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Is scientific inquiry *still* incompatible with government information control? A quarter-century later

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Abstract

Twenty-six years ago, in response to regionally devastating fisheries collapses in Canada, Hutchings et al. asked *"Is scientific inquiry incompatible with government information control?"* Now, a quarter-century later, we review how government science advice continues to be influenced by non-science interests, particularly those with a financial stake in the outcome of the advice. We use the example of salmon aquaculture in British Columbia, Canada, to demonstrate how science advice from Fisheries and Oceans Canada (DFO) can fail to be impartial, evidence-based, transparent, and independently reviewed—four widely implemented standards of robust science advice. Consequently, DFO's policies are not always supported by the best available science. These observations are particularly important in the context of DFO having struggled to sustainably manage Canada's marine resources, creating socio-economic uncertainty and putting the country's international reputation at risk as it lags behind its peers. We conclude by reiterating Hutchings et al.'s unheeded recommendation for a truly independent fisheries-science advisory body in Canada to be enshrined in the decision-making process.

Key words: DFO, Canadian Science Advisory Secretariat, science advice, regulatory capture, salmon aquaculture, Pacific salmon

Introduction

Industrial-scale human activities have long impacted marine ecosystems and the species they sustain (Occhipinti-Ambrogi 2007; Poloczanska et al. 2016; Williams et al. 2016; O'Hara et al. 2021), contributing to widespread declines in marine species (Airoldi et al. 2008; Penn and Deutsch 2022) and a global depletion of marine biodiversity (Sala and Knowlton 2006). If the ocean is to sustain ecosystem function and human livelihoods (Halpern et al. 2012), mitigation and reversal of anthropogenic impacts on the marine environment must be prioritized (Gelcich et al. 2014; Friedman et al. 2020). Scientific insight and the resulting science advice to decision-makers will play an important role in these processes.

In Canada, the bulk of government responsibility to study, manage, and conserve ocean habitats, ecosystems, and fisheries—and to provide associated science advice to decision-makers—falls to the federal department of Fisheries and Oceans Canada (DFO) (Supplementary data, pp. 1–6). For commercially targeted species, DFO considers just over half of stocks with assigned status to be "healthy," but many stocks remain data poor, and the number of stocks at "critical" status has increased in recent years (Fisheries and Oceans Canada 2020; Environment and Climate Change Canada 2022). In two high-profile examples, numerous Pacific salmon (Oncorhynchus spp.) populations are at historically low abundances (Peterman and Dorner 2012; Riddell et al. 2013; Bendriem et al. 2019; COSEWIC 2019), and Canada's Atlantic cod (Gadus morhua) stocks remain in a "critical" state (Fisheries and Oceans Canada 2020). Science advice is integral to DFO's role, but the provision of Canadian fisheries-science advice is challenging, due not only to the diversity and large geographic scale of Canada's ocean environments, but also to the pitfalls inherent in providing science advice.

Hallmarks of robust science advice

Although science can play an important role in the mitigation and reversal of anthropogenic stresses by supplying evidence for policy decisions, competing interests and ideologies can impede the delivery of robust science advice and its integration into government policy decisions. In particular, individuals or groups with vested interests can manipulate the science-policy process through the "disinformation playbook" (Reed et al. 2021)—a collection of strategies that downplay and obscure risk by seeding doubt about scien-

tific consensus (Freudenburg et al. 2008). These tactics can be used to discount the connections between negative health or environmental outcomes and their corporate or industrial causes, at times resulting in regulatory capture, a "process by which regulation… is consistently or repeatedly directed away from the public interest and toward the interests of the regulated industry, by the intent and action of the industry itself" (Carpenter and Moss 2013). Examples of regulatory capture exist in relation to cancers from tobacco use, bird-population declines from dichlorodiphenyltrichloroethane (DDT), ozone-layer depletion from chlorofluorocarbons, and climate change from greenhouse gas emissions (Oreskes and Conway 2010; Anker et al. 2011).

Reassuringly, governments commonly seek to incorporate evidence and scientific findings to strengthen policy and better inform decision-making. A flagship example, the Intergovernmental Panel on Climate Change (IPCC), provides policymakers with regular assessments of the scientific basis for climate change, its impacts and future risks, and options for adaptation and mitigation (Masson-Delmotte et al. 2021). The International Union for the Conservation of Nature (IUCN) assesses the global extinction risks for animal, fungal, and plant species (IUCN Red List 2022). In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Waples et al. 2013) provides species threat-status assessments whose quality and independence are internationally recognized (Waples et al. 2013). Recently, to inform their responses to the COVID-19 pandemic, many national governments drew on science advisory bodies, such as the National Advisory Committee on Immunization (NACI) in Canada (Macdonald and Pickering 2009; Ismail et al. 2010). Such independent bodies enjoy broad legitimacy because they tend to exhibit the hallmarks of robust science advice (Box 1).

Although relying primarily on scientific evidence for decision-making might seem like the obvious way to directly realize the benefits of society's considerable investments in science, scientific understanding is of course not the only factor that reasonably influences decisions. Elected officials and other decision-makers must often balance multiple sets of competing demands, including those of an economic, social, political, or legal nature. In the context of these multiple demands on decision-makers, however, processes that produce the best possible science advice can ensure that *scientific* considerations inform decisions as effectively as possible (Brownson et al. 2006). While we acknowledge the importance of the multiple competing and complementary considerations facing policymakers, we have restricted our review and commentary to *science*-advice processes. We also note that western science has clear limitations. In particular, science-based management often "struggles to recognise and incorporate place-based observations, objectives, and values" (Gayeski et al. 2018; Silver et al. 2022). In this respect, Traditional Knowledge (Reid et al. 2022) is increasingly recognised as an important part of decision-making (Wheeler and Root-Bernstein 2020; Reid et al. 2021). Deciding how decision-makers incorporate Traditional Knowledge in policy decisions should involve the people affected and is beyond both the scope of this paper and our expertise as authors.

To be of greatest utility, science advice to governments should meet several standards (Gluckman 2014; Hutchings and Stenseth 2016), which we consolidate into four "hallmarks" of robust science advice (Box 1). Firstly, science advice must be **impartial**, lacking vested interests in the outcomes of policy- or management-based decisions. Secondly, science advice must be **evidence-based,** formed from the best-available scientific information. Thirdly, science advice must be **transparent**, both in its availability to the public and in its disclosure of methods, conflicts, and funding. Lastly, science advice must be **independently reviewed**, helping to ensure its quality while underpinning the confidence that decision-makers and the public can have in it.

Science advice for Canadian oceans

Lapses in these four hallmarks of science advice have been at the core of critiques of Canada's ability to fulfill national and international obligations to conserve biodiversity, use marine resources sustainably, develop an environmentally responsible aquaculture sector, and manage fisheries in a precautionary manner (Hutchings et al. 2012*a*; Office of the Auditor General of Canada 2016; The Independent Expert Panel on Aquaculture Science 2018; Winter and Hutchings 2020; Standing Committee on Fisheries and Oceans 2023).

One of the first of these critiques asked rhetorically: Is scientific inquiry incompatible with government information control (Hutchings et al. 1997)? The authors argued that the framework of government-administered science, and the near absence of independent peer review that existed in the 1980s and early 1990s, facilitated interference in the communication of science by non-science interests within DFO. The arguments were based empirically on two examples of clashing vested interests: (1) alterations to habitat of Pacific salmon resulting from industrial damage and (2) the collapse of Grand Banks Atlantic cod (*Gadus morhua*) populations due to overfishing. Hutchings et al. (1997) laid out how efforts by the Canadian government to conserve marine biodiversity, rebuild depleted fish populations, and sustain marine fisheries were not always strengthened by the best possible science. Instead, DFO's science-advice processes could be influenced by "the perceived need to balance scientific concerns with the sociopolitical constraints imposed on the decision-making process by a government bureaucracy." The authors state that "political and bureaucratic interference in government fisheries science [compromised] the DFO's efforts to sustain fish stocks and, thereby, the socioeconomic well-being of fishing people and fishing communities." Regarding such failure to sustain "viable fish resources[,]… fishing people and fishing communities" Hutchings et al. concluded that "the economic and societal cost of this failure to Canada has been enormous."

A quarter-century after Hutchings et al. (1997) made their case, a re-examination of the science advice within DFO seems warranted. While the conduct and integration of science advice within DFO has changed over the intervening decades, the core recommendation of Hutchings et al. has gone unheeded; a "politically independent organization of fisheries scientists" to provide science advice for manage-

Box 1. Hallmarks of robust science advice.

Hallmark No. 1—Impartial

To safeguard the integrity of science advice from vested interests, advisors should have no stake in the outcome (although this is unrealistic when taken to the extreme, since, for example, we all have a vested interest in the perpetuation of life on earth). Objectivity, while arguably serving as a laudable ideal, has been repeatedly discredited as unattainable in reality due to humans' inherent subjectivity (Daston and Galison 2021; Reid et al. 2021). Nevertheless, a body seeking to provide impartial advice can draw on multiple perspectives to help counteract or account for individual biases (Hales 2010). Science advice cannot be tied to a specific outcome and those who purport to provide impartial advice but do so to increase the probability of realizing a particular outcome play the role of advocates, not advisors (Pielke and Jr 2007; Rice 2011; Hutchings and Stenseth 2016). Funding sources (e.g., non-governmental organisations, industry, etc.) can also influence research findings; industry-supported research, for instance, displays a tendency towards pro-industry results (Bhandari et al. 2004; Sismondo 2008; Lundh et al. 2017). Explicit disclosure of funding sources can help pressure authors to consider their biases and, critically, encourages circumspection on the part of readers. Along these lines, while industry advisors may serve a valuable role in providing industry context or data, any science-advice process that includes roles for vested interests as authors or reviewers should receive careful scrutiny.

Hallmark No. 2—Evidence-based

Empirical evidence—i.e., information obtained through reproducible observation or experimentation—is the backbone of contemporary science. Use of evidence-based practice and policy has become the gold standard for decision-making (Parkhurst 2017), especially in the medical field, where its widespread application has saved countless lives (Ford et al. 2007; Djulbegovic and Guyatt 2017). By definition, science advice must not be affected by non-science influences (Hutchings et al. 1997). While social, political, and economic considerations play a role in decision-making, these should not influence the contents of the science advice that decision-makers receive (OECD 2015). Science advice must be continually updated with the most recent knowledge and must also be drawn from a variety of sources, not just those that were published by the individual or organization providing the advice, or those that support organizational stances or regimes (Parkhurst 2017; Hutchings 2022). Finally, an absence of evidence cannot be used to justify science advice that is not precautionary in nature (Fisher 2002) (Supplementary data, pp. 7–9).

Hallmark No. 3—Transparent

Transparency is a metaphor used to describe the concept of making information and processes more visible (Elliott 2021). It is commonly associated with the open-science movement, which aims to increase the reproducibility and credibility of science (Nosek et al. 2015; Elliott 2020). Here, we use transparency as an umbrella term to describe several key aspects of science communication (e.g., access to data, disclosure of both negative and positive results, declaration of conflicts of interest, and funding) and reproducibility (e.g., clear explanation of methods and provision of computer code required for analysis) that remove barriers to understanding and assessing the quality of science advice (Elliott 2020). Transparent science advice enables external scrutiny of the science and cultivates confidence from the public and policymakers, which can result in improvements to management policies and sustainability (Mora et al. 2009; Artelle et al. 2018). Equally important to the evidentiary basis of science advice are the communication of uncertainty and accurate description of where there is scientific consensus and where there is not. Points of disagreement indicate where more evidence should be collected and potential for bias reviewed, and where any associated response or policy should be precautionary in the interim. Policymakers benefit from science advice that embraces open scientific debate, gaining a better understanding of the strengths and limitations of the science used to inform policy, in contrast with science advice from only select "trusted" perspectives (Nguyen et al. 2018).

Hallmark No. 4—Independently reviewed

To ensure that science advice does not reflect "unwarranted claims, unacceptable interpretations, or personal views," it needs to be reviewed independently from the body seeking advice (Kelly et al. 2014). We propose that the review of evidence for government science advice should emulate many of the same peer-review standards that have been refined in the world of scientific publishing, where the process shares several key features among fields and publications. We do not suggest that the peer-review process is perfect—improvements and changes will no doubt continue to be implemented—but key elements have long served the scientific community well and are worth emulating. For example, the review process is typically overseen by an independent editor, who solicits reviews from researchers with expertise in the subject of the work (the "reviewers"). The reviewers are expected to be transparent about any conflicts of interest that affect them, and engaging multiple reviewers helps to balance any individual biases. The reviewers' feedback is relayed to the authors via the editor, and this process can repeat several times until the article is either accepted for publication or—should it fail to meet the required standard—rejected. For peer review to reliably assess the quality of research, whether in scientific publishing or for government science advice, reviewers must be independent and external from any focal party that may wish to "tip the scales" (Hames 2008).

ment still does not exist. Indeed, no such body has existed since 1979, when the Fisheries Research Board of Canada was dissolved shortly after DFO's inception, effectively bringing Canadian fisheries science advice under the auspices of a government body prone to political influence.

Canada now lags behind other jurisdictions that have established arms-length, independent councils to provide science advice (e.g., ICES in Europe) (Winter and Hutchings 2020) or that are bound to follow advice from scientific committees (e.g., via the Magnuson-Stevens Act in the USA). Over the last 25 years, DFO has, for its part, built up a series of internal structures for assessing and providing fisheries-related science advice. Top among these is the Canadian Science Advisory Secretariat (CSAS), a body formed in the same year as the original publication by Hutchings et al. (1997), and which serves as the basis for DFO's assertion that its science advice is externally peer reviewed (Box 2). As we describe below, however, the CSAS process lacks independence from political pressures within DFO and has several features that can preclude meaningful peer review.

Here, we use salmon aquaculture in British Columbia (BC) as a case study of how government systems and structures are susceptible to individual, political, and bureaucratic influences, which can inhibit the science-advice process and result in outputs that do not bear the four hallmarks of robust science advice. The BC salmon aquaculture case represents a failure of the Department's attempts to ensure the "quality, integrity and objectivity" of its science advice (Supplementary data, pp. 10–15). While this case study should not be directly extrapolated to other topics handled by DFO, it does reveal systemic weaknesses in DFO science-advice processes that, under certain conditions, can evidently preclude high-quality science advice from reaching decision-makers.

Although some of the examples we raise deal with interactions among individuals, our intention is not to criticise any individual's actions or inactions, but instead to evaluate organisational failings and the system that has generated them. It is the *system* that should be designed to mitigate against human weaknesses, to which neither we as authors nor anyone else is immune. Further, our critique is not focussed on the science from individual DFO scientists, but rather the quality of the *science advice* to decision-makers that emerges from the Department. Naturally, scientists are involved in producing that advice, and we identify several ostensible cases of policy advocacy by scientists themselves, which we expose to illustrate structural weaknesses rather than personal shortcomings per se.

We highlight vulnerabilities in DFO's science-advice framework, in which official science advice from DFO can still be narrative-driven rather than evidence-based, risking not only the health of fisheries and ecosystems but also Canada's international reputation. In concluding, we also note examples where others have identified similar failings within DFO, either systemic or with respect to particular topics outside of aquaculture. Ultimately, we reiterate the recommendation, made by Hutchings et al. a quarter-century ago, for a truly independent fisheries-science advisory body in Canada to be enshrined in the decision-making process.

Salmon aquaculture case study

Background

Salmon aquaculture has had a turbulent history in Canada, particularly on the Pacific coast, where non-native Atlantic salmon comprises 89% of aquaculture production by quantity and 95% by value (FAO Fisheries and Aquaculture 2022). The controversy on the Pacific coast—where the industry is regulated federally, by DFO, rather than provincially, as in Atlantic Canada—is largely due to the amplification of disease and its transmission from farmed to wild salmon, a concern for salmon farming globally (Garseth et al. 2013; Krkošek 2017; Kibenge 2019; Mordecai et al. 2021). The Pacific coast of Canada is perhaps the only region in the world where salmon farming was developed alongside abundant, viable wild salmon stocks (FAO Fisheries and Aquaculture 2022). In this context, widespread declines of many wild Pacific salmon populations (Peterman and Dorner 2012; Riddell et al. 2013; Bendriem et al. 2019, 2019), in parallel with growing evidence of the ecological effects of salmon farms, have eroded the social license for the industry to operate (Wiber et al. 2021; Reid et al. 2022). Much of this scientific and social attention has focussed on salmon farms acting as incubators and reservoirs for parasitic sea lice that transfer to wild juvenile salmon (Krkošek et al. 2005). Considered a benign parasite on adult salmon, sea lice negatively affect the physiology (Jakob et al. 2013; Long et al. 2019*a*), behaviour (Mages and Dill 2010; Krkošek et al. 2011*a*; Peacock et al. 2015), and survival (Krkosek et al. 2006; Jones and Hargreaves 2009) of juvenile salmon, and have been associated with population-level declines in wild Pacific salmon (Connors et al. 2010; Krkošek et al. 2011*b*; Peacock et al. 2013). While research and management have largely focussed on sea lice for the past two decades, there is increasing evidence of impacts from other farm-transmitted infectious agents on wild salmon. For instance, *Piscine orthoreovirus* and *Tenacibaculum maritimum* (among other pathogens) are exceedingly common in farmed salmon populations (Bateman et al. 2021), are transmitted to wild salmon (Bateman et al. 2021; Mordecai et al. 2021), cause or are associated with disease (depending on strain and species; Di Cicco et al. 2018; Santos et al. 2019), and are associated with negative population-level effects for some wild salmon (Bass et al. 2022).

The quality of DFO's science advice on salmon farming in BC is particularly important in the context of growing evidence that (due to multiple causes) wild salmon are not thriving (Peterman and Dorner 2012; Riddell et al. 2013; Bendriem et al. 2019; COSEWIC 2019), and has repeatedly been a cause for concern among scientists, nongovernmental organisations, Indigenous groups, and even government bodies (Proboszcz 2018; Standing Committee on Fisheries and Oceans 2021*a*). Compared to wild-capture fisheries, aquaculture is more susceptible to decision-making that negatively affects conservation, since its success is not directly linked to the health of local ocean ecosystems (Cohen 2012). Indeed, multiple independent national reports from within the federal government have been critical of DFO's science advice on salmon aquaculture and the absence of appropriate research

Box 2. The Canadian Science Advisory Secretariat (CSAS) peer review process.

Since 1997, CSAS has been the body through which DFO provides peer-reviewed science advice to policy and decision-makers within DFO (Supplementary data, pp. 10–15). Guided by the Canadian government's SAGE principles, the CSAS process aims to "review and synthesize data, methods and results of scientific studies and prepare consensus advice based on the conclusions" (Supplementary data, pp. 10–15, Supplementary data, pp. 432–486).

Once science advice on a given topic is sought by managers or senior officials within DFO, a responsible group of managers and scientists is convened, and the CSAS peer-review process is invoked if that group selects CSAS review as the most appropriate course of action. The CSAS office identifies a DFO manager to oversee the process, including setting the terms of reference (Supplementary data, pp. 432–486), choosing the scientists who will contribute, and selecting the group of reviewers. DFO staff, contractors, and collaborators then compile one or more scientific background documents along with a draft science advice document. These documents may be sent for formal unblinded written review by two external experts selected by DFO (Supplementary data, pp. 487–493) before the CSAS process culminates in an in-person meeting, which brings together the report authors, the "formal" reviewers, and a substantial group of invited experts to collectively review the compiled background document(s) and sign off on scientific "consensus" advice to decision-makers. There is no requirement for CSAS meeting participants to be external or independent; in fact, they are often chosen from within the Department or from organisations with vested interests in the outcome of the CSAS process.

Industry bodies and industry advocates tend to defend the robustness of the CSAS process (Atlantic Groundfish Council 2022; Farrell et al. 2022; Fisheries Council of Canada 2022) and call for status quo, whilst environmental organizations and First Nations organizations have repeatedly advocated for reform, highlighting the inclusion of vested interests in the process and the disconnect between DFO's claimed CSAS outcomes of "sound science advice" and "rigorous peer review" (Supplementary data, pp. 10–15) and what occurs in practice (Central Coast Indigenous Resource Alliance 2022).

DFO recently acknowledged the criticisms concerning the participation of some CSAS reviewers (Supplementary data, pp. 432–486) and, in response, developed a conflict of interest policy, released in July 2021 (Supplementary data, pp. 494–499), 24 years after the inception of CSAS. The policy states that participants with a conflict of interest can participate so long as "they agree to be objective," despite an internal review stressing that "external stakeholders cannot be expected to act completely impartially as they are… likely to have a vested interest in the outcome of the science advice" (Supplementary data, pp. 494–499). The current CSAS approach to addressing conflicts of interest may breach certain corporate employees' fiduciary duties to shareholders and is at odds with that of other Canadian science advisory bodies (e.g., the NACI; Macdonald and Pickering 2009; Ismail et al. 2010). In the case of NACI, the committee is currently comprised of government public health professionals and university professors (NACI 2022), who are required to state any potential conflicting associations or interests (see *Hallmark No. 1—Impartial* section), but none of whom work directly for the pharmaceutical companies producing vaccines under discussion.

While the CSAS peer-review process can function well at the best of times, it is on highly contentious topics that science advice most needs to stand up to scrutiny, and where a lack of the hallmarks of robust science advice in the CSAS process has become most apparent. The issues arise before any scientific compilation by DFO staff or peer review begins, as senior managers within DFO have a hand both in setting the specific questions to be asked—or not asked—and in determining how those questions are answered (e.g., Supplementary data, p. 500).

Even as scientific information is compiled and advice is drafted, CSAS authors have at times requested the removal of specific questions that have major regulatory implications. For instance, an author (from the DFO Aquatic Animal Health Section) requested that a 2015 CSAS review, concerning the potential impacts of transferring PRV positive fish into the marine environment, ignore the question of whether PRV causes disease (Supplementary data, pp. 501–503)—an omission that could have resulted in the infectious agent being subject to far fewer constraints under Canadian fisheries regulations (Federal Laws of Canada 2018). Remaining officially unaware of inconvenient information about pathogenicity might greatly simplify management of aquaculture activities. As Upton Sinclair famously wrote, "[i]t is difficult to get a man to understand something when his salary depends on his not understanding it" (Sinclair 1935).

The CSAS review process culminates in a peer-review meeting and production of a Science Advisory Report (SAR), for use by decision-makers. The meeting can deviate from accepted norms of scientific peer review. Internal departmental processes select the meeting chair and reviewers (e.g., Mimeault et al. 2020) analogous to authors of a scientific manuscript being given the ability to choose their handling editor and reviewers. Further, the complement of attendees can affect the outcome of peer review. Since the final science advice, in the form of a SAR, is based on consensus—rather than being carefully balanced by an impartial editor, as in the case of peer review at a scientific journal—groups of participants associated with special interest groups (e.g., the salmon aquaculture industry) can sway opinion or veto inconvenient findings. Many scientific results or theories that are now taken for granted were slow to be universally accepted, and the CSAS policy to only include consensus advice poses the real risk of omitting insight into the most controversial scientific topics, which may be of great relevance to decision-makers. Consider Galileo's heretical assertion that the sun is the centre of our solar system.

Issues with the CSAS peer-review process continue after the meeting itself. Participants are also instructed to "refrain [after the meeting] from re-opening disagreements that were aired and resolved during the peer review meeting, or from raising new areas of disagreements," a policy seemingly at odds with the SAGE principal to review new information as it comes to light (Supplementary data, pp. 487–493, Supplementary data, pp. 432–486). The CSAS process has also been criticized for failing to publish, or not meeting self-imposed publication deadlines, compromising the transparency of the peer-review process (Proboszcz 2018; Archibald et al. 2021).

to inform decision-making (Office of the Auditor General of Canada 2018; The Independent Expert Panel on Aquaculture Science 2018). After chairing the federal inquiry into the 2009 collapse of Fraser River sockeye salmon, Justice Bruce Cohen recommended splitting DFO's "dual mandate" to both protect wild salmon and promote salmon farming (Cohen 2012). In 2018, the Office of the Auditor General of Canada found that DFO "was not monitoring wild fish health," had not "defined how it would manage aquaculture in a precautionary manner in the face of scientific uncertainty," and was "vulnerable to claims that it prioritized the development of the aquaculture industry over the protection of wild fish" (Office of the Auditor General of Canada 2018). These criticisms stand despite DFO's commitment to prioritise the conservation of wild salmon under Canada's Wild Salmon Policy, developed through 5 years of public consultations (Fisheries And Oceans Canada 2005).

Below, we present details of the BC salmon aquaculture case study to highlight how processes within DFO fail to produce science advice that bears the four hallmarks described above (Box 1).

1) Impartial

DFO science advice has been repeatedly criticized for failing to be impartial and free of influence from vested interests (Cohen 2012; Office of the Auditor General of Canada 2018). At the heart of this issue is the dual mandate of DFO: the industry mandate to "support aquaculture development" and the public-interest mandate of protecting wild salmon (Supplementary data, pp. 1–6, 16–51) (Cohen 2012). These conflicting mandates can place scientists and aquaculture staff at odds over scientific findings that directly contravene the policy framework of DFO.

DFO has a policy on science integrity, which attempts to ensure that "any research or scientific products … are free from political, commercial, client and stakeholder interference" and that any conflict of interest is "explicitly recognized, reported and appropriately managed" (Supplementary data, pp. 52–79). Nonetheless, for some, the close relationships between members of the salmon aquaculture industry and DFO personnel raise concerns that these standards of impartiality are not being met. For example, the former Director of DFO's Aquaculture, Biotechnology, and Aquatic Animal Health Science Branch was previously the President of the Aquaculture Association of Canada (Supplementary data, pp. 80–82), an organisation with the objective to "promote, support, and encourage… [the] advancement of aquaculture in Canada" (Supplementary data, p. 83). Similarly, the former Director of the Pacific Biological Station and Head of Aquaculture for DFO later served as Chair of the Science Advisory Council for the BC Salmon Farmers Association, by which he was described as "a strong advocate for the aquaculture industry in BC" (Supplementary data, pp. 84–85). These are just two examples among many. As in other industries (Timoney 2021), the "revolving door" of personnel between industry and its regulator raises obvious questions about the impartiality of DFO employees charged with regulating an industry to safeguard wild fish populations.

A related issue is the frequency with which funding from the salmon aquaculture industry supports research used for DFO's science advice. While not invalidating research findings, industry-funded studies demand increased scrutiny. A large proportion of the aquaculture-related research conducted by DFO has been partly funded by the salmon farming industry (e.g., through the Aquaculture Collaborative Research and Development Program; ACRDP). Industry-funding scenarios have clear implications for impartiality of research and reported research outcomes (Bhandari et al. 2004; Sismondo 2008; Mandrioli et al. 2016; Lundh et al. 2017; Soskolne et al. 2021), but DFO states that the ACRDP "does not involve real, apparent or potential conflict of interests" due to a technical review process and all aquaculture companies having access to the funding source (Supplementary data, pp. 86–103). The research within DFO that is funded or co-authored by the salmon-farming industry has often painted the activities of the industry in a positive light or as posing low risk (Beamish et al. 2005; Dill et al. 2009; Siah et al. 2015, 2020; Garver et al. 2016; Zhang et al. 2019*a*; Polinski et al. 2021)(Supplementary data, pp. 104–106). In contrast, information that may compromise the industry has been downplayed (media reports: Gillis 2018; Binks-Collier 2021). DFO scientists have reported that industry-funded research uncovering "inconvenient truths" is not published, and that the industry's role in science is a de facto form of lobbying that aims to control messaging (media report: Fife and Chase 2020).

DFO's accountability to industry was once again brought to light in 2022 when a prominent DFO research scientist testified in front of a parliamentary committee that DFO's ability to conduct robust, transparent evidence-based risk assessments on aquaculture–wild interactions was compromised by a lack of independence from industry (Standing Committee on Fisheries and Oceans 2021*b*). Examples of the Department's processes for developing salmon-farm regulations, while not examples of science advice, further call industry influence into question. A recent letter to DFO from MOWI Canada West, the largest salmon-farming company in BC, stated that proposed changes to the 2022 conditions of license would have a "significant impact" on the "financial performance of MOWI's operations" and that "regulatory change is outpacing [the] company's capacity" (Supplementary data, pp. 107–108). When DFO subsequently circulated the draft updated conditions of license, the proposed monitoring and treatment requirements for sea lice were less precautionary than previous versions (Supplementary data, pp. 109–120 [old version], pp. 121–131 [draft new version]). The Department's particular motivations cannot be known from the outside; however, it seemingly was not until a freedom of information request revealed these developments—and the public pushed back against them—that the changes were reverted (Supplementary data, pp. 132–143). A similar situation occurred in 2020, when DFO managers recommended that the Minister should not implement a total (rather than average) sea-louse threshold on farms, noting such a change would result in "an unhappy industry" (Supplementary data, pp. 144–147). Together, these examples illustrate how DFO's regulation of aquaculture is not independent of industry and raises con-

cerns about the associated science advice (which often involves some of the same DFO employees). Such signs of regulatory capture erode public trust in government decisions (Carpenter and Moss 2013) and call into question the neutrality of the Department.

While impartiality can clearly be compromised by industrial interests, impartiality of any advice body is not solely achieved by having the right balance of participants. Impartiality also requires the relevant process to embody fairness. For instance, the manner in which a regulatory body sets up an inquiry can manipulate what evidence is placed before decision-makers (Supplementary data, pp. 148–153), and the scope of science advice has at times been restricted to a certain geographic region or species (see Subsection No. 4, where these issues are discussed in more detail). Impartial scientific inquiry must be informed by and pursue the questions emerging from new scientific evidence, unfettered by political or economic considerations.

2) Evidence-based

DFO's dual mandate has repeatedly raised the question: what should the Department do with evidence that salmon farms harm wild salmon? The associated internal-to-DFO struggles have seemed at times to result in economic interests trumping scientific evidence within the advisory process itself, thus allowing non-science considerations to contaminate DFO's science advice. As a result, DFO has repeatedly been caught suppressing evidence, preventing its scientists from publicly commenting on their science, ignoring peer-reviewed evidence, or denying approval for external researchers to conduct scientific investigations (media reports: Gillis 2018; Binks-Collier 2021).

Perhaps the most simplistic case of DFO misusing scientific evidence is its regular claims that there is no evidence of impact to wild salmon of a given salmon farming practice or consequence (CSAS 2015; Mimeault et al. 2019)(Supplementary data, pp. 154–165, 166–171). This *argumentum ad ignorantiam* is a well-known logical fallacy—using the absence of evidence as evidence of absence—and it is at odds with the precautionary principle: in this case that decision-makers should both err on the side of wild salmon when associated risks due to salmon farms are uncertain (Supplementary Data pp. 7–9) and anticipate and prevent environmental degradation before it occurs (UNECE 1990). Two recent federal court decisions roundly rejected DFO's reliance on faulty logic and failure to gather required evidence. In 2015, the Federal Court found that consensus about cause-and-effect is not required to classify a virus as a disease agent—a classification that would legally invoke precautionary measures by restricting the industry's ability to stock farms with infected fish that might in turn infect wild salmon (Morton v. Minister of Fisheries and Oceans and Marine Harvest Canada 2015). Then, in 2019, the Court rejected DFO's reliance on a lack of conclusive evidence of harm to justify the Department's continued failure to implement precautionary measures (Morton v. Canada (Fisheries and Oceans) 2019). In fact, the Court laid out that the precautionary principle (a phrase often used interchangeably with "precautionary approach" in Canadian regulation) (Canada. Privy Council Office 2003) "implies a reversal of the burden of proof"—i.e., the onus is on DFO to prove lack of harm, and absence of evidence of harm does not justify regulatory inaction. Combined with other examples of DFO's transgressions, detailed below, the Department's regular reliance on the long-discredited technique of alluding to an absence of evidence can become particularly worrying.

A revealing example of DFO suppressing evidence on the salmon-aquaculture file is its handling of studies into the effects of sea lice on wild sockeye salmon. In 2012, the Cohen Commission, a $37 million inquiry into the causes of decline in Fraser River sockeye salmon, put the burden of proof on DFO to show by 2020 that salmon farms in the Discovery Islands region of BC were of "no more than minimal risk" to Fraser sockeye (Cohen 2012). Justice Cohen further specified that the Minister's decision needed to be informed by research on sea lice, pathogens, and their cumulative effects. In the lead-up to the 2020 deadline, DFO appears to have internally suppressed evidence: in 2017, a senior DFO veterinarian asked DFO's Aquaculture Management Division (AMD), "How can DFO Science not share with their health management counterparts that they have data indicating that sockeye are the most susceptible species of Pacific salmon?" (Supplementary data, p. 172). This question referenced DFO research, begun in 2015 and first published in 2018, which reported that "relative to Atlantic salmon, infection with *L. salmonis* caused a profound physiological impact to sockeye salmon" (Long et al. 2019*a*). By 2020, DFO had not fulfilled its stated intention to conduct 10 risk assessments (Office of the Auditor General of Canada 2018) for known salmon pathogens in relation to the Discovery Islands salmon farms, ultimately conducting only 9 (Supplementary data, pp. 154–165) and omitting a risk assessment for sea lice (or cumulative effects). As a result, the relevant DFO research (Long et al. 2019*a*) was not able to enter into the formal risk assessment process sparked by the Cohen Commission. This absence of a risk assessment for sea lice was particularly relevant, since the evidence was perhaps the most well developed (Krkošek et al. 2005, 2011*a*, 2011*b*; Connors et al. 2010; Peacock et al. 2013; Godwin et al. 2015; Krkošek 2017; Long et al. 2019*a*). Subsequently, as part of the Minister's consultation with seven First Nations about salmon farm licensing in the Discovery Islands, DFO presented "An overview of sea lice research (*Lepeophtheirus salmonis*) in British Columbia," which omitted any mention of the Department's relevant work concerning sea louse effects on sockeye (Supplementary data, pp. 173–187). Asked later by a reporter for its "assessment of the risk sea lice from farms pose to wild salmon," DFO shared a selection of studies (in a response approved by seven senior DFO staff) but again omitted any mention of DFO's sockeye-relevant findings (Supplementary data, pp. 188–190).

In addition to suppressing evidence, DFO has silenced its own scientists whose work strays from the Departmental line: that salmon farms do not harm wild salmon. After being prevented from speaking publicly about her research by government officials in 2010 and 2011 (media report: Evans Ogden 2016), DFO Research Scientist Dr. Kristi Miller-Saunders was denied permission to release the report from

a farm-focussed 2012 study that "marked the first discovery of PRV [Piscine orthoreovirus] in North America, and the first study to associate this virus to disease in a Pacific salmon species" (media report: Bailey 2022). The findings only came to light a decade later, when the federal Information Commissioner compelled DFO to release the report in March 2022. More recently, the Minister of Fisheries' office asked Dr. Miller-Saunders to summarise the significance of a 2021 study (Mordecai et al. 2021), which concluded that PRV is transmitted from salmon farms to wild Chinook salmon. DFO managers removed Dr. Miller-Saunders' key statements from the report to the Minister and instead pointed to the DFO Fraser sockeye risk assessment, which had concluded that PRV posed minimal risk to an entirely different species of salmon (Supplementary data, pp. 191–224). This tendency within DFO, to ignore inconvenient aquaculture research in its science advice, was highlighted by the federal Independent Expert Panel on Aquaculture Science, which emphasized the need for "ongoing participation of independent external experts in the science process at DFO" (The Independent Expert Panel on Aquaculture Science 2018).

DFO has also, at times, actively prevented research on the impacts of salmon aquaculture. We draw here on an illustrative example (involving two authors of this paper), in which we proposed a study to assess evidence for a causal relationship between sea-louse infestation and survival of pink salmon. While many studies from BC have found a *correlative* link between sea-louse infestations on salmon farms and nearby reductions in wild salmon population productivity (e.g., Connors et al. 2010; Krkošek et al. 2011*a*; Peacock et al. 2013), DFO staff regularly point to the lack of *causal* linkages between the two (Supplementary data, pp. 225–234) (McVicar 2004; Canadian Technical Report of Fisheries and Aquatic Sciences 2006; Saksida et al. 2015). In Europe, large-scale field experiments have routinely found such causal evidence (Krkošek et al. 2013; Vollset et al. 2016), but no such studies have been performed in BC. Our proposed study had funding in place, collaboration from the relevant community hatchery, and full endorsement by the partner First Nation (Supplementary data, pp. 235–240); all that was needed was permission from DFO to conduct the study. Approval was denied at a senior level, with the rationale that "this work is not a priority for either our Science or Salmonid Enhancement Programs" (Supplementary data, pp. 241–247), despite ongoing controversy about the impacts of sea lice on wild salmon. No such experiment has been performed in BC in the years since, and the Department continues to cite the lack of causal evidence for sea louse impacts on wild Pacific salmon (e.g., Supplementary data, pp. 248–254).

Internally, DFO does not ban its scientists from conducting research that may prove awkward for the salmon farming industry; however, Departmental messaging can be suggestive. In DFO's Conflict of Interest Risk Assessment Questionnaire, which employees must fill out about prospective external collaborators, the only example used to illustrate collaborations that "…could compromise the integrity of DFO…" is that "…a collaborator's views, interests, and advocacy position that are against aquaculture would be in conflict with DFO's interests in sustainable aquaculture development" (Supplementary data, pp. 86–103). This may have a chilling effect, in particular on science that would cast scrutiny on the aquaculture industry.

Cumulatively, the above examples show that the Department has not consistently provided evidence-based science advice on the salmon-aquaculture file. DFO's actions are contrary not only to the "evidence-based" hallmark of robust science advice, but also to the Minister's mandate, which has repeatedly entreated DFO to "use scientific evidence and the precautionary principle… when making decisions affecting fish stocks" (Supplementary data, pp. 255–257).

3) Transparent

DFO's lack of transparency on the salmon-aquaculture file is well documented (Cohen 2012; MAACFA 2018; The Independent Expert Panel on Aquaculture Science 2018). Any of the Department's transparency issues appear to be inextricably linked to shortcomings on the other hallmarks of robust science advice. For example, the review process of science advice that happens day to day within DFO lacks transparency to outsiders (discussed in Subsection No. 4). Participation in DFO's science review process does not compel reviewers to disclose conflicts of interest, including ties to the industry under review (Subsection No. 4 and Box 2). DFO scientists also fail to disclose industry funding and conflicts of interest in peer-reviewed papers about salmon farming, which in some cases has led to printed corrections (e.g., Zhang et al. 2019*b*; Polinski et al. 2020*a*). Yet it is both federal government and DFO policy that "any real, perceived or potential conflict of interest is reported and appropriately managed" and that failing to do so is a breach of scientific integrity (Supplementary data, pp. 52–79, Supplementary data pp. 255–257). Although these are all important features of scientific transparency, we touch on them elsewhere and therefore we focus here on transparent data and information sharing.

The availability of data and information related to salmon farming appears to be proportional to the pressure placed on DFO from public, scientific, or political circles. Sea lice, for example, have been a major topic of contention on the Pacific coast and DFO provides an online database of raw industry-reported sea louse counts (Fisheries and Oceans Canada 2022*a*). Although this database is not as useful as Norway's near-real-time reporting of counts (BarentsWatch 2022), it is an improvement over past efforts. In contrast, taxpayer-funded data from DFO audits of benthic monitoring (Fisheries and Oceans Canada 2022*b*), as well as fish-health screening and mortality events (Fisheries and Oceans Canada 2022*c*), which have not become major public issues, have so far been published in a highly aggregated manner of little utility for critical independent assessment (Fisheries and Oceans Canada 2022*d*, 2022*e*, 2022*f*). In other cases, relevant findings are simply not made public. For example, a recent DFO study found that, despite the introduction of new treatment measures, PRV in the effluent of farmed-salmon processing plants remained infectious when released into the marine environment (Supplementary data, pp. 258–263). Despite substantial public concern, this important result was first made public through a freedom of information request,

and to our knowledge no management action has yet been announced to address the findings.

In 2012, the report from the Cohen Commission noted that as a result of the inquiry, "a great deal of information about DFO's inner workings and in-house research has come into the public domain." Justice Cohen "[urged] DFO to continue such openness" in the face of "many public submissions about a lack of transparency in the provision of information about salmon farms to the public" (Cohen 2012).

Highly relevant data remain unreported by DFO, or are made available on a delayed timeline, thereby precluding or delaying independent assessment. For instance, sea-louse bioassays performed by DFO or industry to test for drug resistance are not shared publicly, precluding external assessment of the evolution of sea-louse resistance to chemical treatments (Godwin et al. 2022). Data on the use of antimicrobials and pesticides, which are aggregated annually for each farm rather than reported in raw form, had not been updated since 2020 (as of 5 December 2022; Fisheries and Oceans Canada 2022*g*). Even basic data such as the number and location of active salmon farms are not made available in real time, unlike in other countries (e.g., Norway (BarentsWatch 2022) and Scotland (The Scottish Government 2022)). For information that *is* made publicly available, the DFO website "is something of a labyrinth," making information and data "hard to find," as described by an independent third-party review of the DFO Fish Health Audit and Surveillance Program (Supplementary data, pp. 264–265). These may simply be capacity issues, in which case they underline opportunities for investment in improved transparency.

In certain cases, what appears from the outside as suppression or misfeasance on DFO's part (see examples throughout) could be due to insufficient transparency in a large government bureaucracy. Where this is the case, DFO stands to claim "easy wins." By improving the transparency of Departmental science advice processes, some of the criticisms raised here and by others might be readily diffused.

Several large-scale independent reviews have identified a need for increased transparency with regards to DFO's handling of the salmon-aquaculture file. In 2018, the BC Minister of Agriculture's Advisory Council on Finfish Aquaculture stated that "increased transparency will have a positive effect on public trust" (MAACFA 2018). Later that year, the Independent Expert Panel on Aquaculture Science, convened by the federal Office of the Chief Science Advisor, released a report stating, "the Panel finds that DFO aquaculture science processes are generally not transparent to either the public or the external science community" (The Independent Expert Panel on Aquaculture Science 2018). Most recently, a salmon-aquaculture engagement process overseen by the Parliamentary Secretary to the Minister of Fisheries and Oceans found clear evidence that the public and stakeholders want "data shared in a timely way on a public website to ensure transparency and accountability" (Fisheries And Oceans Canada 2021). Although DFO responded with some steps forward in data and information sharing, the proactive and widespread transparency improvements needed for the sake of public confidence and external validation are still missing.

4) Independently reviewed

There have been several calls for independent review to inform DFO's science advice to policymakers; indeed, it was part of the core thesis of Hutching et al.'s (1997) critique of DFO's relationship with science. The processes for science advice within DFO (reviewed below) have changed somewhat since Hutchings et al. levelled their criticisms. Nevertheless, many of the same issues remain. These issues were recently highlighted by Canada's chief science advisor, who recommended that DFO conduct external peer review to inform its aquaculture management to "ensure that the evidence used is technically defensible, comprehensive, relevant, properly documented and consistent with established quality criteria" (The Independent Expert Panel on Aquaculture Science 2018). In its various forms, science advice within DFO undergoes different versions of review, from wholly internal to a DFO-specific version of peer review via the CSAS (Box 2).

In day-to-day operations, informal science advice must often be communicated within DFO without any external review. For example, the Department provides briefing notes to the Minister prior to Parliamentary Committee hearings (e.g., Supplementary data, pp. 266–322). This type of science advice is necessary for smooth operation of the Department, but because it is generally handled by Departmental managers (who may or may not have scientific training themselves and who have the final say regarding conflicting information or opinions) it provides an opportunity for message control. The system would only be robust were all managers fully impartial (see Subsection No. 1 above), and the risk from the current system is that desired policy outcomes can influence the science being incorporated into advice. Indeed, on issues related to BC salmon aquaculture, DFO managers have been shown to omit from science advice information that implicates salmon farms as a risk to wild salmon. For example, recent advice provided to the Minister and Deputy Minister excluded peer-reviewed science, shared by Dr. Miller-Saunders (Supplementary data, p. 298 and p. 302), linking *T. maritimum*, which is widespread on salmon farms (Frisch et al. 2018), with disease outbreaks in Pacific salmon (Supplementary data, pp. 266–322). At the same time, an initial version of the Department's *T. maritimum* disease assessment concluded that *T. maritimum* was likely to cause disease in wild salmon populations (Supplementary data, pp. 323–338), but this finding was edited so that details of outbreaks on Chinook farms were removed, and the updated document contended that disease in wild fish was unlikely (Supplementary data, pp. 339–342). This edit appears to have been based on a single comment from staff in AMD, which regulates salmon farms but has no mandate to protect wild salmon. Thus, a pathogen, common on farms and transmitted to wild salmon (Shea et al. 2020; Bateman et al. 2022), was assessed as "not a risk," and the associated science advice to the Minister did not reflect the mounting peer-reviewed evidence that *T. maritimum* can cause disease in Pacific salmon (Supplementary data, pp. 266–322).

Beyond the day-to-day operations of the Department, DFO's activities of summarising or generating science advice to policymakers fall under the purview of CSAS. There are two main forms of CSAS: the internal Science Response Process

(SRP; sometimes called a "Rapid Science Response") (Supplementary data, pp. 343–352) and the CSAS peer review process. The SRP does not require any independent review, presumably to enable DFO to respond quickly to emerging evidence. In certain cases, DFO scientists have been tasked with reviewing and providing SRP science advice based on their own work or that of their critics (Supplementary data, pp. 353–359). In other cases, DFO scientists have been neither allowed to provide SRP science advice based on their own work nor respond to (or even see) a critical SRP review of their work (Supplementary data, pp. 148–153, pp. 360–365). Such selective invitation of SRP authors is clearly vulnerable to political and bureaucratic abuse within the Department. Furthermore, in what seems to be a striking contradiction of DFO's own science integrity policy on stakeholder interference (Supplementary data, pp. 52–79), DFO's SRP guidelines state that, "[a]ll reasonable efforts should be made to ensure that those who may be affected by the results of a SRP (e.g., industry) be able to contribute to the process when there is no provision for their inclusion in any subsequent science-related step prior to a decision" (Supplementary data, pp. 343–352). Thus, industry representatives can contribute to and externally review SRPs, ensuring that SRP advice to decision-makers can depend on the views of vested interests.

DFO's answer to the need for peer-reviewed science advice is the CSAS peer review process (outlined in Box 2; Supplementary data, pp. 10–15). Idiosyncrasies of this process, however, preclude independent review and undermine the ability of CSAS to provide robust science advice, especially on controversial topics like salmon aquaculture. In a recent example, DFO authored a CSAS "Science Response Report" on the association between sea lice from salmon farms and infestations on wild salmon. This report was communicated as resulting from a "National Peer Review process," yet the sole external reviewer was an academic who regularly works as an industry consultant, contravening international standards of peer review (Fisheries and Oceans Canada 2023)(Supplementary data, pp. 366–373). Another illuminating example is the set of CSAS processes triggered by the Cohen Commission, which assessed risks posed to Fraser River sockeye salmon by nine infectious agents associated with Discovery Island salmon farms (Supplementary data, pp. 154–165). These risk assessments were reviewed by direct employees of salmon farming companies as well as consultants financially reliant on the salmon farming industry in BC (Supplementary data, pp. 154–165), an issue discussed above (see first hallmark in Box 1, Subsection No. 1).

Even if the CSAS peer review process itself were independent, questions remain about how information enters into—or is withheld from—the peer-review process in the first place. Once again, an illustrative example comes from the Discovery Island CSAS risk assessment of the impacts of PRV, a common virus infecting farmed salmon in BC (Mordecai et al. 2022) on Fraser sockeye. The final version of the associated contextual research document, published in 2019 (Polinski and Garver 2019; Polinski et al. 2020*b*), narrowed the geographic scope to research conducted only in Pacific Canada, leaving the impression that disease challenge trials carried out with an isolate of PRV from BC failed to cause the disease heart and skeletal muscle inflammation (HSMI) in Atlantic salmon. Critically, this narrowing of scope excluded trials run on BC samples by an international expert in Norway (Wessel et al. 2020). One of the authors of the PRV CSAS had previously received (in April 2016) unequivocal confirmation from this expert that "there is no doubt that the isolate [from BC]… causes HSMI" (Supplementary data, p. 374). The CSAS process relies on the integrity of all involved, and independent review itself is of little value if Departmental authors withhold or manipulate information of which external reviewers are unaware.

Further, independent review is only useful if it is actually applied to relevant topics. Acknowledging new evidence as it comes to light is a core scientific principle explicitly described within DFO's Science Advice for Government Effectiveness (SAGE) principles (e.g., Supplementary data, pp. 10–15). Completed CSAS processes have, however, been deployed as barriers to preclude incorporation of emerging science into the decision-making process. For example, a 2012 CSAS review (documents published in 2014) of sea-louse monitoring and non-chemical treatments (CSAS 2014) was used to justify not performing a CSAS review in 2019 on the risk of farm-origin sea lice to Fraser sockeye (Supplementary data, pp. 375–380). This decision was made despite new published research in the intervening years (Godwin et al. 2015, 2017*a*, 2017*b*; Atkinson et al. 2018; Long et al. 2019*b*), including the work by DFO scientists that sea lice can have a "profound physiological impact to sockeye salmon" relative to Atlantic salmon (Long et al. 2019*a*). No science-advice review process—independent or otherwise—can hope to improve science advice that has never been sought in the first place.

Given some of the issues with the CSAS processes, described above, it would be reasonable to expect that the final products may contain flaws. In one notable example, DFO's 2015 CSAS review of PRV states that "the absence of associated mortality or pathology in infected groups exhibiting high viral loads … indicates that the Pacific PRV is non-pathogenic" (CSAS 2015). Even to a non-expert, the error in this logic should be apparent, especially after the global COVID-19 pandemic clearly showed that some individuals infected with a disease-causing virus remain asymptomatic. The fact that such a fundamental scientific error made it through DFO's flagship review process fundamentally calls into question the quality and reliability of that process.

At times, ad hoc DFO review processes, outside of the SRP and the CSAS peer review process, have also failed to meet independence criteria. For example, in 2019 a veterinary workshop convened by DFO as part of an indigenous and multi-stakeholder advisory body (Supplementary data, pp. 381–431) was tasked by DFO with reviewing the Department's case definitions for HSMI, the disease internationally recognised to be caused by PRV in Atlantic salmon (Di Cicco et al. 2017; Wessel et al. 2017, 2020). This workshop operated outside of DFO's own science review guidelines had no legislative basis and was dominated by industry participants (12 of the 17 total worked for the salmon aquaculture industry or organisations that promoted the industry). The workshop findings, deviating from guidance on international case-definition standards (Corsin et al. 2009) in a decidedly pro-industry man-

ner, recommended imposing a Catch-22: DFO need not diagnose HSMI in individual Atlantic salmon in BC without a prior "farm-level diagnosis" of HSMI, which logically requires that individuals on that farm would have had the disease (Supplementary data, pp. 381–431).

Challenges with government versions of scientific review are not unique to the CSAS peer review process. For example, a review of New Zealand's fisheries science peer review processes found that those with vested interests had infiltrated the process to act as advocates in instances where scientific results would have significant economic impact (Fisheries New Zealand 2010). Inclusion of industry in some capacity can result in added insight into operations or the sharing of important data, and fishing industry bodies argue that industry input to the review of science advice is crucial (e.g., Atlantic Groundfish Council 2022; Fisheries Council of Canada 2022), but full participation by members of any industry under scrutiny is antithetical to the principles of independent review and risks giving undue weight to lines of evidence favourable to industry.

Discussion and recommendations

The case for improving fisheries-science advice in Canada has never been stronger. DFO's standard of fisheries-science advice now lags behind international best practice (Hutchings et al. 2012*b*; Winter and Hutchings 2020) as well as Canada's own science advisory bodies, such as COSEWIC and the NACI, which strive to offer advice unfiltered and unaffected by political or bureaucratic influences. Yet DFO continues to allow industry lobbying and other non-science influences to interfere with advice processes (see Impartial section) while publicly claiming that the resulting advice is based on science (Supplementary data, pp. 10–15).

DFO's failures to provide robust science advice related to salmon farming, as we have discussed at length, result from systemic issues. The participation of vested interests in the CSAS process and the conflicts that arise from trying to balance long-term environmental protection with economic development are, however, both conserved across the Department and may cause widespread deficiencies in science advice. Recently, the union representing DFO scientists in Newfoundland and Labrador wrote a public letter describing its "grave concerns about the current status and future direction of the Department's science advice." The union's internal survey found that "30% of DFO respondents… have experienced or witnessed situations where there was an interference with their department's science-based work by businesses or industry lobbyists" (Supplementary data, pp. 504–508).

Problems with DFO's provision of science advice have also been affirmed by the Canadian Courts and by Parliament's Standing Committee on Fisheries and Oceans (Standing Committee on Fisheries and Oceans 2022*b*; Standing Committee on Fisheries and Oceans 2023). Since 2015, DFO has lost three legal cases in which the Court found its management decisions to be unreasonable, based on the scientific evidence available at the time (Morton v. Canada (Minister of Fisheries and Oceans) 2015; Morton v. Canada (Fisheries and Oceans) 2019; Mowi Canada West Inc. v. Canada (Fisheries, Oceans and Coast Guard 2022).

A recent, non-aquaculture example of a suspect science advice process from BC saw DFO managers edit—after the CSAS peer review meeting—the SAR from a CSAS Recovery Potential Assessment for Thompson and Chilcotin steelhead, ultimately downplaying the risk posed by non-selective fisheries (Environmental Law Clinic, University of Victoria 2019). DFO also blocked the release of the original draft SAR and the documents underpinning it. This body of material has still not been released nearly 5 years later (Standing Committee on Fisheries and Oceans 2023). Subsequent to DFO's edits to the official science advice, the two steelhead populations—which had recently declined from over 3000 spawners in the mid-2000s to just 19 and 104 individuals (Ministry of Forests 2022)—were not listed under Canada's Species at Risk Act, despite having been assessed as endangered by COSEWIC (COSEWIC 2020). In the face of Thompson and Chilcotin steelhead population declines, it would appear that DFO has distorted the science-advice process and put fishing interests ahead of public or conservation interests.

In many cases, as discussed above, the issues with DFO science advice are not due to isolated lapses, but are instead structural—locked in to the interdependent way in which the Department approaches science advice and policy—and beyond the reach of incremental corrective measures. We therefore return to the unheeded recommendation, made by Hutchings et al. (1997) a quarter-century ago, for the formation of a politically independent organisation of fisheries scientists to assess and summarise scientific evidence for decision-makers. Upon reviewing the evidence of problems in DFO science-advice processes, the Canadian Parliament's Standing Committee on Fisheries and Oceans recently recommended that Canada's Chief Science Advisor assess the viability of such an independent body (Standing Committee on Fisheries and Oceans 2023). We recognise that DFO, as the government department charged with oversight of the Fisheries Act, is not currently legally required to follow the advice of scientific bodies (unlike in the US; Magnuson-Stevens Fishery Conservation and Management Act 1976). An independent body that provides credible advice to DFO decision-makers could, however, at least guard against and expose industry influence and regulatory capture, and ensure that the department's science advice bears the four hallmarks we have identified above (Box 1).

To offer robust science advice that bears the four hallmarks we have identified, an independent Canadian fisheries-science advisory body would need to be specifically designed to insulate it from non-science influences and regulatory capture (see Table 1 for recommendations). The resulting properties of this independent body would help ensure the quality of its science advice for subsequent incorporation into decision-making alongside other major considerations (e.g., Traditional Knowledge, economics). Such an independent body would need to include the following key features (among others; Table 1), the details of which would depend on practical realities:

1. A legislative basis that ensures the body's advice cannot be circumvented by DFO and that enshrines its science advice into the decision-making process.

2. Clear terms of reference tied to independent evaluation and the regulator's public-interest mandate (e.g., in the case of DFO: protection and conservation of fish and application of the precautionary principle (Supplementary data, pp. 1–9)).
3. A stable source of funding that does not depend on direct contributions from vested interests (e.g., industry).
4. A strict conflict of interest policy that guarantees true independence from the regulator and from the regulated industry.
5. Freedom of scientific inquiry (i.e., the ability to identify issues for investigation and to evaluate them in a comprehensive manner free from political, commercial, and other vested influences).
6. Editorial independence (i.e., freedom to make decisions on publications and recommendations).

Among other benefits, removing the sole responsibility for fisheries-science advice from DFO would go a long way towards reducing pressure on the Department to reconcile its conflicting roles of developing fisheries and aquaculture while also safeguarding Canada's oceans. The resulting independent science advisory body would produce science advice that aimed to be as impartial and evidence-based as possible. This body could take several forms, but the closest comparable example in the Canadian context—in terms of the features highlighted above—is likely COSEWIC (although technical details of the processes would, of course, differ). A truly independent fisheries-science advisory body would provide the transparency and independent review that is currently lacking within DFO, and which is necessary to ensure that fisheries-science advice in Canada is scientifically defensible and free of political influence and vested interests. Ultimately, such a body could provide the advice needed to restore beleaguered fish populations and help to build up the public's eroded faith in DFO's ability to manage fisheries without undue political influence.

Table 1. Recommended features for the proposed independent body for fisheries-science advice in Canada.

Hallmark	Recommended feature
All	• Legislative basis that enshrines resulting science advice in the decision-making process • Clear terms of reference tied to independent evaluation and the regulator's public-interest mandate (in the case of DFO: protection and conservation of fish and fish habitat, and application of the precautionary principle) • Sufficient and secure source of funding that does not rely on direct contributions from industry or other vested interests (but could indirectly make use of license fees, etc.) • Bound by an enforced code of conduct requiring adherence to scientific principles and integrity

Impartial	• A clear and rigorously enforced conflict of interest policy
	• True independence from the regulator and from the regulated industry
	  ○ In recognition that people with industry affiliations may contribute valuable insights, industry employees or contractors could be invited to provide information and context as needed, but must not have a "vote at the table"
	• Free from undue outside influences
	  ○ Freedom of scientific inquiry, such that the body can nominate its own members via an appropriate process, can identify the topics on which it will give science advice (while also addressing topics assigned by DFO), and is able to fully evaluate issues free from political, commercial, and other non-science influences
	  ○ Freedom to make decisions on publications and recommendations (i.e., editorial independence)

Evidence-based	• Advice that considers all available published and emerging evidence • Clear rationales that conform to best practices used internationally for how to weigh conflicting evidence ○ Documentation and justification of departures from internationally accepted best practices and standards • Standards of evidence consistent with the precautionary principle and the regulator's public-interest mandate—for example, an advisory body cannot require absolute proof of harm to ascertain risk or the need for precautionary measures
Transparent	• Publicly accessible or observable deliberations • Timely public disclosure of the science advice • Documentation and disclosure of disagreements among participants—drive for consensus cannot be allowed to obscure legitimate debate and dissent

Independently reviewed	• Advice produced must be peer reviewed by competent, qualified individuals not closely associated with the regulator, any relevant industry, or the science-advice body itself
	• A review process that incorporates relevant best practices of scientific peer review, including:
	  ○ Oversight by an individual at arm's length from the science-advice body (e.g, for reviewer selection, weighing of reviewer comments, oversight of required changes, and final approval)
	  ○ Reviewers that provide an analysis of the merits and flaws of the science advice, with the aim to provide in-depth critique
	  ○ Reviewers that document departures from international standards, best practices, or scientific consensus
	• Reviews to be published along with the science advice (e.g., to clarify scientific disagreements)

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Methodology: SCG, AWB, GM, JAH
Project administration: SCG, AWB, GM
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Competing interests
While the opinions expressed here are their own, SG, AB, and GM are currently employed or funded by the Pacific Salmon Foundation, a non-profit environmental organisation that, based on the collective body of evidence, has taken the position "that British Columbia and Canada must put wild Pacific salmon first and that a move to closed-containment salmon aquaculture is recommended." SJ currently represents, as legal counsel, NGOs and First Nations that have advocated for the removal of open-net salmon farms from the coastal waters of British Columbia.

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Supplementary material

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