Science Applications Forum

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

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Abstract

Fisheries sciences and management involve complex problems not easily addressed by a single set of stakeholders or methodologies from one discipline; accordingly, the Canadian Fisheries Research Network (CFRN) was initiated to increase fisheries research capacity in Canada through interdisciplinary and inclusive research collaborations. We compared the value of the CFRN students' learning experience to that offered in traditional fisheries programs at Canadian universities in training post-graduate students to tackle complex fisheries problems. This paper presents 1) a review of the current state of fisheries education across Canada and 2) reflections on our training within the CFRN, and challenges to implementing its innovative approach to fisheries education. We found few dedicated fisheries programs in Canada and concluded that fisheries research typically relies on securing a supervisor with an interest in fisheries. In contrast, the CFRN enhanced our university training through interdisciplinary and inclusive research collaborations, and by exposure to the realities of industry, government and academics collaborating for sustainable fisheries. We propose a new approach to post-graduate level fisheries education, one that combines interdisciplinarity, collaboration, and inclusivity to produce more capable fisheries scientists and managers. Furthermore, we made recommendations on how universities, researchers, and funding agencies can successfully incorporate these themes into fisheries education.

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

Introduction

Fisheries management and governance are beset by 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, Kulmala and Kuikka, 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 manage fisheries (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 that facilitate an inclusive approach to fisheries management (*e.g.*, Adaptive Co-Management: Holling, 1978; Walters, 1986; Integrated Management: Stephenson and Lane, 1995; Bastien-Daigle, Vanderlinden and Chouinard, 2008; Management Strategy Evaluation: Butterworth, 2007; Fulton, Smith, Smith and Johnson, 2014; and Ecosystem-Based Fishery Management: Pikitch et al., 2004; Long, Charles and Stephenson, 2015). Despite their independent origins, each of these frameworks recognized the importance of an inclusive approach, and suggested means to integrate the ecological, economic, social, and

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institutional dimensions into fisheries management. However, none of these frameworks was explicitly developed to facilitate an interdisciplinary approach to fisheries management.

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, Klein, Bruun and Hukkinen, 2010; Haapasaari, Kulmala and Kuikka, 2012). Transdisciplinarity goes further yet, and involves academic disciplines working jointly with practitioners (Haapasaari, Kulmala and Kuikka, 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 management (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; Goring et al., 2014; Ciannelli et al., 2014). Students must also be able to communicate across disciplines and sectors (*i.e.*, industry, government, academia, NGOs and First Nations), which are characterized by different backgrounds, knowledge, interests, values, and objectives (McMullin et al., 2016).

There is a reported disconnection 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 longstanding and topical concern, warranting a recent Special Issue in the journal Fisheries in 2016 (vol. 41, No. 8). In this special issue, potential employers of fisheries graduates have specifically reported that many skills are lacking in new hires (*e.g.*, strong communication skills, critical thinking and ability to work as a team (McMullin et al.,

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2016), pointing to deficiencies in fisheries education in the United States. This raises the question as to whether Canada, an important producer of fisheries scientists and managers, 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), launched in 2010, was an interdisciplinary, five-year national network of 11 interrelated projects focused on Canadian commercial fisheries. A main impetus for the CFRN was the recognition that university and government research programs were not addressing research questions that industry had identified as a priority. To enhance research capacity, the CFRN aimed to further collaboration between academic researchers, the commercial fishing industry, government scientists and managers across Canada. A second objective of the CFRN was to train a future generation of fisheries researchers and managers capable of addressing complex challenges in an effort to achieve viable and sustainable fisheries. The network 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.

The authors of this paper are a subset of the CFRN students, from diverse backgrounds and disciplines. Given our recent experience as students in Canadian fisheries education programs and as new fisheries professionals we: 1) evaluate the current state of fisheries education in Canada, and 2) reflect on our experience with the CFRN. From this experience, we formulated lessons learned where we 1) reflected on how our participation in the CFRN complemented and enhanced our university programs, 2) commented on the importance of inclusive and interdisciplinary collaborations in fisheries education and research, and 3) reported some of the

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challenges in undertaking this collaborative approach to fisheries. Finally, we developed a series of recommendations on how to improve fisheries education and research globally.

Evaluating 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 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 the spring 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 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 some university websites had poor search functionality, or little course information was available online.

Of 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

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Columbia (19; Fig. 1a; Table S1). The geographic distributions of the 122 fisheries related undergraduate programs identified (Fig. 1b; 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). Out of all 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 modest threshold of >50% of programs moderately or strongly related to fisheries (Fig. 1a, b).

Fisheries Education within the CFRN

Within the CFRN, which was a fisheries-centric network and where all research projects were strongly fisheries-related (Fig. S1 and Table S1), only 19% of students were enrolled in a dedicated fisheries program which further reveals the limited opportunities to get fisheries training in Canada. 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 assessment of McMullin et al., (2016), 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. In addition, at Canadian universities, fisheries programs are typically only available at the graduate level. At most universities, undergraduates only have access to integrative programs (*e.g.*, general biology). The small percent of CFRN students enrolled in dedicated fisheries programs, and our evaluation of the programs offered at Canadian

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universities, supports Dunmall and Cooke (2016) asserting that fisheries-specific degree programs in Canada are uncommon.

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

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 the CFRN students were invited to participate in a series of structured discussions. More than 25% of the CFRN students participated in at least one discussion (from 9 to 14 students; with an average of 11 students per discussion). These structured discussions consisted of 4 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

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management, policy, and research heading; and, 8) our perspective on the current state of fisheries education in Canada.

Lessons learned from the CFRN

The CFRN fostered an inclusive approach to research that was a new working framework for most of us. 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. This strong connection between academics from various disciplines, industry and government partners is a relatively new way to conduct fisheries research in Canada, particularly for natural scientists. Our participation in the CFRN was an overwhelmingly beneficial and rewarding experience, which revealed both successes and challenges to performing fisheries research in a multidisciplinary, multi-stakeholder network environment. From the structured discussions, we extracted the main lessons learned from the CFRN concerning: 1) the importance of institutional support for inclusive fisheries research and student training, 2) the challenges in managing active participation of partners, and 3) the CFRN as a model for an interdisciplinary and inclusive approaches to fisheries education, research, management and governance.

Strong institutional 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, as well as providing opportunities to gain hands-on interdisciplinary research experience and improve communication skills. However, we feel that current academic

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203 institutional convention can represent barriers to collaborative research and interdisciplinary
204 training.

205 ***Lesson learned # 1****: Strong institutional support throughout the entire collaboration is necessary*
206 *for inclusive research collaborations.*

207 Strong logistical support for inclusive research came mostly from the internal structure of
208 the CFRN (*i.e.*, a board of directors, a scientific committee, an independent scientific advisory
209 panel, a director, a general manager, a facilitator helping with communication with industry
210 partners, and principal investigators for each project). These various groups within the CFRN
211 facilitated direct and ongoing access to collaborators, facilities, equipment, training and data,
212 which provided students with cross-sector and cross-discipline networking opportunities,
213 development of strong communication skills, and hands-on research experience. The CFRN also
214 facilitated collaborative research through logistical and financial support for travel to and
215 participation in the CFRN meetings, industry and government meetings, national and
216 international conferences, and work in national and international fisheries science laboratories.
217 Funding and administrative support was also provided for professional development workshops
218 and training opportunities both within the CFRN (*e.g.*, workshops on scientific communication,
219 Bayesian statistics, computer programming) and outside of the CFRN (*e.g.*, stock assessment
220 workshops, visits to other research groups). We would argue that these opportunities are rarely
221 available in more traditional graduate fisheries programs in Canada.

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***Lesson learned #2**: Traditional university regulations can hamper collaborations among university departments or outside academia and impede inclusive and collaborative fisheries research.*

For some students, academic institutional rules represented 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 many circumstances. For example, several universities would not accommodate industry partners, due to lack of university affiliation and credentials to serve on supervisory committees providing guidance and support. Additionally, some students felt the need to complete other academic requirements (*e.g.*, coursework), and felt more pressure to focus on activities that would materially contribute to degree completion, rather than fostering industry collaboration. These examples demonstrate how the significance of collaborative and interdisciplinary work with partners outside academia continues to be unrecognized and unrewarded at many traditional academic institutions.

***Lesson learned #3**: Interdisciplinary training is still challenging in academia despite increased demand for integration of disciplines in fisheries management.*

Our structured discussions indicated that obtaining a truly interdisciplinary education is difficult to accomplish, and that such efforts come at a cost. For example, enrollment in an interdisciplinary degree tends to extend the duration of a program of study. Interdisciplinary or multidisciplinary training are difficult to receive in many disciplines because academia programs are effectively single-disciplined even within programs identified as interdisciplinary and professors with an interdisciplinary training and background are rare. For example, 15% of the CFRN students were registered in interdisciplinary programs, yet some of these students still

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identified more strongly with a single discipline. Canadian fisheries programs do not currently support interdisciplinary training because the resulting products are not yet valued in academia (*e.g.*, reports influencing policy and outreach efforts Goring et al., 2014). In 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. 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.

Challenges in managing active participation of partners

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. Project leaders must identify collaborators from each fisheries sector who can agree on common research goals, who are willing to work through communication barriers, and who are willing to actively participate throughout the research project to attain the agreed upon goals.

Lesson learned #4: *Effective engagement of all partners, at every stage of research, is essential for inclusive fisheries research.*

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 to engage with partners, and some projects proceeded without

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266 government or industry partners. These projects were materially impacted by this absence.
267 Students either had to rely on supervisors to secure research partners, diverting time from student
268 mentoring, or try to establish new collaborations themselves. Furthermore, even with pre-
269 existing collaborations, some students had trouble maintaining cohesive partnerships with some
270 collaborators (*e.g.*, due to different geographic locations, backgrounds, experiences, and
271 obligations outside the network).

272 In the CFRN, there were relatively few partnerships with international or cross-border
273 fisheries, Indigenous communities, and fisheries managers. This proved problematic for some
274 projects, particularly those focused on transboundary fisheries and/or fisheries of high
275 importance to Indigenous communities. Partners are not only significant stakeholders with an
276 interest in research outcomes, but can be also major sources of invaluable resources such as data
277 and analysis tools. With respect to fisheries managers, the CFRN experience demonstrated that
278 there are still significant barriers to involving managers and policy makers in research.
279 Collaborations with government were mainly through scientists and researchers at federal and
280 provincial government departments. Interactions with managers and policy makers were
281 extremely limited, despite numerous attempts to engage them. Accordingly, fisheries programs
282 considering external research partners should approach potential collaborators well in advance of
283 beginning a research program and inform them of their responsibilities if they decide to
284 participate.

285 ***Lesson learned #5***: *An inclusive approach to research requires participants to demonstrate*
286 *flexibility regarding project timelines and to agree upon objectives and expected outcomes.*

287 Managing conflicting needs and expectations between collaborative participants is a
288 challenge to project completion time and outcomes. On the one hand, academics (university

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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, sometimes for the next fishing season (*i.e.*, within one 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.

The CFRN as a model for an interdisciplinary and inclusive approach to fisheries education, research, and management

The CFRN strongly enhanced our fisheries training by incorporating cross-discipline and cross-sector collaborations and by taking an inclusive approach to fisheries. Moreover, the CFRN allowed students to experience cross-disciplinary and inclusive collaboration at multiple scales. This experience afforded a better understanding of the requirements (*i.e.*, resources and time) needed for collaborative projects to succeed independently of scale or scope. The CFRN's approach also provided students with a diverse set of soft skills (*e.g.*, teamwork, science

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311 communication, problem solving) and perspectives necessary for the workplace that would be
312 difficult to achieve in a more traditional fisheries program.

313 ***Lesson Learned #6*****:** *An inclusive approach to fisheries research is possible at multiple scales*
314 *depending on project objectives, and available resources.*

315 The CFRN students engaged in collaborations at several spatial, temporal, jurisdictional,
316 institutional, management, network, and knowledge scales (*sensu* Cash et al., 2006), with the
317 scale of collaboration determining the amount and type of resources required (*i.e.*, human,
318 financial, technical, logistical). Some of the CFRN projects had very specific objectives, which
319 were addressed by one or two students from the same research group collaborating with a few
320 key industry members over one to two years. Small-scale projects such as these required only
321 modest resources yet still brought inclusivity and interdisciplinarity into the educational,
322 research, and management partnerships. In contrast, a larger-scale CFRN was refining a
323 Comprehensive Fisheries Evaluation Framework (CFRN-RCRP, 2014), which involved 11
324 students from three other CFRN projects and five universities across Canada. Throughout this
325 project the group of students met regularly through online meetings and at the end of the project
326 the students were brought together with other participants of the CFRN to share and collaborate
327 on their results. This required much greater logistical and financial resources but resulted in a
328 fisheries evaluation framework with a greater scope.

329 ***Lesson learned #7****: Integrating a variety of soft-skills, technical -skills, approaches, and*
330 *perspectives helps fisheries education, research, and management to address multifaceted*
331 *fisheries problems*

332 The concept of bridging single discipline silos of knowledge – both horizontally (*i.e.*, across
333 geographic space, sectors, or disciplines) and vertically (*i.e.*, across levels of organization) – was

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334 a central theme of the CFRN. High levels of involvement by many different stakeholders
335 introduced us to new technical skills, and unique approaches and perspectives from different
336 disciplines and stakeholders. Meetings and discussions among network members exposed
337 students to novel topics in their fields, improved communication skills with other researchers,
338 provided additional mentorships, and offered a broader perspective on research questions than
339 that offered by a single supervisor; opening the possibility of future collaborations. We gained
340 better understanding of how to apply a variety of techniques or approaches to a question –
341 including practices outside of our own field of study. Industry-led research questions and
342 consultation of harvesters' for their ecological knowledge (Stephenson et al., 2016) helped to
343 identify gaps in current fisheries science. Opportunities were also available to gain first-hand
344 field experience where many students accompanied fish harvesters on their boats and learned
345 how fish were harvested.

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

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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 compared to 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

Wicked problems that derive from fisheries management and governance are complex and therefore require arrangements comprised of different sets of knowledge, skills, expertise, and resource to address them. An education in fisheries science that involves interdisciplinary and inclusive approaches to fisheries research is expected to produce better fisheries scientists and managers (Bigford, 2016). However, there are challenges to implementing approaches to an interdisciplinary education. Here, based on lessons learned from the CFRN, we suggest recommendations to facilitate the implementation of interdisciplinary, collaborative and inclusive research in education.

Recommendation #1 to all participants: *To achieve a broader interdisciplinary perspective, an ideal program in fisheries would involve cross-sector collaboration across a wide range of interested partners (e.g., industry groups, governments, Indigenous peoples, fishing communities, international interests), as well as collaborations across disciplines and universities.*

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Fisheries problems can be large multidisciplinary problems that require larger and more diverse teams to solve. 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 strong collaboration from all parties, 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. For these reasons, it is important to invest in increasing collaborative work among disciplines and expertise (*e.g.*, social sciences, natural sciences, fishing industry, and government). While we encountered several obstacles to implementing interdisciplinary, inclusive, and collaborative research through the CFRN, the quality of our training and of our research products go far beyond what would have been possible in a traditional graduate program.

Recommendation #2 to funding agencies and universities*: Recognize and support interdisciplinary research as a legitimate graduate program in fisheries to develop highly qualified personnel who are well positioned to understand, communicate, facilitate and undertake fisheries research and management.*

Despite the increasing recognition of the advantages of interdisciplinary training in fisheries (Lederman and Carlson, 2016; McMullin et al., 2016), in practice, there is still reluctance within academic programs to accept interdisciplinary studies as a legitimate course of academic study. 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

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to introduce other disciplines and methods to work collaboratively). There is a marked disconnect between training students in fisheries science or fisheries management. In practice, fisheries science tends to be strongly focused on the natural sciences, while fisheries management incorporates more perspectives, including those from the social sciences. Truly interdisciplinary programs can reconcile fisheries research and management. There are merits to both interdisciplinary programs, with roles for both in the future of fisheries education and management.

Recommendation #3 to funding agencies*: Provide sufficient logistical and financial resources to support project management, at both the network and project level.*

We recommend that funding agencies consider the effort and time required to develop and maintain a truly collaborative and inclusive partnership approach in fisheries. First, to fully benefit from, and build on the collaborative and inclusive network approach, large-scale partnerships (like the CFRN or other initiatives) should last more than 5 years or be prioritized for renewal of funding. These partnerships should consider the implications of the typical two to three-year period needed for interdisciplinary and multi-stakeholder project formulation. Second, we need interdisciplinary grants and/or scholarships to address fisheries questions or more flexibility in current funding programs. At the moment, Canadian funding agencies for natural sciences (Natural Sciences and Engineering Research Council; NSERC) and social sciences (Social Sciences and Humanities Research Council; SSHRC) work independently. However, both need to be involved in facilitating fisheries research. Further, funding agencies need to allow compensation of non-academic partners (*e.g.*, industry) for costs incurred while participating in interdisciplinary projects (*e.g.*, travel to meetings, use of their resources).

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Otherwise, non-academics may be prevented from engaging at every phase, thereby hindering research that deals with wicked problems relevant to the fishing industry.

Recommendation #4 to 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 the field of interdisciplinarity. There should be opportunities for students in single discipline programs to receive training on how to participate 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 and identify what obstacles are currently in place that might prevent such collaborations. This could be accomplished through increased flexibility in degree requirements and committee membership rules, and maybe, by the development of novel measures of success (see Goring et al., 2014) to value research outputs from collaborative work (*e.g.*, outreach products, application to policy and management).

Recommendation #5 to 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 students 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) to develop general communication skills,

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446 which are among the soft-skills reportedly sought but often lacking in new fisheries hires
447 (McMullin et al. 2016). These soft-skills are also needed to improve communication across
448 sectors for interdisciplinary research. Workshops on project management, and powerful science
449 communication tools for all participants, including project investigators, might facilitate and
450 benefit the coordination of interdisciplinary projects and can facilitate inclusive research.

451 ***Recommendation #6 to students***: *Students should actively engage themselves in workshops*
452 *and internships to enhance their skill sets to become fisheries professionals.*

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

463 ## General conclusions

464 Is Canada adequately laying the groundwork for the next generation of fisheries scientists
465 and managers, and will they be well prepared to address some of the world's most urgent issues
466 related to fisheries? By virtue of its long history in fisheries research and strong education
467 system, Canada could be at the cutting edge of fisheries science, management, and education

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globally. However, our systematic review of fisheries education programs and courses shows a limited number of options for students seeking university degree-level training in fisheries. Of the university programs and courses offered in Canada, most were weakly associated with fisheries. Within the few programs with strong links to fisheries, opportunities were limited for training in interdisciplinary research. Mentors and educational collaborations among stakeholders would be one way to improve interdisciplinary fisheries training and supplement traditional programs.

Much like fisheries education, fisheries science and management require tools from various disciplines to mitigate ecological, social, economic, and institutional risks to fisheries (Irvine, 2009). Platforms modelled after the CFRN approach, that increase interdisciplinary training and foster collaborations across specialized disciplines and a wide range of stakeholders will ultimately enhance not only fisheries education, but also fisheries research and management. Initiating such an approach to fisheries is complex but lessons learned from the CFRN identify some challenges and successful initiatives, and the recommendations from our experiences will hopefully provide the groundwork to create such programs.

Overall, we hope and believe that the interdisciplinary and collaborative training promoted by the CFRN will be an advantage for those pursuing a career in fisheries. Governments must assess the risks to fisheries from natural science, socio-economic and institutional perspectives. Often policy positions are not prioritized for those with fisheries-specific education and training but are typically open to analysts with a general education background (*e.g.*, economics, social sciences, statisticians). There may be less incentive to pursue interdisciplinary fisheries studies if job prospects seem limited, which is unfortunate as some cross-training is valued by potential employers and could actually improve job prospects (McMullin et al. 2016).

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We propose that fisheries educators, research institutes and future networks adopt an approach similar to the CFRN, where students receive specialized fisheries training but gain the opportunity to learn skills from different disciplines. Students of the CFRN have built capacity to face emerging challenges in fisheries research, and our interdisciplinary network of colleagues is paving the way to improve fisheries sustainability in Canada.

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584 **Table 1.**

Criteria	Programs	Courses
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)

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586 **Table 2.**

Link to fisheries	Graduate	Undergraduate	Courses
Weak	64% (78)	73% (89)	60% (197)
Moderate	26% (31)	20% (25)	17% (55)
Strong	10% (12)	7% (8)	23% (76)
Total number	121	122	328

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Table captions

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

Table 2. Distribution of fisheries-related programs (graduate and undergraduate) and courses at Canadian universities by strength of link to fisheries. Absolute numbers are given in parentheses.

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Figure captions

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 parenthesis represents the number of universities per province.

Fig. 2. Programs and fields in which students were enrolled while involved with the CFRN (Natural sciences, Social sciences, Interdisciplinary).

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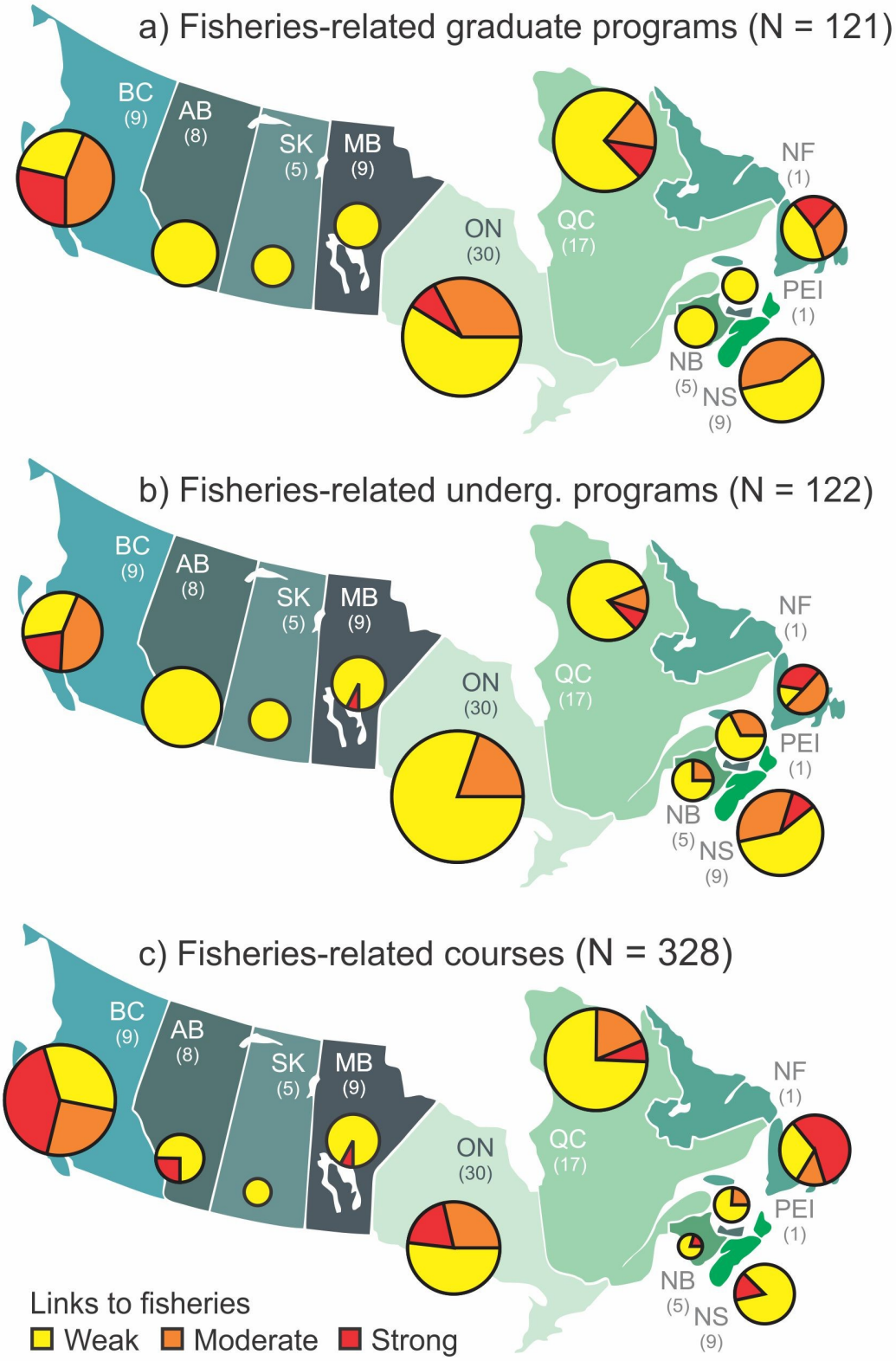

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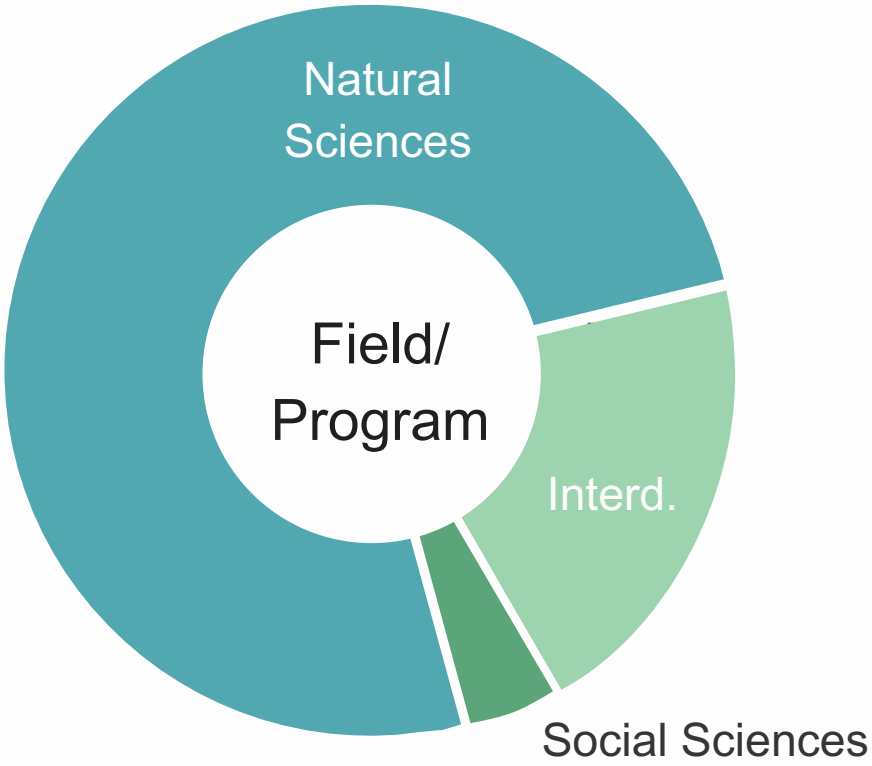

Fig. 2. Programs and fields in which students were enrolled while involved with the CFRN (Natural sciences, Social sciences, Interdisciplinary).

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