) meeting a threshold of 50% of fisheries-related programs moderately or strongly related to fisheries (Figs. 1a and 1b).

For graduate programs, information on training outside of the classroom (i.e., workshops, hands-on experience with the industry or government), the number of faculty working on fisheries, and the number of graduated students with fisheries-oriented theses would have been better indicators of the availability of fisheries training in Canada, but they were not consistently available across universities websites. Despite the limited information on these issues, the main finding of this overview remained clear. At the graduate level, the strength of training in fisheries is highly dependent on the advisor, highlighting the prominence of individuals working in the field rather than programs dedicated to fisheries. This pointed to a vulnerability within the Canadian fisheries education system, in

Table 1. Classification criteria used by the assessors to score the fisheries programs and courses.

Criterion	Program	Course
Weak	Program contains at least one course that is weakly-related to fisheries	Course title and (or) description may mention fisheries. It may also list several other main topics unrelated to fisheries but are foundational to do fisheries sciences (e.g., marine biology or ichthyology)
Moderate	Program contains at least one course strongly-related to fisheries, and (or) degree program designed to potentially (but not necessarily) be strongly-related to fisheries (e.g., Interdisciplinary or Resource Management programs could be very fisheries-focused, depending on the path/project chosen by a particular grad student or their supervisor)	Half of the topics listed in the course description focused on fisheries, fished species, etc., or potentially connected to issues of resource management (e.g., aquatic resource management)
Strong	Program is fisheries-centric where the degree name, description, and goals are directly related to fisheries and where many of the core courses needed for the degree are fisheries oriented.	Course is fisheries-centric (e.g., fisheries ecology/biology, fisheries stock assessment)

Table 2. Distribution of fisheries-related programs (graduate and undergraduate) and courses at Canadian universities by strength of link to fisheries.

	Graduate programs		Undergraduate programs		Courses	
Link to fisheries	No.	%	No.	%	No.	%
Weak	78	64	89	73	197	60
Moderate	31	26	25	20	55	17
Strong	12	10	8	7	76	23
Total	121	—	122	—	328	—

which a continued focus on fisheries is dependent on the hiring of individual faculty members with an interest in fisheries, with no formal commitment from most universities to ensuring a fisheries program or continued capacity to research and teaching of particular areas of focus (e.g., fisheries-focused cultural anthropology, fisheries economics, fisheries population dynamics and stock assessment).

Fisheries education within the CFRN

The CFRN was a capture-fisheries-centric network where most research projects focused on commercial capture fisheries (Fig. S1 and Table S1). Projects within the CFRN were led by an academic principal investigator but were co-constructed and developed from the earliest stages with industry, government, and other academics. Similar approaches have been implemented and recommended in other research networks and groups (Hasler et al. 2011; Chapman et al. 2015), but these partnerships between academics from various disciplines, industry, and government is not commonplace in Canadian fisheries research, particularly for natural sciences.

Overall, the CFRN supported 55 students from 11 universities across Canada, primarily master's (38%) and doctoral students (48%), as well as a few postdoctoral fellows and undergraduate students. From these, only 19% of students were enrolled in a dedicated fisheries program. The remainder were enrolled in non-fisheries programs (61% in biology, 15% in interdisciplinary programs, 4% in social sciences (Fig. 2)). This strongly contrasts with the United States, where 74% of student members of the American Fisheries Society were enrolled in a fisheries-related program and only 26% were in non-specialized natural sciences programs (McMullin et al. 2016). In addition, at Canadian universities, fisheries programs are typically only available at the graduate level. At most universities, undergraduates have access to non-specialized programs (e.g., general biology). The small percentage of CFRN students enrolled in dedicated fisheries programs, and our review of the programs offered at Canadian universities, reveals the reliance on non-specialized programs for fisheries training in Canada, which is supported by Dunmall and Cooke (2016).

Students considered the CFRN to be a good model to implement modern fisheries education and to train highly qualified personnel that will be equipped with skills to address the wicked problems inherent to fisheries management sciences and governance. Most CFRN students came from a university research group that specialized in a particular topic area within fisheries research. However, single-focused research groups can lead to compartmentalized research, which makes it difficult to achieve the interdisciplinary approach that modern fisheries management sciences require. Being part of the CFRN provided opportunities to receive training and experiences outside a student's discipline and university, thereby facilitating capacity for students to approach fisheries problems from an interdisciplinary approach.

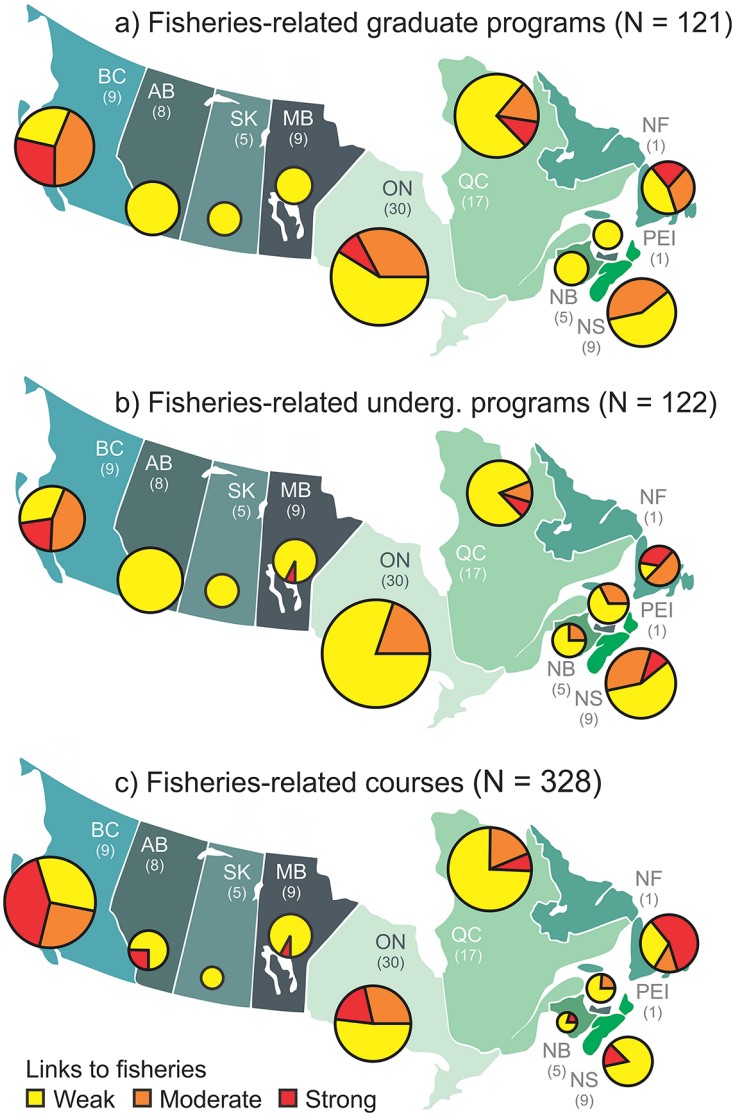

Fig. 1. Proportion and geographical distribution of the (a) fisheries-related graduate programs, (b) fisheries-related undergraduate programs, and (c) fisheries-related courses across Canada. The size of the pie represents the proportion of the programs or courses between provinces. Red represents the proportion of programs or courses with a strong relationship to fisheries, orange represents a moderate relationship, and yellow represents a weak relationship. The numbers in parentheses represent the number of universities per province. The map was produced in R v.3.4.3 (R Core Team 2017) with the following packages: maps v.3.1.0 (Deckmyn et al. 2018), mapdata v.2.3.0 (Brownrigg et al. 2018), maptools v.0.9-4 (Bivand et al. 2018), and scales v.1.0.0 (Wickham and RStudio 2018).

Student reflections on the CFRN

To evaluate the successes and challenges students experienced within the CFRN and to explore the implications for fisheries education, research, and management, all 55 CFRN students were invited to participate in a series of structured discussions. Just over 25% of students participated

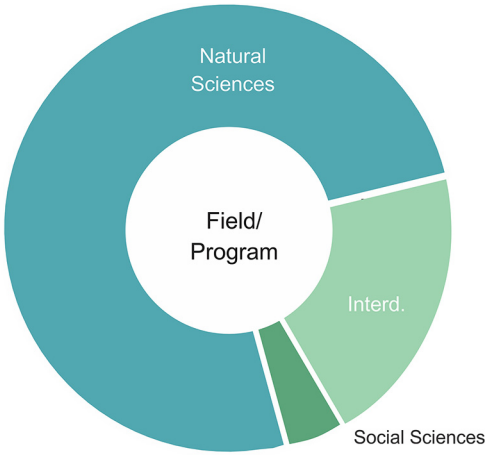

Fig. 2. Programs and fields in which students were enrolled while involved with the Canadian Fisheries Research Network (natural sciences, social sciences, and interdisciplinary).

in at least one discussion (from 9 to 14 students, with an average of 11 students per discussion). These structured discussions consisted of four group meetings covering eight main topics: (1) how the CFRN complemented and enhanced our research programs; (2) how the CFRN experience was unique; (3) what we particularly valued from our experience; (4) issues and (or) problems we faced that may have enhanced or hindered our academic progress; (5) what could have been done differently; (6) what should be kept the same; (7) directions we see fisheries management, policy, and research heading; and (8) our perspective on the current state of fisheries education in Canada. Comprehensive notes of the structured discussions were taken by dedicated note-takers, from which the lessons learned and recommendations that follow were summarized. Participating students were then asked to review and comment to ensure that the lessons learned and recommendations presented accurately reflected the discussion and represented a consensus perspective.

Lessons learned from the CFRN

Our structured discussions revealed that our participation in the CFRN was an overwhelmingly beneficial and rewarding experience, with both successes and challenges to performing fisheries research in a multidisciplinary, multi-stakeholder network environment. The CFRN fostered an inclusive approach to research that was a new working framework for most students, substantially different from the traditional fisheries education that we were receiving. Although the main focus of the CFRN was on commercial capture fisheries within Canada, we see the merit of the inclusive approach and its ready application across a wide range of fisheries research and management such as freshwater, recreational, and Indigenous fisheries, as well as it's benefit to those studying conservation science where socio-ecological complexity needs to be embraced and not avoided (Chapman et al. 2015; Dick et al. 2016).

We extracted seven main lessons learned from the structured discussions, which are organized into three themes: (1) the importance of institutional support for inclusive fisheries research and student training; (2) the challenges inherent in managing the active participation of partners; and (3) the CFRN as a model for an interdisciplinary and inclusive approaches to fisheries education, research, management, and governance.

Theme 1: the importance of institutional support for inclusive fisheries research and student training

Lesson learned No. 1: strong and sustained institutional, financial, and logistical support is needed to achieve inclusive fisheries research and interdisciplinary student training

Many CFRN students benefited from strong institutional support from the CFRN, which facilitated access to industry, government, and academic collaborators outside their immediate disciplines, provided opportunities to gain hands-on interdisciplinary research experience, and improved communication skills. Logistical support came mostly from the internal structure of the CFRN (i.e., a board of directors, a scientific committee, an independent scientific advisory panel, a director, a general manager, a facilitator helping with communication with industry partners, and principal investigators for each project (see Hasler et al. 2011)). The CFRN facilitated direct and ongoing access to collaborators, facilities, equipment, training, and data, which provided students with cross-sector and cross-discipline networking opportunities, the development of strong communication skills, and hands-on research experience. The CFRN also facilitated collaborative research through financial support for travel to and participation in the CFRN meetings, industry and government meetings, national and international conferences, and work in national and international fisheries science laboratories. Additionally, funding and administrative support was provided for professional development workshops and training opportunities through both CFRN-organized events (e.g., workshops on scientific communication, Bayesian statistics, and computer programming) and external events (e.g., stock assessment workshops organized by Fisheries and Ocean Canada, and visits to other fisheries research groups). Our collective impression is that these opportunities are rarely provided in traditional graduate programs in Canada. This support was invaluable in growing our skills and for undertaking inclusive and interdisciplinary research.

Lesson learned No. 2: traditional university regulations can hamper collaborations among university departments or outside academia and can impede inclusive and collaborative fisheries research

For some students, academic institutional rules presented barriers to collaborative research with industry and government partners. The co-construction of research projects and engagement with non-academic research partners was limited in some circumstances. For example, several universities would not accommodate industry partners because of a lack of a university affiliation and credentials to serve on supervisory committees providing guidance and support. Additionally, academic program requirements meant that outputs that would materially contribute to degree completion were prioritized, at times to the detriment of fostering industry collaboration. Collaborative and interdisciplinary work with partners outside academia continues to be unrecognized and unrewarded at many traditional academic institutions, a view shared by conservation scientists (Dick et al. 2016).

Lesson learned No. 3: interdisciplinary training continues to receive little support in fisheries academic programs despite increased demand for the integration of disciplines in fisheries management

Our structured discussions highlighted that obtaining a truly interdisciplinary education is difficult to accomplish and that such efforts can come at a cost. For example, enrollment in an interdisciplinary degree tends to significantly extend the duration of a program of study (Rhoten and Parker 2004). Moreover, interdisciplinary and multidisciplinary training is difficult to obtain because professors with an interdisciplinary training and background are rare and academic programs are effectively single discipline even within programs identified as interdisciplinary. For example, 15% of the CFRN students were registered in interdisciplinary programs, yet some of these students still identified more strongly with a single discipline. In addition, the products resulting from interdisciplinary training are not yet valued in academia (e.g., reports influencing policy and outreach efforts (Goring et al. 2014)) and funding is difficult to obtain, particularly given the demarcation of Canada's federal granting councils (Canada's Fundamental Science Review 2017). There were also concerns about the state of interdisciplinary research as a course of study. Some students reported the widespread

devaluation of interdisciplinary studies because of the seemingly common stereotype within academia that an interdisciplinary degree equates to being a generalist with no specialized skills. This sentiment, echoed by Brewer (1999) and Roy et al. (2013) suggests that an interdisciplinary degree may hinder chances of attaining a tenure track position in academia. In stark contrast, the CFRN students not registered in an interdisciplinary program reported that the exposure to multiple disciplines and interdisciplinary approaches through the CFRN significantly enhanced their fisheries education.

Theme 2: challenges in managing the active participation of partners

Lesson learned No. 4: effective engagement of all partners at every stage of research is essential for inclusive fisheries research

Managing projects that are co-constructed and involve multi-stakeholder participation is challenging, yet is the only way to conduct truly inclusive fisheries research to inform sustainable management and governance. Inclusive fisheries research requires identification of research partners and research questions, regular communication and engagement with partners, and ongoing management of expectations, objectives, and requirements for the duration of the project. Most of the CFRN students had little or no training on how to engage with partners, and some projects proceeded without government or industry partners. These projects were materially impacted by this lack. Students either had to rely on supervisors to secure research partners, diverting time from student mentoring, or students had to try and establish new collaborations themselves. Furthermore, even with pre-existing collaborations, some students had trouble maintaining cohesive partnerships with some collaborators (e.g., because of different geographic locations, backgrounds, experiences, and obligations outside the network).

In the CFRN, there were relatively few partnerships with international or cross-border fisheries, Indigenous communities, and fisheries managers. This proved problematic for some projects, particularly those focused on transboundary fisheries and (or) fisheries of high importance to Indigenous communities. Partners are not only significant stakeholders with an interest in research outcomes, but they can also be major sources of invaluable knowledge and resources such as data and analysis tools. With respect to fisheries managers, the CFRN experience demonstrated that there are still significant barriers to involving managers and policy makers in research. Collaborations with government were mainly through scientists and researchers at federal and provincial government departments. Interactions with managers and policy makers were extremely limited despite numerous attempts to engage them. Accordingly, fisheries programs considering external research partners should approach potential collaborators well in advance of beginning a research program and have a clear articulation of partner responsibilities from the outset.

Lesson learned No. 5: an inclusive approach to research requires participants to demonstrate flexibility regarding project timelines and to agree on objectives and expected outcomes

Managing conflicting needs and expectations between collaborative participants is a challenge for reaching project completion time expectations and project outcomes. On the one hand, academics (university professors) tend to focus on long-term 5+ year research programs and outcomes such as student graduation and publication of peer-reviewed research papers. A student's mandatory course requirements and qualifying exams may delay initiation of a project by 1–2 years, yet students are expected to complete all research and degree requirements within (optimally) a 2- to 4-year period. On the other hand, industry members typically require specific information relevant to their fishery, species, or fishing area on a shorter time scale, in some cases for the next fishing season (i.e., within 1 year or less) or prior to policy or management decisions on emerging issues (i.e., within months). In the CFRN, the realities of these different timelines and expected outcomes were not always clearly understood, appreciated, or valued by all partners, with some students feeling that they were trying to meet conflicting or unrealistic expectations. This situation was exacerbated by the mandated 5 year

life of the CFRN, dictated by the program under which it was funded. This has implications for the duration of networks or partnerships that take a co-construction approach to research, and will determine what deliverables are possible and when they can be expected.

Theme 3: the CFRN as a model for an interdisciplinary and inclusive approach to fisheries education, research, management, and governance

Lesson Learned No. 6: an inclusive approach to fisheries research is possible at multiple scales depending on project objectives and available resources

The CFRN students engaged in collaborations at several spatial, temporal, jurisdictional, institutional, and network scales (Cash et al. 2006), with the scale of collaboration determining the amount and type of resources required (i.e., human, financial, technical, and logistical). Some of the CFRN projects had very specific objectives, which were addressed by one or two students from the same research group collaborating with a few key industry members over 1–2 years (e.g., Gíslason et al. 2017; Haarr et al. 2018; Kincaid et al. 2017). Small-scale projects such as these required only modest resources yet still brought inclusivity and interdisciplinarity into the educational, research, and management partnerships. In contrast, a larger-scale CFRN project was refining a comprehensive fisheries evaluation framework (CFRN-RCRP 2014), which involved 11 students from three CFRN projects and five universities across Canada. Throughout this project the group of students met regularly through online meetings, and at the end of the project the students were brought together with other participants of the CFRN to share and collaborate on their results. This required much greater logistical and financial resources but resulted in a fisheries evaluation framework with a greater scope.

Lesson learned No. 7: integrating a variety of professional skills, technical skills, approaches, and perspectives helps fisheries education, research, and management to address multifaceted fisheries problems

The concept of bridging single discipline silos of knowledge—both horizontally (i.e., across geographic space, sectors, or disciplines) and vertically (i.e., across levels of organization)—was a central theme of the CFRN. High levels of involvement by many different stakeholders introduced students to new technical skills, approaches, and perspectives, including practices outside our own field of study. Meetings and discussions among network members exposed students to novel topics in their fields, provided additional mentorships and openings for future collaboration, and offered a broader perspective on research questions than that offered by a single supervisor. Industry-led research questions and consultation of harvesters for their ecological knowledge (Stephenson et al. 2016) helped to identify gaps in current fisheries science. Opportunities were also available to gain first-hand field experience where many students accompanied fish harvesters on their boats and learned how fish were harvested.

A good technical grounding and hands-on experience in the field of fisheries is not always sufficient in the job market as employers often require additional professional skills such as strong science writing and oral communication, teamwork abilities, and project management skills. McMullin et al. (2016) identified these skills as being in demand by employers but overlooked in traditional fisheries training. The CFRN created opportunities to develop these skills, either directly through training workshops or indirectly through network collaborations. Co-construction of the CFRN research projects enhanced our ability to work with partners from different backgrounds and strengthened our oral communication skills by forcing us to engage diverse audiences in plain language. The benefits realized by involving multiple stakeholders, co-learning, and the development of professional-skills would be difficult to nurture through traditional classroom learning.

Several students also felt that some of their most valuable learning interactions were from interactions with other students (collaborative learning) within the CFRN that studied different research topics and disciplines. Students felt less inhibited to ask questions in these peer interactions than settings

in which supervisors or industry were present, resulting in an increased discussion and understanding of specific disciplinary methods, techniques, theories, and tools, encompassing the ecological, economic, social, and institutional dimensions of the fisheries we were studying.

Recommendations for implementing interdisciplinary, collaborative, and inclusive fisheries education and research

Wicked problems that derive from fisheries management and governance are complex and, therefore, require arrangements consisting of different sets of knowledge, skills, expertise, and resources to address them. Here, based on lessons learned from our experience with the CFRN and our overview of the state of fisheries education in Canada, we suggest recommendations to facilitate the implementation of interdisciplinary, collaborative, and inclusive fisheries research and education to produce better fisheries scientists and managers.

Recommendation No. 1, for all participants: an ideal program (research group or institute) in fisheries would involve cross-sector collaboration among a wide range of interested stakeholders, as well as collaborations among disciplines, departments, and universities

Fisheries problems are large and multidisciplinary in nature and it is very difficult for one—or even two—research groups to possess the broad array of skills required to undertake the increasing scale of research projects in fisheries. To contend with this, we expect that there will be increased collaboration in fisheries research to bridge silos between universities, departments, and research groups. Without the strong collaboration of all parties (e.g., social sciences, natural sciences, fishing industry and other stakeholders, and government), the ability to link research activities to priority questions for all fisheries stakeholders and to translate research findings into relevant fisheries policies for managers is weakened. Although we encountered several obstacles to implementing interdisciplinary, inclusive, and collaborative research through the CFRN, the diversity of our training and research products go far beyond what would have been possible in a traditional graduate program.

Recommendation No. 2, for funding agencies and universities: recognize and support the need for interdisciplinary graduate programs to develop highly qualified personnel who are well positioned to understand, communicate, facilitate, and undertake fisheries research and management

First, despite the increasing recognition of the advantages of interdisciplinary training in fisheries (Lederman and Carlson 2016; McMullin et al. 2016) and conservation science (Dick et al. 2016), in practice there is still reluctance within academia to accept interdisciplinary studies as a legitimate course of academic study (Brewer 1999; Fox et al. 2006). This legitimacy problem impacts students in interdisciplinary programs (e.g., training that integrates the methods, theories, concepts, and models from multiple disciplines) and students in a single discipline program receiving training in interdisciplinary research (e.g., through courses to introduce other disciplines and methods to work collaboratively). There is a marked difference between training students in fisheries science and in fisheries management. Fisheries science tends to be strongly focused on the natural sciences, whereas fisheries management typically incorporates more perspectives, including those from the social sciences. Truly interdisciplinary programs can benefit both fisheries science and management education

programs, and can, in fact, help reconcile the disconnect that is often apparent between fisheries science and management in practice (Stephenson and Lane 1995).

Second, interdisciplinary grants and scholarships should have greater flexibility in current funding programs to address fisheries questions. At the moment, Canadian funding agencies for natural sciences (NSERC) and social sciences (Social Sciences and Humanities Research Council (SSHRC)) work independently. However, the problems that this creates for multidisciplinary research, which is recognized as more impactful and of growing importance, have been noted by a recent science review commissioned by the Government of Canada (Canada's Fundamental Science Review 2017). Both grant councils need to be involved in facilitating fisheries research, and, in their recent budget (i.e., Budget 2018) the Government of Canada has announced its first steps to address this issue (Government of Canada 2018).

Recommendation No. 3, for funding agencies and partners: provide sufficient logistical and financial resources to support project development and management

First, we recommend that funding agencies and potential network partners consider the effort and time required to develop and maintain a truly collaborative and inclusive partnership approach in fisheries. These interdisciplinary and multi-stakeholder partnerships take time, sometimes years, for project formulation and the development of well-functioning working relationships. Consideration should be given to establishing longer-term partnership arrangements that specific initiatives can leverage to shorten project formulation time. This could better support meeting project objectives within the specific funding frame typically available for research projects while still supporting an inclusive and collaborative approach to research.

Second, to increase engagement at every phase, funding agencies could allow compensation of non-academic partners (e.g., industry and NGOs) for costs incurred while participating in interdisciplinary projects (e.g., travel to meetings and use of their resources). It is important to recognize that restricting partnerships to only those that can cover their own costs or provide funding to help support the research means that marginalized and disenfranchised groups are prevented from participating. This can have harmful long-term impacts on the focus of research conducted and the ability of researchers to help address the urgent issues facing fisheries and society.

Finally, if partners wish to continue collaborative research after their initial funding period ends they must begin exploring new funding options early on. This could include funding and (or) in-kind contributions from the partners themselves, perhaps with matching funds from other sectors (e.g., Mitacs programs). In terms of benefits to all partners, these contributions may be seen as an investment for industrial partners (resource protection and industry development), government partners (policy and resource management), and university partners (research and student training).

Recommendation No. 4, for universities and departmental programs: universities should demonstrate more flexibility to facilitate collaborative, interdisciplinary, and inclusive research

We recommend that universities work to reduce the challenges posed by traditional institutional rules and academic devaluation of interdisciplinarity. There should be opportunities for students in single discipline programs to receive training in interdisciplinary and transdisciplinary research. This will require that universities build capacity for the co-construction of research objectives and projects and consider mechanisms for engaging partners outside of academia. We need to identify the obstacles that are currently in place that might prevent such collaborations. This could be

accomplished through increased flexibility in degree requirements and committee membership rules and by the development of novel measures of success (see Goring et al. 2014) to value research outputs from collaborative and interdisciplinary work (e.g., outreach products and application to policy and management).

Recommendation No. 5, for universities and departmental programs: graduate programs with a fisheries orientation should supplement their academic programs with specific workshops and internships

To foster the integration of natural and social sciences for inclusive research and student training, we recommend cross-training courses and workshops be provided to create more opportunities for students from a variety of disciplinary backgrounds to work on shared research and ideas related to fisheries science and management. Fisheries students should be provided with opportunities (workshops, conferences, and industry meetings) to develop general communication skills that are often lacking in new fisheries hires (McMullin et al. 2016). These professional skills are also needed to improve communication across sectors for interdisciplinary research. Workshops on project management and powerful science communication tools for all participants, including project investigators, might facilitate and benefit the coordination of interdisciplinary projects and can facilitate inclusive research.

Recommendation No. 6, for students: students should actively engage themselves in workshops, internships, and networking activities to enhance their skill sets to become fisheries professionals

It is the responsibility of students to actively seek out and participate in opportunities to receive interdisciplinary training in fisheries. Graduating with a degree is only one step toward becoming a fisheries professional (McMullin et al. 2016). To be a competitive candidate for employment, students also need skills not explicitly taught in academic programs. Many universities, research groups, and networks offer personal development workshops to improve scientific communication skills, understand the foundation of project management, and decode policies, politics, and ethics. Moreover, students can further develop their leadership, networking, and communication skills by organizing their own workshops to facilitate knowledge transfer among their peers. In summary, graduate students who seek out diverse experiences will be the most employable (Chapman et al. 2015; Dunmall and Cooke 2016).

General conclusions

Is Canada adequately laying the groundwork for the next generation of fisheries scientists and managers, and will they be well prepared to address some of the world's most urgent issues related to fisheries? By virtue of its long history in fisheries research and strong education system, Canada could be at the cutting edge of fisheries science, management, and education globally. However, our review of fisheries education showed a limited number of options for university-degree-level training in fisheries, and our structured discussions revealed few mentors and educational collaborations with stakeholders. These are the very opportunities and partnerships needed to provide the tools from various disciplines to mitigate ecological, social, economic, and institutional risks to fisheries (Irvine 2009).

If there is interest from government, industry, and universities to continue Canada's tradition as a world leader in fisheries research, then serious consideration should be given to how to ensure ongoing training that meets the current and future fisheries needs. Reliance on the individual interests of professors within general university research programs is unlikely to lead to enduring fisheries training over the long term. This suggests that specific fisheries programs may be warranted. It further suggests that these programs should be interdisciplinary in nature and address the skills needed to support inclusive approaches to research.

We propose that fisheries educators, research institutes, and future networks adopt an approach similar to that used in the CFRN, where students receive specialized fisheries training but gain the opportunity to learn skills from different disciplines, in close collaboration with industry, government partners, and other academics. Initiating such an approach to fisheries education is complex but lessons learned from the CFRN identified some challenges and successful initiatives, and the recommendations from our experiences will hopefully support the groundwork needed for such programs. The end result will be cross-trained workers, valued by potential employers, with improved job prospects in fisheries science and management (McMullin et al. 2016). This next generation of fisheries scientists and managers will have the capacity to face emerging challenges in fisheries, which will improve fisheries sustainability in Canada.

Acknowledgements

This collaborative contribution was supported by the Canadian Fisheries Research Network, which was funded by the Natural Sciences and Engineering Research Council of Canada, and we thank all those involved in the success of this network. We thank Robert Stephenson (Department of Fisheries and Oceans and University of New Brunswick), Melanie Wiber (University of New Brunswick), Bernard Sainte-Marie (Department of Fisheries and Oceans), and Marc Allain (facilitator of the Canadian Fisheries Research Network) for helpful suggestions and comments on an early draft of this manuscript. We would also like to acknowledge the late Christian Brun (1970–2016), a dedicated scientist, advocate, father, and mentor to many in the network.

Author contributions

KT, SCFH, KMD, BKQ, DNE, CW, CEP, AD, MH, BWN, FZ, LB, EA, BLM, and DM conceived and designed the study. KT, SCFH, KMD, BKQ, DNE, CW, CEP, AD, MH, BWN, FZ, LB, EA, BLM, and DM performed the experiments/collected the data. KT, SCFH, KMD, BKQ, DNE, CW, CEP, AD, MH, BWN, FZ, LB, EA, BLM, and DM analyzed and interpreted the data. KT, SCFH, KMD, BKQ, DNE, CW, CEP, AD, MH, BWN, FZ, LB, EA, BLM, and DM contributed resources. KT, SCFH, KMD, BKQ, DNE, CW, CEP, AD, MH, BWN, FZ, LB, EA, BLM, and DM drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper and in the Supplementary Material.

Supplementary material

The following Supplementary Material is available with the article through the journal website at doi:10.1139/facets-2017-0038.

Supplementary Material 1

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