How closed is "closed"? Ambiguity in British Columbia's Closed Containment aquaculture regulations

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Abstract

We examine disease-transmission risks to wild salmon associated with containment technologies proposed in 2025 under British Columbia's transition away from open-net pen aquaculture. To ensure consistent terminology, and to avoid the mischaracterization of marine "semi-closed" flow-through systems as "closed containment," we clarify categories of aquaculture production technologies and compare their containment effectiveness and pathogen risks in relation to current Fisheries and Oceans Canada definitions. While semi-closed systems may reduce parasite infestations such as sea lice, they do not protect farmed or wild fish against microbial pathogens unless inflow and effluent water are effectively treated. The effectiveness of water treatment and filtration in marine semi- and fully-closed containment systems is central to risk reduction and should be evaluated under the precautionary principle through rigorous testing of new technologies to verify efficacy. Our findings underscore the need for robust monitoring, transparent reporting, and adaptive regulatory oversight to ensure that innovation in aquaculture technology genuinely reduces pathogen transmission and protects wild fish.

Salmon Aquaculture Systems and Canada’s Regulatory Ambiguity

Salmon aquaculture conducted in flow-through marine net pens (“open-net pen” farming) is increasingly recognized as a source of ecological risk to wild salmon and trout populations worldwide (Gargan et al. 2025). In British Columbia (BC), Canada, the most pressing concern is the transmission of pathogens and parasites from farmed to wild Pacific salmon (Krkosek et al. 2024). BC’s farms are located directly within coastal nursery and migration corridors of wild salmon — species that, though declining, remain vital to commercial, recreational, and Indigenous fisheries. Pacific salmon are also critical prey for beleaguered Resident Killer Whales (Wasser et al. 2017), and salmon migrations transport marine-derived nutrients into freshwater and terrestrial ecosystems, sustaining bears, eagles, and forests (Cederholm et al. 1999). Consequently, declines in wild Pacific salmon abundance have cascading ecological and economic effects, reducing species resilience, fishery viability, and ecosystem health across coastal and terrestrial systems.

In 2025, under intense public pressure to minimize ongoing declines in wild salmon, the Government of Canada announced its intent to ban open-net pen salmon aquaculture in BC coastal waters by June 30, 2029. Innovation, Science and Economic Development (ISED) Canada was tasked with developing a transition plan, while Fisheries and Oceans Canada (DFO) is reviewing regulations and has introduced categories of “closed containment” into aquaculture licenses. The draft plan promotes “closed containment and other innovative aquaculture technology adoption” (ISED 2024), yet the degree of containment envisioned remains uncertain raising the central question: how closed is “closed”? This commentary examines containment approaches and their capacity to reduce disease transmission to wild fish, aiming to clarify terminology and support biologically meaningful standards for Canada’s aquaculture transition.

Despite the policy’s stated intent, Canada’s regulatory framework remains ambiguous and internally inconsistent. Across departments, “closed containment” has been applied inconsistently (Boulet et al. 2010; DFO 2013), sometimes referring to systems that still exchange untreated water with the marine environment. Currently, ISED’s working definition—systems that “ensure the removal of waste and filtration or treatment of discharged water”—focuses on effluent management but omits mention of pathogen protection. This wording mirrors effluent-management rules for salmon processing plants, where effluent treatment is regulated (under BC provincial jurisdiction) but pathogen removal is not (MECC 2018, 2021), and treatment for pathogens has been partial, at best, despite evidence of viral persistence and infection risk (Garver 2022). Without explicit reference to disease-risk reduction, such definitions conflate waste management with biosecurity, leaving pathogen transmission risks unaddressed. DFO’s own defined categories of “semi-closed” and “closed” containment likewise fail to require elimination of pathogen transfer through inflow or outflow (levels 1-4 Table 1, DFO 2024). Further troubling, DFO currently classifies a farm as semi-closed or closed if it conforms to the relevant definition for just 16 days per month, and hence, farms are considered compliant even when containment is achieved only slightly over 50% of the time (levels 1-4 Table 1, 2024). Based on these definitions, only 13% of active marine atlantic salmon aquaculture operations in BC were categorized as open net pen facilities in 2025, despite many remaining effectively open to the surrounding waters (J. Turple, Head of Aquaculture Management Division Pacific Region, Personal Communication). Together these temporal classifications and ambiguous definitions of “closed” containment aquaculture undermine regulatory efficacy, credibility, and the stated intent of the ban on open-net pens by 2029.

Box 1 summarizes the containment technologies, and Table 1 compares their discharge characteristics and treatment feasibility in relation to regulatory classification and DFO’s 5-levels of containment as currently envisaged. Semi-closed containment systems (SCCSs), originally developed in Norway to reduce sea louse infestations on farms and not to address pathogen risks to wild fish (Haaland 2017; Nilsen et al. 2017), are now being promoted in Canada as a solution to both. Although such alternative production systems have been subject to various environmental criticisms (e.g. Labbe, 2025), many of these considerations fall outside the scope of this communication. Here, we focus specifically on disease risks and implications for wild fish.

In practice, SCCSs remain functionally flow-through when effluent is untreated, offering little improvement over open-net pens in terms of microbial pathogen risks (Espmark et al. 2022), but improvements are possible. Norwegian trials based on disinfection for RASs demonstrated that no single treatment method was sufficient as different pathogens required different approaches (Wennberg et al. 2022). However, if inflow and effluent water were disinfected using combined filtration, UV, and chemical treatment approaches as applied in land-based recirculating aquaculture systems, there is the potential for SCCSs to reach a similar level of disinfection (notwithstanding the technical challenges of operating these systems in the marine environment; (Wennberg et al. 2022; RASs, Box 1).

The Federal Court has affirmed that the precautionary principle governs Canada's regulation of finfish aquaculture and reverses the burden of proof, requiring regulators to demonstrate that operations are unlikely to cause environmental harm before approval (*Morton v. Canada (Fisheries and Oceans)* 2015, para. 41; *Morton v. Canada (Fisheries and Oceans)* 2019, para. 159). Although treatment and filtration have been mentioned in regulatory definitions, the pathogen-reduction efficacy of these approaches has received comparatively less emphasis than operational considerations. To ensure meaningful application of the precautionary principle, the efficacy of biosecurity measures for pathogens and parasites must be rigorously tested before being given regulatory approval. To ensure participation, consultation with First Nations and other stakeholders must occur early in the process, before a finalized plan is presented.

A possible path forward is the development of marine closed-containment systems (Table 1), which could incorporate partial recirculating aquaculture (RAS) and full effluent filtration and treatment to eliminate pathogen release, although such systems have yet to be proven at commercial scale. These partially recirculating systems with inflow and outflow treatment and filtration pathways could, in principle, apply filtration and disinfection technologies to achieve effective waste management and pathogen control (Wennberg et al. 2022). Reducing effluent volumes is a necessary prerequisite to enable effective disinfection and achieve pathogen elimination. While such systems have been conceptualized for bluefin tuna production in Singapore (Seafarming Systems 2024) and tropical fish production in Spain (Chin 2020), however neither has been fully operationalized.

Although conventional SCCSs can substantially reduce sea louse infestations and associated mortality (Nilsen et al. 2017; Øvrebø 2020; Friederich 2022) they do not protect against microbial pathogens unless inflow and effluent are treated to deactivate or remove infectious agents (Nylund et al. 2015), and no farm has yet applied disinfection to effluent. Norwegian research has focused almost exclusively on inflow treatment to protect farmed fish rather than wild populations (Espmark et al. 2022), and the assumption that reducing pathogens in intake water will automatically eliminate those in effluent remains untested. Effective effluent-reduction and effluent-treatment strategies will therefore need to be informed by Norwegian inflow-treatment research but expanded through Canadian studies that validate pathogen-reduction performance with real data. Without this evidence, SCCSs remain functionally FTSs and cannot be considered a true biosecure alternative. If Canada is to employ these systems, it must be willing to lead in refining them for the protection of wild fish—meeting the standards required under the court-mandated implementation of the precautionary principle.

In practice, Canada's aquaculture transition will only be successful in protecting wild salmon if containment terminology, treatment standards, and monitoring protocols are grounded in biological reality. Without clear policies that link containment definitions to measurable outcomes, as relate to harms or risks to wild fish, the transition risks repeating the failures of past regulatory approaches (Cohen 2012) and forfeiting public trust in the promise of sustainable aquaculture.

Box 1. Overview of Aquaculture Production Technologies currently in use

Aquaculture production technologies can be broadly divided into two categories: flow-through systems (FTSs) and recirculating aquaculture systems (RASs) (Lekang 2013; Villar-Navarro et al. 2021). Table 1 summarizes and illustrates examples of these production types.

Flow-through systems (FTSs) allow continuous water exchange between the culture environment and surrounding waters. Open-net pens are one of the clearest examples, relying on tidal currents to exchange water, replenish oxygen, and remove waste. In open-net pen systems, only a permeable net separates farmed fish from the environment, excluding predators but not smaller organisms, including pathogens and plankton.

Recirculating aquaculture systems (RASs) continuously reuse water by employing biological filters, skimmers, degassers, and ozone or ultraviolet treatments (Li et al. 2023). When supported by effective feed management and solids removal, RASs can achieve near-zero discharge (van Rijn 2013; Li et al. 2023). Wastewater is rich in organic compounds and must be managed or repurposed before release (del Campo et al. 2010; van Rijn 2013; Yogev et al. 2020). Untreated effluent may contain infectious agents, requiring elimination to prevent cross-infection between farmed and wild hosts. While RASs offer superior environmental control and effluent treatment potential, their complexity makes them vulnerable to sudden water-quality shifts or pathogen introduction, underscoring the need for rigorous testing and regulation (Martin et al. 2021; Badiola et al. 2012; Lekang 2013).

Semi-closed containment systems (SCCSs) use semi- or fully-impermeable barriers to protect cultured fish—typically from parasites such as sea lice—yet still exchange large volumes of water and therefore remain flow-through systems. These systems could provide partial physical separation while retaining environmental exchange if outflow and inflow are adequately filtered and treated to remove pathogen risks. Developed in Norway primarily to reduce sea-lice exposure on farms—and thereby limit amplification and spread of lice into the environment—SCCSs were driven as much by the economics of continuous louse treatments as by ecological protection (Haaland 2017; Nilsen et al. 2017) . Through the CtrlAQUA Centre for Closed-Containment Aquaculture, Norway conducted an eight-year study (2015–2023) to guide the development of closed-containment systems that optimize fish health, welfare, and performance (CtrlAQUA 2016; Nilsen et al. 2020a; Osdal 2021). SCCSs use impermeable or semi-impermeable barriers and draw intake water from depth (typically 15–25 m) to avoid macroparasites (Nylund et al. 2015; Nilsen et al. 2017; Osdal 2021). However, many ocean-based SCCSs have yet to consistently produce harvest-sized fish, and most transfer post-smolts to open-net pens for grow-out leaving pathogen-exposure risks persistent throughout the farming cycle (Haaland 2017; Øvrebø et al. 2022).

Table 1: Summary of salmon aquaculture production technologies in relation to containment level in comparison to DFO's containment type (Fisheries and Oceans (Canada) 2024). Note that DFO's assessed containment type is defined as the containment level which was in use for at least 16 days of each month for the reporting period, and the anticipated containment type for the six months following the reporting month.

Containment approach	**Production Category**	**Discharge and Containment Level**	**Treatment feasibility**	**Description**	**DFO containment type**	**Examples**
Open-net pens	FTS†	Free-flow; low containment	No effluent treatment available	A net separates farmed fish from the surrounding environment but is permeable to pathogens, flora, and fauna. Water exchange and waste removal depend on tidal currents. Some systems use 'lice shielding skirts' to reduce surface lice infestation.	**Traditional culture method:** containment pens with unmitigated water flow-through, allowing interactions with the surrounding ecosystem.	Almost all Atlantic salmon produced today come from open-net pen systems
Semi-closed containment systems with partial treatment (hybrid-flow through systems)	FTS†	Discharge with variable filtration; moderate containment	Medium effluent volume; inflow and effluent treatment possible using drum filters and UV disinfection (CtrlAQUA 2015, 2016)	Impermeable or semi-permeable enclosure typically in the marine environment, where water is drawn from depth and released back into the environment after limited filtration. These systems typically recirculate little water, though some land-based hybrid-designs incorporate partial reuse. SCCSs offer potential improvement in reducing risks to wild fish over open-net pens only when effective inflow and effluent treatment is applied to reduce pathogen transmission.	**Closed containment levels 1-4 (Fisheries and Oceans Canada 2024):** Containment levels 1-2 focus on physical barriers and waste collection; levels 3 & 4 introduce inflow and outflow treatment (respectively) to reduce pathogen transfer.	Egget (Hauge Aqua 2020), the Preline system (Lerøy Seafood Group 2017; Balseiro et al. 2018), the Neptune net-pen, the Certus net-pen (Cermaq Canada 2020), CO2L Flow (Cool Flow; (Grieg Seafood 2020), hybrid-flow through systems such as those in use by Salmon Evolution (Salmon Evolution 2020)

Marine-based closed containment systems (with-full effluent treatment)	FTS[†] with partial RAS[‡]	Discharge with full filtration; pathogen elimination, and containment	Would require lowering of effluent volume through partial RAS to effectively provide sufficient treatment and filtration to eliminate pathogens Not yet proven at scale	With a recirculating component to minimise effluent volume for treatment. Efficacy has not been demonstrated for a full grow-out cycle	**Closed containment level 5** employing filtration and treatment to support recirculation	These systems have yet to be fully developed (Chin 2020; Seafarming Systems 2024)
Land-based closed containment systems	RAS[‡]	Minimal discharge; high containment	Low effluent volume; thorough filtration and sterilization (treatment required for recirculation)	Systems where effluent is filtered and reused to achieve near-complete water recycling. These systems offer the highest potential for biosecurity and pathogen control but require complex monitoring and energy inputs.	**Closed containment level 5** employing filtration and treatment to support recirculation	Kuterra (Kuterra n.d.), Proximar seafood (Proximar Seafood n.d.)

† Flow-through system ‡ Recirculating aquaculture system.
*Closed containment level 5 may be classified as RAS depending on the level of recirculation.

Rearing Technology Affects Pathogen Risks

Large-scale changes to aquaculture rearing technologies inevitably alter the physiology of cultured fish and the ecology of associated pathogens. The government of Canada's policy to require closed containment by 2029 will likely reduce exposure of both farmed and wild salmon to some pathogens while increasing vulnerability to others. These systems typically draw intake water from depth, where cooler, saltier conditions favor different microbial communities than those found near the surface (Misund et al. 2024). Deep-water intakes designed to avoid infective sea lice may instead draw pathogen-rich water, increasing outbreaks of amoebic gill disease (Misund et al. 2024) and ulcerative conditions caused by *Moritella viscosa* and *Tenacibaculum* spp. (Nylund et al. 2015; CtrlAQUA 2016; Nilsen et al. 2020b; Osdal 2021; Espmark et al. 2022). Moreover, lower water flow rates combined with high fish densities can elevate stress and facilitate pathogen transmission, raising the risk of disease outbreaks when pathogens bypass filtration and treatment measures (Rosten et al. 2013; Espmark et al. 2022).

Compared to FTSs, RASs introduce distinct disease risks linked to system complexity and maintenance. Pathogens may enter through eggs, fry, intake water, contaminated feed, or equipment, and can persist within biofilms or sediments if disinfection is incomplete (Nylund et al. 2015; Figueroa et al. 2017; Cabello and Godfrey 2021; Slette et al. 2025). Reduced water turnover increases organic loading, promoting bacterial growth and oxygen depletion, while rapid water-quality fluctuations and biofilm formation can suppress immunity and trigger disease outbreaks (Yada and Tort 2016; Bjørgen et al. 2024; Slette et al. 2025; Lagadec et al. 2026).

From the perspective of wild salmon, changes in on-farm disease dynamics directly influence pathogen transmission risks. Outbreaks in RASs pose minimal risk if effluent is effectively treated and filtered, whereas semi-closed systems may worsen disease risks if effluent is not fully disinfected. Norwegian studies show that elevated pathogen loads in untreated effluent can sustain or amplify infection pressure to wild fish (Nylund et al. 2015;

Osdal 2021; Misund et al. 2024). To align with the precautionary principle, regulators should invest in testing, monitoring, and refining of containment systems based on empirical data rather than assumed performance so that they can intervene to prevent harm (*Morton v. Canada (Fisheries and Oceans)* 2019, para. 168; *Mowi Canada West Inc. v. Canada (Fisheries and Oceans)* 2026, para 83). Such evidence-driven evaluation will also strengthen public confidence, support adaptive regulation, and ensure that innovation genuinely advances ecological protection.

Water Treatment and Filtration

Effective water treatment and filtration are essential to maintaining animal welfare and biosecurity, not only in closed and semi-closed containment systems, but also in the surrounding environment. To mitigate risks to farmed and wild fish, the location and treatment of water intake are critical, as closed and semi-closed systems depend on proactive pathogen exclusion rather than reactive disease management (Holan et al. 2020). Demonstrating the technical feasibility of intake management, European RAS operations have implemented multi-stage disinfection protocols combining chemical, filtration, and UV treatments that achieve 99.9 % reductions in culturable viruses and bacteria (Wennberg et al. 2022).

Although laboratory results are promising, treatment technologies must be validated under industrial conditions to ensure consistent pathogen removal and system reliability (Zimmer and Dorea 2023). High effluent volumes and long operational lifespans demand continuous filter functionality under variable conditions. For example, a study of the dissolved-air-flotation system at Brown’s Bay Processing Plant showed a 100-fold reduction in Piscine orthoreovirus (PRV) relative to untreated effluent, yet infectious virus persisted and transmitted to Atlantic salmon in challenge trials (Garver 2022). This illustrates the difficulty of achieving complete pathogen removal at scale and underscores the need for caution and rigorous monitoring before deployment.

To protect wild populations, stringent effluent standards must be applied. Proposed treatment methods should be validated in both laboratory and industrial settings to confirm that organic materials and pathogens in effluent pose minimal risk to wild fish. Such evidence-driven validation will ensure that innovation in aquaculture technology genuinely advances environmental protection.

Monitoring, Reporting, and Adaptive Regulation

Proactive, transparent monitoring is essential for detecting impacts of new aquaculture technologies and verifying the efficacy of treatment and filtration systems (Badiola et al. 2012; Lekang 2020). To evaluate the performance of new systems, regulatory employment of comprehensive, repeated monitoring rather than occasional compliance checks is required. This monitoring incorporates data collection on infections and health of farmed fish, pathogen loads, and organic content to evaluate the physical and biological composition of effluent discharged into the environment. Such data would provide regulations with strong evidence of the risks to wild salmon, allow for the detection of exposures, and provide opportunities for intervention when risks to wild fish arise (*Morton v. Canada (Fisheries and Oceans)* 2019, para. 168; *Mowi Canada West Inc. v. Canada (Fisheries and Oceans)* 2026, para 83).

Experience from British Columbia’s open-net pen regulation shows that industry self-monitoring and limited audits are insufficient (Godwin et al. 2021, 2023). Thus, to ensure accountability, independent oversight through robust programs to confirm data quality and integrity are critical. Public trust depends on timely, transparent reporting of open data and independent verification of results.

Molecular tools such as environmental DNA (eDNA) and environmental RNA (eRNA) provide powerful means to evaluate pathogen presence and transmission in flow-through, semi-closed, and recirculating systems (Shea et al. 2020; Bass et al. 2024; Krishna et al. 2025). Although critics of these methods argue they cannot confirm pathogen viability, they can be paired with targeted cultures to validate viable microbial abundances, and for bacterial pathogens, RNA detections indicate active infections (Wood et al. 2020), offering direct insight into disease dynamics. Using these techniques, routine molecular monitoring would allow regulators to quantify pathogen loads, evaluate biosecurity effectiveness, and refine containment standards based on empirical data rather than assumption.

Ultimately, monitoring results are required to drive regulatory decision-making, providing empirical evidence to assess compliance, evaluate environmental impacts, and adjust as new data are available. Integrating molecular diagnostics, independent oversight, and transparent reporting ensures that Canada's transition to new aquaculture technologies is guided by evidence and that regulations evolve to enhance protection for both farmed and wild fish. Such adaptive governance would demonstrate that innovation genuinely advances ecological protection.

Conclusions

1. Clear and consistent terminology remains a critical concern for effective regulation. Terminology should reflect operational reality, with "closed containment" defined by demonstrable elimination of pathogens and parasites in effluent and avoiding the term's use as an informal descriptor. For example, describing flow-through, semi-closed systems such as open-pens with temporary sea-louse shielding skirts as "closed containment" obscures the significant differences in containment levels and pathogen risks between systems.

2. Pathogen risks to both farmed and wild fish must be evaluated comprehensively. Innovative aquaculture systems introduce new risk profiles: while closed and semi-closed designs can reduce environmental interactions, they also create unique vulnerabilities. Outbreaks of otherwise tolerated pathogens may occur under stressful, high density conditions or operational failures, requiring extreme care to prevent spread beyond the farm – particularly in semi-closed systems.
3. For marine-based closed containment systems, filtration, treatment, and disinfection must demonstrably mitigate or eliminate pathogen risks in effluent; adequate containment performance has not yet been proven at industrial scale for a full production cycle.
4. As new technologies are deployed, independent monitoring and robust oversight will be essential to safeguard wild salmon from disease risks. Without strict standards and proactive regulation, pathogen transmission could undermine the environmental and economic benefits of transitioning away from open-net pen salmon farming. Regulations and licence conditions should enable rapid intervention if novel technologies fail to perform or introduce unanticipated risks.
5. While this communication is broadly relevant to the global development and regulation of closed and semi-closed aquaculture, it specifically addresses definitions and classifications used by the Fisheries and Oceans, Canada (DFO), which may understate the risks posed by these technologies. In Canada, Innovation, Science and Economic Development (ISED) Canada is responsible for defining these terms for future regulation under the transition plan and the anticipated upcoming open-net pen ban, yet DFO’s current aquaculture framework remains ambiguous. Clarifying these definitions and linking them to measurable performance standards will be critical to ensuring that innovation translates into real risk reduction for wild salmon.

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Competing Interests Statement:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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