REPORT OF THE INDEPENDENT EXPERT PANEL ON AQUACULTURE SCIENCE

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EXECUTIVE SUMMARY

The Independent Expert Panel on Aquaculture (the Panel) was established in May 2018 with the mandate of providing the Department of Fisheries and Oceans (DFO) with advice and recommendations on the appropriate use of scientific evidence in risk-based aquaculture decision-making, the priority-setting process for aquaculture science at DFO, and the communication of aquaculture science and resulting decisions to Canadians.

Since the mandate was broadly defined, the Panel agreed that recommendations would be high level and focus on best practices and universally accepted principles in the scientific evidentiary process. As a result, the Panel recommendations may also be of interest to other departments and agencies involved in aquaculture science and management.

In its deliberations, the Panel noted that there are several overarching challenges with regard to aquaculture science and management in Canada. First, the fragmentation of responsibilities between several levels of government, as well as between federal departments and agencies, presents challenges in communicating aquaculture science and resulting decisions. This jurisdictional fragmentation of responsibilities is not well understood by the public. Second, the diverse ecosystems and aquaculture activities require distinct risk-based decision-making frameworks. Nonetheless, DFO has overarching science responsibilities for aquaculture and is in a unique position to communicate to Canadians an integrated vision and plan for sustainable aquaculture and ocean protection.

The Panel review found that there are systematic processes for scientific research within DFO, both in terms of production of knowledge and inputs into regulatory decisions. However, there is limited ability to evaluate the application of scientific evidence to broader aquaculture management decisions or to the assessment of the effects of aquaculture management actions on risk levels. Additionally, the Panel found that information on the science considered in specific regulations or policy decisions is not readily accessible. Lastly, it appears that DFO science prioritization and decision-making processes may have become too internal and are insufficiently communicated.

Overall, the Panel recommends that DFO develop an integrated risk management framework that can be used to promote continuous, proactive and systematic processes to understand, manage and communicate risks from an organization-wide perspective. Such an evidence-based approach requires the scientific identification and characterization of all potential risks and impacts associated with aquaculture activities.

The Panel also encourages the development of a clear vision and multi-year plan to govern science activities. Together, these recommendations would help DFO in developing an effective, coordinated and accessible communication strategy with diverse stakeholders, Indigenous communities and the general public.

To achieve this, the Panel recommends that an integrated scientific advisory system consisting of an externally appointed Departmental Science Advisor, as well as an External Advisory Committee on Aquaculture, be established by DFO. This would ensure ongoing participation of independent external experts in the science process at DFO—from research prioritization to peer review and evidence synthesis and interpretation. Additionally, the adoption of an open science framework that includes accessible data and scientific publications is recommended.

Open science represents an important opportunity for meaningful engagement with communities, stakeholders, Indigenous communities and external science experts.

The Panel is providing 10 specific recommendations to the mandate questions it received.

1. **Advice and recommendations on the consideration of scientific evidence in risk-based decision-making and policy development processes that form the basis for the management of aquaculture.**

   Recommendation 1: DFO should implement best practices for synthesizing available scientific evidence on aquaculture risks. This includes incorporation of Indigenous and local knowledge as well as the use of systematic reviews, external peer review and other universally accepted standards.

   Recommendation 2: In consultation with the Departmental Science Advisor, DFO should use best practices to characterize and understand the potential risks and impacts associated with aquaculture.

   Recommendation 3: DFO should use quantitative methodologies and risk-science approaches to develop an Integrated Risk Management Framework (IRMF) that ensures that all relevant factors are properly considered in aquaculture decisions.

2. **Advice and recommendations on the priority-setting process for aquaculture science work at Fisheries and Oceans Canada.**

   Recommendation 4: DFO should establish an External Advisory Committee on Aquaculture.

   Recommendation 5: DFO should develop a clear overarching scientific vision and a corresponding multi-year research plan with the help of the Departmental Science Advisor and the External Advisory Committee on Aquaculture.

   Recommendation 6: The External Advisory Committee on Aquaculture should, under the leadership of the Departmental Science Advisor, conduct an external peer review of research plans and priorities.

   Recommendation 7: The Departmental Science Advisor, with input from the External Advisory Committee on Aquaculture, should establish clear guidelines for DFO science programs that support aquaculture management on the one hand and emerging practices in aquaculture on the other.

   Recommendation 8: DFO should change the science priority-setting processes to give proper consideration to regional priorities using an integrated ecosystem-based approach.

3. **Advice and recommendations on opportunities to improve communication of aquaculture scientific findings and resulting decisions to Canadians.**

   Recommendation 9: DFO should develop a communication plan to proactively communicate aquaculture science. Such a plan must include a revamp of its aquaculture website.

   Recommendation 10: DFO should adopt and implement an open science framework for aquaculture and develop strategic alliances in science communication and outreach.

I. OBJECTIVE

In February 2018, the Minister of Fisheries and Oceans announced on behalf of the Minister of Science that the Chief Science Advisor would lead an independent expert panel to provide recommendations on the appropriate use of scientific evidence in aquaculture decision-making. The panel would also provide advice on the communication of this science and how it informs decision-making.

MANDATE

The mandate of the Independent Expert Panel on Aquaculture Science (the Panel) is to provide advice and recommendations to the Minister of Science and the Minister of Fisheries and Oceans in three areas of concern:

1. The consideration of scientific evidence in risk-based decision-making and policy development processes that form the basis for the management of aquaculture;
2. The priority-setting process for aquaculture science work at Fisheries and Oceans Canada; and
3. Opportunities to improve communication of aquaculture science findings and resulting decisions to Canadians.

METHODOLOGY

To achieve this mandate, the Panel considered information available on government websites, as well as published documents and reports. At the request of the Panel, in-person briefings were also given by officials from the Department of Fisheries and Oceans Canada (DFO), the Pest Management Regulatory Agency (PMRA) and the Canadian Food Inspection Agency (CFIA) to answer questions from the Panel. The Panel also received a presentation from experts on risk-based decision-making.

The recommendations were informed by current scientific knowledge relating to aquaculture and international standards for the use of science in risk-based decisions, as well as international best practices for the use and communication of science for policy. In total, the Panel held two in-person meetings (in Ottawa and Montreal) and two teleconferences to conduct its work.

The Panel agreed that all recommendations would be:

- High level, with some targeted advice to assist in implementation, but not unique to any specific geographical area or regional concern;
- Directed to DFO, recognizing that these recommendations may also be of interest to other departments and agencies involved in aquaculture management; and
- Relevant to all areas of aquaculture and not focused specifically on farmed salmon.

II. CONTEXT

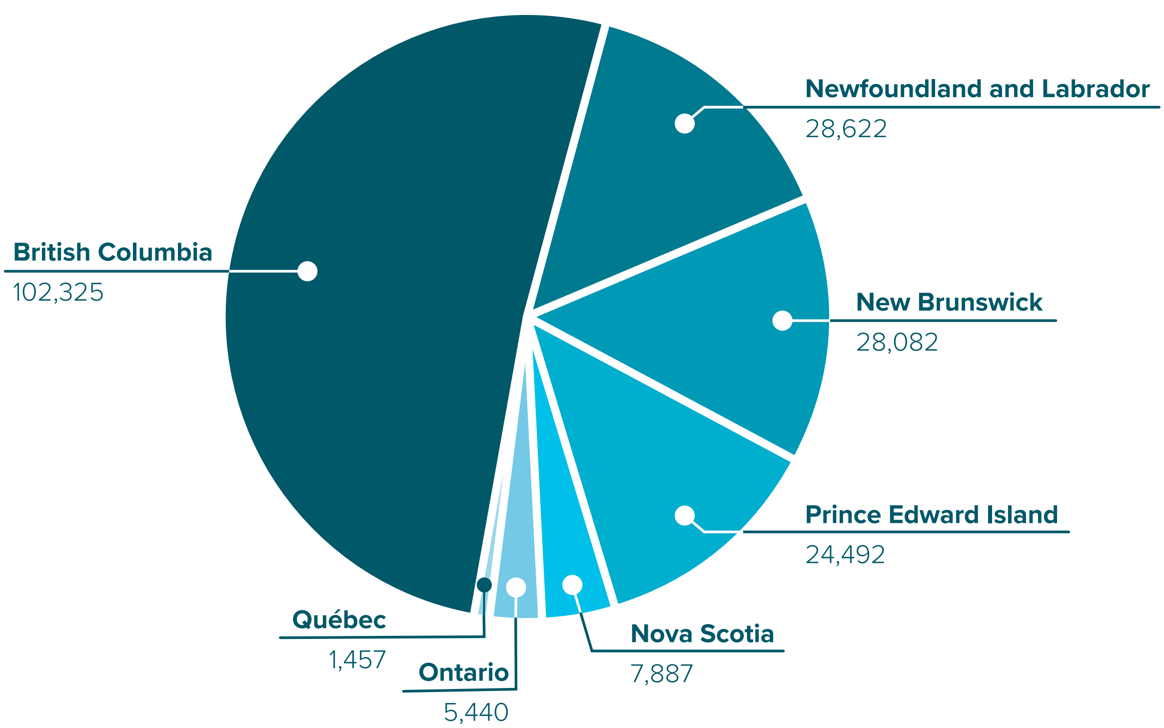
Aquaculture is the farming of aquatic species, both freshwater and saltwater, under controlled conditions. The practice of aquaculture started millennia ago in China. However, intensive production aquaculture is relatively recent, dating from the mid-twentieth century (Nash, 2010). The Food and Agriculture Organization of the United Nations (FAO) estimates that aquaculture is the fastest growing food producing sector, accounting for over 50% of the world's fish consumption in 2014 and represents 25% of the total world marine fisheries production (FAO, 2016).

1. AQUACULTURE DEVELOPMENT IN CANADA

Commercial aquaculture in Canada began in the 1950s, with freshwater trout farming in Ontario, British Columbia and Quebec, and oyster culture in New Brunswick, British Columbia and Prince Edward Island. In the 1970s, a mussel industry emerged on the east coast, along with the first attempts to culture salmon commercially in British Columbia, New Brunswick and Nova Scotia. Commercial-scale marine pen aquaculture

GRAPHIC 1:

Aquaculture Production in Canada in 2016 by Province (Tonnes)



Source: Statistics Canada. Table 32-10-0107-01 Aquaculture, production and value.
Note: Production values for Manitoba, Saskatchewan and Alberta were suppressed to meet confidentiality requirements of Statistics Canada.

production in Canada became significant in the mid-1980s and increased more than fourfold in the 1990s, largely due to growth in British Columbia.

Today, aquaculture takes place in all 10 provinces and the Yukon Territory, with a variety of species of finfish, shellfish and seaweed. According to Statistics Canada, from 2012 to 2016, Canada generated an average of 176,760 tonnes of aquaculture product worth $951 million annually. Fifty five percent of Canada's aquaculture production is exported, primarily to the United States. More than 88% of Canada's aquaculture exports are salmon products. Finfish (primarily salmon) continues to account for the majority of production, with about 80% of total volume and about 93% of total value. Canadian aquaculture is viewed as a high-value product that generates over $1.4 billion in gross output, with salaries and wages accounting for $115 million in 2016. The industry provides year-round jobs to thousands of Canadians, many of whom live in remote, rural or coastal communities. About 50 Indigenous communities are directly involved in commercial aquaculture production in Canada, mostly in British Columbia and Ontario, but also in Atlantic Canada.

Challenges and opportunities of aquaculture

As global seafood demand increases, aquaculture has become an important source of food. According to the World Bank (2013) aquaculture is projected to supply over 60 percent of fish destined for direct human consumption by 2030 from 47 percent in 2006. Canada's aquaculture industry is considered to have significant potential for growth due to Canada's extensive coastline and proximity to the United States market; however, there are ecological concerns around the potential future expansion of the industry.

Like most industries, aquaculture can have effects on the environment, and questions have been raised about the impact of aquaculture on ecosystems and biodiversity. Scientific evidence shows that there are potential impacts of the transfer of pathogens and parasites between farmed and wild stocks, and the impacts that escaped farmed fish can have on native populations and ecosystems. There is also concern about the potential impact of chemicals used in aquaculture practices, such as antibiotics and anti-parasitics, on the marine environment. The use and depletion of wild stocks for feed, impacts on other commercial species, and entanglement of marine mammals in fish farm nets are also issues of concern.

In addition, there are inherent uncertainties and complexities with much of aquaculture science, especially those acting at the ecosystem level. A growing body of scientific literature provides evidence of the potential impacts, although uncertainties remain about population level effects on marine life. Moreover, warming ocean temperatures and ocean pollution and acidification present dynamic challenges ranging from disease spread to animal behaviour that could require revisiting existing scientific methodologies.

2. AQUACULTURE MANAGEMENT IN CANADA

In Canada, aquaculture management is a shared responsibility between federal, provincial and territorial governments. Constitutional authorities and legal rulings have resulted in three different aquaculture management regimes in place across the country:

1. In British Columbia, as a result of a judicial ruling in 2009, DFO became the principal regulator. The *Federal Pacific Aquaculture Regulations* give DFO the responsibility to issue licences and monitor licence conditions.

2. In Prince Edward Island, through a 1928 memorandum of understanding, the province has transferred the responsibility for fisheries management to the federal government. As a result, aquaculture activities are co-managed with DFO.

3. In all other provinces and territories, provincial and territorial authorities manage aquaculture activities, including the issuance of site licences and monitoring. DFO's role in these cases is to provide science advice and support.

Regardless of jurisdiction, DFO provides science advice and support to all regions in Canada because DFO has an overarching mandate for the protection of marine wild fish.

DFO is also responsible for issuing licenses to authorize the intentional release and transfer of live aquatic organisms into both fish-bearing waters and fish-rearing facilities in all provinces and territories, except Quebec (in freshwater), Ontario, Manitoba, Saskatchewan and Alberta, where provincial officials authorize those activities. For example, if an aquaculture company requests a transfer of live animals to marine farms, they would need to seek approval from multiple agencies, including DFO. Finally, DFO has an overarching mandate for the protection of marine wild fish populations, so the potential impacts of aquaculture activities on wild fish are within DFO's responsibilities, regardless of province.

Other federal departments and agencies play roles in regulating the Canadian aquaculture industry as well. Notably, Health Canada's Veterinary Drug Directorate is responsible for approving in-feed medications, including those used in aquaculture production. The Pest Management Regulatory Agency (PMRA) is involved in approving pesticides, such as those used in the control of sea lice. The Canadian Food Inspection Agency (CFIA) ensures that cultured fish produced in Canada meets federal standards for food safety. The CFIA is also responsible for controlling the introduction and spread of serious infectious diseases in aquatic animals, particularly those caused by pathogens affecting international trade.

Thus, aquaculture management is fragmented across Canada and DFO's aquaculture management decision-making is limited to British Columbia and Prince Edward Island, where DFO makes decisions about the issuance of licences, the establishment of licence conditions, and the introductions and transfers of species into the marine environment. For example, should a company want to establish facilities on the east and west coasts of Canada, they would need to seek approval for licences from the provinces (except for Prince Edward Island) on the east coast and from DFO in British Columbia.

As a result, regulatory and management coordination is required among federal, provincial and territorial (FPT) authorities. The Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) is a FPT council that has a commitment to working together to foster sustainable aquaculture development. In the CCFAM 2016-2019 Aquaculture Development Strategy, jurisdictions and industry made a commitment to improving support for regional economic growth by investing in science, research and innovation.

FIGURE 1:

Infographic: How fish farming is regulated in Canada

Source: Fisheries and Oceans Canada.
Available at: http://www.dfo-mpo.gc.ca/aquaculture/publications/fish-farm-pisciculture-eng.htm.

3. USE OF SCIENCE FOR AQUACULTURE MANAGEMENT AT DFO

DFO has three main science programs that support aquaculture management, development and sustainability in Canada.

1. **The Program for Aquaculture Regulatory Research (PARR)**, which is designed to increase scientific knowledge on the interactions between aquaculture and aquatic environments. This program is internally funded and takes place within DFO research facilities. The research is carried out by DFO scientists and it informs aquaculture regulatory decision-making and policy development.

2. **The Aquaculture Collaborative Research and Development Program (ACRDP)**, which promotes collaborative research and development activities between the aquaculture industry and DFO. The program links industry representatives with DFO researchers to improve the competitiveness and sustainability of the Canadian aquaculture industry. Projects are primarily conducted within DFO research facilities, but field work may also take place at industry sites or other partner facilities. Potential projects are jointly proposed and funded by aquaculture producers and DFO.

3. The recently launched **Aquaculture Ecosystems Interaction Program (AEIP)**, which aims to address challenging and complex ecological knowledge gaps that cannot be addressed through the above research programs. The program provides funding to enable DFO scientists to take a leadership role in the development of collaborative research programs/networks with industry, academia, non-governmental organizations, Indigenous groups and international partners. The program seeks to address the indirect effects of aquaculture on wild populations and effects of aquaculture operations on their surrounding ecosystem.

Consequently, DFO has several mechanisms and activities that allow for science to inform decision-making. In addition to the above, synthesis reports on specific management questions are put together by the Canadian Science Advisory Secretariat (CSAS), an internal structure that is designed to gather expert advice from scientists within and outside of government.

Lastly, in response to the report of the *Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (2012),* DFO has also initiated a series of studies of the potential interactions of diseases on wild fish, in an attempt to integrate all scientifically available data to inform future risk assessments.

Freshwater aquaculture science-sediment core sampling. *Photo credit: DFO*

III. OBSERVATIONS AND OVERALL RECOMMENDATIONS

The Panel was mandated to provide advice and recommendations in three areas: the use of scientific evidence in risk-based decision-making, the prioritization of science work and the communication of science findings and decisions to Canadians.

The Panel review found that there are systematic processes for scientific research in terms of both production of knowledge and inputs into regulatory decisions. However, there is limited ability to evaluate the application of scientific evidence to broader aquaculture management decisions or to the assessment of the effects of aquaculture management actions on risk levels. The scope of the scientific evidence that is brought to bear on a decision and the weight it is given relative to other considerations (e.g., commercial, socio-economic) are important factors. Unfortunately, information on the science considered in specific regulations or policy decisions is not readily accessible, nor are the research results easily accessible on the DFO website.

The Panel noted the fragmentation of the scientific activities across regions and locations where regulatory and developmental scientific activities appear intertwined. It also noted that the science prioritization process may be too internalized and difficult to understand from outside the department.

Overall, the Panel recommends **the development of an Integrated Risk Management Framework (IRMF)** that can be used to promote continuous, proactive and systematic processes to understand, manage and communicate risks from an organization-wide perspective. This requires a prudent approach that includes the identification of relevant risks and the characterization of those risks. **Regional ecosystem approaches within an integrated national vision is recommended.**

An integrated scientific advisory system consisting of a Departmental Science Advisor and an External Advisory Committee on Aquaculture, with risk assessment expertise, is recommended. This will ensure ongoing participation of Indigenous groups and external scientific experts in providing advice on long-term science priorities and mechanisms to better inform decision-making. Adopting an open science framework is also recommended because it represents a unique opportunity for meaningful engagement with communities, stakeholders and external science experts.

These observations and overall recommendations are further detailed in response to each mandate question below.

IV. SPECIFIC RECOMMENDATIONS

A. Advice and recommendations on the consideration of scientific evidence in risk-based decision-making and policy development processes that form the basis for the management of aquaculture.

Risk-based Decision making

A risk-based approach to decision-making recognizes that governments cannot regulate all risks or reduce the probability of any specific hazard to zero, and that there is always some level of uncertainty. Therefore, risk-based decision-making asks questions such as: How likely are the potential problems to occur? How severe might the potential problems be? Are the potential problems manageable?

Listing all risks is a primary step in comparative risk assessment and risk reduction. Risk analysis in aquaculture should be used to assess the risks of aquaculture to society and the environment, as well as the risks from the society and the environment (e.g., climate change) to aquaculture. The intensity and type of environmental impacts of aquaculture are dependent on the species farmed, the intensity of production and the farm location.

Scientific evidence in risk assessments

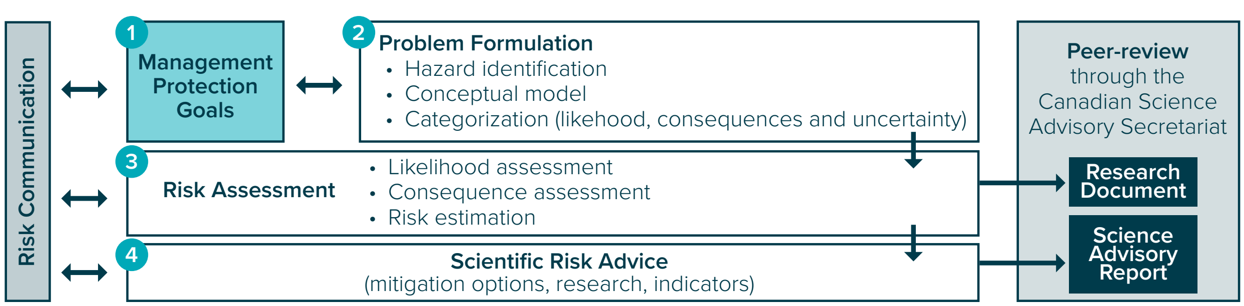
Risk assessment is the step of evaluating the evidence for the likelihood of risk occurrence and associated consequences. Scientific risk assessments are performed according to stipulated standards and processes established within their scientific disciplines. The assessment is informed by the questions to be addressed in support of the eventual decision but is conducted free of influence by policy or decision-makers.

Generation and use of evidence in aquaculture management

DFO's Aquaculture Science Environmental Risk Assessment Initiative (2015) was developed to support the shift of research on aquaculture management to an ecosystem-based approach (Figure 2). This framework was based on the more technically defined Science Advisory Report "Pathways of Effect for Finfish and Shellfish Aquaculture" (2009), as shown in Figure 3. While the Aquaculture Science Environmental Risk Assessment Framework is a reasonable framework, it does not consider the mutual interactions between the stressors and effects.

FIGURE 2:

Overview of Risk Assessment Process Under the Aquaculture Science Environmental Risk Assessment Initiative

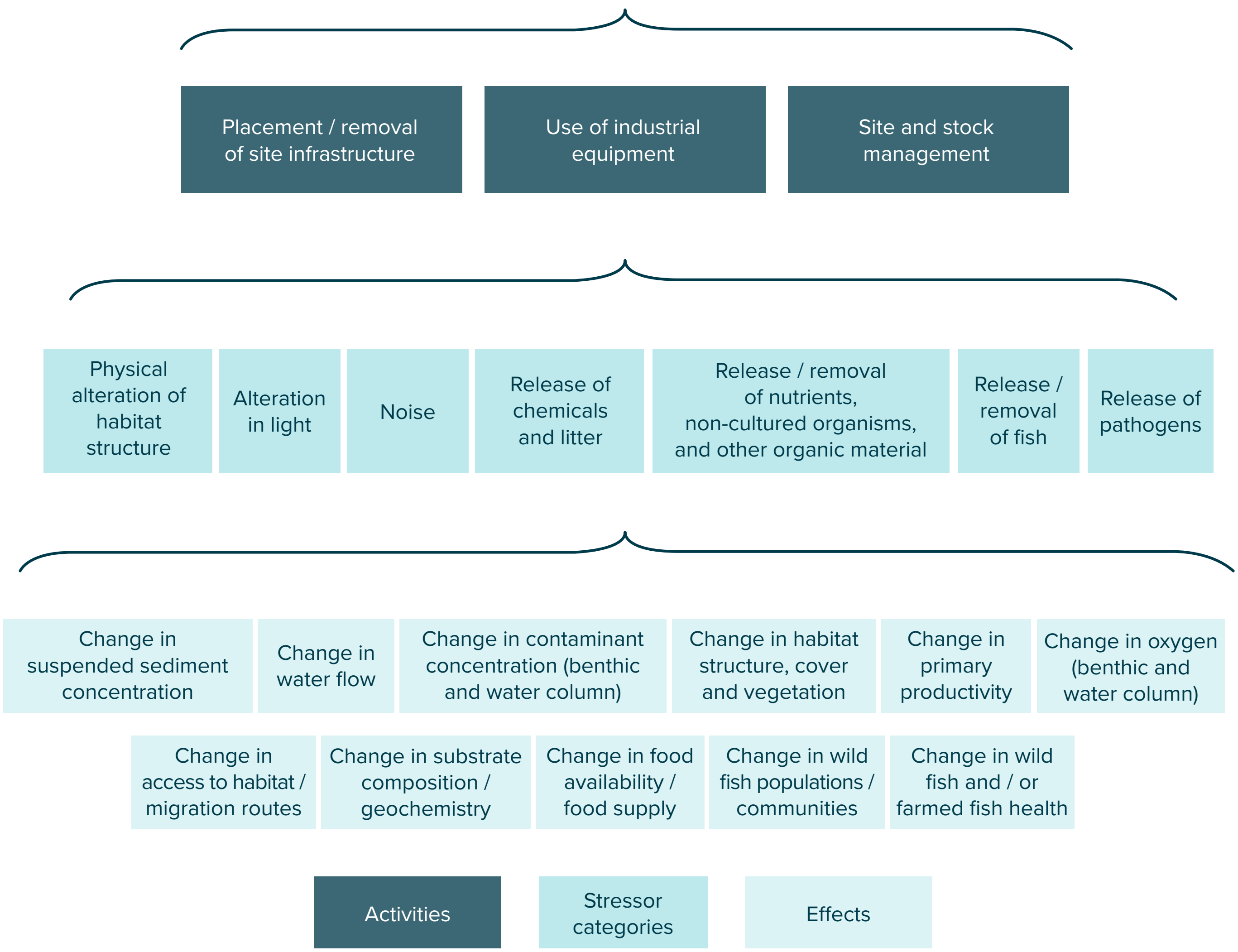


Source: Fisheries and Oceans Canada. Available at: http://www.dfo-mpo.gc.ca/aquaculture/sci-res/aserai-eng.htm.

FIGURE 3:

Aquaculture Pathways of Effects Components:
Activities, Stressor Categories and Effects

AQUACULTURE PATHWAYS OF EFFECTS (POES) COMPONENTS



Source: Fisheries and Oceans Canada. 2009. Pathways of Effects for Finfish and Shellfish Aquaculture Canadian Science Advisory Secretariat Science Advisory Report 2009/071. Available at: http://waves-vagues.dfo-mpo.gc.ca/Library/339745.pdf

DFO's primary internal process for managing the review and dissemination of evidence is coordinated by the Canadian Science Advisory Secretariat (CSAS) http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm. Since the CSAS's inception in 1998, DFO has prepared approximately 130 CSAS reports on specific aquaculture topics. However, the Panel found it difficult to determine how study topics were first prioritized and then chosen, and if and how the resultant studies eventually informed management decision-making. As a result, transparency could be enhanced through a more structured system for responding to CSAS reports.

Recommendation 1:
DFO should implement best practices in synthesizing available scientific evidence on aquaculture risks. This includes incorporation of Indigenous and local knowledge as well as the use of systematic reviews, external peer review and other universally accepted standards.

Methods of evidence validation must be incorporated into science-based decision-making. The use of systematic reviews, expert opinion, structured expert elicitation and evidence weighting are some of the typical methods that can be used to improve the quality of evidence and identify knowledge gaps that need to be addressed. Incorporation of Indigenous and local knowledge should be an integral component of this process.

To help implement this and other recommendations in this report, the Panel deems it necessary for DFO to appoint a Departmental Science Advisor and establish an External Advisory Committee on Aquaculture, with an emphasis on evidence-based methodology expertise, which will provide advice at the highest level of decision-making at DFO.

1.1 Incorporate Indigenous and local knowledge into decision making

The value of Indigenous and local knowledge is increasingly recognized in climate change studies, environmental assessments and wildlife management. DFO has an opportunity, in partnership with Indigenous peoples and local communities, to improve governance of aquaculture management through consideration and incorporation of Indigenous and local people in aquaculture decision-making. This expertise resides within communities and could create a precedent-setting model for aquaculture risk-based decision-making.

1.2 Use systematic reviews

Systematic reviews are a rigorous and transparent form of reviewing existing scientific studies of relevance. They involve identifying, synthesizing and assessing information from all available sources (international and domestic) and evidence, both quantitative (including meta-analysis when appropriate) and qualitative in order to generate an evidence-based answer to a focused question. Originally used in the medical sciences in the 1970s to examine the effectiveness of health-care interventions, they are now being applied in more areas to support the practice of evidence-based decision-making in a number of disciplines (Petticrew, 2001).

Systematic reviews collect and critically analyze multiple research studies or papers by using explicit inclusion and exclusion criteria or by using standard tabulation and study-by-study quality evaluation. **DFO should use systematic reviews as part of its information gathering approach and in assessing the strength and applicability of the evidence.** This will require an investment in the expertise for formal quantitative risk assessment, including meta-analysis methods, within DFO and by collaborating and forging academic relationships to ensure ongoing development of such expertise.

1.3 Establish an external peer review database

External review is conducted to ensure that the evidence used is technically defensible, comprehensive, relevant, properly documented and consistent with established quality criteria. External peer review provides an in-depth assessment of the assumptions, calculations, extrapolations, alternate interpretations, methodology, acceptance criteria and conclusions pertaining to the scientific or technical work product, as well as supporting documentation. To avoid potential and perceived conflict of interest, the evaluations should be conducted by individuals with relevant expertise who have had no involvement with the work being examined (NRC 2009).

To maintain a pool of qualified experts, the department should seek to create an in-house database (pool) of potential high-quality experts in diverse fields such as toxicity and meta-analysis. Such a pool may then be supplemented, as required, by other information sources, such as referrals, literature search, professional societies, universities, other national governments with proven human health and ecosystem risk assessment programs and public calls for experts.

1.4 Solicit expert advice to judge evidence quality and provide knowledge gap proxies

Requesting expert advice is a method for addressing knowledge gaps in cases where scientific data or evidence is sparse, missing or currently unavailable. One structured expert advice method, the “Classical Method” by Cooke (1991), treats expert judgments as statistical data to reduce judgment bias. In Cooke’s method, expert opinion with respect to the target question is weighted according to performance on the seed questions (for which answers are known *a priori*), taking into account both statistical accuracy and uncertainty informativeness of the responses to the seed questions. An important consequence of this performance-based weighting is that the opinions of experts who perform better on seed questions are given greater weight when interpreting expert responses to target questions (for which answers are not known but are important for risk assessment purposes) (Cooke, 1991; Marquart et al., 2012; Boobis et al., 2013).

1.5 Incorporate quality scoring of evidence

Quality scoring of evidence is embedded within the concept of weight of evidence, a common term in the published scientific and policy-making literature, most often seen in the context of risk assessment. In this regard, quality scoring of evidence can provide comprehensive criteria and guidance for evaluations of the inherent quality of data, thus making the decisions taken in the process of assigning different types of evidence to reliability categories more transparent, structured and measured (Lutter et al., 2015; Klimisch et al., 1997).

Recommendation 2:
In consultation with the Departmental Science Advisor, DFO should use best practices to characterize and understand the potential risks and impacts associated with aquaculture.

In order to move towards a risk-based decision-making paradigm, DFO must develop a comprehensive list of relevant risks. This is a primary step in comparative risk assessment and reduction. Additionally, this list of risks should be periodically reviewed. This list will help decision makers so they can plan and conduct the risk assessments and select the most appropriate management strategies. Information on the different types of risk-based decisions and related management approaches can be developed at the problem formulation stage and followed through consistently in the subsequent assessment, evaluation and management stages.

2.1 Update the Aquaculture Pathways of Effects Framework

The existing Aquaculture Pathways of Effects framework is the result of a 2009 science advisory report from DFO's CSAS (Figure 3). It identifies 7 stressors and 11 effects. It is unclear if and how this has been used to inform risk-based decision-making. A first step in identifying potential risks and understanding their impact on the marine environment would be to update this framework using up-to-date knowledge and scientific evidence. Such an exercise needs to follow the best practice elements identified in Recommendation 1.

2.2 Develop performance indicators for use in aquaculture program evaluation

Performance indicators for risk reduction are not clearly linked to inspection tasks and basic science. DFO should first define their management objectives with respect to known environmental risks; determine what performance indicators are most effective as measures of risk and of risk reduction; improve its performance indicators for all risks; and identify thresholds, triggers, acceptable/unacceptable levels and benchmarks. DFO needs to determine what is expected and the anticipated level of risk reduction for any given specific intervention.

2.3 Provide training in formal risk assessment to ensure adequate human resources are available

DFO should identify the required skills and expertise to conduct risk assessments. In addition, future capacity issues may arise from attrition, lack of replacement personnel, loss of institutional knowledge and loss of expertise. To overcome and minimize skills gaps, DFO can be proactive in its ongoing training of existing human resources. Less experienced staff could benefit from specialized training in qualitative and quantitative risk assessment, statistical software packages, cost-benefit and cost-effectiveness analysis, as well as structured group discussions to think critically about how emerging issues may affect aquaculture management.

Recommendation 3:
DFO should use quantitative methodologies and risk-science approaches to develop an Integrated Risk Management Framework (IRMF) that ensures that all relevant factors are properly considered in aquaculture decisions.

An IRMF can be used to promote a continuous, proactive and systematic process to understand, manage and communicate risks in a cohesive and consistent manner. The Integrated Framework for Risk Management and Population Health (Krewski et al., 2007) is an example of this approach that could be used by DFO. The framework is structured to support decision-making, with up-front consideration of a broad array of risk management options. Establishment of an IRMF would also assist DFO in rapidly responding to emerging issues in a transparent manner.

Factors that are not currently addressed in DFO risk management frameworks or evident in decision-making processes include the establishment of risk tolerance levels and triggers for regulatory action. Each would need to be developed with expert guidance for application in the aquaculture context.

Aquaculture-specific criteria and associated metrics would need to be developed. These include the types of harms or adverse outcomes that should be considered, vulnerable risk-bearers (such as specific species and habitat components) and the types of conditions that may lead to an increased risk or severity of these harms. Tiered management strategies could also be developed that could be applied according to the suspected severity of the risk and impact, and used for a limited period. Risk-based decision-making approaches recognize that all hazards need not be inconsequential before decisions are taken. The scientific evidence underlying regulatory decisions should be made explicit and accessible and resulting decisions should be communicated.

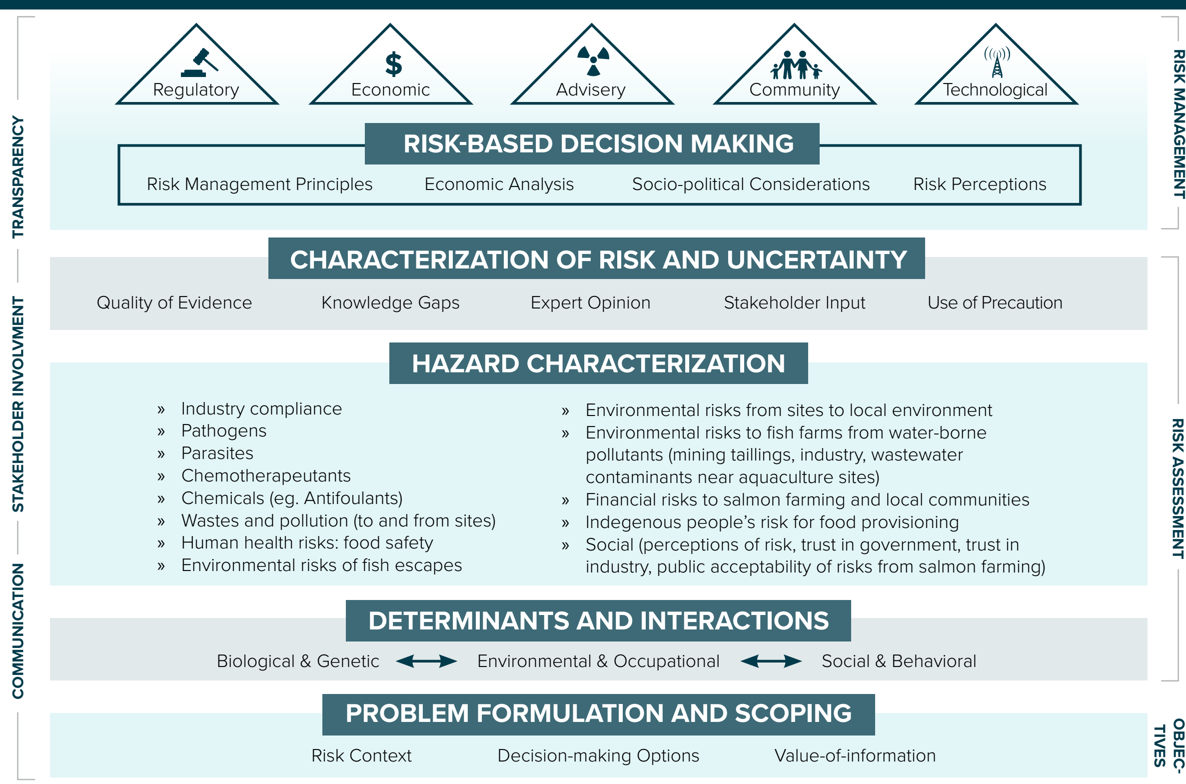
3.1 Establish an Integrated Risk Management Framework (IRMF)

A key element of the IRMF is that a complete assessment of a particular risk factor associated with specific adverse outcome(s) requires consideration of other determinants of those outcome(s) as well as interactions between the risk factor of interest and those determinants. Risk management strategies also consider regulatory, economic, advisory, community-based, ecological or technological factors. The IRMF could also incorporate processes for rapid response to emerging issues and enhance transparency of decision-making. DFO could develop an aquaculture-specific integrated risk management framework as shown in Figure 4 that is similar to the one developed for high-throughput *in vitro* toxicity testing (Krewski et al., 2014).

Such an approach is in line with the *Canadian Impact Assessment Act* (Bill C-69), which mandates an early planning phase that seeks Indigenous and community input and includes assessment of broader potential impacts, including on health, the environment and social-economic conditions. This approach is also perfectly amenable to site/regional focused risk-based decision-making and policy development processes. Moreover, it supports broader stakeholder and community engagement and enhances transparency and accountability.

FIGURE 4:

A Prototypical Integrated Risk Management Framework for Aquaculture Based on a Population Health IRMF Model



Source: Adapted from Krewski D., Hogan V., Turner M.C., Zeman P.L., McDowell I., Edwards N., and Losos J. 2007. An Integrated Framework for Risk Management and Population Health. Human and Ecological Risk Assessment 13: 1288-1312.

B. Advice and recommendations on the priority-setting process for aquaculture science work at Fisheries and Oceans Canada.

Most of the federal government's science and research activities related to aquaculture are carried out, funded or managed by DFO through a set of programs under the Sustainable Aquaculture Program. DFO is engaged in two main types of information provision:

1. the generation of new information through the conduct or funding of research studies, and the collection of information and data through monitoring and other aquaculture management activities carried out by DFO; and,
2. regulatory activities such as inspections, surveys and audits carried out by DFO and by facility operators under their licences.

All research activities address subject matter priorities defined by several key research programs and research plans, whereas the information that is gathered through routine monitoring and regulatory activities is determined by criteria defined by program requirements and regulations.

An ideal priority-setting process for aquaculture science includes one that fills regulatory knowledge gaps, determines thresholds for regulatory action and monitors effectiveness of actions. This process should include proactive consideration of priorities related to a policy framework. Above all, it must be consistent with DFO's overarching mandate with respect to sustainable fisheries (including aquaculture) and ocean protection.

As outlined above, there are three main aquaculture science processes within DFO:

1. The Program for Aquaculture Regulatory Research (PARR): designed to increase scientific knowledge and inform regulatory decision-making and policy development;
2. The Aquaculture Collaborative Research and Development Program (ACRDP): aimed at conducting research that assists the aquaculture sector in improving fish health management and environmental sustainability of aquaculture operations in Canada; and
3. The Aquaculture Ecosystems Interaction Program (AEIP): designed to address knowledge gaps not addressed by the first two programs.

Additionally, in 2017, as part of the Government of Canada's commitment to supporting clean technology, DFO launched the Fisheries and Aquaculture Clean Technology Adoption Program (FACTAP). This program is investing up to $20 million over four years to encourage Canadian fisheries and aquaculture industries to use clean technologies and reduce the environmental impact of its activities. Investments in the science that supports innovations in cleaner aquaculture practices, such as waste water treatment and closed containment technologies, can help protect our environment, while increasing competitiveness and creating jobs for Canadians.

Shellfish lantern nets
Photo credit: Shawn Robinson, DFO

DFO publishes a biannual Canadian Aquaculture Research and Development (R&D) Review listing all the R&D projects in Canada, regardless of whether they are funded by DFO. The latest report from 2017 lists the following DFO programs that support aquaculture review: ACRDP and PARR described above, a "Partnership Fund" of $5 million/year as well as the Genomics Research and Development Initiative (GRDI), which supports use of genomics for aquaculture and wild fishery managements. The National Contaminants Advisory Group (NCAG) is also listed. According to the website (http://www.dfo-mpo.gc.ca/science/environmental-environnement/ncag-gncc/index-eng.html), NCAG engages with scientists from outside of DFO to support research and obtain external expertise in four general priority areas, including aquaculture therapeutants.

The Panel finds that the overall vision of aquaculture science and research objectives at DFO is unclear and that the prioritization processes for these programs are not transparent. For example, it was unclear how and when regional ecosystem issues were considered. Additionally, the process of funding approval appears to be strictly internal and its relation to CSAS reports is not evident. **The articulation of a long-term vision for aquaculture-relevant science with short and longer term objectives is essential.** The identification of potential risks and impacts, and the development of the relevant risk assessments, as suggested in Recommendation 2, should better inform priority setting. Adoption of universally accepted standards of external peer review as provided in Recommendation 1 would strengthen the priority-setting exercise as well as the effective conduct of aquaculture-relevant research at DFO and through collaborations with extramural scientists. **To enhance the priority-setting process for aquaculture, the Panel recommends the following:**

Recommendation 4:
DFO should establish an External Advisory Committee on Aquaculture.

The Panel finds that DFO aquaculture science processes are generally not transparent to either the public or the external science community. The Panel recommends that, with the help of the DFO Science Advisor and/or the Government Chief Science Advisor, DFO establish an External Advisory Committee on Aquaculture. Such an external advisory body could help DFO in identifying research priorities that meets its vision in a transparent manner. It would also provide unbiased advice on the feasibility of research projects and their scientific excellence, build collaborations with external scientists, and assist in the communication of scientific findings. Composed of scientists, the committee could also include representatives from Indigenous and local communities.

Recommendation 5:
DFO should develop a clear overarching scientific vision and a corresponding multi-year research plan with the help of the Departmental Science Advisor and the External Advisory Committee on Aquaculture.

The development of an integrated research plan for aquaculture research would be greatly facilitated by the adoption of an IRMF for aquaculture, per Recommendation 3. Identification of knowledge gaps should inform research priorities with respect to regulatory science and identify areas where technological innovations are most likely to support development of sustainable aquaculture. Such an integrated priority-setting exercise would have clear considerations for regional ecosystems specificities and be prioritized in such a way as to support refinements of DFO risk assessment needs.

As part of this exercise, DFO needs to determine which research activities will be conducted within the department (intramural) and which research objectives are best carried out as collaborations. This will help DFO ensure that its science workforce and research infrastructure can support its science programs.

Recommendation 6:
The External Advisory Committee on Aquaculture should, under the leadership of the Departmental Science Advisor, conduct an external peer review of research plans and priorities.

In keeping with the above recommendations, DFO should consider incorporating external peer review into the normal conduct of its research plan development, funding approval and project evaluation exercises. External peer review offers the added benefit of identifying potential external collaborations and partnerships. The establishment of the External Advisory Committee on Aquaculture will greatly assist in identifying suitable reviewers and collaborators.

Recommendation 7:
The Departmental Science Advisor, with input from the External Advisory Committee on Aquaculture, should establish clear guidelines for DFO science programs that support aquaculture management on the one hand and emerging practices in aquaculture on the other.

DFO conducts regulatory science to support aquaculture management, as well as non-regulatory science focused on improving the competitiveness and sustainability of the Canadian aquaculture industry. This dual role could present perceived or, at times, actual conflict of interest.

While the results of both regulatory and non-regulatory science can inform and support each other, it is good practice to establish program objectives, guidelines, adjudication processes and eligibility criteria specific to each activity. To minimize potential conflict of interest, the Panel recommends that clear guidelines be put in place at the outset that cover the purpose of the research and how it is managed, the contributions of all parties, declarations of conflict of interest, intellectual property rights, and the dissemination of research and scientific findings.

The Panel encourages DFO to develop and apply a conflict of interest framework that upholds the credibility of its regulatory risk assessment, management and communication roles, especially for partnerships and extramural programs.

For all research programs, DFO should publicly disclose research priorities, adjudication processes and the projects ultimately selected to be funded. In keeping with Recommendation 3, the results of DFO research must be made publicly available in a timely manner. In addition, and in keeping with international best practices, DFO should commission extramural evaluations of its research programs on a cyclical basis.

In addressing this recommendation, DFO may find it helpful to consider existing programs and practices at similar international organizations. For example, the aquaculture science and research program at the U.S. National Oceanic and Atmospheric Administration (NOAA) includes the Saltonstall Kennedy Grant Program, the NOAA Small Business Innovation Research Program, the Sea Grant National Aquaculture Initiative and regional aquaculture pilot projects, which all have clear objectives and application processes.

Recommendation 8:
DFO should change the science priority-setting processes to give proper consideration to regional priorities using an integrated ecosystem-based approach.

PARR uses an internal process to identify annual science priorities, which are reviewed collectively by DFO staff from all regions of Canada. This process includes a call for proposals and management reviews to ensure that science feeds directly into national science priorities. The benefit of a national program is that resources can be aligned to scientific expertise, regardless of region, thereby reducing duplication of work. Furthermore, a centralized program allows for enhanced communication among partners and fewer individuals working in silos, enabling scientists to learn from developments in other areas.

Aquaculture management should be anticipatory and forward-thinking, and DFO should plan to conduct the research needed to support future decision-making. DFO should map all activities that impact the marine ecosystem and ecosystem services at a regional/local level to identify science priorities for decision-making. Norway's BarentsWatch (https://www.barentswatch.no/en/) provides a good example of transparency of aquaculture activities that may inform public decisions.

Progress towards program objectives must be reviewed regularly and inform any necessary program adjustment. The results of the research conducted should be made public in a timely manner after appropriate peer review, either in the form of a technical report or a published scientific manuscript. In accordance with international best practices, these publications must clearly indicate the research funding sources.

C. Advice and recommendations on opportunities to improve communication of aquaculture scientific findings and resulting decisions to Canadians.

As the lead federal department for aquaculture, DFO is in a unique position to communicate aquaculture science research findings, how scientific evidence is used to make aquaculture decisions and the decisions themselves. Indeed, DFO must be viewed as a trusted source of aquaculture information as a result of increasing public focus on environmental sustainability, health safety and food security. This may not be an easy task given the fragmented Canadian regulatory landscape. Nonetheless, it is an important responsibility for the public interest in an era of multiple unverified sources of information and conflicting messages that erode public confidence.

An effective communication plan would aim for ongoing community and stakeholder engagement. The adoption of an Integrated Risk Management Framework as per Recommendations 1, 2 and 3 will support such engagement. Proactive communication of evidence and research results in summary format accessible to non-expert audiences is critical and helps to enhance science literacy and understanding. Lastly, but no less important, adoption of an open science framework including Recommendations 5, 6 and 7 is key to building public trust and improving communication of scientific findings with experts and the general public.

These three considerations (effective communication, proactive communication and an open science framework) must be at the heart of a harmonized aquaculture science communication plan that uses all available modern tools to communicate effectively with diverse stakeholder groups. To achieve these objectives, bold improvements to the DFO communication strategy may need to be considered. The Panel offers the following specific recommendations.

East Coast Aquaculture Site
Photo credit: DFO

Recommendation 9:
DFO should develop a communication plan to proactively communicate aquaculture science. Such a plan must include a revamp of its aquaculture website.

As a key vehicle for information sharing, the DFO aquaculture website needs to be redesigned in such a way as to allow easy access to information on aquaculture science, scientific publications and information on science-related activities at DFO. The Panel found it challenging at times to retrieve information on existing science reports, research programs or research findings. Creating a single portal for aquaculture organized according to the target audience would be an important step. Audience categories could include consumers, the general public, scientists and industry. Such an approach would allow information on scientific findings, scientific uncertainties and science-informed decisions to be communicated at the appropriate level. A "frequently asked questions" feature should be incorporated with searchable themes and easy-to-understand responses. The portal would include information on upcoming public consultations and public events, as well as links to other relevant and trusted sources of information.

Recognizing that science priorities reflect regulatory responsibilities, which are interjurisdictional, there may be a need for DFO to clearly communicate its authority and to develop communication strategies at the regional level. This should include identifying needs of all audiences and recognizing that, for aquaculture, there may not be a one-size-fits-all communications and engagement approach. For decisions of significant public interest, DFO should consider alternative communication media beyond the web, such as townhall meetings, technical briefings, symposia and public meetings.

The development and roll-out of a proactive communication plan would require dedicated expert staff in science communication and public outreach combined with a close interaction with DFO scientists. The communication plan must include a scheme for ongoing monitoring and evaluation to ensure relevance and effectiveness in meeting stated goals.

Recommendation 10:
DFO should adopt and implement an open science framework for aquaculture and develop strategic alliances in science communication and outreach.

Open science helps build public trust, support multidisciplinary and multi-sectoral collaborations and stimulates innovation. DFO routinely conducts scientific research, monitoring and knowledge synthesis activities that inform decision-making through its own funding and partnerships. Consistent with earlier recommendations, information on these activities and their outcomes should be readily accessible on the DFO aquaculture portal. The information would include science prioritization and science advice. A comprehensive list of research projects under each program and the resulting publications must be readily accessible. A lay summary of each publication, including CSAS reports, conference proceedings and advisory notes, would greatly improve public access to DFO's scientific activities. **The development of an open science strategy is an opportunity to improve communication of aquaculture science findings to Canadians and could position DFO as a leader in science communication.**

DFO science communication activities can achieve the dual goal of informing citizens while contributing to broad science education objectives. Drawing on best practices and successes in other science intensive fields with inherent uncertainties (such as human health) might offer interesting opportunities. This could include partnerships with the Science Media Center of Canada and the Canada Science and Technology Museum, major aquaria and other natural history museums. Such strategic alliances will reach Canadians beyond those who sign up for DFO social media outlets and make aquaculture science information available in publicly accessible places.

V. CONCLUSION

The decision-making process for aquaculture is fragmented in Canada by jurisdictions and federal departments. Nonetheless, providing science advice is a pan-Canadian responsibility for DFO and, therefore, science advice is a means to support all jurisdictions in their regulatory deliberations.

Challenges and opportunities vary on our three coasts and depend on the species farmed, the local environment and other local activities. By embracing a systematic, integrated ecosystem approach and best practices for risk-based decision-making, DFO has the opportunity to develop a multi-year research plan that would benefit from the advice and scrutiny of external experts. Such a plan would consider regulatory priorities and emerging practices in aquaculture separately, recognizing the importance of innovation to mitigate risks and ecological aquaculture impacts. Greater ongoing stakeholder engagement in the context of an open science process would enhance public trust and scientific understanding.

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