Monterey Bay Aquarium
Seafood Watch®

Rainbow Trout

Oncorhynchus mykiss

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Canada

Freshwater net pens
Freshwater raceways, ponds, tanks

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About Seafood Watch

Monterey Bay Aquarium's Seafood Watch program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Watch Assessment. Each assessment synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives" or "Avoid." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, Seafood Watch seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying assessments will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Watch assessments in any way they find useful.

Guiding Principles

Seafood Watch defines sustainable seafood as originating from sources, whether fished[1] or farmed that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following guiding principles illustrate the qualities that aquaculture farms must possess to be considered sustainable by the Seafood Watch program. Sustainable aquaculture farms and collective industries, by design, management and/or regulation, address the impacts of individual farms and the cumulative impacts of multiple farms at the local or regional scale by:

1. **Having robust and up-to-date information on production practices and their impacts available for analysis;**
   Poor data quality or availability limits the ability to understand and assess the environmental impacts of aquaculture production and subsequently for seafood purchasers to make informed choices. Robust and up-to-date information on production practices and their impacts should be available for analysis.
2. **Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level;**
   Aquaculture farms minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges.
3. **Being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats;**
   The siting of aquaculture farms does not result in the loss of critical ecosystem services at the local, regional, or ecosystem level.
4. **Limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms;**
   Aquaculture farms avoid the discharge of chemicals toxic to aquatic life or limit the type, frequency or total volume of use to ensure a low risk of impact to non-target organisms.
5. **Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains;**
   Producing feeds and their constituent ingredients has complex global ecological impacts, and the efficiency of conversion can result in net food gains or dramatic net losses of nutrients. Aquaculture operations source only sustainable feed ingredients or those of low value for human consumption (e.g. by-products of other food production), and convert them efficiently and responsibly.
6. **Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes;**
   Aquaculture farms, by limiting escapes or the nature of escapees, prevent competition, reductions in genetic fitness, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems that may result from the escape of native, non-native and/or genetically distinct farmed species.

[1] "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

7. **Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites;**
   Aquaculture farms pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites, or the increased virulence of naturally occurring pathogens.
8. **Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture;**
   Aquaculture farms use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture, or where farm-raised broodstocks are not yet available, ensure that the harvest of wild broodstock does not have population-level impacts on affected species. Wild-caught juveniles may be used from passive inflow, or natural settlement.
9. **Preventing population-level impacts to predators or other species of wildlife attracted to farm sites;**
   Aquaculture operations use non-lethal exclusion devices or deterrents, prevent accidental mortality of wildlife, and use lethal control only as a last resort, thereby ensuring any mortalities do not have population-level impacts on affected species.
10. **Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals;**
    Aquaculture farms avoid the international or trans-waterbody movements of live animals, or ensure that either the source or destination of movements is biosecure in order to avoid the introduction of unintended pathogens, parasites and invasive species to the natural environment.

Once a score and rating has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ratings and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Buy first—they are well managed and caught or farmed in ways that cause little harm to habitats or other wildlife.

Good Alternatives/Yellow: Buy, but be aware that there are concerns with how they are caught or farmed.

Avoid/Red: Do not buy—they are overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Rainbow trout produced in net pens and land-based raceways/ponds/tanks in Canada.

	Net Pens		Land-based
Approximate annual production	8,990 mt		400 mt
Criterion	**Scores**		**Scores**
C1 Data	**8.18**		**7.00**
C2 Effluent	**7.00**		**9.00**
C3 Habitat	**8.67**		**8.67**
C4 Chemicals	**8.00**		**8.00**
C5 Feed	**4.67**		**4.67**
C6 Escapes	**10.00**		**10.00**
C7 Disease	**5.00**		**5.00**
C8X Source of Stock	**0.00**		**0.00**
C9X Wildlife and Predator Mortalities	**–2.00**		**–2.00**
C10X Introduction of Secondary Species	**–1.00**		**–1.00**
Total	48.52		49.38
Final score (0–10)	6.93		7.01

OVERALL RATING

Final score	6.93		7.01
Initial rating	**Green**		**Green**
Red criteria	0		0
Interim rating	**Green**		**Green**
Critical criteria?	0		0
Final rating	**Green**		**Green**

Scoring note—Scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Two or more Red criteria or one Critical criterion trigger an overall Red rating.

Summary

- The final numerical score for rainbow trout (*Oncorhynchus mykiss*) produced in freshwater net pens in Canada is 6.93 out of 10, which is in the Green range. The final rating is Green.
- The final numerical score for rainbow trout (*Oncorhynchus mykiss*) produced in land-based raceways/ponds/tanks in Canada is 7.01 out of 10, which is in the Green range. The final rating is Green.

Executive Summary

Canada's rainbow trout production (*Oncorhynchus mykiss*) has varied between approximately 8,000 mt and 9,000 mt since 2016, but saw a substantial decline to approximately 6,679 mt in 2022 (largely due to a disease outbreak in Ontario). This represents approximately 5% of Canada's total aquaculture production, behind Atlantic salmon (*Salmo salar*) and various shellfish species. Approximately 1,000 mt of rainbow trout are reported to be exported from Canada to the United States each year (992 mt in 2021). The province of Ontario produces approximately two-thirds of the national production, and has shifted from land-based systems (raceways, ponds, and tanks) to now almost exclusively using net pens in Lake Huron. (The Ontario disease outbreak was managed promptly, and production is expected to return quickly to 2021 levels.) The province of Saskatchewan's production is dominated by a single net pen farm in Lake Diefenbaker. Small amounts (approximately 400 mt per year) are produced in small land-based systems, mostly in the province of Quebec, with cottage industry scales of production in several other Canadian provinces. A large farm operating a floating tank system in Lois Lake in British Columbia has recently closed and is not considered in the scoring of this assessment.

This assessment of Canadian rainbow trout production focuses on the dominant net pen farms in Ontario and Saskatchewan, but also considers raceways, ponds, and tanks (referred to here as land-based systems), using Quebec as the primary example. Rainbow trout produced in recirculating systems (RAS) are not included but are covered by a separate global RAS Seafood Watch assessment.[2]

Regarding rainbow trout terminology: some *O. mykiss* grown in freshwater are marketed as "steelhead," and there is some confusion between the names "steelhead" and "rainbow trout." The Pacific Salmon Foundation currently describes the classification as hotly debated (see the Introduction for further information). This Seafood Watch assessment relates to freshwater production of *O. mykiss* only; that is, marine-grown *O. mykiss* (marketed as rainbow trout or steelhead) are not included, but freshwater-grown *O. mykiss* (marketed as both rainbow trout and steelhead) are included.

The assessment involves criteria covering the impacts associated with effluent, habitats, wildlife mortalities, chemical use, feed production, escapes, introduction of secondary species (other than the farmed species), disease, the source stock, and general data availability.[3] Two separate assessments have been conducted for net pens and land-based systems (raceways/ponds/tanks), but the emphasis is on the large dominance of net pens. Note that Seafood Watch has separate recommendations for farmed rainbow trout certified to various assurance schemes. See Seafood Watch information on certified seafood here.[4]

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[2] A separate assessment for recirculating systems is available from Seafood Watch.
[3] The full Seafood Watch Aquaculture Standard is available at: http://www.seafoodwatch.org/seafood-recommendations/our-standards
[4] https://www.seafoodwatch.org/recommendations/certified-seafood

Criterion 1—Data
The dominant net pen producers in Ontario and Saskatchewan typically collate substantial amounts of data for third-party certification audits, and they completed data requests for this assessment. In addition, they were responsive to all requests for further information on their practices. Although some monitoring data are available publicly through industry websites and/or regulators such as DFO or CFIA, more data were provided directly for this assessment, and triangulated where possible with official data. Because of the small scale of land-based production, mostly in Quebec, there are fewer reporting requirements, and less specific information was available. But regulatory measures and some national monitoring data were available, and personal communications with industry representatives and various agencies in Quebec (particularly Quebec's Ministry of the Environment, the Fight Against Change Climate, Wildlife and Parks [MELCCFP]) greatly assisted understanding the relevant risks and concerns for the small-scale land-based production. Overall, the data quality for the dominant net pen farms was good, and the final score for Criterion 1—Data is 8.2 out of 10. For land-based producers, the final score for Criterion 1—Data is 7.0 out of 10.

Criterion 2—Effluent
Net Pens
Water-quality monitoring data for rainbow trout farms in Lake Huron and Lake Diefenbaker reflect the typical findings of the academic literature, with some samples showing elevated levels of nitrogen and phosphorous in the water column in the immediate farm area (within 50 m to 100 m) compared to reference stations. Nevertheless, even the elevated values continue to reflect the natural trophic state of the relevant waterbodies. Similarly, the benthic monitoring results from farms in Lake Huron and Lake Diefenbaker reflect the established academic literature and demonstrate a concentrated zone of deposition around the net pens. This has a negative effect on the benthic community in the immediate farm area (reduced abundance and diversity of benthic macroinvertebrates, with abundance approaching or reaching zero directly under the net pens), but these impacts return to reference values within approximately 50 m of the net pens. The increased abundance of organisms seen beyond approximately 50 m (compared to more distant reference stations) also indicates some minor benthic enrichment from primary wastes or secondary products (e.g., settling phytoplankton) at greater distances (>200 m), and therefore a broader impact of the farm; however, this is considered here to be a minor impact. If the farms were to be moved, removed, or fallowed for long periods, it could be argued that the localized impacts are temporary, but in light of the ongoing operation of the farms, the impacts are considered here to be continuous. Deepwater oxygen depletion has been demonstrated in sites that have little water exchange at depth (Type 1 and 2 sites), and two such sites in Canada were closed in the late 1990s. One Type 2 site in Lake Wolsey (in Lake Huron) may still be operational at a very small scale, but it is considered an anomaly among all other sites in Type 3 locations that have sufficient flushing to ensure that significant water quality impacts are unlikely. The total area affected by the current farms in Lakes Huron and Diefenbaker is minor compared to the occupied embayments or to the lakes as a whole, and the farms are sufficiently separated (or solitary, in the case of Lake Diefenbaker) that there are not considered to be any cumulative impacts between farms.

Overall, there are considered to be ongoing impacts in the immediate vicinity of the farms, but no significant contributions to cumulative impacts at the waterbody or regional scale. Therefore, the final score for Criterion—2 Effluent for net pens is an intermediate 7 out of 10.

Land-based systems

In contrast to the availability of effluent and water quality monitoring data relating to net pen trout farms, there are few data or demonstrably relevant academic research available from land-based farms; this is most likely the result of the small scale of operation in Quebec and Ontario (mostly in the former). Thus, the risk-based assessment was used, for which the efficacy of the regulatory management system for effluent is a key aspect (using Quebec as the primary example and the Regulation of Activities Based on their Impact on the Environment [REAFIE]). Using phosphorous (P) as the dominant effluent concern in freshwater environments, the management system in Quebec sets relative P limits (an Environmental Target, or CER in French, defined per mt of production) at the farm level, and defines environmental limits based on the receiving waterbody (the Environmental Discharge Objective, or OER in French). Using recent studies on the typical generation of P wastes by rainbow trout, it can be calculated that the CER in Quebec results in a reduction of approximately 48% of the typical rainbow trout P discharge. The CER also acts as a cap on total P discharges from a farm, which results in a waste discharge score (Factor 2.1) of 6 out of 10. The OER applies to the receiving waterbody, and operates in combination with zoned areas of surplus P in Quebec at a regional level. In Quebec, the MELCCFP's Environmental Control Center is responsible for compliance inspections (in Ontario, the MECP), which are based on annual reports from farms and Environmental Compliance Approvals. The Register of Administrative Monetary Penalties (SAP) supports a finding that enforcement is active, and indicates that infringements relating to aquaculture are uncommon and mostly related to failures to submit monitoring records. Overall, these management measures are considered comprehensive, and they are a key factor in the small number and size of land-based fish farms operating today in Quebec. The management effectiveness score (Factor 2.2) is 10 out of 10. Factors 2.1 and 2.2 combine in a final score of 9 out of 10 for Criterion 2—Effluent for raceways, ponds, and tanks.

Criterion 3—Habitat

Noting that the operational impacts of settling particulate wastes on benthic habitats have previously been addressed in the Effluent Criterion, the direct habitat impacts of floating net pens are minimal and can be immediately reversed, if desired, by removing the structures. Though studies from marine net pen farms describe a range of potential impacts (e.g., increased surface area or shading), there is no evidence that these impacts occur to any significant extent in freshwater lakes. With a small total number of net pen farms in Lake Huron, and a single farm in the dammed reservoir in Saskatchewan, there is a quite limited risk of cumulative habitat impacts. The score for Factor 3.1—Habitat Conversion and Function is 9 out of 10 for net pens. For land-based systems, the industry is small and stable, indicating that there are unlikely to have been substantial recent habitat impacts resulting from new or expanded sites. A survey of satellite images indicates that farms are located within extensive agricultural and forested landscapes, are widely dispersed, and have been constructed in land historically cleared for agriculture. With minimal impacts to ecosystem services (but some uncertainty across all sites), the score for Factor 3.1—Habitat Conversion and Function is also 9 out of 10 for land-based systems.

The three provinces of most interest here have comprehensive regulatory systems involving multiple agencies. For net pens, the focus appears to be on avoiding specific high-value habitats such as native fish spawning, nesting and nursery grounds, or areas of importance to species at risk. For land-based systems in Quebec, Ministerial Authorizations under REAFIE require examination of any aspects of environmental impact, including habitats and wildlife. Evidence of enforcement activities is also available in the SAP register. In practice, the industry is relatively small and is dispersed over a large area, such that area-based and/or cumulative habitat impacts are highly unlikely. Although the potential for industry expansion in net pens is recognized, examples of feasibility studies for new sites in the Great Lakes (e.g., Thunder Bay in Lake Superior) recognize the complex regulatory systems in place, and are currently considering locations far from the existing industry in Lake Huron. With comprehensive systems, the score for Farm Siting Regulation and Management (Factor 3.2) is 8.0 out of 10 for both net pens and land-based systems. Despite their clear differences, neither net pen nor land-based systems have a substantial risk of habitat impacts, and Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 8.7 out of 10 for both systems.

Criterion 4—Chemical Use

With a focus on antimicrobials, data provided by the industry (in addition to currently incomplete data from DFO) show that chemical use is typically low in Canadian rainbow trout farms, with occasional treatments for endemic bacterial pathogens such as *Flavobacterium* that are typically triggered by high-stress events such as extreme temperatures (see Criterion 7—Disease). The data also show that the industry in Canada (like elsewhere) is vulnerable to emerging pathogens, with an outbreak of *Weissella* in Saskatchewan in 2017–18 and of *Lactococcus* in Ontario in 2020–21 that led to increases in antimicrobial use and a peak of 560 kg in the available data in 2017 (annual sales of medically important antimicrobials in Canada are approximately 1.3 million kg, mostly for livestock). Nevertheless, rapid responses from the industry regarding vaccine developments and improved fish husbandry led to rapid post-outbreak declines in antimicrobial use. Considering the combined antimicrobial use in fingerling and grow-out production of the dominant producers through the *Lactococcus* outbreak in Ontario, the total relative use is estimated to have been an average of 35.8 g/mt between 2020 and 2022, but in 2023 has been zero (as of mid-December). Antimicrobial use has also been close to zero in Saskatchewan over the same period. Based on medicated feed sales, the peak use in recent years in Ontario (2020) represented <0.5% of the total feed sold, and therefore of production. Although antimicrobial use at the fingerling stage is somewhat common through the warmer months, detailed batch-treatment data show that a small proportion of fish are treated and at a small average size (12.7% of batches, at an average fish weight of 4.6 g). The use of antimicrobials is therefore demonstrably less than once per production cycle. The only authorized treatments for aquaculture in Canada are listed as highly important to human medicine by the World Health Organisation (WHO); however, with a low apparent concern regarding resistance at this time, the initial score for Criterion 4—Chemical Use is 8 out of 10. Much less data are available that could be related conclusively to land-based raceway, pond, or tank systems (except for the low chemical use in land-based hatcheries, as noted), and this situation is currently hampered by the low confidence in the DFO data (which is not an apparent fault of the industry). Without sufficient justification to consider otherwise (e.g., based on disease occurrences or any other data), the same score of 8 out of 10 is applied to land-based systems on the assumption that antimicrobial treatments are likely to be less than once per production cycle on average.

The Seafood Watch Aquaculture Standard allows a trend adjustment in cases where data show that a decline in chemical use over time is sufficient to give confidence that improved management practices are leading to clear reductions in use and the risk of impacts. Considering the timeframes of the primary data provided here, it is clear that antimicrobial use is typically low, and has increased only in response to specific outbreaks (e.g., in 2017–18 and 2020–21), which have rapidly been controlled. Although antimicrobial use has declined post-outbreak in both cases (and improvements in management practices are recognized as reducing the risk of future disease outbreaks), there is not considered to be sufficient justification to apply a trend adjustment here, and the final score for Criterion 4—Chemical Use remains 8 out of 10.

Criterion 5—Feed
Information on the inclusion levels of marine ingredients in Canadian rainbow trout feeds was provided by two feed companies, and the other major ingredients were listed by the dominant company. An academic reference feed from a review of rainbow trout nutrition was also used to create a best-fit feed formulation for this assessment. An average economic feed conversion ratio value of 1.36 was used, based on recent production data covering all net pen producers in Ontario and Saskatchewan. The feeds have low levels of fishmeal (a weighted average of 8.2%), but moderate levels of fish oil from whole fish (a weighted average of 5.3%). The Forage Fish Efficiency Ratio (FFER) based on fish oil was 1.29. This means that, from first principles, 1.29 mt of wild fish would need to be caught to supply the fish oil to produce 1 mt of rainbow trout in Canada. The sources of marine ingredients are mostly from fisheries certified to the MarinTrust or the Marine Stewardship Council, and the combined score for Factor 5.1—Wild Fish Use was 4.8 out of 10. With a high average feed protein content of 41.5%, there is a substantial net loss of protein of 72.2%, and a score of 2 out of 10 for Factor 5.2. The feed footprint calculated as the embedded climate change impact (kg CO_2-eq) resulted in an estimated 12.8 kg CO_2-eq per kg of farmed seafood protein, equivalent to a score of 7 out of 10 for Factor 5.3. The three factors combine to give a final Criterion 5—Feed score of 4.67 out of 10.

Criterion 6—Escapes
With a single netting barrier containing the fish in a net pen farm, there is considered to be a high risk of escape, either from catastrophic events such as storms or ice damage, or from trickle losses of small numbers of fish during routine operations. Ontario's Aquaculture Risk and Security Policy classifies net pen systems as Low Security Facilities from which losses are considered inevitable—potentially in large numbers. Although no recent data are publicly available, documented escape events in Lakes Huron and Diefenbaker support this classification. Land-based farms situated above regional flood levels and using multiple escape

prevention barriers are considered (by the Ontario Ministry of Natural Resources and Forestry) to be of moderate risk of escape. The high risk of escape results in scores for Factor 6.1 of 2 out of 10 for net pens and 4 out of 10 for land-based systems. Rainbow trout is a nonnative species in the areas covered in this assessment, but was established across Canada from the late 1800s. Hundreds of millions of rainbow trout have been stocked into Lake Huron for recreational fisheries, and stocking continues: for example, between the Ontario and Michigan Departments of Natural Resources and community hatcheries in Ontario, at least 1.17 million rainbow trout have been released into Lake Huron in the last 5 years (2018–22, with an annual average of 234,038). Other nonnative salmonids such as brown trout, Chinook salmon, and coho salmon also continue to be stocked into Lake Huron. In Lake Diefenbaker, rainbow trout was similarly introduced and actively stocked into the artificial reservoir (although this has now ceased). There have also been widespread introductions of rainbow trout in Quebec, but aquaculture and stocking are now restricted to limited areas of the province, to reduce further spread. The historic introduction and establishment of nonnative rainbow trout has had a variety of ecological impacts, but the ongoing stocking by the government and community hatcheries of rainbow trout (and other nonnative salmonids) means that any aquaculture escapes are considered unlikely to cause significant additional ecological impacts to wild fish populations in the areas where farms operate. Potential genetic interactions of escaped farmed rainbow trout with now-naturalized rainbow trout populations are not a conservation concern in this assessment. Therefore, the score for Factor 6.2—Competitive and genetic interactions is 10 out of 10. The combined scores mean that, despite the high risk of escape, the quite low risk of significant impacts results in a final score for Criterion 6—Escapes of 10 out of 10 for all production systems.

Criterion 7—Disease

Diseases in rainbow trout farms in Canada are sporadic, and mostly occur during periods of environmental stress such as unusually high surface water temperatures. The relevant pathogens are typically those that are ubiquitous in freshwater environments. But farms in Saskatchewan and Ontario have recently been affected by outbreaks of novel pathogens such as *Weissella* and *Lactococcus* (again associated with unusually high temperatures). In both cases, the industry responded rapidly with the development of vaccines and improved husbandry practices. With ongoing vaccination programs, further outbreaks have been avoided to date. Federally reported diseases have only rarely been reported in farmed rainbow trout, and the regions of relevance to this assessment are declared free from most of them (some occur in other species of salmonid and/or in marine environments). The Ontario Animal Health Network (OAHN) has developed a comprehensive Aquaculture Biosecurity Manual (publicly available to farms in other provinces), and overall, it can broadly be concluded that management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm. In the event of a disease outbreak on farms, there is a high likelihood that wild fish would be exposed to the pathogens from the open systems. But the risk that wild fish would succumb to those pathogens beyond the more stressful farm environment is uncertain. Therefore, the risk assessment option has been used, and while it can be argued that infections or mortalities at the "typical" farm are low, temporary, or infrequent, the recent outbreaks with mortality rates exceeding 80% in some farms indicate that the occasional outbreak of highly virulent pathogens inevitably increases the concern for potential impacts to wild fish. Therefore, the final score for Criterion 7—Disease is an intermediate score of 5 out of 10, and is applied to all production systems.

Criterion 8X—Source of Stock

Rainbow trout is native to western North America but has been selectively bred for decades around the world for beneficial traits such as growth rate and disease resistance. The farmed strains are now considered to be domesticated for aquaculture purposes, and there is no significant use of wild stocks for the supply of broodstock, eggs, or fingerlings. Criterion 8X—Source of Stock is a deduction of 0 out of –10.

Criterion 9X—Wildlife Mortalities

Wildlife mortality records provided by net pen farms in Ontario and Saskatchewan show that a variety of mammal and bird species are attracted to the fish and other farm supplies, such as feed. Despite various deterrents, the records show that animals may become lethally entangled or, if persistent, require lethal control as a last resort. Mortality numbers are low, with approximately <1 animal mortalities per site per year for net pen farms and 4.5 per year in land-based broodstock and fingerling sites (not including mice or rats). Because of the small scale of land-based grow-out production, there are no formal reporting requirements, but the available information, supported by expert opinion, indicates that mortalities there can be considered similar to those of the land-based systems. Various national and provincial wildlife regulations are in place, but most species of bird and animal (except those listed in Canada's Species at Risk Act [SARA]) can be harassed, captured, or killed (without a license) if they are doing damage to property. In 2023, the policy of the dominant broodstock fingerling producers changed, such that lethal control is now only used in exceptional life-threatening circumstances for farm workers, and mortality numbers are now considered low on all farms and to be exceptional events. None of the species affected have been listed by SARA (at least between 2018 and 2023) and, given the Least Concern status from the International Union for the Conservation of Nature (IUCN) for all the affected species, there is not considered to be any significant impact at the population level. With good data availability for net pen farms, the evidence-based assessment was used, and the final score for Criterion 9X—Wildlife Mortalities is a deduction of –2 out of –10 for net pen farms. For other land-based grow-out farms, without specific data, the risk assessment must be used. But with clear similarities to the land-based broodstock and fingerling producers, and with expert support, it is also considered to be highly unlikely that wildlife interactions at land-based farms would significantly affect the health of the wild populations. The final score for Criterion 9X—Wildlife Mortalities is also a deduction of –2 out of –10 for land-based farms.

Criterion 10X—Introduction of Secondary Species

The OAHN Aquaculture Biosecurity Manual notes an extreme risk for the entry and exit of pathogens or other organisms during live animal movements (broodstock, juveniles, or eggs). DFO and/or provincial partners approve the intentional movements into, between, and within Canadian watershed and fish-rearing facilities of billions of aquatic organisms of hundreds of species each year for many purposes, including aquaculture and stocking purposes. The rainbow trout aquaculture industry is dependent on the movements of fertilized eyed eggs from breeding facilities to hatcheries, and the subsequent movement of fingerlings from nurseries to grow-out sites, primarily in open net pens. Considering the dominant region of production in Ontario, movements of fingerlings are considered to be within the same Lake Huron watershed, and the majority of eggs (75% to 80%) are sourced from in-province breeding centers. These aspects vary somewhat between provinces; for example, the major producer in Saskatchewan has its own hatchery on site and does not need to ship fingerlings, but does rely on imported eggs from the United States. Overall, approximately 42% of the industry in Canada is considered dependent on trans-waterbody shipments of live trout, primarily in the form of eggs, and the score for Factor 10Xa—International or trans-waterbody animal shipments is 5 out of 10.

Across Canada, movements are authorized and licensed following the federal-provincial-territorial National Code on Introductions and Transfers of Aquatic Organisms; however, requirements vary by province. For example, in Ontario, an Aquaculture License is the only requirement for movements (in addition to the biosecurity measures described in Criterion 10X). Introductions and Transfers Committees must apply an aquatic organism risk assessment that includes a "parasite or fellow traveler" component, and movements must be screened for key pathogens. The sources of trout eggs are considered to have the potential for high biosecurity in tank-based recirculating systems, in addition to the ability to screen and surface disinfect eggs before shipment. Routine independent and industry screenings of hatcheries and of fingerlings before movements also substantially reduce the risk of unintentionally shipping secondary organisms during fingerling movements. The score for Factor 10Xb (based on the source of live movements) is 8 out of 10. Overall, the limited trans-waterbody movements and the potential for substantial biosecurity to reduce the risk of an organism entering shipments at the source combine for the final score for Criterion 10X—Introduction of Secondary Species of a small deduction of –1 out of –10.

The final numerical score for rainbow trout (*Oncorhynchus mykiss*) produced in freshwater net pens in Canada is 6.93 out of 10, which is in the Green range. With no Red criteria, the final rating is Green.

The final numerical score for rainbow trout (*Oncorhynchus mykiss*) produced in land-based raceways/ponds/tanks in Canada is 7.01 out of 10, which is in the Green range. With no Red criteria, the final rating is Green.

Introduction

Scope of the analysis and ensuing recommendation

Species
Rainbow trout (*Oncorhynchus mykiss*)

Geographic Coverage
Canada

Production Method(s)
Freshwater net pens
Freshwater raceways, tanks, and ponds (land-based systems)

Species Overview
Rainbow trout (*Oncorhynchus mykiss*) is a species of fish in the family Salmonidae, which includes Pacific salmon and trout (genus *Oncorhynchus*), Atlantic salmon and brown trout (genus *Salmo*), chars (genus *Salvelinus*; e.g., brook trout and Dolly Varden trout), and whitefishes (Coregoninae) and Arctic grayling (*Thymallus arcticus*) (Behnke 2002). The native distribution of rainbow trout is entirely west of the Rocky Mountains, from northwest Mexico to the Kuskokwin River, Alaska; however, the species has been extensively introduced around the world for sport fishing, and later for aquaculture purposes, and can now be found in waterways on all continents except Antarctica (Cowx 2005).

Different strains of *O. mykiss* display different life histories. Most rainbow trout permanently inhabit freshwater environments; some remain within localized areas throughout their life cycles, traveling short distances from natal streams to adjacent, larger waterbodies. One strain of *O. mykiss*, known as steelhead, has developed an anadromous life history in which juveniles migrate to the ocean and spend their adult life in marine waters, returning to freshwater streams to spawn (Scott and Crossman, 1973)(Wooding, 1994)(Cowx, 2005).

Note that *O. mykiss* produced in freshwater only (i.e., not in marine sites) may be marketed as "steelhead," which may cause some confusion in seafood supply chains and with consumers. This is part of a broader debate about the classification of steelhead; see the Terminology section at the end of the Introduction.

Production Statistics
Aquaculture production statistics for "trout" published by Fisheries and Oceans Canada (DFO[5]) show a total production of 7,306 mt in 2022; however, these figures include various species of trout, and combine freshwater and marine production. There does not appear to be a readily available, specific source of data on freshwater rainbow trout production in Canada, but as

[5] https://www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm

discussed as follows, reasonable estimates can be made from various sources. Note that any rainbow trout grown in marine production systems or recirculating aquaculture systems (RAS) is not included in these discussions.

The DFO production statistics for "trout" are shown in Figure 1, but include brook trout produced for the table (in addition to larger production for stocking; not included here). Only the 2022 figures from DFO include values for Saskatchewan, Manitoba, and Alberta (i.e., these were previously unreported). In an effort to fill in the provincial gaps in the DFO data, the largest farm in the three unreported provinces (Wild West Steelhead [WWS] in Saskatchewan) reported an annual production of approximately 1,000 mt (pers. comm., D. Foss, WWS, September 2023). This value has been added to the DFO data in Figure 1.[6] Figures for Alberta and Manitoba before 2022 were not readily available and have been calculated here by subtracting the known production from DFO's totals, and included as an "Other" category. Quebec's most recent commercial fisheries and aquaculture statistics from 2019 (MAPAQ, 2020) show a similar value to DFO's of 441 mt of rainbow trout (DFO reported 435 mt for 2019) and is assumed here to be table fish as opposed to fish for stocking. A 2020 review of Canadian aquaculture described fish farming in Manitoba as largely a cottage industry, and provided no details for Alberta (CAIA, 2020). A value for Ontario in 2022 (3,790 mt) has also been added to Figure 1, from Moccia and Burke (2023), and other provincial 2022 figures maintained consistency with 2021 figures. In British Columbia, freshwater rainbow trout production has been dominated by a farm in Lois Lake (West Coast Fishculture [Lois Lake] Ltd., most recently operated by Agrimarine), but this farm's license has not been renewed in 2023, and it is no longer considered operational (pers. comm., Anon, October 2023).

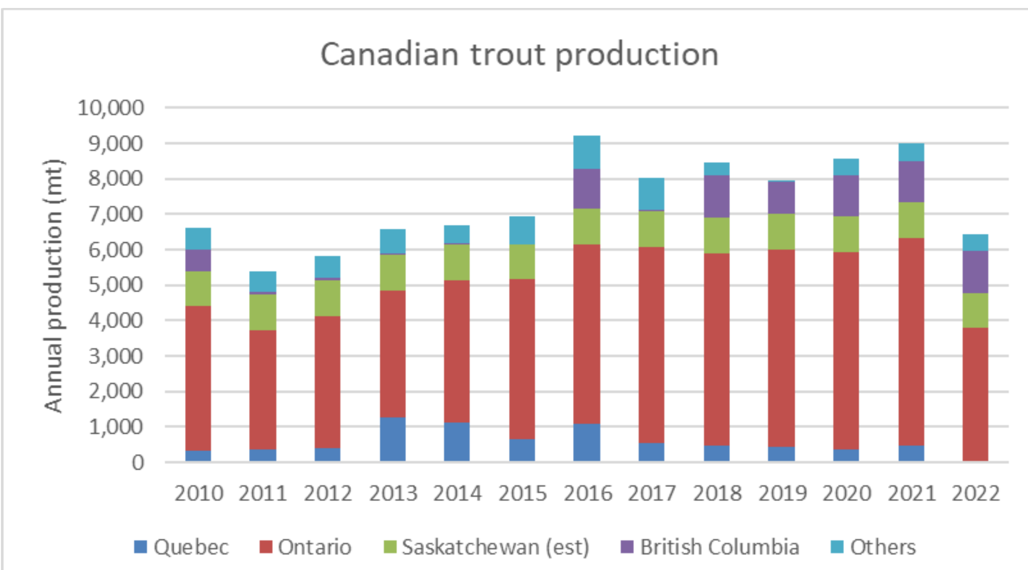

Figure 1: Estimated annual Canadian trout production in mt. The "Others" category includes Manitoba and Alberta. Data from DFO and from Moccia and Burke (2023).

[6] The recent annual production of approximately 1,000 mt has been added as a constant over the period of the graph, even though there is likely to have been some annual variation and/or growth over this period.

The available data show that the total annual production of rainbow trout in Canada up to 2021 was between approximately 8,000 mt and 9,000 mt, with an average between 2019 and 2021 of 8,504 mt. But in 2022, there was a substantial decline caused primarily by a reduction in Ontario's output. Up to 2021, Ontario had a 3-year average of 5,677 mt (2019–21), or approximately two-thirds of the Canadian total (66.8% of the 2019–21 average), but 2022 production was 3,790 mt (DFO data and Moccia and Burke, 2023). The decline was primarily due to a disease outbreak (Moccia and Burke, 2023; see Criterion 7—Disease). It is estimated here (by excluding the perceived marine production from the DFO data, and adding other data sources) that the total freshwater trout production in Canada in 2022 was 6,679 mt.

The University of Guelph produces an annual Aquastats publication,[7] and Figure 2 shows Ontario's production of rainbow trout and other species[8] from 1988 to 2022 (from Moccia and Burke, 2023). While Moccia and Burke (2022) had predicted an increase in rainbow trout aquaculture in Ontario from 5,873 mt in 2021 to 6,460 mt in 2022, the actual decline due to the disease outbreak is clear. Nevertheless (as discussed in Criterion 7—Disease), the disease outbreak was managed promptly, and Ontario's production is expected to return to 2021-level harvests (Moccia and Burke, 2023).

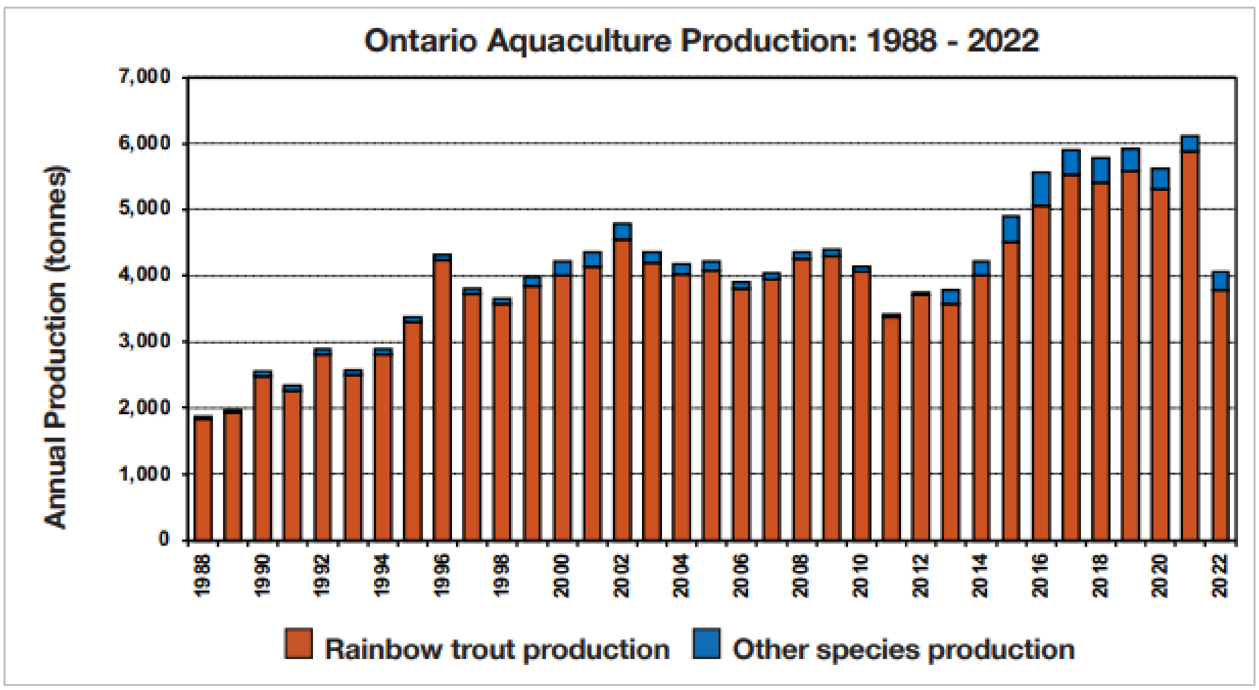

Figure 2: Ontario annual aquaculture production of rainbow trout and other species (Arctic charr, tilapia, barramundi, coho salmon). Image reproduced from Moccia and Burke (2023).

[7] https://animalbiosciences.uoguelph.ca/aquacentre/information/publications.php
[8] Other species listed in the Aquastats report are Arctic char (*Salvelinus alpinus*), tilapia, barramundi (*Lates calcarifer*), and coho salmon.

As discussed in the following Production Systems section, the combined Ontario and Saskatchewan production has been dominated by a small number of large net pen producers: 10 in Ontario and 1 in Saskatchewan. Thus, approximately 90% of Canadian rainbow trout (90.3% of the 2019–21 average) is produced by 11 farms, of which 10 are in Ontario. These producers are the focus of this assessment, but other producers using raceways, tanks, and ponds are assessed, using Quebec as a provincial example.

Production Systems and Locations

The Canadian Aquaculture Industry Alliance states[9] that rainbow trout (or "steelhead" trout) is produced in nine provinces—British Columbia, Ontario, Alberta, Saskatchewan, Manitoba, Quebec, New Brunswick, Nova Scotia, Newfoundland and Labrador, and Prince Edward Island. Considering the production statistics and anecdotal information described, the production of significant amounts of freshwater trout for the table is considered limited to the first five (British Columbia, Ontario, Alberta, Saskatchewan, Manitoba, Quebec).

In the dominant rainbow trout producing province of Ontario (with approximately two-thirds of Canada's total), the production system has almost completely shifted from land-based production (raceways, ponds, and tanks) in the 1990s to net pens today (Moccia and Burke, 2023). Figure 3 from Moccia and Burke (2023) shows this shift, and the same authors report that 95.8 % of the 2022 trout production came from 10 net pens sites in Lake Huron

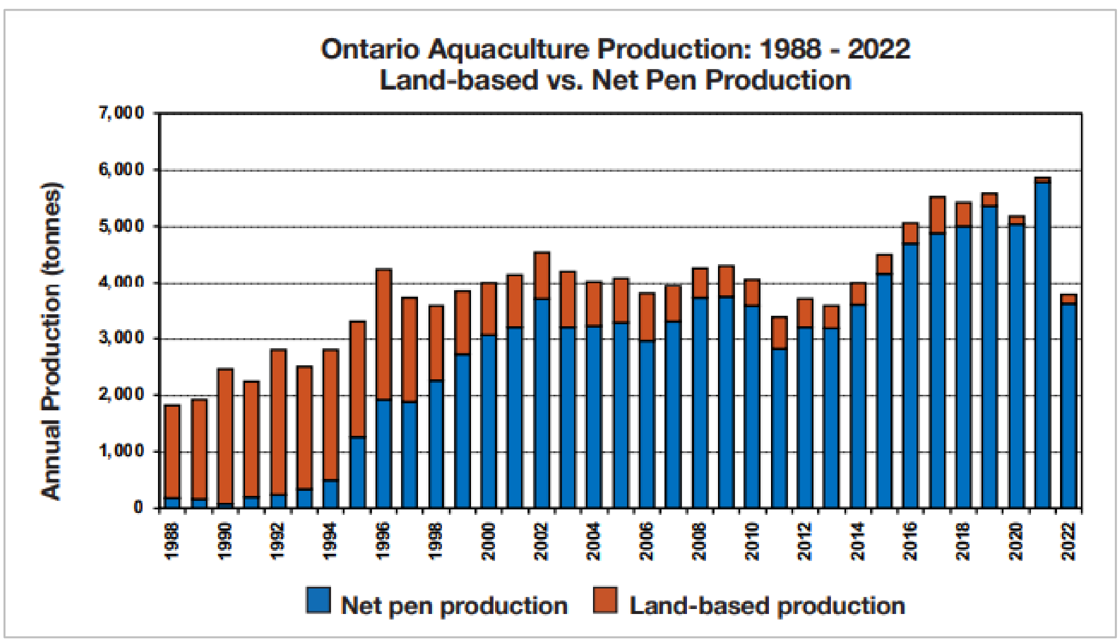

Figure 3: Aquaculture production in land-based and net-pen production systems in Ontario from 1988 to 2022 (note the dominance of rainbow trout in Ontario's total aquaculture production—Figure 2—and therefore the relevance of this graph to rainbow trout). Image reproduced from Moccia and Burke (2023).

[9] https://aquaculture.ca/products-regions-index

(Manitoulin and Parry Sound Districts). While several companies operate in Ontario, one—Cole Munro—dominates ownership, with 91% of production (pers. comm., S. Higgins, Cole Munro, September 2023).

The single large producer in the province of Saskatchewan also uses net pens (in Lake Diefenbaker), and there are no other farms producing food fish in the province (there are four farms producing fingerlings for pond stocking) (pers. comm., S. Naylor, DFO, June 2024). Finally, one significant producer in British Columbia has been operating[10] a floating tank system in Lois Lake (which was initially a net pen system) and is considered here to have produced the majority of the 1,177 mt total production from BC in 2021 (according to DFO statistics). As noted, this farm is no longer considered in operation, but any recent information of relevance to this assessment may still be discussed in the criteria.

Based on these farms, it can be estimated that 88.6% of Canada's freshwater rainbow trout production occurs in net pens or similar systems in freshwater lakes. It is also likely that some small producers use simple net pen systems in smaller lakes in Canada. Net pens therefore represent the dominant production system in this assessment.

By contrast, in Quebec, trout farming occurs exclusively on land in a variety of raceways, tanks, and ponds (net pen aquaculture in lakes is prohibited by Quebec provincial regulations). These vary from outdoor flow-through systems and aquaponics to increasing levels of recirculation and indoor tank systems. A challenge for the scope of this assessment is determining the use of water recirculation, because Seafood Watch has a separate recommendation for aquaculture in Recirculating Aquaculture Systems (RAS)—defined as ≥90% recirculation. For example, the largest rainbow trout producer in Quebec (Bobines Fish Farm) utilizes RAS with a >90% recirculation rate[11] and is not included in this assessment. Therefore, the remaining non-net pen production in Ontario (approximately 1.4% of the total), plus the smaller producers in Quebec, British Columbia, Alberta, and Manitoba, represent a second group of land-based production systems considered to be a mix of raceways, ponds, and tanks.

Fingerling production typically takes place in flow-through tanks and then raceway systems, with approximately seven facilities in Ontario (pers. comm., RJ Taylor, OAA, September 2023). Because of the relatively small scale of fingerling production, the focus of this assessment is on grow-out to harvest-size fish; however, where specific circumstances merit mention, aspects of the hatcheries are discussed in relevant criteria.

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[10] At the time of writing (October 2023), some fish remain in the farm, but without a renewed license, the farm will close after the last fish are harvested (pers. comm., Anon, October 2023).
[11] https://www.lesbobines.com/fr/entreprise/installations-d-elevage

Import and Export Sources and Statistics

Figure 4 shows the annual United States imports of "trout" from Canada, from NOAA Fisheries[12] data. Note that these figures do not differentiate by species nor between freshwater or marine-grown trout and steelhead, and include various categories of product. The category "fresh farmed rainbow trout" is the only one specified as "farmed," but others include various fresh and frozen categories (whole and fillets) identified as NSPF (not specifically provided for).

The figures appear to be somewhat variable, but with an approximate total annual production of 9,336 mt of "trout" in 2021 (DFO statistics: all species plus freshwater/marine production), the export of 992 mt in 2021 represents 10.2% of production. Also shown in Figure 4 are the annual export values of trout from Canada to the United States, in millions USD, obtained from Canadian Government online trade data.[13] Again, these figures are not differentiated by trout species or production/harvest method.

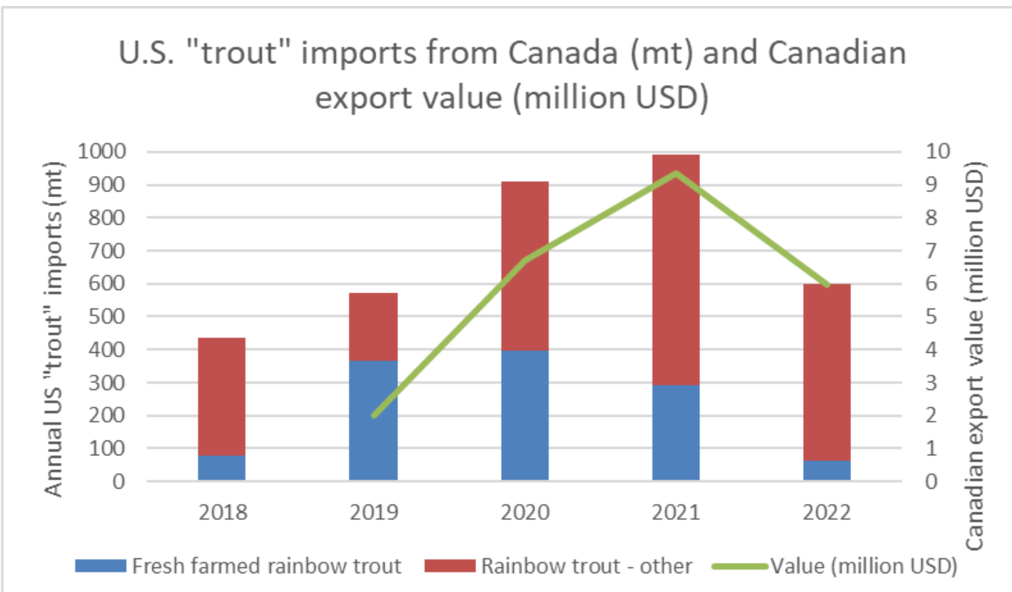

Figure 4: Annual United States imports of "trout" (all species plus freshwater/marine production) from Canada from 2018 to 2022 (blue bars: categorized as fresh farmed; red bars: uncategorized rainbow trout). Green bars show the Canadian export value of "trout" (species not defined) using the secondary (right) y-axis. Data from NOAA Fisheries and Canadian Government online trade data.

[12] https://www.fisheries.noaa.gov/

[13] https://ised-isde.canada.ca/site/trade-data-online/en

Common and Market Names

Scientific Names	*Oncorhynchus mykiss*
Common Names	Rainbow trout, steelhead trout, steelhead
French (Canada, Europe)	La truite arc-en-ciel
United States	Rainbow trout
Spanish	Trucha arcoiris
Japanese	虹鱒 (Torauto)

Product Forms
Fresh and frozen fillets, butterfly cuts, and head-on gutted or dressed fish. Value-added products like smoked cuts and canned spreads may be available.

Terminology: rainbow trout versus steelhead trout
With the marketing of some *O. mykiss* grown in freshwater as "steelhead," it is important to note that there is some confusion between steelhead and rainbow trout. The Pacific Salmon Foundation (PSF)[14] describes their classification as hotly debated. According to the PSF, steelhead are increasingly seen as being similar to other Pacific salmon species that have a freshwater only variation; e.g., the kokanee trout is the freshwater variation of sockeye salmon (*Oncorhynchus nerka*), and thereby rainbow trout is the freshwater-only version of steelhead. In some cases, the specific genetics of the fish produced in farms may indeed be the migratory strain of rainbow trout; for example, the major trout egg producer Troutlodge[15] supplies "steelhead" eggs originally derived from a migratory population. The PSF notes a large dominance of freshwater-only populations of rainbow trout in the wild (within their native range and at a global level), so it is understandable that "freshwater-only" rainbow trout would generally be considered the dominant form of *O. mykiss*. Thus, it can be argued that the marketing of *O. mykiss* when grown only in freshwater as "steelhead" is confusing with regard to other rainbow trout; however, given the debate described by the PSF, this marketing terminology can also be argued to be appropriate in terms of the classification of steelhead. In either case, note that marine-grown steelhead is not included in this assessment (but freshwater produced fish marketed as "steelhead" is included).

[14] https://psf.ca/info/steelhead/
[15] https://www.troutlodge.com/en/trout-genetics/trout-eggs/steelhead/

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

- Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.
- Sustainability unit: the ability to make a robust sustainability assessment
- Principle: having robust and up-to-date information on production practices and their impacts available for analysis.

Criterion 1 Summary

	Data Quality	
C1 Data Category	**Net Pens**	**Land-based**
Production	10.0	10.0
Management	10.0	10.0
Effluent	7.5	7.5
Habitat	7.5	7.5
Chemical Use	7.5	5.0
Feed	7.5	5.0
Escapes	7.5	7.5
Disease	5.0	2.5
Source of Stock	10.0	10.0
Wildlife Mortalities	10.0	5.0
Introduction of Secondary Species	7.5	7.5
C1 Data Final Score (0–10)	**8.2**	**7.0**

Brief Summary

The dominant net pen producers in Ontario and Saskatchewan typically collate substantial amounts of data for third-party certification audits, and they completed data requests for this assessment. In addition, they were responsive to all requests for further information on their practices. Although some monitoring data are available publicly through industry websites and/or regulators such as DFO or CFIA, more data were provided directly for this assessment, and triangulated where possible with official data. Because of the small scale of land-based production, mostly in Quebec, there are fewer reporting requirements, and less specific information was available. But regulatory measures and some national monitoring data were available, and personal communications with industry representatives and various agencies in Quebec (particularly Quebec's Ministry of the Environment, the Fight Against Change Climate, Wildlife and Parks [MELCCFP]) greatly assisted understanding the relevant risks and concerns for the small-scale, land-based production. Overall, the data quality for the dominant net pen farms was good, and the final score for Criterion 1—Data is 8.2 out of 10. For land-based producers, the final score for Criterion 1—Data is 7.0 out of 10.

Justification of Rating

In a review of the environmental implications of freshwater aquaculture, Johnson and McCann (2017) noted that, while there has been a great deal of research conducted to identify and understand the implications of aquaculture in marine ecosystems, the implication for freshwater aquaculture is still an area that needs attention. Nevertheless, the readily available public information relating to rainbow trout production in Canada—in addition to data provided by producers, producer organizations (often collated as requirements of third-party certification schemes), and other key stakeholders—generally allows a robust understanding of the industry, as follows. Direct input from the dominant net pen producers was a key aspect of this assessment, with all requests for information granted within reason. These are referenced throughout as: pers. comm., RJ Taylor, Ontario Aquaculture Association (OAA); S. Higgins, Cole Munro; D. Foss, Wild West Steelhead (WWS); September–November 2023. Other data provided by RJ Taylor may be referenced to the Cedar Crest company (pers. comm., RJ Taylor, Cedar Crest, September–November 2023).

Because of the small scale of the land-based production, mostly in Quebec, there were fewer readily available data, but contacts with regulators and the industry body (Table filière de l'aquaculture en eau douce du Québec [TFAEDQ],[16] roughly translated as Quebec Freshwater Aquaculture Industry Table) were useful. The Ministry of the Environment, the Fight Against Climate Change, Wildlife and Parks (Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs [MECCFLP]) provided the necessary support to understand the regulatory systems in Quebec (specifically, the Main Directorate of Expertise on Aquatic Fauna—Direction principale de l'expertise de la faune aquatique [DPFEA]). Where possible, all requests for information in Quebec were made in French (using online translation applications).

See the relevant criteria in this report for the full documentary references and additional personal communications for the data and information used in this assessment. For brevity and clarity, they are not repeated in Criterion 1.

Industry or Production Statistics

For Canada as a whole, Canada's Department of Fisheries and Oceans (DFO) publishes annual aquaculture statistics, although their specific relevance to rainbow trout is hampered by the inclusion of brook trout or other species in a "trout" category. Production data are also not reported in provinces where small numbers of farms clash with DFO's privacy obligations. For the bulk of production in Ontario, the University of Guelph's Aquastats annual publication provides useful and more recent details. A more robust understanding of the industry's

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[16] The TFAEDQ and the Aquaculture Association of Quebec (L'Association des Aquaculteurs du Québec [AAQ]) are closely affiliated and in the process of merging (pers. comm., M. Debasly, TFAEDQ, June 2024). The TFAEDQ is mostly referred to here unless specific information comes from the AAQ.

production characteristics and volumes was facilitated through discussions with key producers and stakeholders. The locations of net pen farms in Ontario and Saskatchewan are publicly available; for example, from the Ontario Aquaculture Association. The locations of all aquaculture farms in Quebec are known to be available from the Ministry of Agriculture Fisheries and Food in Quebec (Ministry of ministère de l'Agriculture, des Pêcheries et de l'Alimentation [MAPAQ]), but were not able to be obtained in time for this assessment. The locations of 23 aquaculture farms in Quebec were available as members of the Aquaculture Association of Quebec (L'Association des Aquaculteurs du Québec [AAQ]), but only 3 stated that they produced rainbow trout for consumption (as opposed to stocking for angling). Annual production figures from Quebec were available. Information on production at the farm in Lois Lake in British Columbia was challenging to access, and it was not possible to contact the company; however, an anonymous industry expert clarified the current situation. Overall, although a single source of accurate information is not readily available, a robust picture can be obtained, and the data score for industry and production statistics is 10 out of 10.

Management

Although DFO has oversight at the national level, several provincial government agencies as well as First Nation Councils are responsible for the management of aquaculture across the various provinces. Various regulatory measures and documents are publicly available; however, because of their volume and complexity, it is typically challenging to understand how they are implemented and/or enforced (including differences between net pens and land-based production). Personal discussions with regulatory experts in DFO, Ontario, and Quebec, in addition to practical information provided by producers (e.g., aquaculture license documents, First Nation agreements, and various monitoring data), allowed a reasonable understanding across the provinces and production systems. With engagement from the producers, and particularly with assistance from regulators in Ontario and Quebec, all management information is considered to be fundamentally available, and the data score for industry management is 10 out of 10.

Effluent

The dominant net pen producers in Lake Huron publish water quality data on the Ontario Aquaculture Reports website, although to date (accessed October 26, 2023) the most recent data are from 2021. The most recent 2022 monitoring reports were provided by the industry for this assessment, in addition to examples of benthic monitoring. Water quality and benthic monitoring data were also provided by the dominant company in Saskatchewan. More broadly, phosphorous impacts in freshwater ecosystems have been the subject of considerable study, including in relation to aquaculture. Otu et al. (2017) provide a highly useful review relating to freshwater aquaculture in Canada, including Lake Huron, and several additional studies relate to Lake Diefenbaker in Saskatchewan. The Georgian Bay Association (GBA) provided information on their concerns regarding effluent wastes from net pen farms in the region, and a series of technical studies provide a detailed analysis of a specific GBA site of concern (Lake Wolsey). The State of the Great Lakes report provides useful overview information on the broader ecosystem. The data provided along with established academic literature provide a reliable representation of the impacts, so the data score for net pens is 7.5 out of 10.

In contrast, fewer specific data were available relating to nutrient discharges from land-based systems, although the review by Otu et al. (2017) is also useful. Information on the practical small size of the farms and the constraints of the regulatory system regarding effluent were provided by the TFAEDQ. Full details of the regulatory system in Quebec are available from MECCFLP, including summary documents and full legislation; however, the details can be challenging to fully understand due to the technical and legal complexities, and their volume. Various experts at MELCCFP (also MAPAQ and DFO) provided the necessary support and explanation, particularly of the phosphorous discharge limits and their development. Enforcement evidence in Quebec is available within the Register of Administrative Monetary Penalties (Registre des sanctions administratives pécuniaires [SAP]). Therefore, although direct monitoring data were not available, the information available relating to the small, land-based farms is considered to provide a reliable representation of the operations and their impacts, and the data score for effluent for land-based systems is also 7.5 out of 10.

Habitat

The approximate locations of net pen farms are available (e.g., from the Ontario Aquaculture Association) and precise locations of all the net pen farms in Canada can be identified from various sources. An overview of each location's primary habitats in Lakes Huron and Diefenbaker can be seen from publicly available satellite images (e.g., Google Earth). Further general information is available from the State of the Great Lakes Report (for Lake Huron), and from general information on the prior damming and development of Lake Diefenbaker. Noting that operational benthic habitat impacts and any impacts on native fish populations from increased nutrients or excess feed are addressed in the Criterion 2—Effluent, information on specific habitat impacts of the floating net pens is difficult to identify. The general list of potential impacts in marine net pen systems in McKindsey (2011) provides a useful background. The habitat data score for net pens is 7.5 out of 10.

The locations of land-based trout farms (primarily in Quebec) are available from MAPAQ, but were not obtained in time for this assessment. The AAQ lists 24 member farms, of which 20 have visible aquaculture facilities, but this includes farms for species other than rainbow trout (mostly char), other systems (e.g., RAS), and other purposes (mostly restocking). Only two farms could be robustly attributed to food production of rainbow trout, for which readily available satellite images (e.g., Google Earth Pro) allow the local and landscape habitats to be identified, in addition to historic development if the clarity of images allow. Given the likely similarity with the typical habitats of other aquaculture farms, all 24 members were analyzed using satellite images where possible. Broader regulatory measures can be found from government websites; for Ontario, a review is provided in Moccia and Bevan (2018b), which is still considered largely relevant and updated here with personal communications with various agencies; however, it can be challenging to determine how these are applied in practice, particularly regarding the small scale of production. In Quebec, the MELCCFP provides all relevant regulation, in addition to species zoning maps for aquaculture and evidence of enforcement in the SAP. Overall, there are some gaps in the readily available information on the habitat impacts of land-based rainbow trout farms, although the impacts are considered to be largely defined by the small and stable nature of the present industry (i.e., a lack of development of new or expanding farms). The data score is 7.5 out of 10.

Chemical Use

A variety of data sources are available, but they are somewhat piecemeal in nature, reflecting different timeframes, reporting units, scope, and accuracy. DFO's National Aquaculture Public Reporting Data provide chemical use data for land-based and freshwater aquaculture from 2016 to 2022 (accessed April 15, 2024), and would be expected to be a single complete source of the data required, but it is currently considered incomplete (see Criterion 4—Chemical Use). It is also difficult to identify land-based farms producing table fish as opposed to stocking. Sales of medicated feed data and total antimicrobial use (by treatment type) were provided by the dominant feed company and were considered to represent all grow-out production in Ontario (and therefore the majority of production in Canada). Fish health reports from major hatcheries in Ontario were provided for this assessment, including detailed batch-specific treatments from recent years. Antimicrobial use data were also provided by the major producer in Saskatchewan. Antimicrobial veterinary sales data for aquaculture (combined marine and freshwater) in Canada were also provided for this assessment by the Public Health Agency of Canada. The country has an Integrated Program for Antimicrobial Resistance Surveillance (CIPARS), but the latest report of specific relevance to aquaculture is from 2018. The lead author of the 2018 study was available for personal communication. Supporting discussions with veterinary experts relating to disease challenges of the industry and the needs for treatment also helped clarify the recent use. Despite the piecemeal nature of the data, the provision of data directly from the industry in Ontario and Saskatchewan (representing most of the production in Canada) allows a robust understanding of chemical use, and the data score is 7.5 out of 10. The data score for land-based systems is 5 out of 10.

Feed

Data on marine ingredient inclusions were provided by Skretting North America and Bluewater Feeds for this assessment. A simple list of additional major nonmarine ingredients was also provided by Skretting. To establish an appropriate "typical" formulation for a Canadian rainbow trout feed, the generalized feed formulation in Kamalan et al. (2020) was used. Values for eFCR were provided by all net pen producers in Ontario and Saskatchewan for all 2021 stocked fish and completed cycles (harvested 2022). The dominant feed supplier, Skretting, provided information on their marine sourcing policies, and the company at the global level is part of the Ocean Disclosure Project (ODP).[17] Information on the certification of marine ingredients was provided, with partial information on specific fisheries. No specific data for feeds or eFCR values were available for land-based farms, but the net pen feed data are considered broadly applicable. The data score for feed is 7.5 out of 10 for net pens, and 5 out of 10 for land-based farms.

Escapes

[17] https://oceandisclosureproject.org/

General literature highlights the escape risk from net pen farms. Escapes data are not publicly available, while aggregated data from 2012 to May 2024 were provided by the Ontario Ministry of Natural Resources and Forestry (OMNRF) for this assessment. Additional and more detailed unpublished data from OMNRF were provided by the Georgia Bay Association for 1996 to 2023. The Aquaculture Risk and Security Policy from the OMNRF codifies best-management practices in relation to net pen rainbow trout farms in Ontario, and also for land-based farms in relation to flooding. DFO publishes "Annual national escape reports," but these data appear to be limited to marine net pens, and have not been updated since 2017 (accessed November 7, 2023). Now-dated studies such as Johnston and Wilson (2014) demonstrate the fundamental vulnerability of the systems. Various studies document the historic introduction of rainbow trout across Canada and the species' ecological interactions, and there are various sources of information on historic and ongoing stocking; for example, the Ontario GeoHub website and similar data in Ontario's Fish On-line database. Additional Great Lakes stocking data are available from U.S. organizations such as the Michigan Department of Natural Resources. Overall, there are limitations in the publicly available escape reporting data, but the studies on potential interactions and the detailed stocking data provide sufficient information with which to understand the potential impacts of escaped rainbow trout. The escapes data score is 7.5 out of 10 for all systems.

Disease

The industry in Ontario and Saskatchewan provided a summary of disease challenges on farms, and this could be compared to the Ontario Animal Health Network's (OAHN) Aquatic Animal Health Report. The Canadian Food Inspection Agency (CFIA) provides information on the detection of various reportable diseases and the free/infected status of Canadian provinces for the relevant pathogens. Provincial regulations also specify which disease (from either net pen or land-based farms) must be reported. The Ontario Animal Health Network (OAHN) Aquaculture Biosecurity Manual was also a useful source of information on biosecurity practices. Personal communications with trout farmers, veterinary experts, and regulators highlighted specific pathogens and measures to address them. An OAHN video on a recent *Lactococcus* outbreak in Ontario also provided substantial background information. Nevertheless, while the disease characteristics of the net pen industry were well understood, there remains little information with which to understand the impacts, if any, of the transmission of pathogens from farms to wild fish. Little specific information could be related to land-based producers. Thus, the data score for disease is 5 out of 10 for net pens, and 2.5 out of 10 for land-based producers.

Source of Stock

The global domestication of rainbow trout for aquaculture production is well established and documented in academic literature. Personal communications with the industry identified the sources of rainbow trout eggs as domesticated strains within Canada (primarily in Ontario), in addition to United States breeding programs such as Troutlodge or Riverence. These are established breeding programs, and there is certainty that the industry does not use wild sources of eggs, fingerlings, or adults. The data score is 10 out of 10 for all production systems.

Wildlife Mortalities

Copies of predator interaction and mortality logs from rainbow trout farms in Ontario and Saskatchewan were provided for this assessment. The records covered various timeframes between 2018 and 2023 and covered all the net pen farms in Canada in addition to the major broodstock/fingerling producers in Ontario. The records showed the type of animals affected and causes of mortality or other notes on the interactions. Companies also provided copies of wildlife interaction policies or management plans, and key regulations at the national and provincial level are available. The species reported could be checked against the Species At Risk Act (SARA) registry in addition to the International Union for the Conservation of Nature (IUCN) population status. Thus, the wildlife interactions and potential population level impacts for net pens (and their fingerling producers) are well understood and the data score is 10 out of 10. For land-based grow-out farms, some details can be inferred from similar land-based broodstock and fingerling sites, and the same regulations apply. Expert opinion considers the wildlife interactions to be a similar (low) concern between net pens and land-based production systems, but without any mortality records, the data score is 5 out of 10 for land-based grow-out farms.

Introduction of Secondary Species

There are substantial documented examples of introductions of nonnative species during live fish movements, and more broadly, the introduction of many species by various means into the Great Lakes has been well studied (for example, documented in the Great Lakes Aquatic Nonindigenous Species Information System [GLANSIS]). DFO provides categorical data on introductions and transfers of aquatic organisms in Canada, from which some useful information on rainbow trout can be gleaned. Specific information on the use of eggs from national and international sources and the movements of fingerlings came primarily from direct communications with the industry. Risk assessment processes from organizations such as the Great Lakes Fish Health Committee are available, and the National Code on Introductions and Transfers of Aquatic Organisms is available from DFO. Further information on biosecurity is available from the Canadian Food Inspection Agency (CFIA). Provincial regulations are also available, but their specific application is less visible; for example, efforts to contact the Ontario Introductions and Transfers Committees were not successful. Overall, the nature of live fish movements, the biosecurity practices, and regulatory requirements are readily available, although the practical risks of unintentionally introducing a nonnative organism (such as an emerging pathogen) remain uncertain. The data score is 7.5 out of 10 for all production systems.

Conclusions and Final Score

The dominant net pen producers in Ontario and Saskatchewan typically collate substantial amounts of data for third-party certification audits, and they completed data requests for this assessment. In addition, they were responsive to all requests for further information on their practices. Although some monitoring data are available publicly through industry websites and/or regulators such as DFO or CFIA, more data were provided directly for this assessment and triangulated where possible with official data. Because of the small scale of land-based production, mostly in Quebec, there are fewer reporting requirements, and less specific information was available. But regulatory measures and some national monitoring data were available, and personal communications with industry representatives and various agencies in Quebec (particularly Quebec's Ministry of the Environment, the Fight Against Change Climate, Wildlife and Parks [MELCCFP]) greatly assisted understanding the relevant risks and concerns for the small-scale land-based production. Overall, the data quality for the dominant net pen farms was good, and the final score for Criterion 1—Data is 8.2 out of 10. For land-based producers, the final score for Criterion 1—Data is 7.0 out of 10.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: Aquaculture species, production systems and management methods vary in the amount of waste produced per unit of production. The combined discharge of farms, groups of farms or industries contribute to local and regional nutrient loads.
- Sustainability unit: The carrying or assimilative capacity of the local and regional receiving waters.
- Principle: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Net pens—Evidence based assessment.

C2 Effluent Final Score (0–10)	7	Green

Land-based raceways, ponds, tanks—risk-based assessment.

C2 Effluent parameters	Value	Score
F2.1a Waste (nitrogen) production per of fish (kg N ton^{-1})	65.18	
F2.1b Waste discharged from farm (%)	52.00	
F2 .1 Waste discharge score (0–10)		6
F2.2a Content of regulations (0–5)	5	
F2.2b Enforcement of regulations (0–5)	5	
F2.2 Regulatory or management effectiveness score (0–10)		10.0
C2 Effluent Final Score (0–10)		**9**
Critical?	No	**Green**

Brief Summary

Net Pens

Water quality monitoring data for rainbow trout farms in Lake Huron and Lake Diefenbaker reflect the typical findings of the academic literature, with some samples showing elevated levels of nitrogen and phosphorous in the water column in the immediate farm area (within 50 m to 100 m) compared to reference stations. Nevertheless, even the elevated values continue to reflect the natural trophic state of the relevant waterbodies. Similarly, the benthic monitoring results from farms in Lake Huron and Lake Diefenbaker also reflect the established academic literature and demonstrate a concentrated zone of deposition around the net pens. This has a negative effect on the benthic community in the immediate farm area (reduced abundance and diversity of benthic macroinvertebrates, with abundance approaching or reaching zero directly under the net pens), but these impacts return to reference values within approximately 50 m of the net pens. The increased abundance of organisms seen beyond approximately 50 m (compared to more distant reference stations) also indicates some minor benthic enrichment from primary wastes or secondary products (e.g., settling phytoplankton) at greater distances (>200 m), and therefore a broader impact of the farm; however, this is considered here to be a minor impact. If the farms were to be moved, removed, or fallowed for long periods, it could be argued that the localized impacts are temporary, but in light of the ongoing operation of the farms, the impacts are considered here to be continuous. Deepwater oxygen depletion has been demonstrated in sites that have little water exchange at depth (Type 1 and 2 sites), and two such sites in Canada were closed in the late 1990s. One Type 2 site in Lake Wolsey (in Lake Huron) may still be operational at a very small scale, but it is considered an anomaly among all other sites in Type 3 locations that have sufficient flushing to ensure that significant water quality impacts are unlikely. The total area affected by the current farms in Lakes Huron and Diefenbaker is minor compared to the occupied embayments or to the lakes as a whole, and the farms are sufficiently separated (or solitary, in the case of Lake Diefenbaker) that there are not considered to be any cumulative impacts between farms. Overall, there are considered to be ongoing impacts in the immediate vicinity of the farms, but no significant contributions to cumulative impacts at the waterbody or regional scale. Therefore, the final score for Criterion—2 Effluent for net pens is an intermediate 7 out of 10.

Land-based systems

In contrast to the availability of effluent and water quality monitoring data relating to net pen trout farms, there are few data or demonstrably relevant academic research available from land-based farms; this is most likely the result of the small scale of operation in Quebec and Ontario (mostly in the former). Thus, the risk-based assessment was used, for which the efficacy of the regulatory management system for effluent is a key aspect (using Quebec as the primary example and the Regulation of Activities Based on their Impact on the Environment [REAFIE]). Using phosphorous (P) as the dominant effluent concern in freshwater environments, the management system in Quebec sets relative P limits (an Environmental Target, or CER in French, defined per mt of production) at the farm level, and defines environmental limits based on the receiving waterbody (the Environmental Discharge Objective, or OER in French). Using recent studies on the typical generation of P wastes by rainbow trout, it can be calculated that the CER in Quebec results in a reduction of approximately 48% of the typical rainbow trout P discharge. The CER also acts as a cap on total P discharges from a farm, and results in a waste discharge score (Factor 2.1) of 6 out of 10. The OER applies to the receiving waterbody, and operates in combination with zoned areas of surplus P in Quebec at a regional level. In Quebec, the MELCCFP's Environmental Control Center is responsible for compliance inspections (or in Ontario, the MECP), which is based on annual reports from farms and Environmental Compliance Approvals. The Register of Administrative Monetary Penalties (SAP) supports a finding that enforcement is active, and indicates that infringements relating to aquaculture are uncommon and mostly related to failures to submit monitoring records. Overall, these management measures are considered comprehensive, and are a key factor in the small number and size of land-based fish farms operating today in Quebec. The management effectiveness score (Factor 2.2) is 10 out of 10. Factors 2.1 and 2.2 combine in a final score of 9 out of 10 for Criterion 2—Effluent for raceways, ponds, and tanks.

Justification of Rating

Net pens: Evidence-based assessment

Because the effluent data quality and availability is good (i.e., Criterion 1 score of 7.5 or 10 of 10 for the Effluent category), the evidence-based assessment was utilized. With a large portion of Canada's rainbow trout aquaculture taking place in net pens in northern Lake Huron (Ontario), this area is the focus of this criterion, but the additional large farm in Lake Diefenbaker in Saskatchewan is equally considered.

In a review of the environmental implications of freshwater aquaculture by the University of Guelph, Johnson and McCann (2017) noted a popular concern over increasing nutrient concentrations, but stated that no studies in Canadian freshwater have reported eutrophication caused by net-pen aquaculture waste. But a comprehensive review by Otu et al. (2017a) noted that, while there is a good understanding of rainbow trout metabolism and digestion of fish feeds (and therefore the characterization of waste release is well known), the literature on the ecological effects of waste release in freshwaters is sparse.

Interpreting scientific literature can also be challenging. In a recent study, "Addressing Phosphorus Waste in Open Flow Freshwater Fish Farms: Challenges and Solutions," Nathanailides et al. (2023) stated that "aquaculture induced eutrophication continues to be a major environmental issue" but provide minimal support for this statement, largely referring to Ahmed et al. (2017), which in turn provides minimal evidence and mischaracterizes the term "eutrophication." Thus, it is common for misconceptions to perpetuate, even in peer-reviewed academic literature.

Regarding the popular concern over increasing nutrient concentrations, the Georgian Bay Association (GBA)[18] notes instances where poorly situated sites have been associated with water quality concerns. The GBA cites examples of Lake Wolsey (a freshwater lake on Manitoulin Island partly connected to Lake Huron), La Cloche (located in the north channel of Lake Huron), and Lake Heney in Quebec. But Johnson and McCann (2017) noted that studies finding significant increases in nutrient concentrations associated with net-pen aquaculture are usually found in literature where there were excessively high feed conversion ratios, or in literature concerning fish farming in poorly suited shallow basins or small basins with reduced flushing rates. Otu et al. (2017a) describe how aquaculture sites in Ontario's Lake Huron are classified based on their suitability for aquaculture production, which in turn is based on a system developed by Boyd et al. (2001):

- Type 1 is defined as an enclosed basin with limited flushing, hence greater vulnerability to eutrophication and thus deemed inappropriate for aquaculture.

[18] Georgian Bay constitutes the eastern basin of Lake Huron in which the rainbow trout farms are located. The Georgian Bay Association is a nonprofit advocacy group. https://georgianbay.ca/

- Type 2 is defined as a partially exposed site with good epilimnetic and metalimnetic flushing rates, but where the hypolimnion does not exchange water and aquaculture needs to proceed with caution.
- Type 3 is defined as a very exposed site with hypolimnetic waters flushed frequently.

According to Otu et al. (2017a), the La Cloche site would have been classified as Type 1, and Lakes Wolsey and Lake Heney are considered Type 2 (Diep and Boyd, 2016). It is important to note that the trout farms at La Cloche and Lake Heney were closed in 1998 and 1999, respectively. The current operational status of the Lake Wolsey site is uncertain, and the specific case of Lake Wolsey will be discussed in a separate section.

Previously, Diep et al. (2013) noted that the potential for water quality effects ranges from negligible at exposed, well-flushed sites to eutrophication effects at sheltered sensitive sites, and noted that most commercial-scale net pen aquaculture operations are located in exposed open-water areas (Type 3) of the North Channel/Georgian Bay. As indicated in the preceding definition, Type 3 locations are not susceptible to hypolimnetic[19] oxygen depletion and are unlikely to exhibit significant nutrient-related water quality effects (Diep et al., 2013). Similarly, Rennie et al. (2019) noted that aquaculture-related nutrient release can be dramatic and cause significant increases in primary productivity in smaller or more enclosed systems, and noted therefore that increased nutrient loading is one of the primary environmental concerns surrounding impacts of aquaculture in freshwater ecosystems. But Rennie et al. (2019) also noted that more muted responses have been observed in practice on the Great Lakes.

Taking a substantial step toward addressing the sparsity of literature on the ecological effects of waste release in freshwaters, the review by Otu et al. (2017a) provides background information on the phosphorous cycle, its dynamics in freshwater, and (of particular relevance to this assessment) a detailed analysis of phosphorous dynamics at net pen aquaculture sites, including in the north channel area of Lake Huron where the net pen rainbow trout farms are concentrated. It is not the intent here to duplicate or reproduce the review of Otu et al. (2017a), and the reader is referred to the open access paper[20] for detailed information. But given its direct relevance, the salient points are discussed as follows, along with supporting information and more recent publications. The reader is also referred to Otu et al. (2017a) for the reviewed source information, and these references are not duplicated here. It is also noted here that additional recent global reviews of phosphorous in aquaculture are available; e.g., Nathanailides et al. (2023) and Luo (2023), but the Canada-specific review of freshwater aquaculture by Otu et al. is selected as the most relevant here.

In brief, phosphorus (P) is the nutrient most often limiting primary production in freshwater, so anthropogenic additions of P raise concerns for potential impacts on lake productivity. Open net-pen finfish aquaculture operations in freshwaters release waste directly into aquatic

[19] Hypolimnion - the lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant.
[20] https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40643761.pdf

environments, and these wastes contain P in the form of particulate P (e.g., feces and uneaten feed) or dissolved P (e.g., soluble P released from feed, feces, and metabolic excretions of the fish) (Otu et al., 2017a). Additions of P to freshwater can have diverse effects on the ecosystem, such as increased primary productivity, changes in algal and benthic community composition, and bottom-up enhancement of fisheries. Excessive P additions to aquatic ecosystems have historically been associated with nuisance algal production, deep-water oxygen declines (hypoxia), and fish kills (Otu et al., 2017a). It is noted here that rainbow trout farms typically have limits placed on their P discharge, either as a limit on total feed inputs (in addition to requirements for low P feeds) and/or as a specific P limit. For example, the aquaculture license for Wild West Steelhead in Lake Diefenbaker stipulates a maximum annual discharge of 25 mt of P (license provided by pers. comm., D. Foss, WWS, October 2023).

Approximately two-thirds of phosphorus waste from net pen aquaculture operations are in the form of solid particulates (feces, and to a lesser extent as uneaten feed and "fines"), and the remainder is in soluble form (Otu et al., 2017a). Therefore, most particulate P is transported to sediments below the net pens, while the fate of most dissolved P is transformation to particulate organic P by uptake or adsorption to particles, cycling through the food web, and then eventual loss of particulate P to the sediments (Otu et al., 2017a). Potential impacts in the water column and also on the lakebed are considered here, and it is noted that the two are connected; that is, P in particulate wastes from the lake bed can become soluble and diffuse up into the water column (although as Otu et al. describe, the sediment chemistry of this process and the amount dissolved is somewhat complex). In addition, it is noted here that the disposal of fish mortalities on farms (whether at background levels or in cases of increased mortality such as disease) is regulated via the Nutrient Management Act of 2002. For example, in Ontario, Reg. 106/09 under the Nutrient Management Act covers the prompt removal of carcasses and their appropriate disposal, to minimize their breakdown and release into the environment.[21]

Net pens: Soluble effluent in the water column

In the past, phosphorus concentrations were elevated throughout many of the Great Lakes, notably Lake Erie, and the estimation of total P loading to the Great Lakes began in 1967 in an effort to mitigate the effects of eutrophication (i.e., decades before net pen aquaculture reached a significant volume) (Otu et al. 2017a). Because of successful initiatives to reduce P inputs, and partly because of invasive dreissenid mussel species, the phosphorous levels in Lake Huron are now considered too low. For example, the 2022 State of the Great Lakes Report (referenced here as SGL, 2022) describes the long-term trend in the nutrient status of Lake Huron as declining, with the following rationale: "Offshore phosphorus concentrations have declined to values that are well below objectives and there is no indication of a recovery. Concentrations may be too low to support a healthy level of lake productivity based on the historic food web, and nutrient conditions are therefore assessed as Fair and the long-term

[21] The Nutrient Management Act of 2002 is primarily directed at terrestrial agriculture, and Ontario Reg. 106/09 does not specifically mention fish, but "cultured fish" are included in the scope (pers. comm., A. Reid, OMAFRA, April 2024).

trend is assessed as deteriorating." Note the "Fair" status is midway between Good and Poor in the SGL assessment.

SGL (2022) does state that elevated nutrients may be contributing to nuisance algae growth in some nearshore areas of the Great Lakes, and eutrophic (nutrient-rich) nearshore conditions may be persisting (or resurging) despite low offshore nutrient concentrations; however, they note that, in Lake Huron, this is restricted to southern areas of Georgian Bay and in Saginaw Bay (both remote from any fish farms), where agricultural and land use stressors, such as run-off from farms and urban areas, are more common. Figure 5 shows total phosphorous levels in the Great Lakes in 2018–19, and shows quite low levels offshore in Lake Huron, with high levels in Saginaw Bay (note the net pen rainbow trout farms are located in the Manitoulin Island area).

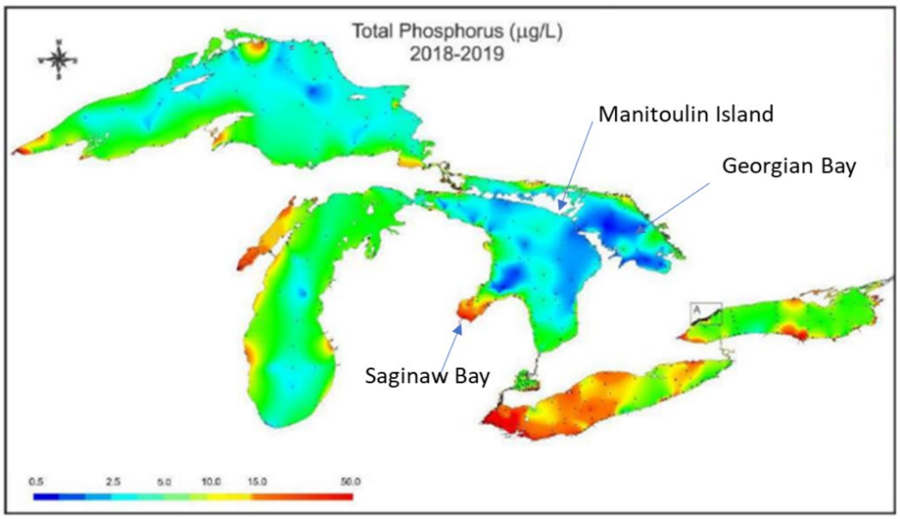

Figure 5: Map of total phosphorous in the Great Lakes from 2018 to 2019. Relevant locations in Lake Huron are labeled. Image reproduced from SGL (2022).

These findings do not absolve the fish farms in Lake Huron of any concern, but Otu et al. (2017a) note that there are no reports of elevated chlorophyl concentrations or changes in the phytoplankton community composition at fish farms in Lake Huron. Otu et al. (2017a) also note that most cage aquaculture in Canada now uses low P content feeds, and given the oligotrophic and P-limited status of Lake Huron, they conclude that there is little evidence that P additions from aquaculture have resulted in a perceptible rise in total P concentrations in the water column near farms. For example, in Ontario, the cage culture license conditions require feed to contain less than 1.3% P. It is noted here that developments in low P fish feeds are ongoing; for example, in a recent commercial scale trial, Dolsgaard et al. (2023) further reduced the P discharge from existing "low-phosphorous" rainbow trout feeds by 37% without a loss of fish performance, indicating that further declines in P discharges per mt of trout production are possible.

The findings of these academic studies are supported by recent water quality monitoring data available from the rainbow trout farms in Lake Huron. The Ontario Aquaculture Reports website[22] publishes farm-level data from eight net pen sites in Lake Huron analyzed by independent laboratories. At the time of writing (February 4, 2024), the most recent data were from 2021, but data from 2022 were provided directly by the farms (pers. comm., S. Higgins, Cole Munro, October 2023)(pers. comm., RJ Taylor, OAA, October 2023). The monthly samples are collected as part of the regulatory compliance requirements and are from near-cage and reference locations for each site (maps/images of the net pen arrays and sampling locations are detailed in each laboratory report). The sample values are compared here to a eutrophic P status of >0.024 mg/l, a mesotrophic P range of 0.012 mg/l to 0.024 mg/l, and an oligotrophic status of <0.012 mg/l, based on the Trophic Status Index (Carlson, 1977)(Carlson and Simpson, 1996). The Ontario Ministry of Natural Resources (OMNR) also has a guideline limit of 0.1 mg/l P.

As an example of two sites selected at random from the group of farms in northern Lake Huron, Figure 6 shows the annual variation in total phosphorous at the Fisher Harbour and Eagle Rock sites and their associated reference sites in 2022 (the reference points are approximately 500 m and 700 m from the net pens, and an aerial view of the net pens and the reference sampling locations are provided in Appendix 1). While there is some variation in the values between the near site and reference points, the values are all low and fall within the oligotrophic range.

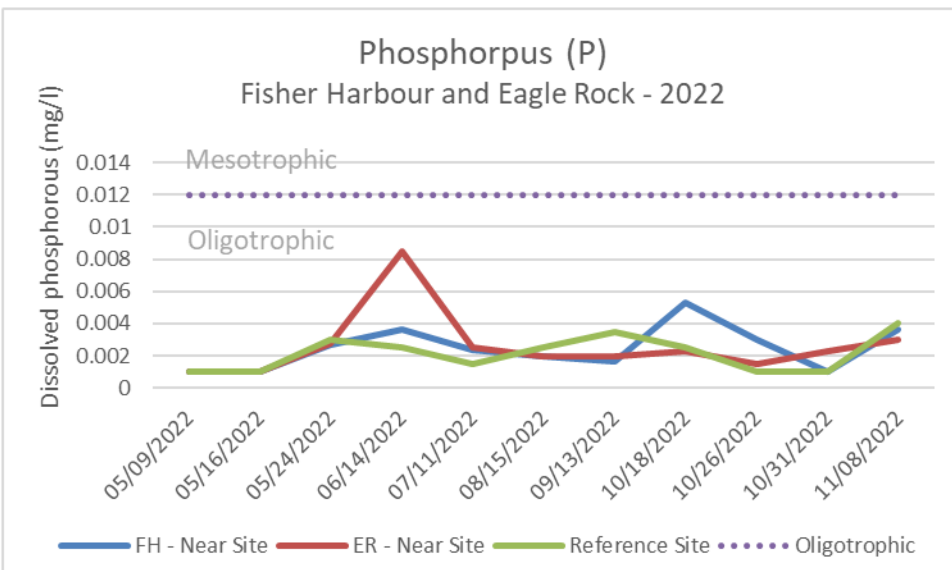

Figure 6: Total phosphorous levels at Fisher Harbour, Eagle Rock, and reference sites in Lake Huron through 2022. FH: Fisher Harbour; ER = Eagle Rock. Data provided by Cole Munro (pers. comm., S. Higgins, Cole Munro, October 2022).

[22] A collaboration between the University of Guelph and the Ontario Aquaculture Association: https://www.onaquaculturereports.ca/

Across all the eight sites for which data are available in Lake Huron, Figure 7 shows the average of each site's total phosphorous measurements alongside their respective reference points. Again, although there is some variation by site, and through the year (as indicated by error bars showing one standard deviation), the average near-site values are similar to those at the reference points, and all average values are well below the oligotrophic/mesotrophic threshold.

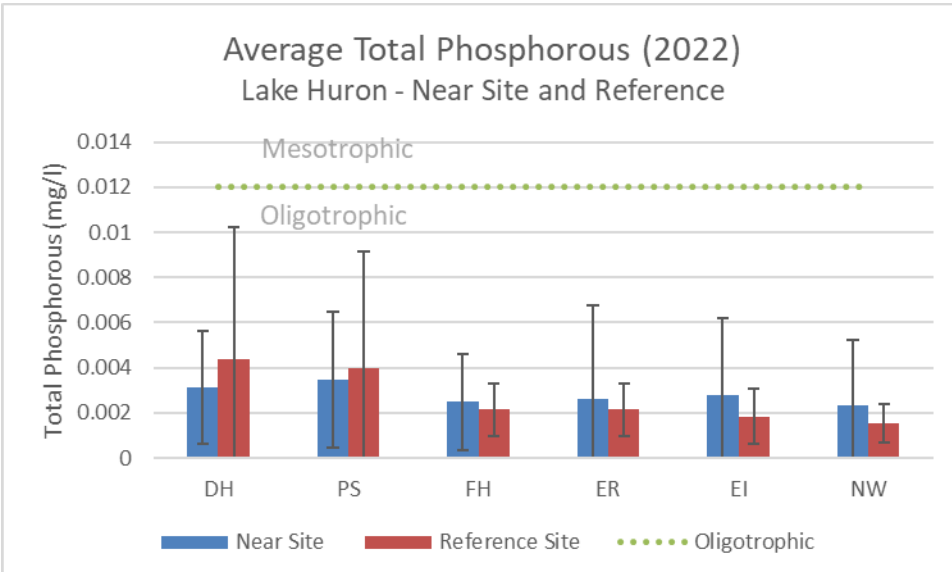

Figure 7: Average total phosphorous (mg/l) at eight rainbow trout farm sites in Lake Huron in 2022, alongside their respective reference sampling sites. Error bars show +/– one standard deviation. (DH: Depot Harbour; PS: Parry Sound; FH: Fisher Harbour; ER: Eagle Rock; EI: Eastern Island; NW: Northwinds). Data provided by Cole Munro and Cedar Crest (pers. comm., S. Higgins, Cole Munro, October 2022)(pers. comm., RJ Taylor, OAA, October 2022).

It is noted here that the aquaculture license conditions in Ontario state that, in the event of water quality (or sediment monitoring) failing the requirements (listed in Schedule C of the license), the annual feed allocation for the farm may be reduced in order to reduce the impact.

Lake Diefenbaker in Saskatchewan was established following the construction of two dams on the South Saskatchewan and Qu'Appelle rivers for the purposes of hydropower generation and agricultural irrigation. The lake supplies water to 70% of the population of Saskatchewan (Chilima et al., 2021). A now-dated State of Lake Diefenbaker report from 2012[23] listed several human activities known to increase nutrients in surface waters, including (in no particular order) effluent discharge from wastewater treatment plants, fertilizers used by agricultural producers and homeowners, manure from livestock and livestock operations, other industries, and aquaculture. Morales-Marín et al. (2017) stated that changes in land use in the reservoir's catchment over the past several years (e.g., expansion of urban areas and industrial developments) have heightened concerns about future water quality in the catchment and in the reservoir, particularly noting the intensification of agricultural activities and increased application of manure and fertilizer for crops and pasture. Otu et al. (2017b) describe Lake

[23] https://www.wsask.ca/wp-content/uploads/2021/03/State-of-Lake-Diefenbaker-Report-October-19-2012.pdf

Diefenbaker as a mesotrophic waterbody, but note that it may be particularly susceptible to pollution, considering the large catchment size of 150,000 km^2. Morales-Marín et al. (2017) reported that fertilizer and manure applied to agricultural fields within this catchment area contribute the greatest proportion of nitrogen and phosphorous entering the lake.

Recently, Abirhire (2023) noted that the lake is susceptible to episodic algal blooms, especially in the summer and fall after calm periods—a finding that was also noted by Abirhire et al. (2015). Although now somewhat dated, Abirhire et al. (2015) showed that the primary source of phosphorous in the lake was the inflow from the South Saskatchewan River, and total phosphorous levels declined along the lake, including past the fish farm—see Figure 8, where the location of the aquaculture facility is indicated (note the flow through the lake travels from left to right across the graph and map). The trophic status of all indicators assessed by Abirhire et al. (2015) declined in the same way along the lake.

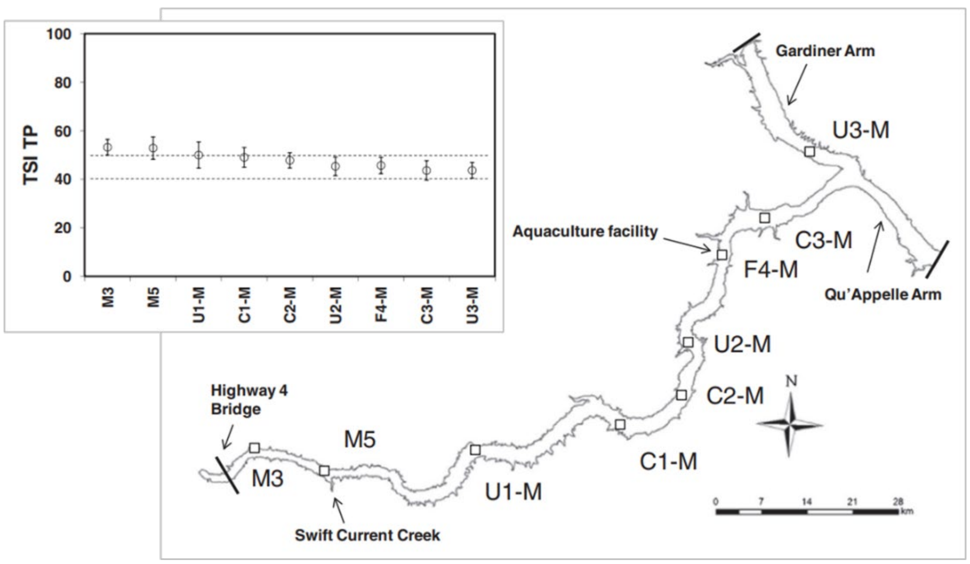

Figure 8: Map of Lake Diefenbaker with the sampling locations of Abirhire et al. (2015). The fish farm is labeled at the F4-M sampling point. The graph shows the Trophic Status Index (TSI) for total phosphorous (TP), with the lower and upper dashed lines indicating oligotrophic and eutrophic conditions (with the interim zone being mesotrophic). Image reproduced from Abirhire et al. (2015).

It is of interest that, with the title of the paper, “Environmental factors influencing phytoplankton communities in Lake Diefenbaker” and the inclusion of a sampling location at the fish farm (F4-M), the discussion and conclusion in Otu et al. (2015) did not mention the aquaculture facility. Otu et al. (2017b) did study the farm (in “Seasonal and inter-annual variability of phytoplankton in central Lake Diefenbaker proximal to a large commercial aquaculture farm”) and noted that water sampling at the very edge of farm net pens had measured detectable increases in total P at the surface water (by a mean of 0.025 mg/l) and 20 m water depth (by a mean of 0.057 mg/l) relative to an upstream site 400 m away; but with a rapid turnover of phosphorus in the lake, there was considered to be a highly rapid uptake of P (potentially on the order of minutes), and no detectable elevation was detected at the subsequent sampling site approximately 600 m downstream of the farm. Regarding the variability of phytoplankton dynamics, Otu et al. (2017b) failed to provide evidence of a fish farm effect. Overall, it is clear that the rainbow trout farm in Lake Diefenbaker, like those in Lake Huron, is a direct contributor of phosphorous (and nitrogen, etc.) to the lake; however, Otu et al. (2017b) calculate the contribution of the farm to represent 1.5% of the total external P loads to the lake, so it also appears clear that the quantities are not sufficient to significantly contribute to any water quality concerns in the lake.

In support of these academic findings, water quality monitoring data were provided by the sole trout farm in Lake Diefenbaker for this assessment. Figure 9 shows the annual pattern of total phosphorous at sampling points upstream of the farm, in the center of the net pens, at 75 m from the net pens, and 450 m east of the farm in the center of the lake (the lake is approximately 1,600 m or 1 mi wide near the farm). As expected, the phosphorous level is elevated at the net pens, but the values at 75 m are similar to those at the upstream reference point and at 450 m. Average total phosphorous values at the Lake Diefenbaker site in 2022 are shown in Figure 10, and these also show an increase in the immediate vicinity of the farm. For reference, nitrogen (as ammonia) shows a similar pattern (Figure 11).

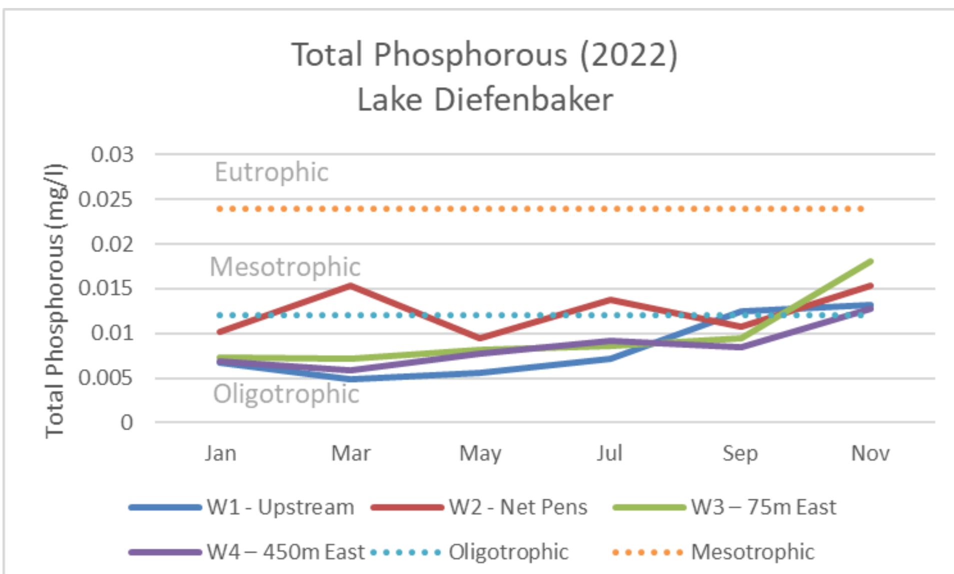

Figure 9: Water quality monitoring results from the rainbow trout farm in Lake Diefenbaker, showing total phosphorous at four sampling locations. Thresholds for trophic states are shown by dotted lines. Data provided by Wild West Steelhead (pers. comm., D. Foss, WWS, October 2023).

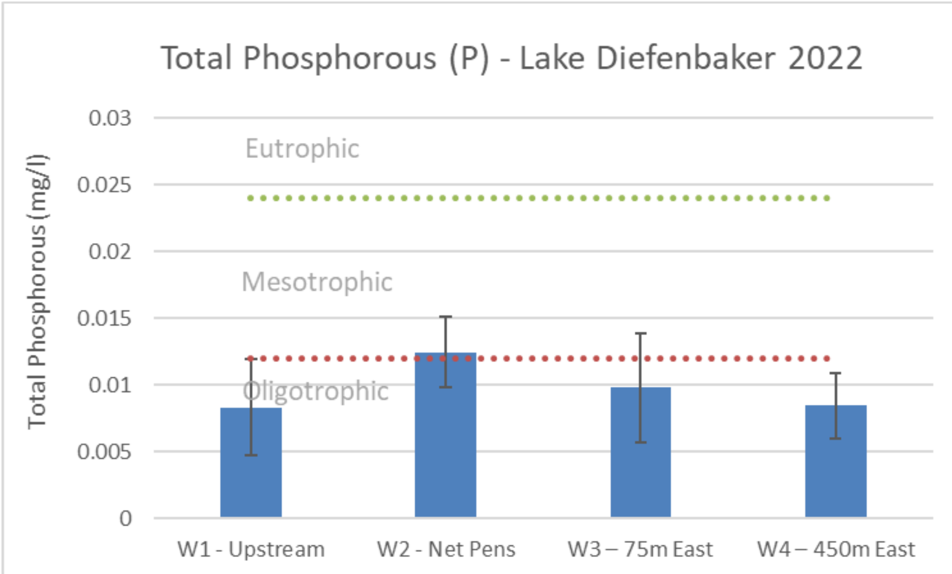

Figure 10: Average total phosphorous at four sampling points relative to the rainbow trout farm in Lake Diefenbaker. Trophic states are shown in grey and separated by dotted lines. Data provided by Wild West Steelhead.

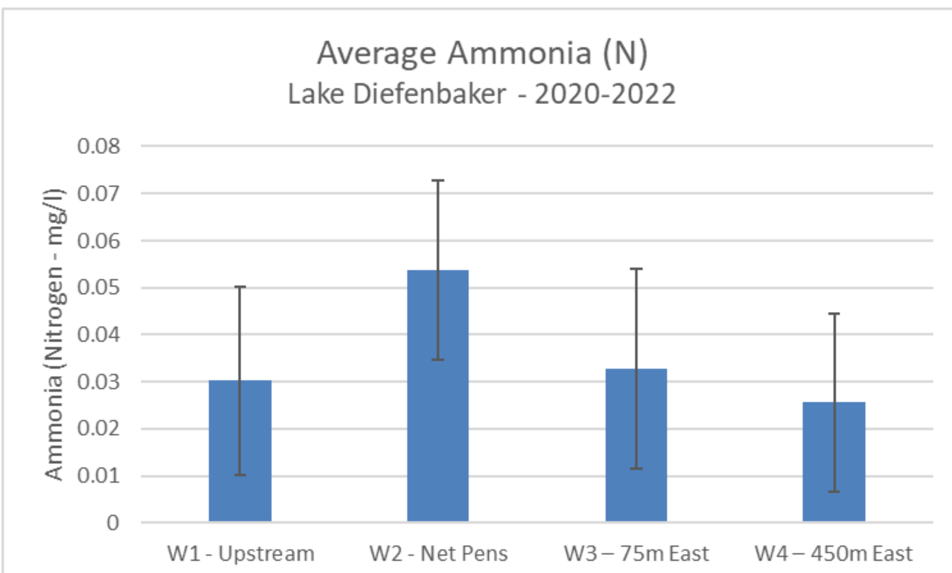

Figure 11: Average ammonia (nitrogen) at four sampling points relative to the rainbow trout farm in Lake Diefenbaker from 2020 to 2022. Data provided by Wild West Steelhead.

Overall, the considerable academic research, supported by farm-level data from both Lake Huron and Lake Diefenbaker, show that there is an increase in important parameters such as phosphorous and nitrogen due to the release of soluble farm wastes. But these increases are limited to the immediate farm area, and although elevated, reflect the natural trophic state of the relevant waterbody. Because of the small scale of the industry and the demonstrable separation of the farm sites, there are not considered to be any cumulative impacts of multiple farms in the water column.

Net pens: Benthic impacts
As noted, approximately 60% of the total P waste from fish farms is in the form of particulates—feces, uneaten feed pellets, and feed "fines" or dust (Otu et al., 2017a). It is also noted that the fate of dissolved P effluent after uptake by water column food webs is also eventual settlement as particulates on the lake bed, but the focus here is on the direct impacts below and in the vicinity of the net pens. Particulate P sedimentation and distribution is characterized by the settling velocity and current velocities. In studies of net pen rainbow trout farms in Canada (with relatively low current speeds; for example, compared to tidally situated marine net pens), the primary area affected is typically restricted to the area under the pens, with detectable deposits out to 30–50 m. In this area, the sediment P concentrations are significantly elevated (Out et al., 2017a).

The form of sedimented P from fish farms is largely composed of apatite P (a mineral form of phosphate that is highly insoluble and thus not readily bioavailable), and is unlikely to become soluble unless conditions become highly acidic (Otu et al., 2017a). Nevertheless, Canadian studies in a small lake (57 acres) in the Experimental Lakes Area of northwestern Ontario show that, after 3 years of intensive aquaculture production in Lake 375 (considered to be a "worst case scenario" due to the scale of trout production compared to the scale and hydrographic characteristics of the lake), background P concentrations doubled in the metalimnion[24] and quadrupled in the hypolimnion (although still remaining low overall). These elevated deepwater P concentrations were associated with changes in primary producers, particularly mobile plankton like cyanobacteria, dinoflagellates, and cryptomonads that are able to migrate through the water column to assimilate dissolved P below the thermocline and photosynthesize in the epilimnion.[25] Otherwise, the release of deepwater P from sediments is relatively inaccessible to algae in the surface waters.

The decomposition of wastes below the net pens can reduce the oxygen concentration in the sediments and in the water above them, particularly in areas with low current flows. But where organisms remain, particulate P waste at the lake bottom can also be taken up, assimilated, and recycled by deposit-feeding biota like oligochaete worms. The most heavily affected area is directly under the net pens and a short distance from them (depending on the depth and any currents); for example, over 30,000 worms per m^2 were found within 10–30 m of fish cages (i.e., a heavily enriched area) at three commercial aquaculture operations studied in Lake Huron (Otu et al., 2017a, referencing DFO, unpublished data). Farther from the fish cage operations (i.e., 20–50 m), there can also be invertebrate biomass that exceeds reference conditions and represents a zone of enhancement. Assimilation of organic matter by deposit feeders is reflected in higher relative abundances and increased body size of some taxa, and these deposit

[24] Metalimnion - the middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called thermocline.
[25] Epilimnion - the upper layer of water in a stratified lake.

feeders also play a direct role in recycling P into the water column. It is the intent of the aquaculture licensing conditions in Ontario to ensure that nontoxic sediment conditions are occurring in the near-field waste footprint through ongoing waste assimilation, and to ensure that the waste depositional footprint of the cage aquaculture operation does not exceed the authorized area (Schedule D, Part 2b). Similar requirements are in Schedule A of the Saskatchewan aquaculture license conditions.

Considering Lake Diefenbaker, it is noted again that the lake is an artificial dammed reservoir, so the benthic effluent impacts are perhaps a lower concern because the affected habitats are already heavily modified from the prior terrestrial environment. North et al. (2015a) noted that the lake was a significant sink for P, retaining 91% of the external total phosphorus (TP) loaded from the tributaries (i.e., containing agricultural, municipal, and other wastes from beyond the lake boundaries) and 41% of the dissolved reactive phosphorus (DRP). North et al. noted that the external tributary total P loads to Lake Diefenbaker were 78.1–94.2% particulate P. Thus, at the lake scale, the particulate waste from the trout farm can be considered minor compared to the particulate P entering the lake through its tributaries. Reservoirs function as large sediment traps, retaining nutrients and improving the overall water quality of downstream lakes, but North et al. (2015a) noted that this phosphorus can subsequently be released from sediments in the lake in a biologically available form (e.g., dissolved reactive phosphorus [DRP]), which makes it more accessible to primary producers than external P loads. This is also likely to be the case with wastes originating within the lake from the trout farm (although the fish farm was not mentioned by North et al. in their study of the internal nutrient loading in the lake). But overall, the annual reservoir mass balance for Lake Diefenbaker does not indicate a large influence of internal P loading. Nevertheless, the site-level impacts below and in the immediate area of the net pens are likely to be substantial, but highly spatially limited.

Benthic monitoring data provided by the farm in Lake Diefenbaker show an example of the expected benthic community pattern described previously in this criterion in Otu et al. (2017a). Figure 12 shows the benthic invertebrate density and taxa richness from 350 grab samples taken from 70 stations extending from below the edge of the net pens out to 300 m from them (depth range of approximately 19 m to 35 m).

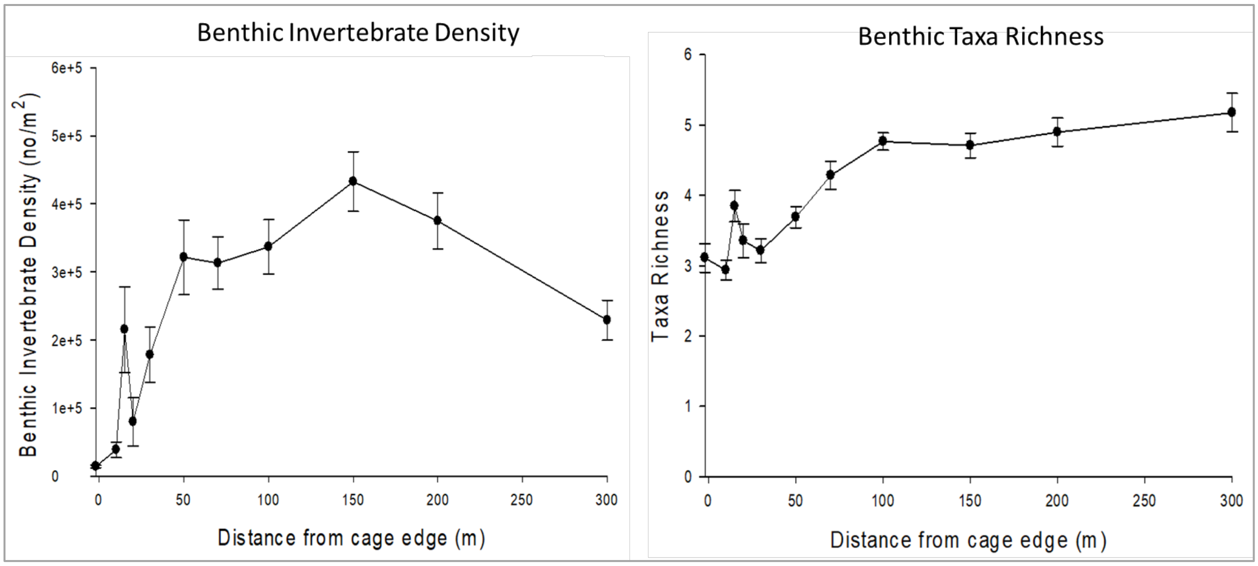

Figure 12: Benthic invertebrate density (number of organisms per m^2) and taxa richness at Lake Diefenbaker with increasing distance from the net pens (cages). Data from DFO sampling, provided by Wild West Steelhead.

These results show a quite low invertebrate density directly below the net pens, but the density increases rapidly and exceeds the reference density value (sample at 300 m) within 50 m of the net pens. Beyond approximately 40 m of the net pens, the density continues to exceed that of the 300 m location, indicating that there must be some increased sedimentation of fish farm wastes or their decomposition products at these distances (i.e., enrichment). Despite the artificial nature of the reservoir, minimizing benthic impacts remains important to optimizing the ongoing ecosystem services provided by it.

In Lake Huron, an example of independent benthic monitoring data provided for the Fisher Harbour site shows a similar pattern from 12 near-site sampling stations distributed between 15 m and 45 m from the net pens (18 m to 24 m depth). These stations are intended to focus on the primary expected area of deposition and are compared to seven reference sites (pers. comm., S. Higgins, Cole Munro, October 2023). Sediment chemistry results (from an independent laboratory) show the expected increases in the near-field station, with an average of 4.8 times higher P than the average of the reference stations (Figure 13). Total nitrogen is also substantially elevated (2.6 times the reference stations), and organic carbon and zinc are also slightly elevated. Copper levels are reduced at the near-field sites.

With regard to the macroinvertebrate community, Figure 14 shows that, in the near-field stations, the community had a greatly increased number of worms (38,673 per m^2) compared to the reference stations (4,198 per m^2), but a reduced numbers of insects and no detections of amphipods, isopods, or water mites that were present at a low abundance at the reference stations.

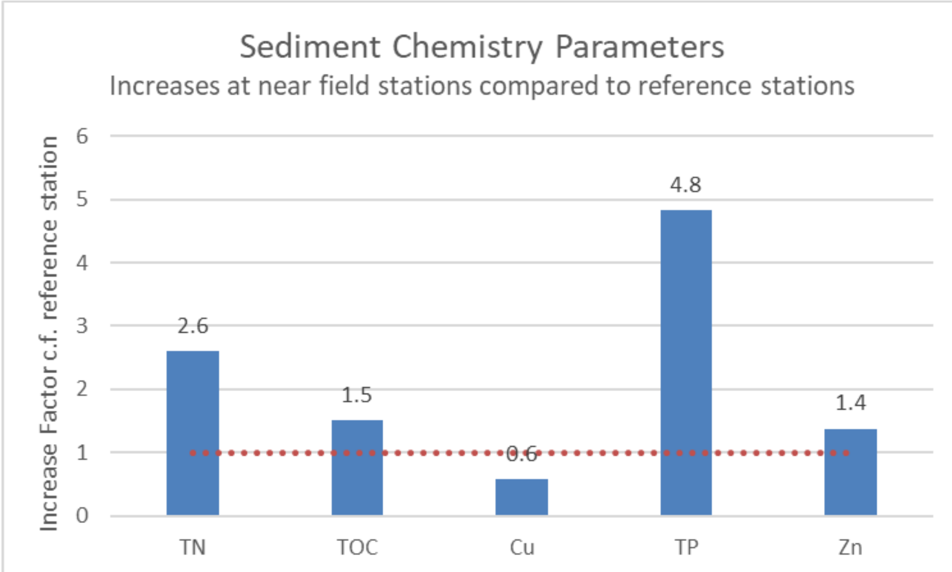

Figure 13: Sediment chemistry parameters comparing the increase in near-field values to reference station values at Fisher Harbour in Lake Huron (i.e., if the near field value was double the reference station, then the value shown here would be 2.0; if they were the same, the value would be 1.0—shown by the dotted line). TN: total nitrogen; TOC: total organic carbon; Cu: copper; TP: total phosphorous; Zn: zinc). Data provided by Cole Munro.

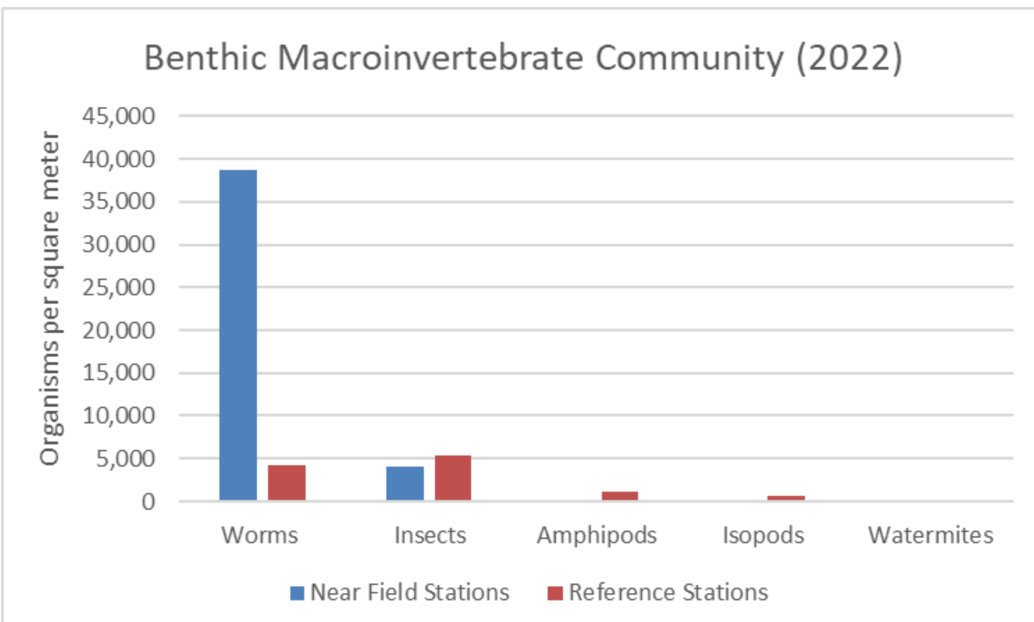

Figure 14: Benthic macroinvertebrate community structure (species groups and abundance in organisms per m^2) at the near-field and reference stations at Fisher Harbour in Lake Huron. Data provided by Cole Munro.

Although these results at Fisher Harbour do not allow an understanding of any potential impacts beyond the near-field sampling stations, one of the stations at 25 m was considered by the analytical laboratory to be demonstrably beyond the primary settlement zone (due to reduced chemistry values and benthic community; that is, the benthic community was not enhanced compared to the reference stations due to a lack of deposition of fish farm nutrients).

As noted, the aquaculture license conditions in Ontario specify that, in the event that sediment monitoring results fail the license requirements (listed in Schedule D of the aquaculture license), the annual feed allocation for the farm will be reduced (i.e., reducing the scale of production).

Regarding deepwater and benthic oxygen levels, it has been demonstrated that, in poorly flushed sites, the decomposition of rainbow trout effluent wastes (which have a high biological oxygen demand) can contribute to or cause deepwater anoxia (e.g., in the case of Lake Wolsey, discussed separately). An analysis of publicly available oxygen monitoring data from the Ontario Aquaculture Reports website (in addition to more recent data provided by the companies) shows a greater variation of oxygen levels at depth compared to the surface (consistent with seasonal water turnover patterns), but no indication of significantly reduced oxygen levels at depth. An example of an annual oxygen monitoring dataset for 2022 for a site in Lake Huron (Eastern Island, selected at random) is shown in Figure 15. The minimum dissolved oxygen value in the 2022 dataset at this site was 7.4 mg/l.

According to the Ontario aquaculture license conditions, in the event that deepwater oxygen drops below Provincial Water Quality Objectives (PWQOs—listed in Schedule B of the aquaculture license conditions), then the lake manager[26] must be informed and feeding must immediately be reduced to a maintenance ration while further monitoring and potentially reduced feeding measures are established.

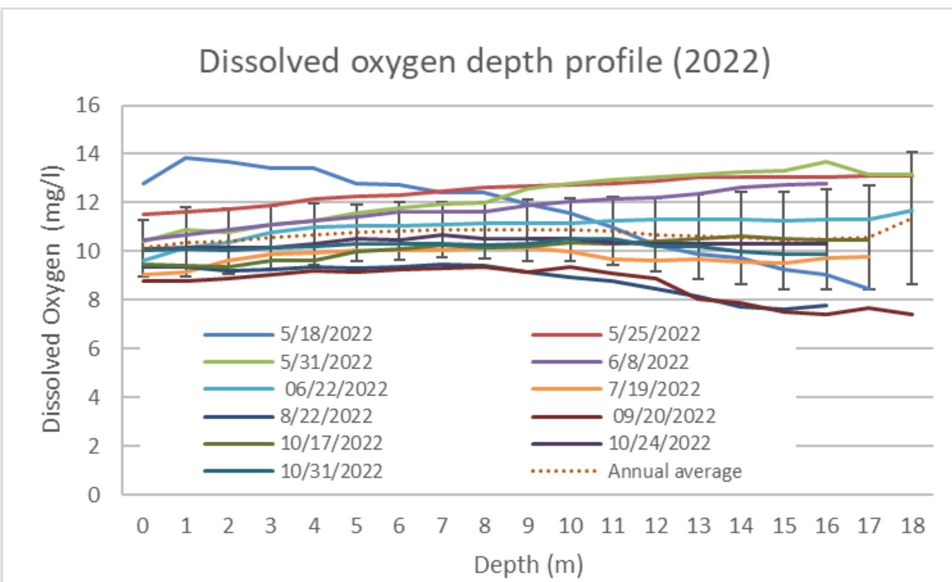

Figure 15: Dissolved oxygen depth profile at Eastern Island farm site on 11 sampling occasions in 2022. The annual average is shown by a dotted line, with error bars of one standard deviation. Data provided by Cole Munro.

[26] In the case of Lake Huron, the lake manager is the Upper Great Lakes Management Unit Lake Manager of the Ministry of Natural Resources and Forestry.

Overall, the benthic monitoring results reflect the established academic literature and demonstrate a limited zone of deposition around the net pen rainbow trout farms. This has a negative effect on the benthic community in the immediate area (reduced abundance and diversity), but this returns to reference values within approximately 40–50 m of the net pens. The increased abundance of organisms seen beyond that area also indicates some deposition of primary wastes or secondary wastes (e.g., settling phytoplankton), and therefore an impact of the farm; however, this is considered here to be a minor impact. Although these impacts could be reversed by removing the farm (or potentially by extended fallowing), and therefore could be considered temporary, they are more appropriately considered to be continuous regarding the ongoing farm operations. The total area affected is minor compared to the occupied embayments or the larger Lakes Huron and Diefenbaker, and farms are sufficiently separated (or solo) that there are not considered to be any cumulative benthic impacts between farms.

Net pens: Changes to fish populations
In a whole-ecosystem experiment to study impacts of freshwater aquaculture on fish communities, Rennie et al. (2019) observed "significant and dramatic effects of aquaculture on fish populations" and noted that this was largely consistent with expectations of effects due to nutrient additions from feed and wastes from the farmed rainbow trout in an experimental lake in Canada. The effects were species-specific: for example, prey species such as minnow species increased dramatically during the production phase but declined sharply after it ceased, and white sucker (*Catostomus commersonii*) abundance and body condition declined during and after aquaculture. The adult abundance of lake trout (*Salvelinus namaycush*) doubled during aquaculture, due to increased growth rates of young trout combined with earlier age and larger sizes at maturation. During 4 years of production in the experimental lake, the optimal oxy-thermal habitat and densities of freshwater opossum shrimp (*Mysis diluviana*) declined dramatically, and both measures show continued impairment a decade after the end of the experiment.

These experimental observations are noted (in addition to other related studies such as Wellman et al. 2017); however, as discussed previously (regarding the worst-case scenario of the experiments in the small experimental lakes), there is a challenge in translating these findings to the commercial production at more open sites in the broader Lake Huron ecosystem (or Lake Diefenbaker). It appears likely that these aspects will be expressed to some extent, but like other effluent impacts, perhaps less intensely than in the small experimental lakes.

Net pens: Lake Wolsey
The rainbow trout farm at Lake Wolsey on Manitoulin Island (Lake Huron) represents a small portion of the total production of Ontario and of Canada. For example, although the current production is not publicly available, studies of the lake in 2016 and 2019 used an estimated annual feed input of 375 mt[27] (Diep and Boyd, 2016)(Diep and Boyd, 2019)(Diep et al., 2019). As noted, the farm had an official closure order in 2020, but has continued to operate under an agreement with its host, the Sheshegwaning First Nation. Anecdotal evidence indicates that

[27] A range of 212 mt to 468 mt was reported (Diep and Boyd, 2019).

current and/or future production may have recently been reduced or even ceased (pers. comm., Rupert Kindersley, Georgian Bay Association, September 2023)(pers. comm., RJ Taylor, OAA, October 2023). Lake Wolsey is relatively self-contained and connected to the larger Lake Huron via the North Channel through an artificial causeway, with variable flow/flushing rates according to lake levels.

In a 2014 expert peer-review meeting on the ecosystem impacts from dissolved and particulate waste phosphorus from freshwater cage aquaculture, the Lake Wolsey site was described as an oddball in the whole group of farms from the North Channel in Lake Huron (DFO, 2015). Nevertheless, as the sole example of a farm in a Type 2 location in Lake Huron,[28] and a focus of industry criticism, it is necessary to address the site here. The primary anecdotal concerns are an accelerating series of blue-green algae (cyanobacteria) blooms, including every year from 2015 to 2018 (GBA, 2021), in addition to a more comprehensively studied deepwater anoxia phenomenon described in the following.

The review of Otu et al. (2017a) also devoted a specific section to Lake Wolsey, but the series of reports by Diep and Boyd, who studied the water quality and nutrient loading sources in the lake, are referred to here (Diep and Boyd, 2016a,b; 2019; Diep et al., 2019; published by the Ontario Ministry of Environment, Conservation and Parks). Again, it is not the intent to review or replicate the content of these comprehensive assessments, but rather to provide salient findings and conclusions.

In brief: the historical and current limnological conditions indicate that, although Lake Wolsey is a clear water, mesotrophic system with moderate productivity, the water quality has declined and the lake is experiencing significant eutrophication effects with recent and severe dissolved oxygen depletion and extensive hypolimnetic[29] anoxia, which has not been observed historically. According to Diep and Boyd (2019), an evaluation of the current and historical temperature and dissolved oxygen (DO) profile data indicate that changes in the DO condition have occurred over time, with progressively more severe hypolimnetic DO depletion leading to anoxia in the mid-2000s. Widespread DO depletion and anoxia (where the hypolimnion is depleted of oxygen with limited or no oxygenated cool/cold water habitat anywhere in the lake) is a recent occurrence, and after the mid-2000s a near-absence of oxygen throughout the entire hypolimnion began to be observed.

Nutrient source loading assessments (Diep and Boyd, 2016a, 2019) showed that the rainbow trout farm was the main industrial activity in the watershed of Lake Wolsey, representing 44% of the annual phosphorous load to the lake (34% as particulate P, and 10% as dissolved P; Figure 16); thus, the trout farm was also the largest contributor of high biochemical oxygen demand (BOD) organic materials to the lake, and particularly to the deep hypolimnion.

[28] Lake Wolsey is described as a semi-enclosed embayment of the Great Lakes, located on Manitoulin Island in the North Channel.
[29] Hypolimnium: the dense, bottom layer of water in a thermally stratified lake.

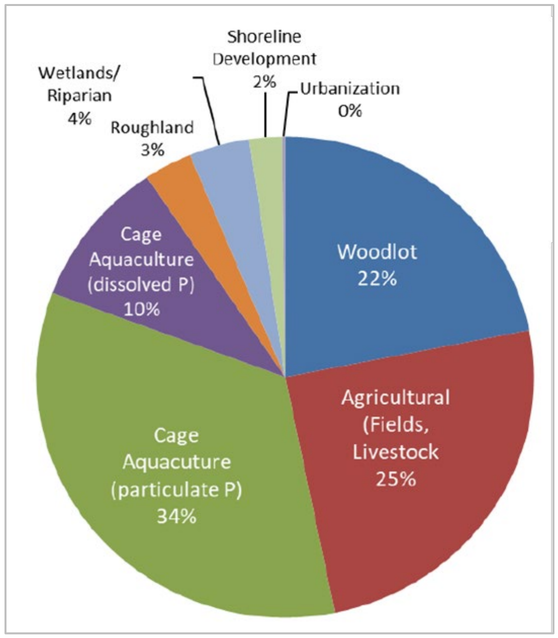

Figure 16: Allocation of phosphorus load to land-use categories and sources in Lake Wolsey and its watershed. Image and title reproduced from Diep and Boyd (2019).

The water quality in the lake continues to be monitored as part of the farm's arrangement with the Sheshegwaning First Nation, although results are not yet available (pers. comm., N. Rooney, University of Guelph, October 2023). It is also noted that, due to the decreased production and the introduction of nonnative dreissenid mussels, the lake is recently considered to have returned to an oligotrophic state (pers. comm., S. Naylor, DFO, November 2023).

The available information indeed defines the Lake Wolsey rainbow trout farm as somewhat of an outlier or anomaly among other net pen trout farms in Canada (with the possible exception of the former floating tank farm in Lois Lake, British Columbia), in that it is sited in a Type 2 location with limited deepwater flushing. Thus, with particular attention to the minor, reduced, and/or ceased production status, the farm plays a minor role in the scoring of this criterion.

Net pens: Conclusions and final scores

Water quality monitoring data for rainbow trout farms in Lake Huron and Lake Diefenbaker reflect the typical findings of the academic literature, with some samples showing elevated levels of nitrogen and phosphorous in the water column in the immediate farm area (within 50–100 m) compared to reference stations. Nevertheless, even the elevated values continue to reflect the natural trophic state of the relevant waterbodies. Similarly, the benthic monitoring results from farms in Lake Huron and Lake Diefenbaker also reflect the established academic literature and demonstrate a concentrated zone of deposition around the net pens. This has a negative effect on the benthic community in the immediate farm area (reduced abundance and diversity of benthic macroinvertebrates, with abundance approaching or reaching zero directly under the net pens), but these impacts return to reference values within approximately 50 m of the net pens. The increased abundance of organisms beyond approximately 50 m (compared to more distant reference stations) also indicates some minor benthic enrichment from primary wastes or secondary products (e.g., settling phytoplankton) at greater distances (>200 m), and therefore a broader impact of the farm; however, this is considered here to be a minor impact. If the farms were moved, removed, or fallowed for long periods, it could be argued that the localized impacts are temporary, but in light of the farms' ongoing operation, the impacts are considered to be continuous. Deepwater oxygen depletion has been demonstrated in sites that have little water exchange at depth (Type 1 and 2 sites), and two such sites in Canada were closed in the late 1990s. One Type 2 site in Lake Wolsey (in Lake Huron) may still be operational at a quite small scale, but is considered to be an anomaly among all other sites in Type 3 locations that have sufficient flushing to ensure that significant water quality impacts are unlikely. The total area affected by the current farms in Lakes Huron and Diefenbaker is minor compared to the occupied embayments or to the lakes as a whole, and farms are sufficiently separated (or solitary, in the case of Lake Diefenbaker) that there are not considered to be any cumulative impacts between farms. Overall, there are considered to be ongoing impacts in the immediate vicinity of the farm, but no significant contributions to cumulative impacts at the waterbody or regional scale. Therefore, the final score for Criterion—2 Effluent, for net pens, is an intermediate 7 out of 10.

Land-based systems: Risk-based assessment

In contrast to the data and academic studies relating to net pen trout farms available for this assessment from public sources and particularly from the industry, there are few data and little demonstrably relevant academic research available from raceway, pond, and tank farms. This is due to the small scale of production and the way these farms are regulated; for example, the entire aquaculture production of Quebec (all land-based) of 839 mt in 2022 came from 50 farms (an average of 16.8 mt per farm) (pers. comm., M. Debasly, TFADQ, June 2024). Based on the regulatory system (a description follows), a reliable representation of these small operations and their impacts can be deduced, and the data score for effluent in Criterion 1—Data is 7.5 out of 10. Although the evidence assessment could be used (i.e., the data score is >5 out of 10), the lack of readily available, specific impact-monitoring data, plus the reliance on the management aspects, mean that the risk-based assessment is more appropriate. This method involves assessing the amount of waste produced by the fish, then the amount of that waste that is discharged from the farm. The effectiveness of the regulatory system in managing waste from multiple farms is used to assess the potential cumulative impacts from the industry as a whole.

Factor 2.1 in the Seafood Watch Aquaculture Standard uses nitrogen as a proxy for nutrient dynamics, due to the ability to readily assess nitrogen inputs and outputs from the protein content of feed and of harvested fish. But phosphorous may be the main driver of impacts in some environments, particularly freshwater. Because of the focus of the regulatory framework in Quebec on phosphorous, plus the availability of specific phosphorous profiles for rainbow trout wastes, both nutrients are used to determine the appropriate production system discharge score (Factor 2.1b).

Factor 2.1—Waste discharged per ton of fish production (raceways, ponds, tanks)

Factor 2.1a—Biological waste production per ton of fish

This section considers the nutrient inputs in feed and the outputs in harvested rainbow trout, and therefore the initial net waste production per ton of farmed trout.

Nitrogen inputs—feed

As discussed in Criterion 5—Feed, the average total protein content of feed is 41.5%, and with a protein-nitrogen factor of 1.6 (i.e., protein is 16% nitrogen), there is approximately 66.4 kg N per mt of feed. With an economic feed conversion ratio (eFCR) of 1.36 (also discussed in Criterion 5), there is a nitrogen input of 90.3 kg N per mt of trout production.

Nitrogen outputs—harvested trout

Regarding the protein outputs in harvested trout, the whole-body protein content of *Oncorhynchus mykiss* is 15.7% (Dumas et al., 2007), so using the same protein-nitrogen factor of 1.6, there is a protein output of 25.1 kg N per mt of trout production.

By comparing the protein outputs and inputs, there is a net nitrogen waste production of 65.2 kg N per mt of rainbow trout production. This is consistent with the nitrogenous waste loadings for rainbow trout stipulated by Diep and Boyd (2019), who stated a range of 53.0 to 67.5 kg N per mt of production,[30] based on an eFCR of 1.3.

Factor 2.1b—Production system discharge

It is likely that raceway, pond, or tank-based rainbow trout farms in Canada use a variety of water flow characteristics, from flow-through to high recirculation (noting again that recirculating farms are not included in this assessment). In addition, it is likely that they use a variety of water treatment processes to reduce the amount of waste directly discharged in effluent water. Though the specific effluent reduction methods may vary between farms, the primary discharge characteristic of land-based farms in Quebec is that they must meet the phosphorous discharge limits of 4.2 kg P per mt of trout production in their permits (in addition to other restrictions based on the receiving water of the farm, as discussed in Factor 2.2).

In practice, this is done with low-P feeds, plus the collection of P-rich particulate wastes (sludge) in settling ponds or other collection methods (for example, the Commercial Aquaculture Regulations[31] require all farms to collect solid wastes between harvest and subsequent restocking; Chapter 5, Section 2.6). Although Factor 2.1b is based on nitrogen, the value of 4.2 kg P per mt of trout production allows some simple calculations to determine equivalent discharge characteristics. For example, according to Diep and Boyd (2019), rainbow trout culture produces a total P load of 6.2 to 11.3 kg P per mt of production, or an average of 8.75 kg P per mt (based on standard feeds, 1% feed waste, and an eFCR of 1.14). Previously, the

[30] Diep and Boyd (2019) stated a range of 32 to 44 kg dissolved N per tonne feed used and 7.8 to 7.9 kg particulate N per tonne feed used. Using an eFCR of 1.3, these values equate to the nitrogenous waste per mt of trout production stated in the text.

[31] https://www.legisquebec.gouv.qc.ca/fr/document/rc/A-20.2,%20r.%201?langCont=fr#ga:l_i-h1

2010 Sustainable Development Strategy for Freshwater Aquaculture in Quebec (Stratégie de développement durable de l'aquaculture en eau douce au Quebec [STRADDAQ])[32] used an estimated average annual P release from aquaculture farms (all species) of 7.2 kg per mt of production. Based on the more recent rainbow trout-specific value from Diep and Boyd (2019), the requirement to reach 4.2 kg P per mt means that, on average, 48% of the P typically generated as waste by the rainbow trout must be removed before discharge.

Given that P is the primary impact concern for aquaculture discharges in freshwater (and is the driver of the regulatory system described in Factor 2.2), the typical 48% reduction in the typical nutrient wastes produced by the rainbow trout (and therefore the reduction in the primary potential effluent impact risk) can be applied equally to the nitrogen that is used to drive the scores in the Seafood Watch standard. Therefore, land-based farms are considered here to operate with a production system discharge (Factor 2.1b) of 0.52; that is, 52% of the waste produced by the fish (equivalent to 33.9 kg N per mt of production calculated in Factor 2.1a) is considered to be discharged from the farm. This results in a score for Factor 2.1—Waste Discharge of 6 out of 10.

Factor 2.2—Management of farm-level and cumulative impacts (raceways, ponds, tanks)
Given that the majority of Canada's land-based rainbow trout farms operate in Quebec, this province is the focus of this assessment, but aspects of Ontario's management are included.

<u>Factor 2.2a—Content of effluent management measures</u>
Quebec's Ministry of the Environment, the Fight Against Change Climate, Wildlife and Parks (Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs [MELCCFP]) states[33] that, since the early 1980s, Quebec has made staunch efforts to prevent the pollution of rivers and lakes by phosphorus (P), and currently the province operates under the 2018–2030 Quebec Water Strategy[34] (la Stratégie québécoise de l'eau [SQE] 2018–2030).

The MELCCFP provides an overview of the regulatory framework for aquaculture,[35] listing 13 acts and regulations. Although these are somewhat voluminous and complex, explanations and clarifications were provided by staff at the MELCCFP (pers. comm., Anon, MELCCFP, June 2024), and a summary document plus other guidance documentation are available from MELCCFP.[36]

An aquaculture site is defined within, and the rules governing their establishment and operation are laid out in, the Regulation of Activities Based on their Impact on the Environment (Règlement sur l'encadrement d'activités en fonction de leur impact sur l'environnement [REAFIE]).[37] This forms part of the Law on the Quality of the Environment (Loi sur la qualité de

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[32] https://www.environnement.gouv.qc.ca/milieu_agri/aquacole/Straddaq_2010.pdf
[33] Nutrients in waterbodies and watercourses (gouv.qc.ca)
[34] https://www.environnement.gouv.qc.ca/eau/strategie-quebecoise/
[35] Aquaculture - Regulatory Framework (gouv.qc.ca)
[36] https://www.environnement.gouv.qc.ca/milieu_agri/aquacole/recapitulatif-formulaires-projet-aquacole.pdf
[37] https://www.legisquebec.gouv.qc.ca/fr/document/rc/Q-2,%20r.%2017.1

l'environnement).[38] In addition, the Commercial Aquaculture Act (Loi sur l'aquaculture commerciale) and the Commercial Aquaculture Regulations (Règlement sur l'aquaculture commerciale) relate primarily to farm licensing processes and administrative measures.

Under the REAFIE, in order to establish an aquaculture farm, a potential trout farmer must obtain authorization from the Minister of the Environment, through a process of applications that include detailed infrastructure plans showing the size and characteristics of the production units, water flow characteristics, water treatment, and waste disposal. Applications are submitted through various documents, including the following (Table 1) selected for their relevance to this Effluent criterion. The related activities in Table 1 are simplified for clarity, and more details can be found in the regulations referenced above, or in a summary document from MELCCFP. (Note: AM refers to Autorisation Ministérielle, or Ministerial Authorization.)

Table 1: Selection of relevant ministerial authorizations associated with the REAFIE. Note: the related activity description is simplified for clarity, and full details can be found in the MELCCFP summary document referenced in the text, or the associated legislation.

Application	Related activity
AM159	Implementation and operation of the site Storage of sludge before treatment
AM204	Treatment of wastewater
AM18d	Discharge of effluent
AM18b	Impact on surface water, groundwater, and soil
AM168	Water sampling
AM16c	Identification of activities and impacts in relation to waste disposal, including fish sludge
AM245	Disposal of aquaculture sludge and other residual materials, including as fertilizer
AM245a	Mechanical, chemical, or biological treatment applied to sludge and other residual organic matter
AM22a	Handling of slaughtering wastes and release of contaminants

During operation, the primary measures relating to effluent discharges and their potential impacts are an Environmental Target (Cible Environnementale de Rejet [CER]) and an Environmental Discharge Objective (Objectif Environnementaux de Rejets [OER]), in combination with zoned areas of surplus P in Quebec, as discussed in the following.

As noted in Factor 2.1, the Environmental Target (CER) is a relative phosphorous discharge limit of 4.2 kg P per mt of aquaculture production. This applies in all cases and is based on previous requirements within the 2010 Sustainable Development Strategy for Freshwater Aquaculture in Quebec (Stratégie de développement durable de l'aquaculture en eau douce au Quebec [STRADDAQ]). Given that Diep and Boyd (2019) estimated that rainbow trout culture produces a total P load of 6.2 to 11.3 kg P per mt of production, or an average of 8.75 kg P per mt, the value of 4.2 kg P per mt of production represents a strict limit on discharges (pers. comm., M.

[38] https://www.legisquebec.gouv.qc.ca/fr/document/lc/Q-2

Debasly, TFAEDQ, June 2024). Previously, Lefrançois et al. (2010) had described similar limits at that time as "stringent." In practice, this limit can be achieved by reducing P inputs (low P feeds and improved feed conversion ratios) or by reducing P outputs through various options for filtration, sedimentation (settling ponds), or other forms of treatment.

The level of 4.2 kg P per mt is a relative limit, but for existing farms wishing to increase production, the total discharge per year is also addressed with a cap on total production, based on the type of farm, where Type 1 produces <5 mt per year, Type 2 produces between 5 mt and 20 mt, and Type 3 produces >20 mt per year. But the maximum discharge is capped at 20 mt × 4.2 kg $P.mt^{-1}$ or 84 kg P per year, so a larger farm requires more complex measures to reduce its P waste production and/or discharge.

In addition to the Environmental Target, the Environmental Discharge Objective (OER) relates to the concentration of phosphorous in the receiving water, which must not exceed 0.03 mg /L or 0.02 mg/L in any environment deemed sensitive by the MELCCFP (for example, fish spawning grounds). But within this limit, the OER is specific to each farm application and is derived from the calculation of the concentrations and loads of contaminants that can be discharged into an aquatic environment without compromising water uses and aquatic life; i.e., the carrying capacity of the receiving water (pers. comm., Anon, MELCCFP, June 2024).

The main decision tool for establishing the limits for each farm application is an Environmental Analysis Matrix[39] for fish farms based on total P (Grille d'analyse environnementale pour les piscicultures en fonction des rejets en phosphore total). This was developed in 2014 and informed by STRADDAQ, and is still active today.[40] The decision matrix was designed for flow-through fish farming projects involving the rearing of domesticated salmonids in which their effluent is discharged into different freshwater aquatic environments, and relates to any planned increases in production at existing farms or the establishment of new farms. The full methodology is available (in French), referenced here as MELCC (2014).

The salient aspects of the decision-making matrix relate to the type of categories of environment where the discharge is located, and the maximum amount of phosphorous discharged. Receiving waters are categorized as follows:

1. lakes, reservoirs, and enclosed bays
2. upstream of lakes, reservoirs, and enclosed bays
3. watercourses where the watershed has an area of 5 square kilometers or less upstream of the discharge point
4. watercourses designated as phosphorus surplus watersheds

[39] https://www.environnement.gouv.qc.ca/milieu_agri/aquacole/mesures-encadrement.htm

[40] According to the Ministry of the Environment website accessed October 20, 2023. Aquaculture - Other Framework Measures (gouv.qc.ca)

5. watercourses with a particular use to be protected (spawning ground, water intake, beach, etc.).
6. other watercourses.

At the regional level, both the Environmental Target and the Environmental Discharge Objective are applied according to the farm's (or proposed farm's) location relative to Quebec's watercourses designated as Phosphorous Surplus (Figure 17). This zone includes the majority of the population of Quebec and approximately 80% of its fish farms (pers. comm., G. Castro, MAPAQ, October 2023) (and note the rainbow trout aquaculture zone discussed in the following). For existing farms in the surplus zone, they can only expand to a maximum of 20 mt annual production, unless they are able to maintain P discharges at the equivalent of 20 mt at an Environmental Target of 4.2 kg $P.mt^{-1}$ (84 kg P per year as discussed previously) and meet the Environmental Discharge Objective. The establishment of any new fish farm with discharge into a watercourse in the P surplus zone is normally prohibited, whereas outside the P surplus zone, compliance with OER and CER are the main standards to respect (pers. comm., G. Castro, MAPAQ, October 2023).

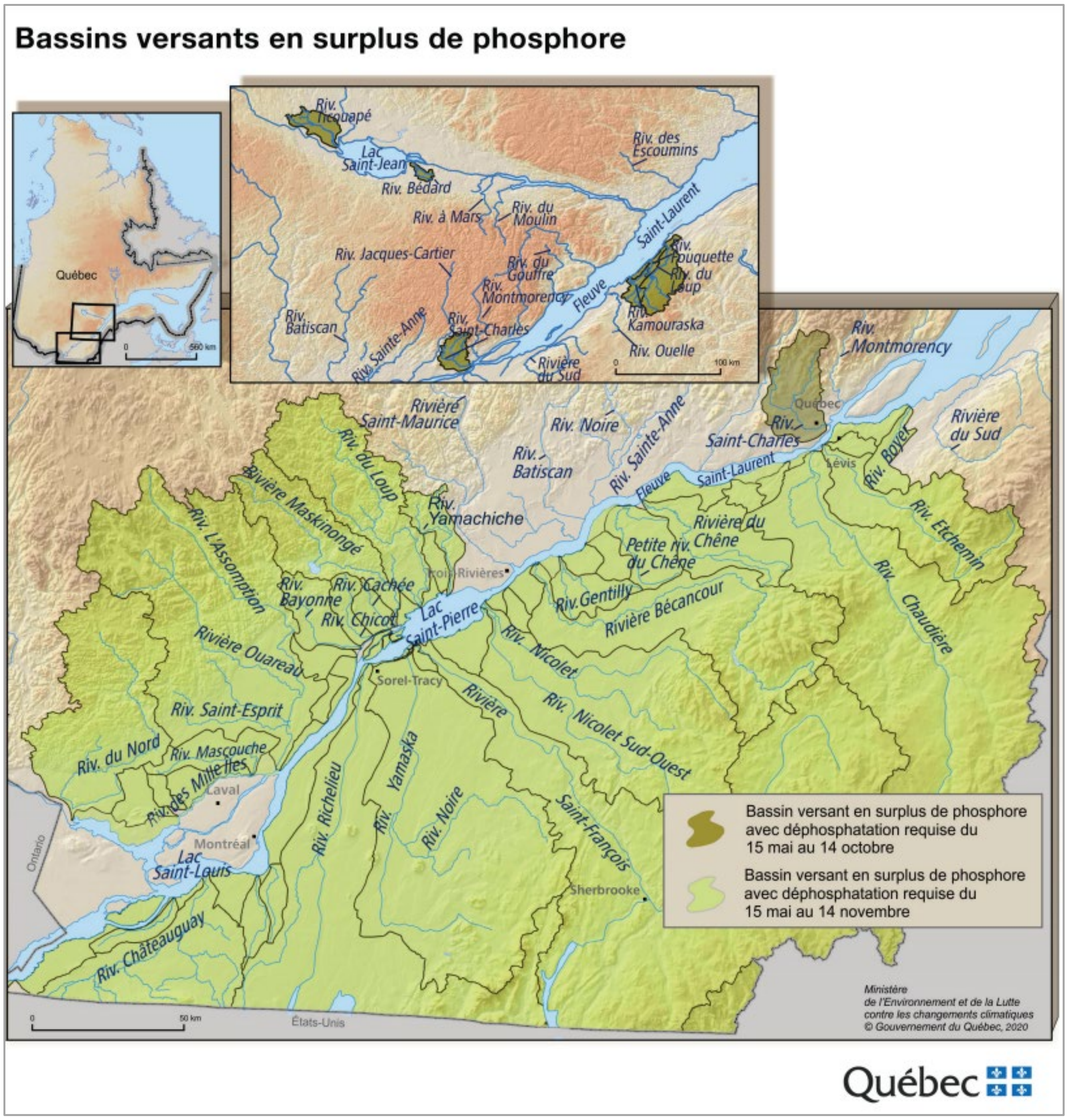

Figure 17: Quebec's surplus phosphorous watersheds. Green areas denote watersheds with surplus phosphorous and phosphorous removal. Map available from MECCLFP.[41]

Quebec also has a species-specific aquaculture zoning system in place[42] (Figure 18) which relates primarily to the species being cultured and the desire not to increase the ranges of nonnative species through aquaculture or stocking of waterbodies for sport fishing. But it can be seen that rainbow trout farming is largely restricted to the P surplus zone, and therefore must comply with the relevant restrictions described previously.

[41] https://www.environnement.gouv.qc.ca/eau/eaux-usees/reduc-phosphore/bv-surplus-phosphore.pdf

[42] https://www.quebec.ca/agriculture-environnement-et-ressources-naturelles/faune/gestion-faune-habitats-fauniques/ensemencement-plans-eau/encadrement

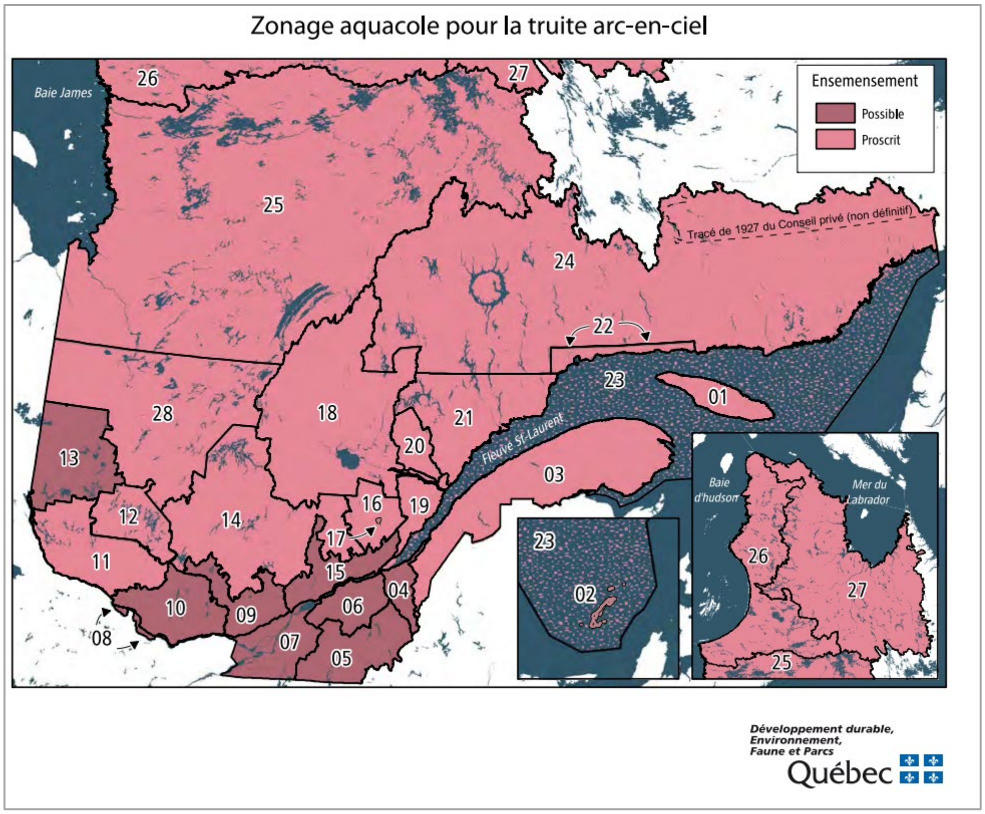

Figure 18: Quebec's permitted zones for the culture of rainbow trout shown in darker red in the SW of Quebec. Map reproduced from Supervision of the seeding of water bodies | Government of Quebec.

Briefly regarding Ontario, all land-based fish farms must have an Environmental Compliance Approval (ECA) from the Ontario Ministry of the Environment, Conservation and Parks (MECP), which dictates water quality parameters (notably total suspended solids and total phosphorus), guidelines, and sampling/reporting frequency. This information must be reported to the Ministry, and as noted, a request for this data has not yielded results at the time of writing.

Overall, the dominant land-based production region of Quebec has substantial measures in place to manage effluent discharges from aquaculture at the farm level, and in relation to the receiving waterbody and broader phosphorous-surplus zones at the regional level. These demonstrate that Quebec has a system that sets relative and farm-specific effluent limits that consider the carrying capacity of the receiving environments, and that this is applied at an area-based cumulative management system that considers other industries and/or sources of phosphorous. Thus, the score for Factor 2.2a: Content of effluent management measures is 5 out of 5.

Factor 2.2b: Enforcement of effluent management measures

Under REAFIE (Article 18a) an applicant for a new farm in Quebec (or expansion to an existing farm) must include a description of the proposed monitoring, maintenance, surveillance, and control measures. Within the ministerial authorization (under Article 25a), this may be accepted, modified, or a new environmental monitoring program prescribed. Such a monitoring program may include (but is not limited to) the following:

- The P content of feed (records of analysis)
- Feed quantities
- Effluent flow rates and temperatures
- Fish production records
- Sludge management records
- pH
- Records of chemicals or prophylactics
- Records of suspended solids in the effluent

The MELCCFP's Environmental Control Center is responsible for compliance inspections in Quebec, which are primarily based on monitoring of annual reports from farms. Briefly, in Ontario, a similar process in the MECP generates Environmental Compliance Approvals (pers. comm., S. Naylor, DFO, June 2024). It is relevant to note that the current requirements for enforcement of the effluent limits in Quebec (established in the 2010 STRADDAQ process) were supported by extensive monitoring and compliance testing of farms in Quebec between 2010 and 2016, with analysis by MAPAQ and MELCCFP (pers. comm., M-E. Carbonneau, MAPAQ, May 2024).

While the Law on the Quality of the Environment allows some citizen access to documents held by public bodies, and it is possible to make information requests, this is limited by a protection of personal information; instead, the public Register of Administrative Monetary Penalties (Registre des sanctions administratives pécuniaires [SAP]) was used here to identify evidence of enforcement. The register is updated monthly, and though it is unwieldy to search (due to the volume of records, translation, and the limited use of aquaculture-relevant keywords in the records[43]), some aquaculture-related records could be identified (Table 2).

Table 2: Selection of aquaculture-related infringements in Quebec's Register of Administrative Monetary Penalties (SAP) (searched June 28, 2024, using various aquaculture-related search terms for the years 2017 to 2024, in addition to specific SAP numbers provided as examples by MECCFLP).

SAP#	Year	Penalty ($ CAN)	Nature of breach
402047567	2021	2,500	Failure to submit records
402026741	2021	500	Failure to submit records
402006815	2021	5,000	Failure to submit records
401745435	2018	2,500	Lack of flow meters on intake

Searches under the relevant regulatory articles of the Environmental Quality Act did not provide additional aquaculture-related results (e.g., Article 20: discharge of a contaminant;

[43] Records could be found using terms such as "pisciculture" (aquaculture) only if they appeared in the company/person name. The "nature of breach" section was mostly composed of legal references, or used language that could not be identified to aquaculture, for example, failure to submit environmental monitoring data.

Article 22: activity carried out without authorization; Article 30; activity incompatible with the authorization; and Article 123.1: noncompliance with the conditions of authorization). Various other infringements relating to the operation of ponds could be identified (searching for étang in French[44]) but aquaculture-specific records could not be distinguished (e.g., from agricultural irrigation ponds). Overall, these results support a finding that enforcement is active, and infringements relating to aquaculture are uncommon and mostly related to failures to submit monitoring records.

At the regional level, it is clear that government of Quebec plays an active role in freshwater management, and (for example) has a substantial water quality monitoring system as illustrated by publications such as the Report on the State of Water Resources and Aquatic Ecosystems in Quebec (MELCCFP, 2020) or the Canadian Environmental Sustainability Indicators: Nutrients in the St. Lawrence River report (ECCC, 2021). Given the dominant concerns in these reports regarding agricultural and urban impacts on nutrient and pesticide levels in freshwater ecosystems (attributable mainly to field crops including corn and soybean, and high concentrations of livestock in some watersheds), there are no details relating to the small production scale of rainbow trout farms. Anecdotally, the 2018–30 Quebec Water Strategy (MELCCFP, 2018) notes that measures under the sustainable development strategy for freshwater aquaculture (STRADDAQ) have reduced phosphorus emissions from the aquaculture sector (all species) by 40% in recent years.

Overall, enforcement is considered to be comprehensive, with activities related to the farm level, receiving waters, and the regional level. The process is intended to be transparent, and evidence of penalties for infringements is available. Thus, the score for Factor 2.2b is 5 out of 5. Combined with the Factor 2.2a score of 5 out of 5, the final Factor 2.2 score is 10 out of 10. It is also noted that the content and application of these comprehensive regulations is considered a dominant factor in the small scale of the aquaculture industry in Quebec in terms of farm sizes and numbers (pers. comm., M. Debasly, TFAEDQ, June 2024).

Land-based systems: Conclusions and final score

In contrast to the availability of effluent and water quality monitoring data relating to net pen trout farms, there are few data or demonstrably relevant academic research available from land-based farms; this is most likely the result of the small scale of operation in Quebec and Ontario (mostly in the former). Thus, the risk-based assessment was used, for which the efficacy of the regulatory management system for effluent is a key aspect (using Quebec as the primary example and the Regulation of Activities Based on their Impact on the Environment [REAFIE]). Using phosphorous (P) as the dominant effluent concern in freshwater environments, the management system in Quebec sets relative P limits (an Environmental Target, or CER in French, defined per mt of production) at the farm level, and defines environmental limits based on the receiving waterbody (the Environmental Discharge Objective, or OER in French). Using recent studies on the typical generation of P wastes by rainbow trout, it can be calculated that

[44] Because of the number of records, the use of online translation engines was not possible in addition to searching.

the CER in Quebec results in a reduction of approximately 48% of the typical rainbow trout P discharge. The CER also acts as a cap on total P discharges from a farm, and results in a waste discharge score (Factor 2.1) of 6 out of 10. The OER applies to the receiving waterbody and operates in combination with zoned areas of surplus P in Quebec at a regional level. In Quebec, the MELCCFP's Environmental Control Center is responsible for compliance inspections (or in Ontario, the MECP), which is based on annual reports from farms and Environmental Compliance Approvals. The Register of Administrative Monetary Penalties (SAP) supports a finding that enforcement is active, and indicates that infringements relating to aquaculture are uncommon and mostly related to failures to submit monitoring records. Overall, these management measures are considered comprehensive, and they are a key factor in the small number and size of land-based fish farms operating today in Quebec. The management effectiveness score (Factor 2.2) is 10 out of 10. Factors 2.1 and 2.2 combine for a final score of 9 out of 10 for Criterion 2—Effluent for raceways, ponds, and tanks.

Criterion 3: Habitat

Impact, unit of sustainability and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical “ecosystem services” they provide.
- Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.
- Principle: being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary

	Net Pens		Land-Based	
C3 Habitat parameters	**Value**	**Score**	**Value**	**Score**
F3.1 Habitat conversion and function (0–10)		9		9
F3.2a Content of habitat regulations (0–5)	4		4	
F3.2b Enforcement of habitat regulations (0–5)	5		5	
F3.2 Regulatory or management effectiveness score (0–10)		8.0		8.0
C3 Habitat Final Score (0–10)		**8.67**		**8.67**
Critical?	No	**Green**	No	**Green**

Brief Summary

Noting that the operational impacts of settling particulate wastes on benthic habitats have previously been addressed in the Effluent criterion, the direct habitat impacts of floating net pens are minimal and can be immediately reversed if desired by removing the structures. Though studies from marine net pen farms describe a range of potential impacts (e.g., increased surface area or shading), there is no evidence that these impacts occur to any significant extent in freshwater lakes. With a small total number of net pen farms in Lake Huron, and a single farm in the dammed reservoir in Saskatchewan, there is a quite limited risk of cumulative habitat impacts. The score for Factor 3.1—Habitat Conversion and Function is 9 out of 10. For land-based systems, the industry is small and stable, indicating that there are unlikely to have been substantial recent habitat impacts resulting from new or expanded sites. A survey of satellite images indicates that farms are located within extensive agricultural and forested landscapes, are widely dispersed, and have been constructed in land historically cleared for agriculture. With minimal impacts to ecosystem services (but some uncertainty across all sites), the score for Factor 3.1—Habitat Conversion and Function is also 9 out of 10.

The three provinces of most interest here have comprehensive regulatory systems involving multiple agencies. For net pens, the focus appears to be on avoiding specific, high-value habitats such as native fish spawning, nesting and nursery grounds, or areas of importance to species at risk. For land-based systems in Quebec, Ministerial Authorizations under REAFIE require examination of any aspects of environmental impact, including habitats and wildlife. Evidence of enforcement activities is also available in the SAP register. In practice, the industry is relatively small and is dispersed over a large area, such that area-based and/or cumulative habitat impacts are highly unlikely. Although the potential for industry expansion in net pens is recognized, examples of feasibility studies for new sites in the Great Lakes (e.g., Thunder Bay in Lake Superior) recognize the complex regulatory systems in place and are currently considering locations far from the existing industry in Lake Huron. With comprehensive systems, the score for Farm Siting Regulation and Management (Factor 3.2) is 8.0 out of 10 for both net pens and land-based systems. Despite their clear differences, neither net pen nor land-based systems have a substantial risk of habitat impacts, and Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 8.7 out of 10 for both systems.

Justification of Rating

Factor 3.1—Habitat conversion and function

Net Pens
In Ontario, most net pen production sites are concentrated around Manitoulin Island in northern Georgian Bay in Lake Huron, with an additional two sites in Parry Sound to the east of Georgian Bay.[45] In Saskatchewan, the single net pen producer is in Lake Diefenbaker, an artificial reservoir created in the 1960s by damming the South Saskatchewan and Qu'Appelle Rivers for hydropower, agricultural irrigation, and municipal water supplies (Carr et al., 2020)(Wikipedia). The previous operation in Lois Lake in British Columbia was also in a dammed reservoir on the Powell River, constructed in 1942. A recent assessment of Ontario's farmed trout sector and market (Rosenstein et al., 2023) considered a growth plan through which the industry could triple production in 5 years. The potential for industry expansion is considered here largely in the context of the abilities of the regulatory and management systems to ensure that it is done in an appropriate manner.

The Great Lakes (of which Lake Huron is one) are one of the world's largest surface freshwater ecosystems and represent approximately 84% of North America's surface fresh water, or about 21% of the world's supply of surface fresh water (EPA, 2023)(SGL, 2022). The Georgian Bay Association describes the Georgian Bay and its North Channel to the Manitoulin Island area as a particularly unique water basin that represents one of the most pristine ecosystems in the Great Lakes, and notes that the eastern side of Georgian Bay, which comprises the Thirty Thousand Islands, marks the largest freshwater archipelago in the world (GBA, 2020). This shoreline is recognized by the United Nations as a World Heritage Site, designated as the Georgian Bay Littoral Biosphere Reserve[46] (GBA, 2020). Two rainbow trout farm sites in Parry Sound fall within the boundary of the reserve but are not in defined core or buffer areas; nevertheless, the importance is clear of the broader habitats and ecosystem where Canadian net pen rainbow trout farms are located.

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[45] Ontario Aquaculture Association. https://ontarioseafoodfarmers.ca/meetfarmers/
[46] https://en.unesco.org/biosphere/eu-na/georgian-bay

In Lake Huron, the aquaculture sites represent a quite small portion of the lake's vast total area of 59,500 km^2 (23,000 mi^2), but are concentrated around Manitoulin Island, and in some cases are separated by only a few miles. In contrast, in Lake Diefenbaker, Wild West Steelhead is the only aquaculture operation in the lake's 225 km length (surface area of 394 km^2) (Carr et al., 2020).

With approximate locations of Ontario sites available from the Ontario Aquaculture Association, and the single company operating in Lake Diefenbaker, the net pen sites can be located on publicly available satellite imaging services (e.g., Google Earth). Specific site locations and diagrams of the net pen arrays in Lake Huron can also be found in the water quality monitoring reports on the Ontario Aquaculture Reports website discussed in Criterion 2—Effluent. An example of a site in Lake Huron (selected at random) is shown in Figure 19, and in Lake Diefenbaker in Figure 20. In the whole-lake context, it is immediately apparent from these images that the direct habitat impacts associated with the construction of the floating farms are minor.

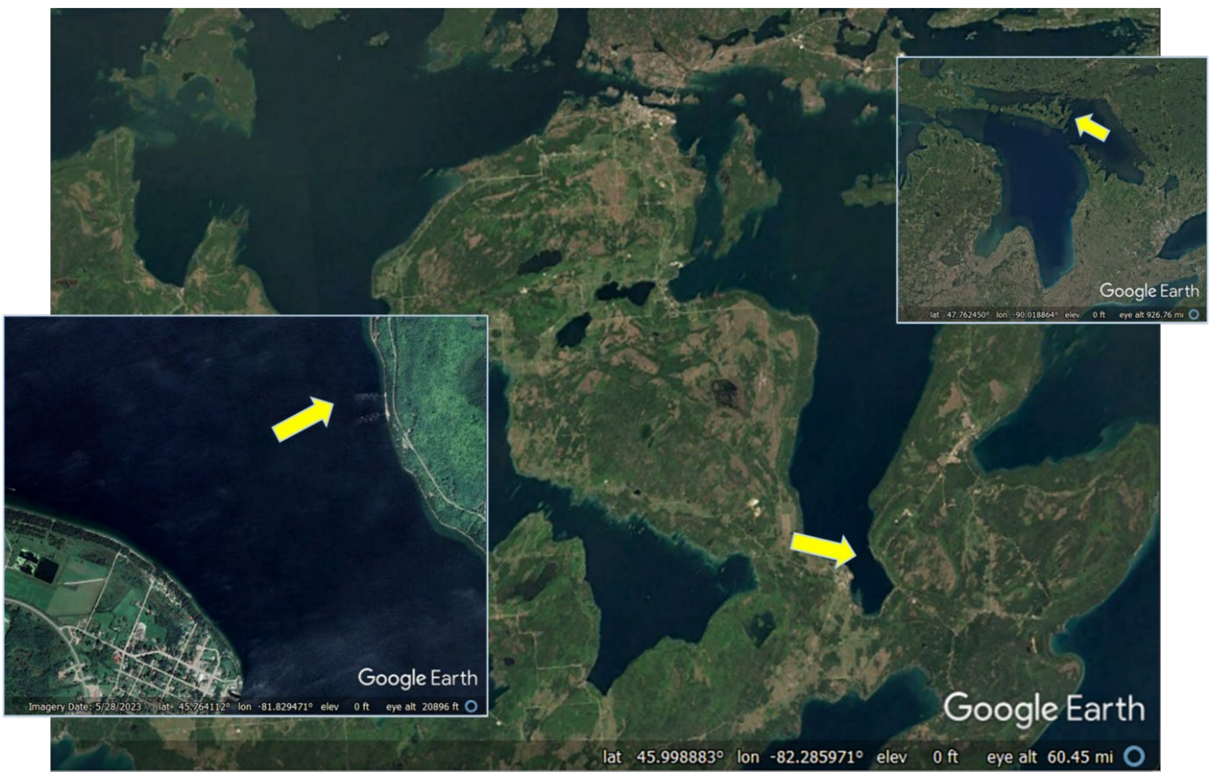

Figure 19: Example of a net pen site in Lake Huron, Manitoulin Island. The main image shows the eastern section of Manitoulin Island, the left inset shows the net pens, and upper right inset shows the general location within Lake Huron. Images all reproduced from Google Earth Pro.

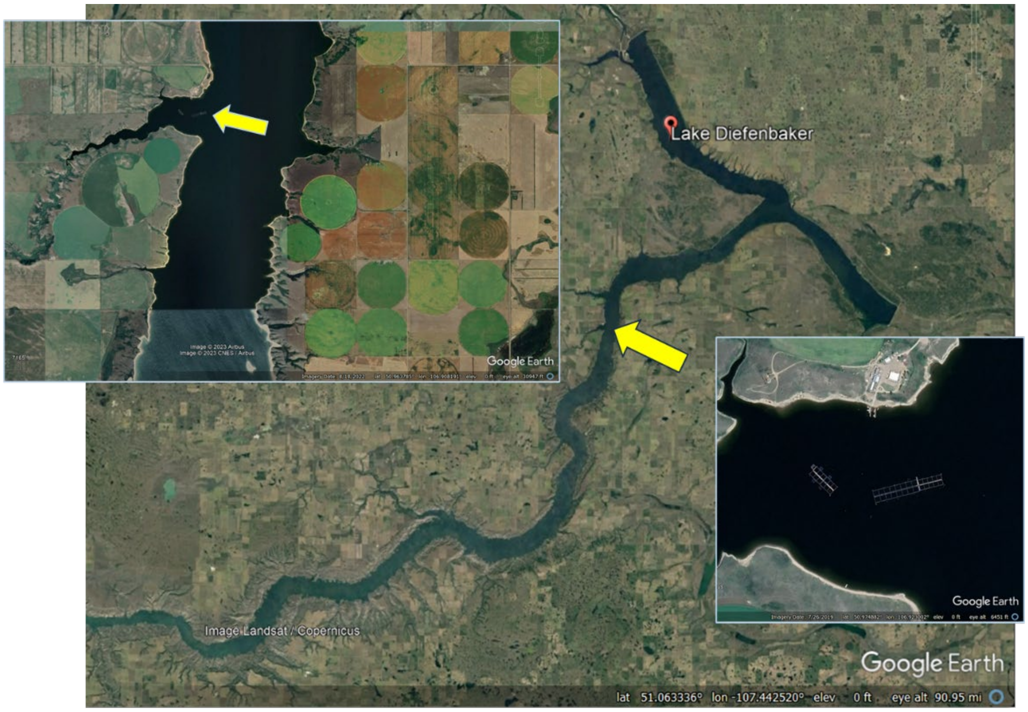

Figure 20: Overview of the net pen site in Lake Diefenbaker. The main image shows the whole lake, the left inset shows the farm location, and the right inset shows the net pens and shore base. Images reproduced from Google Earth.

The general areas of the site locations around Manitoulin Island and Parry Sound have a low population density; for example, approximately 12.4 people per square mile on Manitoulin Island.[47] The Canadian Encyclopedia[48] describes the primary industries as tourism and agriculture, following the decline of forestry and commercial fishing. Lake Diefenbaker is located within the expansive agricultural landscape of the Canadian prairies. Some farms on Manitoulin Island are operated by or under agreements with First Nation Councils; for example, Figure 19 shows the Buzwah Fisheries farm operated by the Wiikwemkoong First Nation.

Regarding the broader habitat impacts of dam construction (and although the farm in Lois Lake is no longer in operation), it is noted here that the Lois River in British Columbia (along with neighboring Powell River and Theodosia River, which were also dammed) was once a major spawning ground for sockeye, coho, chum (*Oncorhynchus keta*), and pink (*O. gorbuscha*) salmon, sea-run coastal cutthroat trout (*O. clarkii*), and steelhead, supporting hundreds of thousands of spawning salmon. But the dams on these rivers had major habitat impacts by blocking upstream migration, and made large areas of upstream spawning grounds inaccessible (Francis, 2022).

[47] The total area of Manitoulin Island is 1,068 mi^2, with a population (2016 data) of 13,255. Data sourced from https://en.wikipedia.org/wiki/Manitoulin_Island
[48] https://www.thecanadianencyclopedia.ca/en/article/manitoulin-island

Studies in temperate coastal waterbodies have shown that the net pens and their supporting infrastructures (i.e., the floats and weights, and the mooring ropes, buoys, and anchors) contribute much physical structure to nearshore habitats, and impose on the physical environment at the farm location by modifying light penetration, currents, and wave action as well as providing surfaces for the development of rich biotic assemblages that may further increase the complexity of the habitat (McKindsey, 2011). But the applicability of this 2011 study to net pens in freshwater lakes is tenuous, particularly in the case of the single farm in the artificial reservoir of Lake Diefenbaker. Figure 21 shows an example of reduced wave action downwind of a rainbow trout farm at Mink Island at the southern end of the Wabuno Channel, but it is challenging to attribute any specific habitat impacts to this effect.

Figure 21: Example of an apparent surface effect of the net pen array on small wave action downwind of the farm. Image reproduced from Google Earth.

The Georgian Bay Association considers the net pens and their structures to be an attractive habitat for nonnative, invasive bivalve species such as zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. bugensis*), and considers this one of the association's concerns with net pen aquaculture;[49] but as yet, there are no published data or evidence to support this notion (pers. comm., Rupert Kindersley, GBA, Sept 2023), and this aspect is not considered further here.

The potential operational impacts of the farm effluents on the immediate area and on local fish populations were assessed in Criterion 2—Effluent, and there do not appear to be any direct

[49] https://georgianbay.ca/fisheries/cage-aquaculture-issue/

habitat conversion impacts associated with the construction of the floating net pen farms. Thus, the potential habitat impacts appear to be limited primarily to visual and physical obstruction of other activities such as tourism. Although some sites around Manitoulin Island are relatively close (2 miles separate the closest pair), overall, given the small number of sites and the large scales of the broader habitats, these impacts appear relatively minor and unlikely to significantly affect any ecosystem services provided by those habitats. This is considered the case both at individual sites and cumulatively across all sites in Lake Huron, and particularly in the case of the single farms in the dammed reservoirs of Lake Diefenbaker. Overall, there is considered to be a minimal impact on ecosystem service delivery, habitat usability, and resource delivery/support, and the score for Factor 3.1—Habitat conversion and function for net pens is 9 out of 10.

Land-based systems: Raceways, ponds, and tanks

In the 1990s, the majority of Canada's rainbow trout aquaculture took place in land-based productions systems (see Figure 3 in the Introduction). Today, the majority occurs in net pens, and land-based farms are mostly located in Quebec. Quebec's total production of rainbow trout for the table (as opposed to stocking for sport fishing) is small (approximately 400 mt), and phosphorous (P) limits mean that farms are typically small (as noted in the Introduction, the average farm production in Quebec is 16.8 mt). The P limits also mean that establishing new farms in Quebec is challenging (pers. comm., G. Castro, MAPAQ, October 2023). Under these circumstances, it is considered unlikely that there are significant ongoing, or recent, land use changes attributable to the industry.

In Quebec, land-based rainbow trout farms are restricted to permitted zones for the culture of rainbow trout in southwest Quebec (see Figure 18 in Criterion 2—Effluent). From readily available satellite images, it can be seen that these areas are dominated by agriculture, natural forests, and commercial forestry. The locations of farms in Quebec are available from the Ministry of Agriculture Fisheries and Food in Quebec (Ministry of ministère de l'Agriculture, des Pêcheries et de l'Alimentation [MAPAQ]) but were not able to be obtained in time for this assessment. Among 24 aquaculture farms on the member list of the Aquaculture Association of Quebec (L'Association des Aquaculteurs du Québec [AAQ]), 3 stated that they produced rainbow trout for consumption (as opposed to stocking for angling), and 2 have aquaculture systems visible on satellite images. Figures 22 and 23 show a pond farm, and Figures 24 and 25 show a combined tank/pond farm, with both clearly located in an agricultural and forestry landscape.

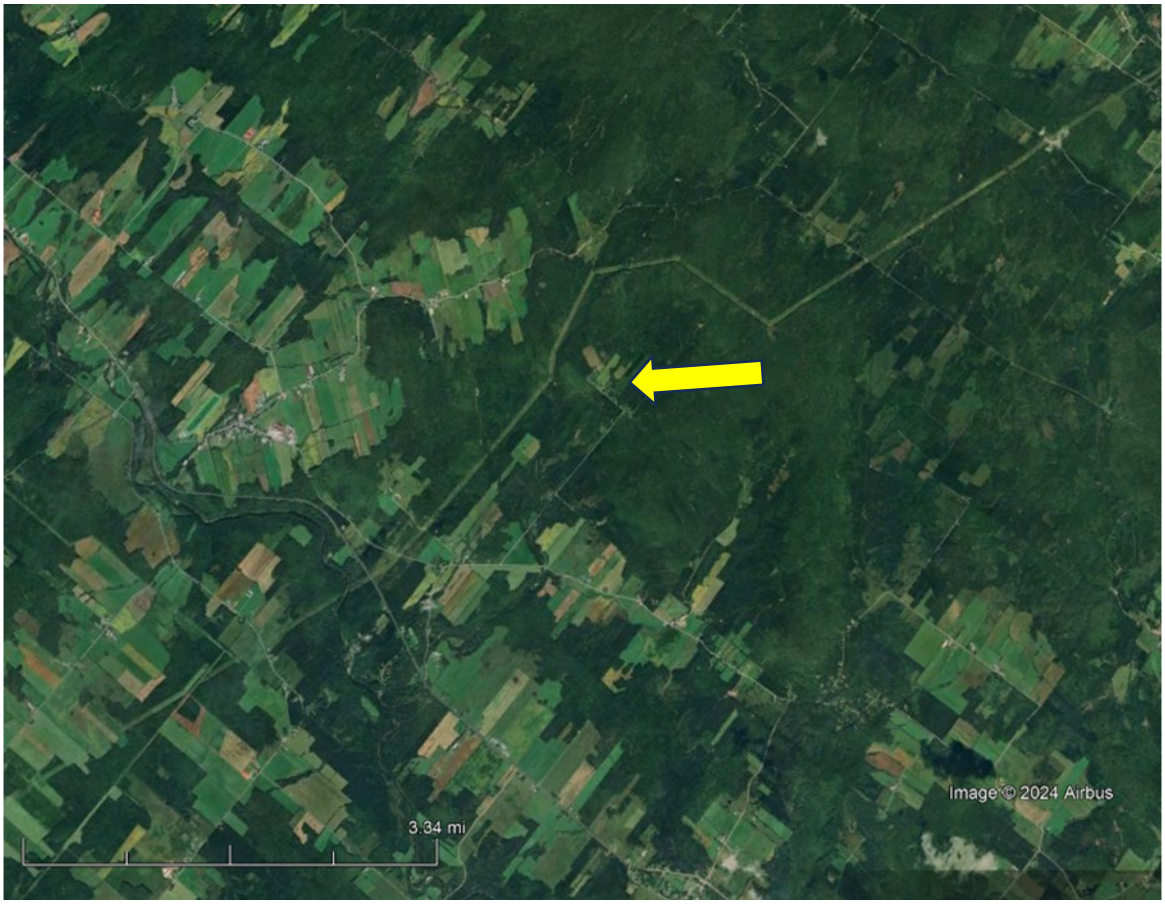

Figure 22: Landscape view of a rainbow trout farm near Chesterville in Quebec. The yellow arrow indicates the location of the farm. Image reproduced from Google Earth Pro.

Figure 23: Close view of a rainbow trout farm near Chesterville in Quebec, with ponds visible. Image reproduced from Google Earth Pro.

Figure 24: Landscape view of a rainbow trout farm near Armagh in Quebec. The yellow arrow indicates the location of the farm. Image reproduced from Google Earth Pro.

Figure 25: Close view of a rainbow trout farm near Armagh in Quebec, with ponds visible and tanks likely in the covered building (yellow arrow). Image reproduced from Google Earth Pro.

An extended survey of all 24 aquaculture members of the AAQ (all species, systems, and purposes; i.e., including stocking) shows a variety of surrounding habitats, mostly in mixed agriculture and forest, including some in riparian forest locations. Using the historical images function of Google Earth Pro, it can be seen that, in all cases where the images were clear enough (for four members, the addresses provided had no visible aquaculture facilities), the land had previously been cleared for agriculture before 2000, and in many cases (where older images were available), before 1985. This was also the case for farms that were effectively surrounded by forest; that is, the forest had initially been cleared for agriculture (e.g., grazing), and there is no apparent significant clearance of forest land for the construction of ponds.

This small sample of farms indicates that land-based rainbow trout farms have been constructed primarily in former agricultural land and thus have had no significant impacts on the habitat functionality or ecosystem services of those areas. Nevertheless, even though these examples are likely to be representative of all land-based farms in Quebec (or Ontario), the sample is small, and it is considered here that some farms may have had some (minimal) impacts to their former habitats. Therefore, the score for Factor 3.1 is 9 out of 10, on a precautionary basis.

Factor 3.2—Farm siting regulation and management
DFO has oversight of Canadian aquaculture nationally through the Aquaculture Activities Regulations, but siting aspects are considered here to be managed predominantly at the provincial level. With most of the Canadian rainbow trout production occurring in Ontario, this province is the focus of this assessment. Salient aspects (particularly, significant differences) in Saskatchewan and Quebec (land-based farms) are also noted where relevant. Identifying the precise aspects of complex aquaculture legislation that relate to the specific habitat impacts relevant to this criterion, including their implementation and enforcement, can be challenging (noting that water quality and benthic sediment impacts are addressed in Criterion 2—Effluent).

<u>Factor 3.2a—Content of habitat management measures</u>
Moccia and Bevan (2018) published a review of aquaculture legislation in Ontario, which, although 6 years old, is considered here to be largely representative of the current situation. According to Moccia and Bevan (2018): "The legislative and regulatory systems affecting aquaculture in Ontario are complex and dynamic. No single agency is responsible for all aquaculture-related regulations." Regarding provincial management, including siting, the Ontario Ministry of Natural Resources and Forestry (OMNRF) and the Ontario Ministry of Environment, Conservation and Parks (OMECP—previously Ontario Ministry of the Environment and Climate Change [OMECC]) are the primary organizations.

In addition, First Nations communities in Ontario have been developing a governance framework—the Giigoonh Chi-Naaknigewin—to issue licenses, leases, permits, rules, and requirements for establishing aquaculture operations on First Nations' traditional lands and waters, and these may vary from the provincial requirements (as listed by Moccia and Bevan, 2018).

Tables 3 and 4 summarize the large number of provincial and federal agencies and the legislation relating to aquaculture. Note that these tables are included as a simple overview, based on similar tables in in Moccia and Bevan (2018b) and amended with recent changes from OMAFRA (pers. comm., A. Reid, M. McQuire, OMAFRA)(pers. comm., S. Naylor, D. Madeiros, R. Haesevoets, DFO, April 2024). Thus, they may not include all details or reflect recent changes.

It appears that several aspects of these legislations (based on their titles) will be of relevance to potential habitat impacts of net pens and/or land-based aquaculture systems (for example, the Fish and Wildlife Conservation Act, the Conservation Authorities Act, Beds of Navigable Waters Act, Endangered Species Act, the Environmental Protection Act, Environmental Assessment Act, and the Species at Risk Act), yet it remains challenging to determine in which ways, if any, these relate to potential habitat impacts of either net pen farms or raceways, ponds, or tank farms. For example, the licensing process, though taking up to 2 years for approval, requires the proponent of an aquaculture facility to complete an acceptable risk analysis; however, the risk assessment is intended only to ensure that aquaculture operations do not result in introductions (through escapement of cultured fish) of species that will harm the environment.

Table 3: Summary of provincial legislation and regulations pertaining to aquaculture in Ontario. Table is based on Moccia and Bevan (2018b) with amendments based on personal communications (see text). Note that this is an overview and may not include all relevant aspects or fully reflect any recent changes.

Provincial Government Agencies	
Administrative Agency and Legislation	**Summary of Principle**
Ontario Ministry of Natural Resources and Forestry	
Fish and Wildlife Conservation Act + Ontario Regulation 664/98	Provides management, perpetuation, and rehabilitation of wildlife.
The Lakes and Rivers Improvement Act	Ensures that alterations to water flow do not pose a hazard.
The Conservation Authorities Act	Preservation of habitat lying within established flood plains.
Beds of Navigable Waters Act	A lake-bed lease is required for cage culture operations.
Public Lands Act	Provides controlled use of public land, and cage culture areas
Provincial Parks and Conservation Reserves Act	Provides controlled use of public land, and cage culture areas.
Aggregate Resources Act	Regulates aggregate removal from watercourses.
Endangered Species Act	Restricts activities that may affect endangered species.
Ontario Ministry of the Environment and Climate Change	
Ontario Water Resources Act	Management of surface and groundwater quality and quantity.
The Environmental Protection Act	Provides protection and conservation of the natural environment.
Pesticides Act	Controls the availability and use of pesticides.
Environmental Assessment Act	Allows environmental assessment to be carried out.
Conservation Authority	
The Conservation Authorities Act	Controls development within flood plains (see OMNR).
Ontario Ministry of Municipal Affairs and Housing and local Municipality	
The Planning Act	Allows orderly planning and development of land use.
Provincial Municipal Act	Bylaws established by local government to regulate land use, etc.
The Niagara Escarpment Planning and Development Act	Additional control of development in this area.
Ontario Ministry of Agriculture, Food and Rural Affairs	
The Drainage Act	Controls drainage of land, including the discharge of surface water.
The Veterinarians Act	Regulates drug use.
Nutrient Management Act	Management of materials containing nutrients to enhance protection of the natural environment.
	Disposal of fish mortalities (deadstock).
Animal Health Act	Regulates aquatic and terrestrial animal health threats.
	Selling of livestock medicines.
Food Safety and Quality Act	Inspection of products to ensure safety and quality.
Ontario Ministry of Labour	
Occupational Health and Safety Act	Protect workers against health and safety hazards.
Ontario Ministry of Transportation	
Highways Act	Wells and structures next to highways.

Table 4: Summary of federal legislation and regulations pertaining to aquaculture in Ontario. Table is based on Moccia and Bevan (2018b) with amendments based on personal communications (see text). Note that this is an overview, and may not include all relevant aspects or fully reflect recent changes.

Federal Government Agencies	
Administrative Agency and Legislation	**Summary of Principle**
Government of Canada	
Standards Council of Canada	Organic aquaculture standards
Fisheries and Oceans Canada	
Fisheries Act of Canada	Protection of fisheries and their habitat. Import/export of fish.
Aquaculture Activities Regulations	Provides mechanism for regulatory control of aquaculture
Ontario Fishery Regulations	
Species at Risk Act	Fisheries and habitat, species at risk protection.
Canadian Food Inspection Agency	
Health of Animals Act	Import and registration of biologics and fish vaccines.
	National Aquatic Animal Health Program.
Feeds Act	Regulates feed quality and drugs in feed.
Safe Food for Canadians Act	Inspects processing plants.
Health Canada and Pest Management Regulatory Agency	
Food and Drugs Act	Approval of drugs used in animals, including fish and smoked.
Pest Control Products Act	Registration of pesticides.
Environment Canada	
Canadian Environmental Assessment Act	Integrates environmental factors into planning process.
Impact Assessment Act	Provides protection and conservation of the natural environment.
Migratory Birds Convention Act	Protection of certain bird species.
Species at Risk Act	Protection of wildlife species at risk, including fish.
Transport Canada	
Canada Shipping Act	Vessel requirements and safety
Navigation Protection Act	Any work or structure placed in navigable water requires approval.
Canada Customs and Revenue Agency	
Goods and Services Act	Goods and Services Tax and Harmonized Sales Tax (consumption tax).

Otu et al. (2017a) noted that there are various restrictions in place on appropriate site locations for net pen farms in Lake Huron (Table 5). Though it is notable that these restrictions include important habitat siting aspects, such as proximity to whitefish spawning areas or species at risk, or potential cumulative impacts relating to the separation distances between farms, it is another stark example of the challenge of interpreting the practical aspects of aquaculture regulation that Otu et al. (2017a) refer to these siting requirements (Table 5) as "DFO unpublished data."

Table 5: Rules used for demarcating areas inappropriate for cage culture siting for GIS layers (DFO unpublished data). Table and title reproduced from Otu et al. (2017).

Layer	Red Zone Ruling
Operational Cage Sites	No new cage site within 3000 m of an existing site
Water Protection Act Obstructions	No cage site within a minimum of 100 m of an existing NWPA obstruction
Navigable Waters Protection Act (NWPA) Obstructions	No cage site within a minimum of 100 m of an existing NWPA obstruction
Whitefish Spawning Area	No cage site within 100 m of spawning area
National/Provincial Parks and NGO Reserves	No cage site within 100 m of park/reserve boundary
Tributary Mouth	No cage site within 1000 m of tributary mouth
Species At Risk	No cage site within 5000 m of a location where SAR has been found

Although the relevant agencies have abundant information and links on their websites, and the texts of various regulations and acts are available, the ability to understand the practical requirements for aquaculture siting regarding habitat and ecosystem functionality and/or land use changes does not seem to have improved since Otu et al. presented DFO's unpublished data in 2017. A feasibility assessment for the development of aquaculture (including rainbow trout) in Thunder Bay, Lake Superior (TBCEDC, 2021) recognizes the regulatory structure described previously, and at least in this example, demonstrates the potential to expand in areas that are far from the current production in Lake Huron.

A similar situation exists in Quebec, and the Ministry of the Environment, Climate Change, Wildlife, and Parks (MELCCFP) provides an overview of the regulatory framework for aquaculture.[50] As discussed in Criterion 2—Effluent (Factor 2.2a), the Commercial Aquaculture Act and the Commercial Aquaculture Regulations relate primarily to farm-licensing processes and administrative measures, but an aquaculture site is defined within the REAFIE, as well as the rules governing their establishment and operation.[51] This forms part of the Law on the Quality of the Environment (Loi sur la qualité de l'environnement).[52]

Under the REAFIE, in order to establish an aquaculture farm, a potential trout farmer must obtain authorization from the Minister of the Environment through a process of applications, which include detailed infrastructure plans showing the size and characteristics of the production units. Applications are submitted through various documents related to Ministerial

[50] https://www.environnement.gouv.qc.ca/milieu_agri/aquacole/cadre-reglement.htm
[51] https://www.legisquebec.gouv.qc.ca/fr/document/rc/Q-2,%20r.%2017.1
[52] https://www.legisquebec.gouv.qc.ca/fr/document/lc/Q-2

Authorizations,[53] and in addition to those that relate to effluent (Table 1 in Criterion 2—Effluent), AM17a refers to the history of the land (soils) but is focused on any previous commercial activities on the land that might affect the current application (e.g., contamination). AM314a refers to any construction in wetlands (translated as "humid or watery environments"). All projects submitted to the MELCCFP are analyzed by a multidisciplinary team to cover all aspects that could affect the environment, and in addition to environmental engineers or biologists, this team includes a wildlife expert who considers an assessment of risks to wildlife, particularly native fauna, at the proposed site (pers. comm., Anon, MELCCFP, June 2024). It is also noted that Quebec has an aquaculture zoning system[54] through which the culture of rainbow trout is restricted to specific areas in the south of the province (Figure 18 in Criterion 2—Effluent). Although this process is intended to protect the integrity of the diversity of wildlife in Quebec's waterbodies, it relates primarily to the species being cultured and the desire to not increase the ranges of nonnative species through aquaculture or stocking of waterbodies for sport fishing.

Overall, it is clear that there is a comprehensive array of authorities and legislation that could be applied to aquaculture in key rainbow trout-producing provinces in Canada. For net pens in Ontario, in practice, the industry is relatively small and dispersed over a large area (while still representing a relatively small total area within the larger Lake Huron), such that area-based and/or cumulative habitat impacts are highly unlikely. The potential for industry expansion has been recognized, but current considerations (e.g., in Lake Superior) would not be associated with a significantly different concern regarding site-specific or cumulative habitat impacts. For land-based farms, primarily in Quebec, it is unlikely that there have been significant recent expansions of the industry, but a comprehensive application and environmental assessment system is in place. Thus, the score for Factor 3.2a—Content of habitat management measures is 4 out of 5.

<u>Factor 3.2b—Enforcement of habitat management measures</u>

The organizations responsible for the enforcement of aquaculture management in key Canadian provinces are readily identifiable, as noted. Regarding net pen farms, the potential habitat impacts besides water quality and benthic impacts (assessed in Criterion 2—Effluent) are unclear, except for the measures listed by Otu et al. (2017a) based on unpublished DFO information. Because the relevant measures stated by Otu et al. are relatively straightforward, it is considered likely that these would be taken into account in any permitting and siting processes. Examples of aquaculture licenses from active sites were provided for this assessment. Simple aspects, such as site separation distances, can be observed in publicly available satellite images. Otherwise, though evidence of water quality and benthic monitoring is available (and has been provided for this assessment), records or other evidence of enforcement related to habitat-specific aspects of land-use change or associated ecosystem

[53] A summary document is available: https://www.environnement.gouv.qc.ca/milieu_agri/aquacole/recapitulatif-formulaires-projet-aquacole.pdf

[54] https://www.quebec.ca/agriculture-environnement-et-ressources-naturelles/faune/gestion-faune-habitats-fauniques/ensemencement-plans-eau/encadrement

services are not readily available, most likely because they are not considered relevant to floating net pens.

In Quebec, the MELCCFP is the primary enforcement agency associated with the Ministerial Authorizations for farm construction, and as discussed in Criterion 2—Effluent (Factor 2.2b), the public Register of Administrative Monetary Penalties (SAP) provides a lengthy example of enforcement activities covering a wide range of topics. As discussed in Criterion 2, few examples can be found that relate to aquaculture, and those available relate to errors in the submission of effluent monitoring results and documentation. Though no direct results are apparent that relate to aquaculture habitat impacts or construction, various other infringements relating to the operation of ponds could be identified (searching for étang in French[55]). These appear to relate to agricultural irrigation ponds, but support a finding that enforcement is active, and infringements relating to aquaculture are uncommon and mostly related to failures to submit monitoring records.

From communications with MAPAQ, it was generally considered that the phosphorous requirements relating to effluent discharges were the primary limiting factor in any future expansion of the land-based industry in Quebec, either for new sites or the expansion of existing sites (pers. comm., G. Castro, MAPAQ, October 2023). In this regard, the reality of the small number of farms with a minimal total annual production of approximately 400 mt means that the industry either can be considered effectively enforced by organizations such as MELCCFP or is to some extent self-enforcing and choosing not to expand due to the limited siting potential (or other reason). From either route, the outcome is clear: the small scale of production is unlikely to result in significant and/or cumulative habitat impacts in Quebec (or elsewhere in Canada in land-based systems).

Overall, there is confidence that the enforcement of the regulatory process for establishing a rainbow trout farm in either net pens or land-based systems is comprehensive and results in a challenging process for potential trout farmers. The score for Factor 3.2b is 5 out of 5. Combined with the Factor 3.2a score of 4 out of 5, the final score for Factor 3.2—Farm Siting Regulation and Management is 8.0 out of 10.

Conclusions and Final Score

Noting that the operational impacts of settling particulate wastes on benthic habitats have previously been addressed in the Effluent criterion, the direct habitat impacts of floating net pens are minimal and can be immediately reversed if desired by removing the structures. Though studies from marine net pen farms describe a range of potential impacts (e.g., increased surface area or shading), there is no evidence that these impacts occur to any significant extent in freshwater lakes. With a small total number of net pen farms in Lake Huron and a single farm in the dammed reservoir in Saskatchewan, there is a quite limited risk of cumulative habitat impacts. The score for Factor 3.1—Habitat Conversion and Function is 9 out

[55] Because of the number of records, the use of online translation engines was not possible in addition to searching.

of 10. For land-based systems, the industry is small and stable, indicating that there are unlikely to have been substantial recent habitat impacts resulting from new or expanded sites. A survey of satellite images indicates that farms are located within extensive agricultural and forested landscapes, are widely dispersed, and have been constructed in land historically cleared for agriculture. With minimal impacts to ecosystem services (but some uncertainty across all sites), the score for Factor 3.1—Habitat Conversion and Function is also 9 out of 10.

The three provinces of most interest here have comprehensive regulatory systems involving multiple agencies. For net pens, the focus appears to be on avoiding specific, high-value habitats such as native fish spawning, nesting, and nursery grounds or areas of importance to species at risk. For land-based systems in Quebec, Ministerial Authorizations under REAFIE require examination of any aspects of environmental impact, including habitats and wildlife. Evidence of enforcement activities are also available in the SAP register. In practice, the industry is relatively small and is dispersed over a large area, such that area-based and/or cumulative habitat impacts are highly unlikely. Although the potential for industry expansion in net pens is recognized, examples of feasibility studies for new sites in the Great Lakes (e.g., Thunder Bay in Lake Superior) recognize the complex regulatory systems in place, and are currently considering locations far from the existing industry in Lake Huron. With comprehensive systems, the score for Farm Siting Regulation and Management (Factor 3.2) is 8.0 out of 10 for both net pens and land-based systems. Despite their clear differences, neither net pens nor land-based systems have a substantial risk of habitat impacts, and Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 8.7 out of 10 for both systems.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.
- Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments
- Principle: limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms.

Criterion 4 Summary—all production systems

C4 Chemical Use parameters		Score
C4 Chemical Use Score (0–10)		**8.0**
Critical?	No	**Green**

Brief Summary

With a focus on antimicrobials, data provided by the industry (in addition to currently incomplete data from DFO) show that chemical use is typically low in Canadian rainbow trout farms, with occasional treatments for endemic bacterial pathogens such as *Flavobacterium* that are typically triggered by high-stress events such as extreme temperatures (see Criterion 7—Disease). The data also show that the industry in Canada (like elsewhere) is vulnerable to emerging pathogens, with an outbreak of *Weissella* in Saskatchewan in 2017–18 and of *Lactococcus* in Ontario in 2020–21 that led to increases in antimicrobial use and a peak of 560 kg in the available data in 2017 (annual sales of medically important antimicrobials in Canada are approximately 1.3 million kg, mostly for livestock). Nevertheless, rapid responses from the industry regarding vaccine developments and improved fish husbandry led to rapid post-outbreak declines in antimicrobial use. Considering the combined antimicrobial use in fingerling and grow-out production of the dominant producers through the *Lactococcus* outbreak in Ontario, the total relative use is estimated to have been an average of 35.8 g/mt between 2020 and 2022, but in 2023 has been zero to date (as of mid-December). Antimicrobial use has also been close to zero in Saskatchewan over the same period. Based on medicated feed sales, the peak use in recent years in Ontario (2020) represented <0.5% of the total feed sold, and therefore of production. Although antimicrobial use at the fingerling stage is somewhat common through the warmer months, detailed batch-treatment data show that a small proportion of fish are treated and at a small average size (12.7% of batches at an average fish weight of 4.6 g). Thus, the use of antimicrobials is demonstrably less than once per production cycle. The only authorized treatments for aquaculture in Canada are listed as highly important to human medicine by the World Health Organisation (WHO); however, with a low apparent concern regarding resistance at this time, the initial score for Criterion 4—Chemical Use is 8 out of 10. Much less data are available that could be related conclusively to land-based raceway, pond, or tank systems (except for the low chemical use in land-based hatcheries, as noted), and this situation is currently hampered by the low confidence in the DFO data (which is not an apparent fault of the industry). Without sufficient justification to consider otherwise (e.g., based on disease occurrences or any other data), the same score of 8 out of 10 is applied to land-based systems on the assumption that antimicrobial treatments are also likely to be less than once per production cycle on average.

The Seafood Watch Aquaculture Standard allows a trend adjustment in cases where data show that a decline in chemical use over time is sufficient to give confidence that improved management practices are leading to clear reductions in use and the risk of impacts. Considering the timeframes of the primary data provided here, it is clear that antimicrobial use is typically low, and has increased only in response to specific outbreaks (e.g., in 2017–18 and 2020–21), which have rapidly been controlled. Although antimicrobial use has declined post-outbreak in both cases (and improvements in management practices are recognized as reducing the risk of future disease outbreaks), there is not considered to be sufficient justification to apply a trend adjustment here, and the final score for Criterion 4—Chemical Use remains 8 out of 10.

Justification of Rating

DFO's National Aquaculture Public Reporting Data[56] provide chemical use data for land-based and freshwater aquaculture from 2016 to 2022 (accessed April 15, 2024), but this dataset appears to be incomplete because it lacks data known to be reported from net pen farms in Ontario and Saskatchewan in recent years (pers. comm., RJ Taylor, OAA; S. Higgins, Cole Munro; D. Foss, WWS; October 2023). DFO is aware of this technical problem in the reporting data and is working to publish complete data (pers. comm., S. Naylor, DFO, October 2023). Nevertheless, data provided directly from the dominant producers in Ontario and Saskatchewan (particularly on antimicrobial use), in addition to supporting information explaining chemical use (e.g., disease outbreaks and subsequent vaccine use), allow a robust understanding, as discussed in the following.

The available DFO data show that the reported chemicals from freshwater aquaculture farms in Canada include antimicrobials, two pesticides, and the broad-spectrum formalin treatment. As will be discussed, these are used in variable frequencies and quantities in rainbow trout production, but the focus is on antimicrobials and pesticides as the group of chemicals with the highest associated level of concern.

<u>Antimicrobial Use</u>

As discussed in Criterion 7—Disease, occasional bacterial pathogen challenges require treatment with antimicrobials. Moccia and Burke (2016) described the earlier use of antibiotics in Ontario rainbow trout culture as possibly "heavy" when confronting bacterial coldwater disease (caused by the bacterium *Flavobacterium psychrophilum*); however, no further details,

[56] https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383

timeframes, or other context were provided. Instead, several more recent sources of data are now available from the government and the industry that better represent current use.

The DFO antimicrobial data (National Aquaculture Reporting Data, reported as part of Canada's Aquaculture Activities Regulations) are presented here for information, but as noted, are known to be incomplete (see Figure 26). In addition, the DFO data are reported for all freshwater species and production systems, and although separated by company name, a challenge remains in identifying the companies producing rainbow trout for human consumption (also not including those farms in recirculating RAS systems). Similarly, some farms produce several species, so their total chemical use may overstate what was used specifically for rainbow trout, but these potential errors are not considered significant for this assessment. Instead, the focus was on antimicrobials and pesticides as the chemicals of greatest environmental concern. The dataset includes quite occasional use of formalin (e.g., 30.2 kg at the Lois Lake farm in British Columbia in 2020), but this has not been included in this assessment.

Under these assumptions and caveats, the DFO data show that, between 2016 and 2021, the only reported chemical use was in the dominant producing province of Ontario, and was primarily of the antimicrobial oxytetracycline, with minor amounts of florfenicol (Figure 26). Both oxytetracycline and florfenicol are listed by the World Health Organisation (WHO) as highly important antimicrobials for human medicine (WHO, 2019), and are included on Canada's List-A[57] of chemicals important in human medicine. Again, it is emphasized here that these data are considered incomplete and are presented here for reference only. DFO's list of veterinary drugs authorized for use in food-producing aquatic animals[58] (accessed February 2, 2024) includes oxytetracycline, florfenicol, and the combination of sulfadimethoxine/ormetoprim; however, the latter treatment has not been permitted since 2018 as a result of changes to the regulations, such as requirements for prescriptions for all List-A treatments (pers. comm., M. Chiasson, University of Guelph, September 2023).

As noted in Criterion 5—Feed, Skretting North America is the dominant rainbow trout feed provider in Canada for grow-out feeds and considered the exclusive provider of medicated grow-out feeds for the large net pen farms in Ontario (the second-largest feed producer, Bluewater, does not produce medicated feeds; pers. comm., Anon, Bluewater Feeds, November 2023). Skretting provided medicated rainbow trout feed sales data and total antimicrobial use

[57] https://www.canada.ca/en/public-health/services/antibiotic-antimicrobial-resistance/animals/veterinary-antimicrobial-sales-reporting/list-a.html
[58] https://www.canada.ca/en/health-canada/services/drugs-health-products/veterinary-drugs/legislation-guidelines/policies/list-veterinary-drugs-that-authorized-sale-health-canada-use-food-producing-aquatic-animals.html

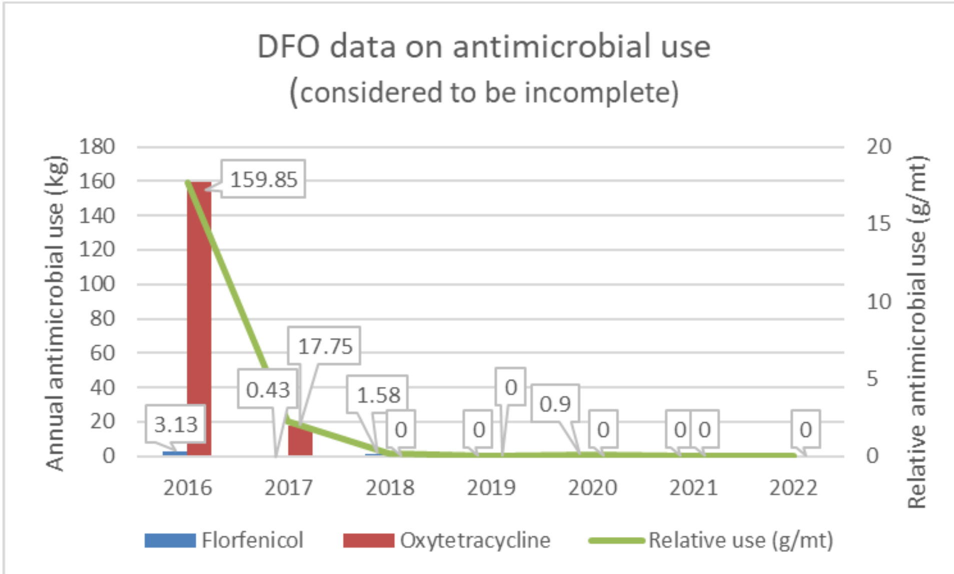

Figure 26: DFO National Aquaculture Reporting Data on antimicrobial use in land-based and freshwater rainbow trout aquaculture in Canada from 2016 to 2022. All reported uses identified for rainbow trout were from Ontario. The data (accessed April 15, 2024) are considered incomplete. Vertical bars show annual use in kilograms, and the green line (on the right secondary vertical axis) shows the relative use in grams of active ingredient per mt of trout production. Callout values are for annual use of florfenicol and oxytetracycline.

(as active ingredient)[59] for Ontario from 2017 to mid-December 2023 (pers. comm., S. Cook, Skretting, December 2023). Figure 27 shows that antimicrobial use was zero from 2017 to 2019, but spiked to 394.7 kg of oxytetracycline in 2020.

According to an industry veterinarian, the primary cause of occasional antimicrobial uses in net pens in Lake Huron is the pathogen *Flavobacterium columnaris*, but the higher use of antimicrobials by the dominant producers in 2020 and 2021 was also driven by a novel outbreak of *Lactococcus* infections, which caused substantial mortalities in net pen farms (pers. comm., N. LePage, fish veterinarian, October 2023). With the rapid development of a vaccine[60] and a province-wide vaccination program, the disease has been controlled to date, and antimicrobial use has declined (pers. comm., N. LePage, fish veterinarian, October 2023). Figure 27 shows that the total use decreased rapidly to 17.4 kg of florfenicol in 2022, and zero in 2023 to date. These antimicrobial treatments were reported to DFO (pers. comm., RJ Taylor, OAA, October 2023) but are not yet represented in the DFO data in Figure 26.

[59] The commercial antimicrobial products contain relatively small amounts of antimicrobial as active ingredients; for example, the product Terramycin 200 contains 20% oxytetracycline as the active ingredient (i.e., 200 g per kg).
[60] The vaccine is autogenous—meaning it is somewhat “simply” developed from a dead strain of the bacteria isolated from the diseased fish.

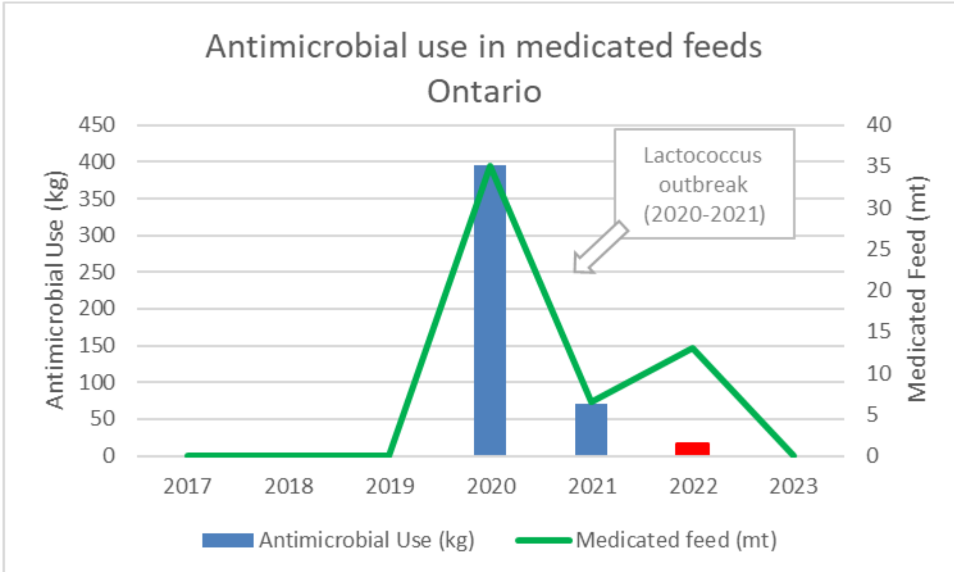

Figure 27: Antimicrobial use (in kg; blue bars are oxytetracycline, red bars are florfenicol) in grow-out feeds in Ontario and total medicated feed sales (in mt; green line and right vertical axis). Data are to mid-December 2023. Data provided by Skretting.

The outbreak of *Lactococcus,* in addition to recent experiences of unusually high water temperatures, has led to broader management improvements in the industry for fingerling quality, stocking times, and the emergency use of systems such as aerated upwellers to reduce stress during extreme water temperature events. These measures also support the rapid decline in antimicrobial use seen in Figure 27. By reducing the impact of stressful water conditions, these measures are also likely to reduce the risk of outbreaks of other pathogens that are triggered by unfavorable conditions.

Considering an eFCR of 1.36 and the annual Ontario production in 2020 of 5,583 mt, it can be estimated that the medicated feed sales of 35 mt in 2020 represent approximately 0.46% of the total feed applied in that year. In relative terms (i.e., grams of antimicrobial administered per mt of production), the estimated relative use in 2020 was 70.7 g/mt, declining to 12.1 g/mt in 2021 and 2.7 g/mt in 2022 (with 2022 calculations based on the predicted 2022 production from Moccia and Burke, 2022). According to the medicated feed data from Skretting, the current medicated feed and antimicrobial use in 2023 (as of mid-December) has been zero.

In Saskatchewan, the large net pen producer also provided antimicrobial data, which show a similar pattern, albeit due to a different disease outbreak (pers. comm., D. Foss, WWS, October 2023). Figure 28 shows that, in 2017, an outbreak of Weissellosis (see Criterion 7—Disease) resulted in 560.2 kg of antimicrobial use, or approximately 493.8 g/mt of production.[62]

[62] Based on data for total annual feed use, and calculated annual production calculated using a generic eFCR of 1.3.

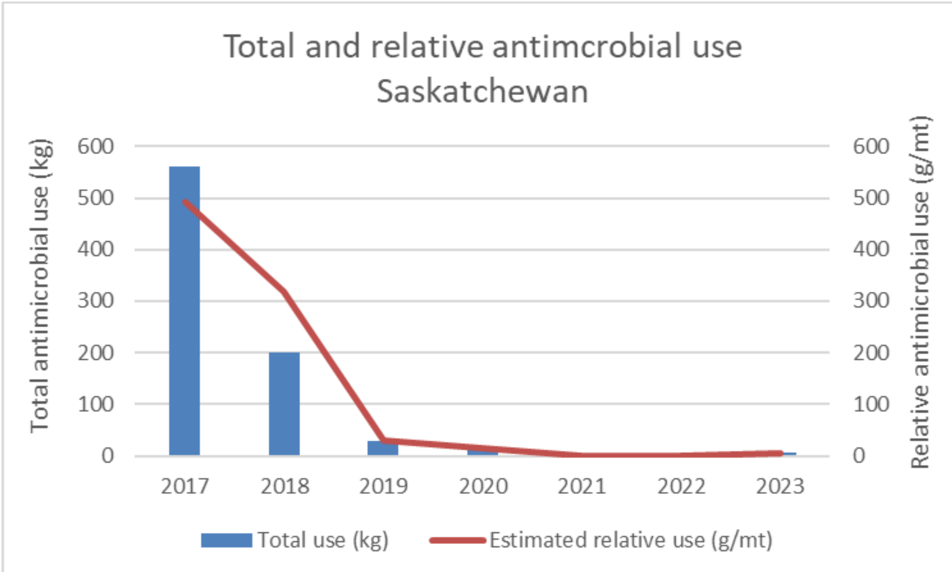

Figure 28: Antimicrobial use for the dominant rainbow trout producer in Saskatchewan (total kg: blue bars; estimated relative use in g/mt: red line and right vertical axis). The value for 2023 (5.2 kg florfenicol) is to date as of October 24, 2023. Total use and total feed data provided by Wild West Steelhead (pers. comm., D. Foss, WWS, October 2023).

Preceding the rapid vaccine development seen in Ontario for *Lactococcus* in 2021–22, an autogenous vaccine was also rapidly developed in Saskatchewan, and with its use beginning in September 2018, antimicrobial use declined rapidly and has been zero or close to zero since 2020 (to date as of October 2023). Oxytetracycline was the only antimicrobial used from 2017 to 2020, but a small amount of florfenicol has been used in 2023 (5.2 kg as of October 24).

The data from Saskatchewan are considered to include use in the hatchery/fingerling stage, whereas the medicated feed data from Skretting for Ontario was only for grow-out feeds. It is noted again here that these data are not represented in the DFO National Aquaculture Reporting Data, but were reported to DFO as part of the Aquaculture Activities Regulations (pers. comm., RJ Taylor, OAA, October 2023). Antimicrobial data from the dominant hatcheries/fingerling producers in Ontario (Cedar Crest/Blue Springs) were also provided for this assessment and show the regular use of small amounts of antimicrobials to treat common pathogens, typically in response to stressful conditions such as higher temperature anomalies. But only a small proportion of batches each year are treated, and with very small fish (pers. comm., RJ Taylor, Cedar Crest, October 2023).

For example, detailed fingerling fish health reports for 2021 and 2022 provided for this assessment show an average of 12.7% of separate batches of fish were treated with antimicrobials, at an average fish weight of 4.7 g. These treatments were associated with the movement of fish from indoor, controlled, early rearing tanks to outdoor, river-fed raceways, and before the full development of the fish’s immune systems. Therefore, hatchery use of antimicrobials can be considered low.

Antimicrobial sales for aquaculture use

As a final dataset associated with antimicrobial usage, antimicrobial sales data for veterinary use are reported by the Veterinary Antimicrobial Sales Reporting system (VASR)[63] of the Public Health Administration of Canada (PHAC/ASPC). These data are for "medically important" antimicrobials on Canada's List A,[64] which include oxytetracycline and florfenicol. At the time of writing, aquaculture antimicrobial sales data are not included in the VASR reporting documents, and were provided by personal communication (pers. comm., A. Bosman, PHAC/ASPC, October 2023). The antimicrobial sales data were compared to the antimicrobial use for marine and freshwater aquaculture reported by DFO (noting that these do not appear to be complete, as described previously) (Figure 29).

Although there is substantial variation in the reports of the total quantity sold versus used (the discrepancy ranges from sales being about 3,800 kg greater than the reported use to 450 kg less than the reported use), the decline in both (at least to 2021) is clear (Figure 29). The increase in sales in 2022 appears likely to have been associated with a dramatic increase in antimicrobial use in one large marine salmon farming company in British Columbia (Cermaq), whose relative use increased from 67.6 g/mt in 2021 to 609.98 g/mt in 2022, according to data from the Global Salmon Initiative.[65]

It is also clear from Figure 29 that the total antimicrobial use in freshwater and land-based farms is much lower than in marine aquaculture farms in Canada (noting that aquaculture production in freshwater is also much lower). In 2021, the total aquaculture-related antimicrobial sales (for marine and freshwater production of all species) were 5,997 kg, which is 0.58% of Canada's total veterinary antimicrobial sales for animals in the same year of 1,027,865 kg (all species of livestock).

Antimicrobial resistance

At the global level, Preena et al. (2020) consider that the emergence of antimicrobial resistance (AMR) in cultured fishes is one of the major challenges faced in aquaculture. Those authors note (again at the global level) that "a high prevalence of bacterial infections in fishes leads to frequent use of antibiotics and thus their persistence in the aquatic environment, which in turn results in the proliferation of antibiotic resistant bacteria. As such, the AMR in aquaculture can be transferred to clinically important strains of natural environment through horizontal gene transfer, thereby affecting the whole ecosystem."

[63] https://health-infobase.canada.ca/veterinary-antimicrobial-sales/

[64] List A: List of certain antimicrobial active pharmaceutical ingredients. List A - List of Certain Antimicrobial Active Pharmaceutical Ingredients - Canada.ca

[65] https://globalsalmoninitiative.org/en/sustainability-report/

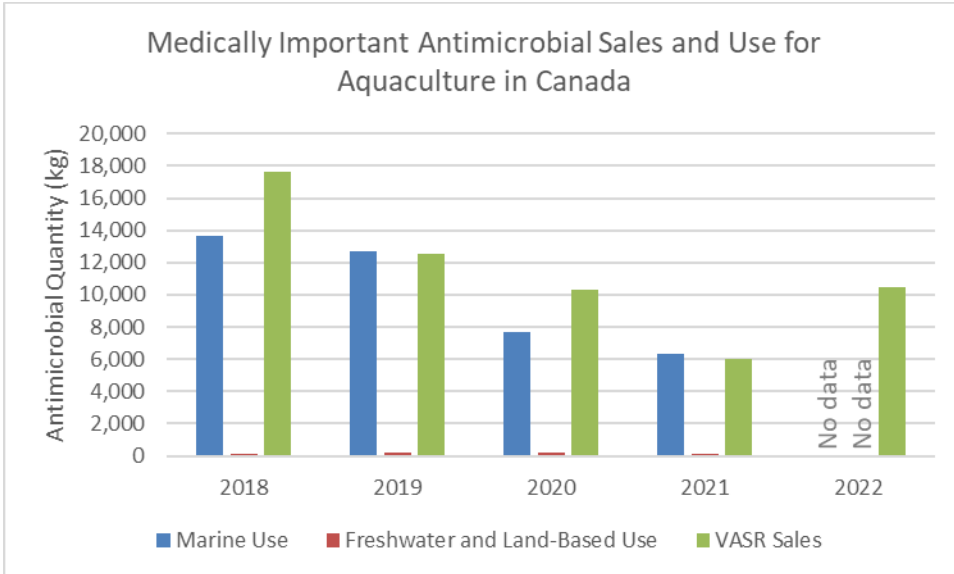

Figure 29: Annual quantity (kg) of medically important antimicrobials sold by manufacturers and importers for use in aquaculture, Canada (green bars) compared to DFO's reported use of antimicrobials in marine aquaculture and freshwater and land-based aquaculture in Canada (blue and red bars, respectively). Sales data obtained from PHAC/ASPC (pers. comm., A. Bosman, PAHC/ASPC, October 2023), and use data from DFO.

In Canada, with approximately <0.5% of total grow-out feed being medicated, the infrequent use of relatively small quantities of antimicrobials in rainbow trout culture implies a substantially reduced concern (for example, compared to that expressed by Preena et al.). Canada has an Integrated Program for Antimicrobial Resistance Surveillance (CIPARS),[66] and the Canadian Antimicrobial Resistance Surveillance System (CARSS) Report of 2022[67] indicates that the total use in rainbow trout culture in Canada is minor. For example, the recent peak antimicrobial use during the 2020 *Lactococcus* outbreak of 408 kg oxytetracycline can be compared to a total of 1.3 million kg of medically important antimicrobials sold in Canada in 2020, of which 82% were sold for use in production animals and 17% for use in people. Health Canada's Veterinary Antimicrobial Sales Reporting (VASR)[68] shows that, of the 1,027,865 kg of medically important antimicrobials sold for use in animals in Canada in 2021, more than half (517,908 kg) was oxytetracycline. Therefore, again, the use of antimicrobials in Canadian trout aquaculture appears to be minor, so it is presumed to be a minor contributor to the emergence of antimicrobial resistance.

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[66] https://www.canada.ca/en/public-health/services/surveillance/canadian-integrated-program-antimicrobial-resistance-surveillance-cipars.html
[67] https://www.canada.ca/en/public-health/services/publications/drugs-health-products/canadian-antimicrobial-resistance-surveillance-system-report-2022.html#a4.1.1
[68] https://health-infobase.canada.ca/veterinary-antimicrobial-sales/

A study on Antibiotic Resistance in Ontario Aquaculture (Chiasson et al., 2018) detected some strains of common bacteria that had reduced sensitivity to antimicrobials in fish sampled from Ontario aquaculture farms (sampled between 2016 and 2018). Table 6 shows the results of this study, with the most common antimicrobials used in aquaculture at that time highlighted. It is important to note that these are laboratory (in vitro) Minimum Inhibitory Concentration (MIC) tests, and though one category of the results is labeled “resistant—R”, this is not formal clinical resistance whereby treatments in-vivo have failed. Clinical guidelines to determine resistant, intermediate, or sensitive strains of bacteria do not yet exist for freshwater pathogens (other than *Aeromonas*), and the categories of sensitive, intermediate, and resistant in Table 6 are simple divisions of the MIC values seen in the in-vitro tests (pers. comm., M. Chiasson, University of Guelph, December 2023). Of 60 bacterial cultures of five key pathogens, 10 were categorized as resistant to oxytetracycline (i.e., they demonstrated the greatest reduction in susceptibility in a laboratory) and 13 were of intermediate resistance, while all but one of the cultures remained sensitive to florfenicol. The results for sulphadimethoxine show that all cultures of *Flavobacterium* species were resistant, but it is not clear how frequently this antimicrobial was used in aquaculture (and it has not been permitted since 2018); for example, the DFO National Aquaculture Reporting from 2016 to 2021 does not mention this treatment. Most *Flavobacteria* have intrinsic resistance to sulfonamide antimicrobials (pers. comm., A. Reid, OMAFRA, April 2024).

Table 6: Results of minimum inhibitory concentration (MIC) testing for 18 antimicrobiotics for the five most commonly cultured fish pathogens. S: sensitive; I: intermediate; and R: resistant. Florfenicol and oxytetracycline (highlighted) are the most commonly used antimicrobials approved for use in food fish production. The number in brackets represents the sample size. Table and title reproduced from Chiasson et al. (2018).

Antimicrobic	*Aeromonas salmonicida* (n = 13)	*Aeromonas hydrophila* (n = 10)	*Flavobacterium columnare* (n = 11)	*Flavobacterium psychrophilum* (n = 7)	*Yersinia ruckeri* (n = 20)
Amoxicillin	S	R	S	S	S/I
Ceftiofur	S	I/R	I	S	S/I
Clindamycin	R	R	S	S	R
Enrofloxacin	S	S	S	S	S
Erythromycin	I	I/R	S	I	I/R
Florfenicol	S	S	S	S	S/I
Gentamicin	S	S/I	S	S	S/I
Neomycin	S	S	I	S/I	I
Novobiocin	I/R	R	S/I	I	S/R
Oxytetracyline	S/R (7/5)	S/I/R (8/1/1)	S	S/I (5/2)	S/I/R (6/10/4)
Penicillin	S/I	R	S	S	S/I/R
Spectinomycin	R	I/R	S/I	S/I	S/I/R
Streptomycin	S/I	S	/S	S	S/I
Sulphadimethoxine	S/I	S/R	R	R	S
Sulphathiazole	S	S/R	S/I	I	S
Tetracycline	S/R	S/I/R	S	S/I	S/I/R
Trimethoprim/ Sulfamethoxazole	S	S	S	S	S
Tylosin	I/R	R	S	S	I/R

It is notable that the bacterial cultures isolated from farmed fish also included many strains that were categorized as “resistant” (or were of intermediate resistance) to a variety of antimicrobials that are not used in aquaculture (nonhighlighted rows in Table 6), and this indicates (along with the supporting information on the much larger use of antimicrobials in terrestrial livestock and humans) that other sources of antimicrobial use are driving these results. The lead author of the 2018 study confirmed this aspect, and stressed that correlation does not equal causation in this situation; that is, the presence of bacteria that are resistant to (or are of intermediate resistance to) antimicrobials used in aquaculture does not mean that the use in aquaculture caused the detected resistance (pers. comm., M. Chiasson, University of Guelph, September 2023).

Regarding the specific outbreak of Lactococcosis in 2020–21 in Ontario, Sultani et al. (2021) noted (in an Australian study) that the practical use of antimicrobials in fish farms is often not effective due to the reduced appetite (antimicrobials are administered in feed) and/or an ineffective metabolism of antimicrobials in the diseased fish. This was noted as the case in Ontario, and was a further driver for the development of a vaccine (pers. comm., N. LePage, fish veterinarian, October 2023). Therefore, although Sultani et al. (2021, and references therein) noted that multiple resistance to erythromycin, lincomycin, and oxytetracycline has been frequently reported in *Lactococcus garvieae* isolates (in laboratory MIC tests), the rapid development of a vaccine and the reduction in antimicrobial use seen in both Saskatchewan and Ontario is considered to represent a small risk of the development of resistance in this regard in Canada.

<u>Other chemicals</u>
The DFO national Aquaculture Reporting Data for land-based and freshwater facilities shows quite occasional use of emamectin benzoate and hydrogen peroxide (both considered to be used to treat copepod parasites) and more regular use of formalin, although it must be noted that it is not easy to identify the specific use in rainbow trout from these data. The detailed fish health reports from the dominant facilities in Ontario show highly occasional treatments (single treatments per year) of emamectin benzoate in limited numbers of broodstock fish. Considering the infrequent use and small quantities, the focus of this assessment remains on antimicrobials.

Conclusions and Final Scores
With a focus on antimicrobials, data provided by the industry (in addition to currently incomplete data from DFO) show that chemical use is typically low in Canadian rainbow trout farms, with occasional treatments of endemic bacterial pathogens such as *Flavobacterium* that are typically triggered by high-stress events such as extreme temperatures (see Criterion 7—Disease). The data also show that the industry in Canada (like elsewhere) is vulnerable to emerging pathogens, with an outbreak of *Weissella* in Saskatchewan in 2017–18 and of *Lactococcus* in Ontario in 2020–21 that led to increases in antimicrobial use and a peak of 560 kg in the available data in 2017 (annual sales of medically important antimicrobials in Canada are approximately 1.3 million kg, mostly for livestock). Nevertheless, rapid responses from the industry regarding vaccine developments and improved fish husbandry led to rapid post-

outbreak declines in antimicrobial use. Considering the combined antimicrobial use in fingerling and grow-out production of the dominant producers through the *Lactococcus* outbreak in Ontario, the total relative use is estimated to have been an average of 35.8 g/mt between 2020 and 2022, but in 2023 has been zero (as of mid-December). Antimicrobial use has also been close to zero in Saskatchewan over the same period. Based on medicated feed sales, the peak use in recent years in Ontario (2020) represented <0.5% of the total feed sold, and therefore of production. Although antimicrobial use at the fingerling stage is somewhat common through the warmer months, detailed batch-treatment data show that a small proportion of fish are treated and at a small average size (12.7% of batches at an average fish weight of 4.6 g). Thus, the use of antimicrobials is demonstrably less than once per production cycle. The only authorized treatments for aquaculture in Canada are listed as highly important to human medicine by the World Health Organisation (WHO); however, with a low apparent concern regarding resistance at this time, the initial score for Criterion 4—Chemical Use is 8 out of 10. Much less data are available that could be related conclusively to land-based raceway, pond, or tank systems (except for the low chemical use in land-based hatcheries, as noted), and this situation is currently hampered by the low confidence in the DFO data (which is not an apparent fault of the industry). Without sufficient justification to consider otherwise (e.g., based on disease occurrences or any other data), the same score of 8 out of 10 is applied to land-based systems on the assumption that antimicrobial treatments are also likely to be less than once per production cycle on average.

The Seafood Watch Aquaculture Standard allows a trend adjustment in cases where data show that a decline in chemical use over time is sufficient to give confidence that improved management practices are leading to clear reductions in use and the risk of impacts. Considering the timeframes of the primary data provided here, it is clear that antimicrobial use is typically low, and has only increased in response to specific outbreaks (e.g., in 2017/18 and 2020/21), which have rapidly been controlled. Although antimicrobial use has declined post-outbreak in both cases (and improvements in management practices are recognized as reducing the risk of future disease outbreaks), there is not considered to be sufficient justification to apply a trend adjustment here, and the final score for Criterion 4—Chemical Use remains 8 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

- Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.
- Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- Principle: sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains.

Criterion 5 Summary—all production systems

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	1.29	
F5.1b Source fishery sustainability score (0–10)		5
F5.1: Wild fish use score (0–10)		4.84
F5.2a Protein INPUT (kg/100 kg fish harvested)	564.4	
F5.2b Protein OUT (kg/100 kg fish harvested)	15.70	
F5.2: Net Protein Gain or Loss (%)	–72.2	2.00
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	12.81	7.00
C5 Feed Final Score (0–10)		4.67
Critical?	No	Yellow

Brief Summary

Information on the inclusion levels of marine ingredients in Canadian rainbow trout feeds was provided by two feed companies, and the other major ingredients were listed by the dominant company. An academic reference feed from a review of rainbow trout nutrition was also used to create a best-fit feed formulation for this assessment. An average economic feed conversion ratio value of 1.36 was used, based on recent production data covering all net pen producers in Ontario and Saskatchewan. The feeds have low levels of fishmeal (a weighted average of 8.2%), but moderate levels of fish oil from whole fish (a weighted average of 5.3%). The Forage Fish Efficiency Ratio (FFER) based on fish oil was 1.29. This means that, from first principles, 1.29 mt of wild fish would need to be caught to supply the fish oil to produce 1 mt of rainbow trout in Canada. The sources of marine ingredients are mostly from fisheries certified to the MarinTrust or the Marine Stewardship Council, and the combined score for Factor 5.1—Wild Fish Use was 4.8 out of 10. With a high average feed protein content of 41.5%, there is a substantial net loss of protein of 72.2%, and a score of 2 out of 10 for Factor 5.2. The feed footprint calculated as the embedded climate change impact (kg CO_2-eq) resulted in an estimated 12.8 kg CO_2-eq per kg of farmed seafood protein, equivalent to a score of 7 out of 10 for Factor 5.3. The three factors combine to give a final Criterion 5—Feed score of 4.7 out of 10.

Justification of Rating

Two main feed companies dominate the supply in Canada: Skretting North America and, to a much lesser extent, Bluewater Feeds. In Ontario, Skretting supplies approximately 80% of the feed (pers. comm., Anon, Bluewater Feeds, November 2023), and it is the dominant supplier of the single large farm in Saskatchewan (pers. comm., D. Foss, WWS, October 2023). Data on marine ingredient inclusions were provided by both companies for this assessment, and on marine ingredient sourcing from Skretting. A simple list of major nonmarine ingredients was also provided by Skretting.

To fill in the inclusions for nonmarine ingredients and generate an approximate "typical" feed formulation for a Canadian rainbow trout feed, the generalized feed formulation in Kamalan et al. (2020)[69] has a sufficient match with the dominant ingredient lists provided by the two feed companies. Weighted average values from the two feed companies were used for marine ingredients (weighted based on market share: 83% Skretting and 17% Bluewater Feeds)[70] (Table 7). Without specific data to differentiate the feed suppliers or to identify any specific characteristics of feeds used in different production systems, the feeds used in land-based systems are considered the same as those used in net pens.

Table 7: Best-fit feed formulation based on marine ingredient inclusion levels from two feed companies in Canada, a list of nonmarine ingredients, and the general rainbow trout formulation from Kamalan et al. (2020).

Ingredient	Aggregated or estimated inclusion level (%)
Fishmeal (from whole fish)	4.8
Fishmeal (from by-products)	2.2
Fish oil (from whole fish)	4.7
Fish oil (from by-products)	0.7
Soy meal	16.0
Whole wheat flour	20.0
Corn gluten	10.0
Canola oil	10.0
Poultry meal	11.0
Feather meal	11.0
Poultry oil	5.0
Vitamins and minerals/other	4.6
Total	**100.0**

[69] Kamalan et al. (2020) provided a review of the "Nutrition and Feeding of rainbow trout (*Oncorhynchus mykiss*)."
[70] Weighting is based on 80% Skretting in Ontario plus 100% Skretting in Saskatchewan, using approximate 2022 production figures.

Economic feed conversion ratio (eFCR)
The eFCR (calculated by dividing the total feed use by the total harvest) is an important parameter in this assessment. Fry et al. (2018) considered a typical range of eFCRs of 1.0 to 2.0 for rainbow trout (in different production systems). eFCR values were provided from all net pen producers in Ontario and Saskatchewan for all 2021 stocked fish and completed cycles (pers. comm., S. Higgins, Cole Munro; D. Foss, WWS; RJ Taylor, OAA, November 2023). These values ranged from 1.28 to 2.04, noting that the highest value of 2.04 reflected a single cage that was affected by *Lactococcus* mortality. By weighting the eFCR values according to the quantities of rainbow trout harvested, a weighted average value of 1.36 is used here. Specific data from land-based farms were not available; therefore, given the dominance of net pen production in Canada, the value of 1.36 is used here for a single Canada-wide feed assessment.

Factor 5.1—Wild Fish Use
Factor 5.1 combines an estimate of the wild fish used to produce farmed rainbow trout with a measure of the sustainability of the source fisheries.

Factor 5.1a—Feed Fish Efficiency Ratio (FFER)
Marine ingredient inclusion data from the two feed companies are shown in Table 8, based on a weighted average of 83% Skretting and 17% Bluewater. These show a low level of fishmeal (for example, the general formulation in Kamalan et al. (2020) had 22% fishmeal), but typical levels of fish oil (7.0% in Kamalan et al.). The default yield values of 22.5% for fishmeal and 5.0% for fish oil were used (from Tacon and Metian, 2008).

Table 8: Fishmeal and fish oil inclusion levels from whole fish and by-product sources, eFCR values, and calculated FFER values for rainbow trout in raceways.

Parameter	Data
Fishmeal inclusion level (total)	**7.0%**
Fishmeal inclusion level (whole fish)	4.8%
Fishmeal inclusion level (by-product)	2.2%
Fishmeal yield	22.5%
Fish oil inclusion level (total)	**5.4%**
Fish oil inclusion level (whole fish)	4.7%
Fish oil inclusion level (by-product)	0.7%
Fish oil yield	5.0%
Economic Feed Conversion Ratio	**1.36**
FFER fishmeal	0.30
FFER fish oil	1.29
Assessed FFER	**1.29**

The calculated FFER values are 0.30 for fishmeal and 1.29 for fish oil. From first principles, this indicates that 1.29 mt of wild fish would need to be caught to supply the fish oil to produce 1 mt of rainbow trout in Canada.

Factor 5.1b—Sustainability of the Source of Wild Fish

The dominant feed supplier Skretting provided information on their marine sourcing policy[71] and their Sustainability RoadMap 2025,[72] and Skretting at the global level is part of the Ocean Disclosure Project (ODP).[73] The relevance of the approximately 60 global fisheries listed in the ODP data to the specific feeds for rainbow trout in Canada is uncertain, but Skretting North America states that it sources its marine ingredients from fisheries that are MarinTrust (MT) or Marine Stewardship Council (MSC) certified, or subject to a Fishery Improvement Project (FIP). In general, Skretting North America reported that 93% of their marine ingredients come from MSC- and MT-certified fisheries, and specific data (for fish oil only) for their 2023 sourcing (as of mid-November 2023) showed that 62% of fish oil sources were MT certified and 38% were MSC certified (pers. comm., S. Cook, Skretting North America, October/December 2023). This indicates that a small proportion of fishery sources (for fishmeal) come from FIPs. Considering the dominant mix of MSC-[74] and MT-certified sources (scores for Factor 5.1b of 6 out of 10 and 4 out of 10, respectively) the score for Factor 5.1b—Sustainability of the Source of Wild Fish is 5 out of 10. Combined, the Factor 5.1a and Factor 5.1b scores result in a final Factor 5.1—Wild Fish Use score of 4.8 out of 10.

Factor 5.2—Net Protein Gain or Loss

Weighted average total feed protein contents were provided by Skretting (41%) and Bluewater Feeds (44%). The weighted average of these values (based on an 83:17 ratio of estimated use) is 41.5%. Table 9 shows that, with an eFCR of 1.36, there is a net protein input in feed of 557.6 kg protein per mt of trout production. Regarding the protein outputs in harvested trout, the whole-body protein content of *O. mykiss* is 15.7% (Dumas et al., 2007), so there is a protein output of 157.0 kg per mt of trout production.

Table 9: Values used to calculate net protein gain or loss.

Parameter	Data
Protein content of feed (%)	41.5
Protein content of whole harvested rainbow trout (%)	15.7
Economic Feed Conversion Ratio	1.36
Total protein INPUT per mt of farmed rainbow trout (kg)	564.4
Total protein OUTPUT per mt of farmed rainbow trout (kg)	157.0
Net protein gain or loss (%)	**–72.2% loss**
Seafood Watch Score (0–10)	**2**

These figures indicate there is a substantial net loss of protein of 72.2% during the production of rainbow trout, which results in a score of 2 out of 10 for Factor 5.2. It is noted (as listed in Table 7) that a substantial amount of the feed protein comes from land animal by-product

[71] skretting.com/siteassets/20220303-skretting-marine-sourcing-policy-final.pdf
[72] 20210308-roadmap-2025-brochure-final.pdf (skretting.com)
[73] https://oceandisclosureproject.org/
[74] It is assumed here that the MSC-certified fisheries may have some conditions, which scores 6 out of 10 in the Seafood Watch Aquaculture Standard for Factor 5.1b (MSC-certified fisheries without conditions score 8 out of 10).

sources; however, these ingredients also have an ecological cost of production that is recognized here and in Factor 5.3.

Factor 5.3—Feed Footprint

Factor 5.3 approximates the embedded global warming potential (kg CO_2-eq, including land-use change [LUC]) of the feed ingredients required to grow 1 kg of farmed seafood protein. This calculation is performed by mapping the ingredient composition of a typical feed used against the Global Feed Lifecycle Institute (GFLI) database to estimate the global warming potential (GWP) of 1 metric ton of feed, then multiplying this value by the eFCR and the protein content of whole harvested seafood. If an ingredient of unknown origin is found in the GFLI database, an average value between the listed global "GLO" value and worst listed value for that ingredient is applied; this approach is intended to create incentives for data transparency and provision. In cases where a global value was not available (e.g., fishmeal and fish oil), the most appropriate and/or most geographically relevant ingredient listings were used. The detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Table 10 shows the ingredient categories selected from the GFLI database according to the above methodology for ingredients of unknown origins. For fishmeal and fish oil, including by-products, the values at processing plants in the neighboring United States were considered the

Table 10: Estimated embedded global warming potential of 1 mt of rainbow trout feed in Canada. GFLI refers to the Global Feed Lifecycle Institute. Single-line items either do not have a global (GLO) value in the GFLI data or are single items in the data.

Ingredient	Ingredient listing in the GFLI Database	Inclusion %	kg CO_2 eq/ mt feed
Fishmeal	Fishmeal, from fishmeal and oil production, at plant/U.S. Economic S	7.0	78.4
Fish oil	Fish oil, from fishmeal and oil production, at plant/U.S. Economic S	5.4	41.1
Soybean meal	Soybean expeller, from crushing (pressing), at plant/GLO Economic S	16.0	535.2
	Soybean expeller, from crushing (pressing), at plant/BR Economic S		
Poultry meal	Animal meal, poultry, from dry rendering, at plant/RER Economic S	11.0	87.7
Feather meal	Maize gluten meal, from wet milling (gluten drying), at plant/GLO Economic S	11.0	83.2
Wheat flour	Wheat flour, from dry milling, at plant/GLO Economic S	20.0	143.8
	Wheat flour, from dry milling, at plant/ES Economic S		
Corn gluten	Maize gluten meal dried, at processing/U.S. Economic S	10.0	79.9
Canola oil	Crude rapeseed oil (pressing), at processing/U.S. Economic S	10.0	280.0
Poultry oil	Fat from animals, poultry, at processing/RER Economic S	5.0	102.5
Vitamins, minerals	Total minerals, additives, vitamins, at plant/RER Economic S	3.5	30.8
Total		**100.0**	**1,472.1**

most representative listings available in the GFLI database. For the crop ingredients (soy, wheat, canola, and corn), considering the abundance of North American sources, U.S. values were selected (Canadian values were not available). For the land animal by-product ingredients, single values only were available in the GFLI database, based on European production (RER). Because of the licensing agreement, the specific values for each ingredient from the GFLI database are not reproduced here, but the calculated value per mt of feed for each ingredient is shown.

The total estimated embedded GWP of 1 mt of rainbow trout feed is 1,472.1 kg CO_2-eq. Considering a whole harvested farmed rainbow trout protein content of 15.7% (from Factor 5.2) and an eFCR of 1.36, it is estimated that the feed-related GWP of 1 kg farmed trout protein is 12.81 kg CO_2-eq. This results in a score of 7 out of 10 for Factor 5.3—Feed Footprint.

Conclusions and Final Score

Information on the inclusion levels of marine ingredients in Canadian rainbow trout feeds was provided by two feed companies, and the other major ingredients were listed by the dominant company. An academic reference feed from a review of rainbow trout nutrition was also used to create a best-fit feed formulation for this assessment. An average economic feed conversion ratio value of 1.36 was used, based on recent production data covering all net pen producers in Ontario and Saskatchewan. The feeds have low levels of fishmeal (a weighted average of 8.2%), but moderate levels of fish oil from whole fish (a weighted average of 5.3%). The Forage Fish Efficiency Ratio (FFER) based on fish oil was 1.29. This means that, from first principles, 1.29 mt of wild fish would need to be caught to supply the fish oil to produce 1 mt of rainbow trout in Canada. The sources of marine ingredients are mostly from fisheries certified to the MarinTrust or the Marine Stewardship Council, and the combined score for Factor 5.1—Wild Fish Use was 4.8 out of 10. With a high average feed protein content of 41.5%, there is a substantial net loss of protein of 72.2%, and a score of 2 out of 10 for Factor 5.2. The feed footprint calculated as the embedded climate change impact (kg CO_2-eq) resulted in an estimated 12.8 kg CO_2-eq per kg of farmed seafood protein, equivalent to a score of 7 out of 10 for Factor 5.3. The three factors combine to give a final Criterion 5—Feed score of 4.67 out of 10.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage , spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

C6 Escape parameters	Net Pens		Raceways, ponds, tanks	
	Value	Score	Value	Score
F6.1 System escape risk (0–10)	2		4	
F6.1 Recapture adjustment (0–10)	0		0	
F6.1 Final escape risk score (0–10)		2		2
F6.2 Invasiveness score (0–10)		10		10
C6 Escape Final Score (0–10)		**10**		**10**
Critical?	No	**Green**	No	**Green**

Brief Summary

With a single netting barrier containing the fish in a net pen farm, there is considered to be a high risk of escape, either from catastrophic events such as storms or ice damage, or from trickle losses of small numbers of fish during routine operations. Ontario's Aquaculture Risk and Security Policy classifies net pen systems as Low Security Facilities from which losses are considered inevitable—potentially in large numbers. Although no recent data are publicly available, documented escape events in Lakes Huron and Diefenbaker support this classification. Land-based farms situated above regional flood levels and using multiple escape prevention barriers are considered (by the Ontario Ministry of Natural Resources and Forestry) to be of moderate risk of escape. The high risk of escape results in scores for Factor 6.1 of 2 out of 10 for net pens and 4 out of 10 for land-based systems. Rainbow trout is a nonnative species in the areas covered in this assessment, but was established across Canada from the late 1800s. Hundreds of millions of rainbow trout have been stocked into Lake Huron for recreational fisheries, and stocking continues: for example, between the Ontario and Michigan Departments of Natural Resources and community hatcheries in Ontario, at least 1.17 million rainbow trout have been released into Lake Huron in the last 5 years (2018–22, with an annual average of 234,038). Other nonnative salmonids such as brown trout, Chinook salmon, and coho salmon continue to be stocked into Lake Huron. In Lake Diefenbaker, rainbow trout was similarly introduced and actively stocked into the artificial reservoir (although this has now ceased). There have also been widespread introductions of rainbow trout in Quebec, but aquaculture and stocking are now restricted to limited areas of the province to reduce further spread. The historic introduction and establishment of nonnative rainbow trout has had a variety of ecological impacts, but the ongoing stocking by the government and community hatcheries of rainbow trout (and other nonnative salmonids) means that any aquaculture escapes are considered unlikely to cause significant additional ecological impacts to wild fish populations in the areas where farms operate. Potential genetic interactions of escaped farmed rainbow trout with now-naturalized rainbow trout populations are not a conservation concern in this assessment. Therefore, the score for Factor 6.2—Competitive and genetic interactions is 10 out of 10. The combined scores mean that, despite the high risk of escape, the quite low risk of significant impacts results in a final score for Criterion 6—Escapes of 10 out of 10 for all production systems.

Justification of Rating

This criterion assesses the risk of escape (Factor 6.1) with the potential for impacts according to the nature of the species being farmed and the ecosystem into which it may escape (Factor 6.2). Evidence of recaptures is a component of Factor 6.1. Aspects such as historical introductions and establishments, in addition to ongoing stocking for purposes other than aquaculture (e.g., sport fishing), are included in Factor 6.2. See the Seafood Watch Aquaculture Standard for further details on all scoring tables and calculations.

Factor 6.1—Escape Risk

All aquaculture operations carry the risk of escapes (Diana, 2009), but the degree of risk depends on the type of production system and the effectiveness of management, including the proper training of employees and emergency plans in the case of escapes (Halwart et al., 2007)(Jensen et al., 2010).

There do not appear to be any publicly available escape records at the national or provincial scale in Canada; DFO publishes Annual National Escape Reports,[75] but these data appear to be limited to marine net pens and have not been updated since 2017 (accessed April 15, 2024). Three aspects of escape risk are considered here: the fundamental nature of the production system, anecdotal evidence of escape events from various sources, and detections of domesticated (and therefore presumed escaped) trout in the wild.

Net pens

With net pen systems, there is an inherently high risk of fish escaping into natural habitats because there is only a net barrier between the fish and the wild. Losses can be caused by several internal and external factors that result in the occasional release of a large number of individuals (massive escape events) and/or the recurrent release of a small number of fish (chronic or leakage escapes) (Glover et al., 2017)(Atalah & Sanchez-Jerez, 2020). These statements are referenced to studies of marine net pen salmon farms, but the risks in freshwater net pen systems are considered broadly similar.

[75] https://www.dfo-mpo.gc.ca/aquaculture/protect-protege/escape-prevention-evasions-eng.html#annual

Aquaculture license conditions require farms to have a Fish Containment Plan (e.g., Schedule B, 8, in the Ontario license conditions), but according to the Aquaculture Risk and Security Policy (FisPp.9.2.5),[76] the Ontario Ministry of Natural Resources and Forestry (OMNRF) classifies net pen systems as Low Security Facilities (denoted as F3, as opposed to F2—Medium Security and F1—High Security). As F3 systems, they are considered to pose a high risk of escape, and losses are considered inevitable—potentially in large numbers.

Although somewhat dated, Blanchfield et al. (2009) state that the escape of freshwater fish from net pens in Canada is "common," typically in small numbers because of handling errors or in large numbers from storm damage or vandalism. Annual escape may be about 3–5% of the total net pen production (as reviewed in Blanchfield et al. 2009) or as low as 0.3% (as reviewed in Anderson 2015). In a study of trout farms in Lake Huron, Johnston and Wilson (2014) note that farmed fish are lost from the net pens to the surrounding environment during fish transfer activities (stocking, size grading, harvesting) and through gaps in the mesh caused by routine wear, animals, or storm damage. It is noted here that damage to net pens from shifting ice is a particular concern in Canadian rainbow trout production (pers. comm., RJ Taylor, OAA, October 2023)(pers. comm., D. Foss, WWS, October 2023).

It is also of particular interest here to note that, although the aquaculture license conditions in Ontario and Saskatchewan require a farm to report any large-scale fish escapements greater than 1,000 fish within a 24-hour period, a license holder in Ontario is not required to report escapes that "might reasonably be expected through routine operations," though this is not further specified or quantified (Schedule B, 16).

OMNRF reported (for this assessment) that approximately 209,000 fish have escaped from net pen aquaculture sites since 2012, encompassing 9 escapement events, with the number of fish escaping ranging from 10,000 to 55,000 in each event (typically from 1 to 2.5 kg in weight) (pers. comm., M. Smith, OMNRF, May 2024). These escapes were attributed to various factors, including severe storms, damaged nets, and fish grading issues, which cause small fish to pass through the cage mesh. These values match more detailed, unpublished OMNRF data provided by the Georgia Bay Association from 1996 to 2023 (R. Kindersley, GBA, April 15, 2024). These data are shown in Figure 30 (note that two escape values have been estimated here due to the escape numbers being reported as a range; e.g., 1,000–2,000; the midpoint was used, or 1,500 in this example).

The aggregated total escapes over this period (1996 to 2023) were 1.34 million fish of sizes varying from 10 g to 3 kg. But the structural design and construction of net pens is considered to have improved (pers. comm., M. Smith, OMNRF, May 2024), and the data indicate that the total annual escape numbers have declined substantially from a peak of 320,000 in 2002 to zero in the most recent three data years (2021–23). Similarly, the annual number of reported events has declined from a peak of seven in 2004 to zero in the most recent three years. Of those

[76] https://www.ontario.ca/page/aquaculture-risk-and-security-policy-fispp925

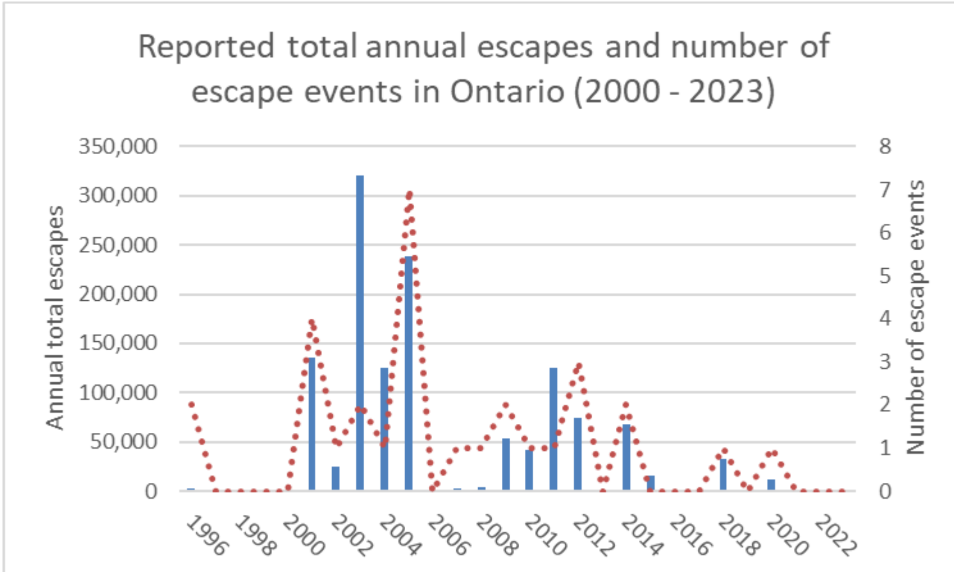

Figure 30: Reported total annual escapes (blue bars) and annual number of reported escape events (dotted red line) from rainbow trout farms in Ontario between 1996 and 2023. Data from OMNRF (unpublished), provided by the Georgia Bay Association (R. Kindersley, pers. comm., April 15, 2024).

escape reports that included a specific cause (552,250 escapes), 85.8% were associated with storm events. Other reasons include vandalism (6.2%) and otter damage to nets (6.0%).

Johnston and Wilson (2014) reported total escapes from 1999 to 2012 (which largely match the data presented above in Figure 30), but considered the total annual escapement of domestic rainbow trout into northern Lake Huron to be difficult to determine. They noted that, although relatively large escapements have occurred occasionally when storms or shifting ice have damaged cage structures, most escape events are probably small and frequent. This situation is likely to be similar in Lake Diefenbaker, where shifting ice damaged nets and caused large escapes in 2000 (pers. comm., D. Foss, WWS, September 2023), but it is also likely that smaller and more frequent escape events occur (and may not need to be reported). Similarly, in Lois Lake in British Columbia (and in the connected Khartoum Lake), an amendment to the angling regulations was proposed and enacted in January 2023 to increase the allowed daily quota of rainbow trout, because “Escapes from the facility net pens have been occurring for several years” (Regulation Number: 2023-02-02).[77] It is noted that the farm in Lois Lake had been operating an experimental floating tank system; therefore, it may not have been representative of the broader net pen rainbow trout industry in Ontario or Saskatchewan.

Multiple scientific studies have documented the presence of escaped rainbow trout in the wild in Lake Huron, with genetic and observational studies distinguishing “domestic” (i.e., escaped) fish from naturalized “wild” fish. For example, Johnston and Wilson (2014) identified approximately 88% of captured rainbow trout as domestic fish using genetic tests (and 80% by visual identification) in tributaries near the focal point of net pen aquaculture in the north

[77] https://apps.nrs.gov.bc.ca/ahte/content/lois-lake-and-khartoum-lakes

channel of Lake Huron, compared to tributaries on the south side of Manitoulin Island or to the west of the island (Figure 31). It is noted here (and discussed in Factor 6.2) that these observations of escaped rainbow trout were primarily limited to the local area of the farms.

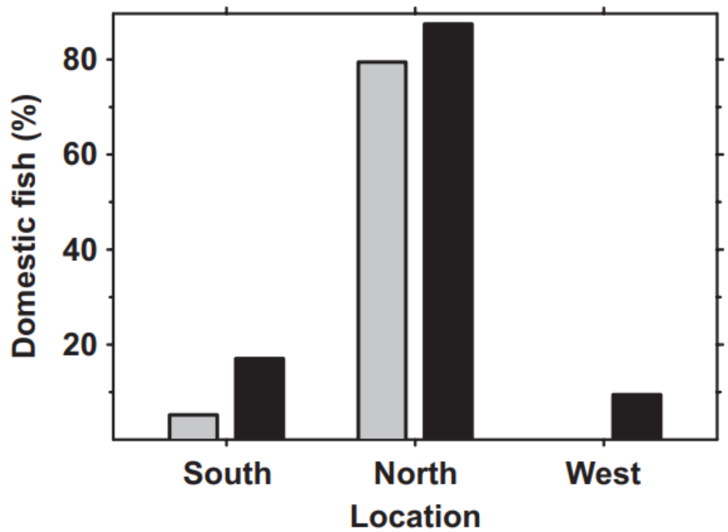

Figure 31: Percentage of rainbow trout sampled from northern Lake Huron tributaries in spring 2005 and 2006 that were categorized as domestic (i.e., escaped) based on visual assessment (grey bars) and genotypic classification (black bars). Sampling locations were spawning tributaries on the south side of Manitoulin Island (South), in the North Channel region (North), and in the St. Mary's River region (West). No fish from the West location were classified as domestic based on visual inspection. Graph and title reproduced from Johnston and Wilson (2014).

Most net pen rainbow trout farms in Canada are certified to the Best Aquaculture Practices (BAP) scheme,[78] which audits compliance with the requirements of the BAP Farm Standard. The requirements relate to the design, operation, and maintenance of net pen holding systems, in addition to related aspects such as a written containment policy, staff training, and record keeping/reporting. The reduction in reported escape numbers and escape events in recent years is recognized, as are the limitations in the reporting requirements. As an open system that operates established best-practice standards, the score for Factor 6.1—Escape Risk is 2 out of 10, which reflects the high escape risk acknowledged by the OMNRF's high-risk F3 classification.

Land-based farms—Raceways, ponds, and tanks

The same OMNRF classification system[79] considers earthen ponds or other systems located in flood plains to be at high risk of escape unless they are specifically raised above flooding risk elevations. Without the flood risk, and where multiple barriers on outflows are used, the OMNRF system classifies them as a moderate risk. Although not specifically stated in the

[78] Accessed Octobe 30, 2023, BAP lists 8 net pen farms in Ontario, and one in Saskatchewan. https://www.bapcertification.org/Producers

[79] https://www.ontario.ca/page/aquaculture-risk-and-security-policy-fispp925

OMNRF classification, this is considered to be intended to apply to flow-through systems, in addition to those that reduce and/or recirculate water.

Quebec's Commercial Aquaculture Regulations[80] have a simple statement (Chapter 5, section 2, Article 31, 5): "[T]he aquaculture site or fishing pond is operated in such a way as to ensure the containment of fish or amphibians and to prevent their escape into the natural environment." Articles 33 and 34 require a license holder to report escapes to the Minister of Agriculture, Fisheries and Food. As discussed in more detail in Criterion 2—Effluent (Factor 2.2a), Ministerial Authorizations for fish farms under the REAFIE environmental impact regulations require comprehensive information on the design and operation of the systems. And, although many aspects of effluent treatment will have some impact on the escape risk in land-based systems (e.g., infrastructure aspects such as settling ponds, screens, drum filters, and drainage ditches), the prevention of escapes must be detailed specifically in AM18e. These aspects must be approved by the minister, which involves multidisciplinary scrutiny, including aquaculture engineers and biologists.

Although details on the practical implementation of these requirements on containment practices in land-based systems are not readily available, the OMNRF notes that most existing Ontario trout farms are currently licensed as medium security facilities[81] (i.e., they must be located or engineered to be above the regional floodplain, and have multiple inflow and discharge barriers appropriate to the cultured species and size). Based on this classification, the score for Factor 6.1 for raceways, ponds, and tanks is 4 out of 10.

Recapture

Noting that only escapes of >1,000 fish from net pen farms must be reported, the aquaculture license conditions (in Ontario) also state that, where practical, attempts to recapture escaped fish immediately following an escapement may be permitted, provided that written approval is obtained from the Lake Manager[82] for each incident of escapement (Schedule B, 16). Given the likely sporadic nature of significant escape events, there is no readily available information on how often this written permission is either requested or given. Similarly, in Saskatchewan, only fish accidentally released during pen transfers may be recaptured, but only using dip nets within 2 m of the net pens (Schedule A,3 of the Saskatchewan aquaculture license conditions).

Regarding the potential for recapture (for example, using nets), Blanchfield et al. (2009) studied the survival and behavior of rainbow trout released from an experimental aquaculture operation, and other studies give further indications of the potential movements and/or further interactions in the wild (e.g., Miller et al., 2020; Johnston and Wilston 2014; Martens et al., 2014; Patterson and Blanchfield, 2013). These and other salmonid escape studies can give some glimpses of the likely dispersal of rainbow trout in certain circumstances, such as particular

[80] https://www.legisquebec.gouv.qc.ca/fr/document/rc/A-20.2,%20r.%201
[81] https://www.ontario.ca/page/aquaculture-risk-and-security-policy-fispp925
[82] In the case of Lake Huron, the lake manager is the Upper Great Lakes Management Unit Lake Manager of the Ministry of Natural Resources and Forestry.

sizes of fish, times of year, and locations. For example, Blanchfield et al. (2009) considered that the post-escape survival of farmed rainbow trout from net pens was low and that escaped trout are attracted to the aquaculture site, and while this behavior could serve to aid in recapture, it cannot be assessed without relevant data. There is substantial angling pressure in Lake Huron and Lake Diefenbaker, but there is also a lack of specific data on the effects of these activities on escape numbers. If there were an escape from a land-based farm (which could occur into a variety of waterways such as lakes, rivers, or streams), there is a similar lack of information available on recapture efforts or their results, and a recapture adjustment is also not applied. Overall, without robust information on recapture efforts or on the results of any such consented efforts, a recapture adjustment is not applied here.

Factor 6.2—Competitive and Genetic Interactions

In Ontario, according to the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS),[83] rainbow trout is not native to the Great Lakes, but naturalized populations have been established from stocking events dating to the late 1800s (Fuller et al., 2023)(Johnston and Wilson, 2014, and references therein)(Thibault et al., 2010). For reference, the native range of *O. mykiss* extends along the Pacific coast of North America from the Kuskokwim River, Alaska to (at least) Rio Santa Domingo, Baja California, Mexico (USGS[84]).

The time series of data in the USGS NAS database show that the Great Lakes were one of the earliest areas in the U.S. where rainbow trout was stocked and established, and of the various exotic salmonids (*Oncorhynchus* spp. and *Salmo* spp.) stocked into the Great Lakes, rainbow trout has arguably been the most successful at establishing self-sustaining populations across a wide geographic range (Johnston and Wilson, 2014). The 2021 environmental priorities of the Lake Huron Committee of the Great Lakes Fishery Commission refer to Fish Community Objectives to "Establish a diverse salmonine community that can sustain an annual harvest of 2.2 million kg with lake trout the dominant species and anadromous (stream-spawning) species also having a prominent place" (LHC, 2021)(LHTC, 2007). Rainbow trout and other nonnative salmonids established in the Great Lakes are considered to be included in the latter category. Whelan and Johnson (2004) stated that 253,000,000 salmonids had been stocked into Lake Huron since 1963.

The stocking of rainbow trout in Ontario continued after 2004 and is ongoing. Figure 32 shows a screenshot from the Ontario Geohub database[85] filtered for rainbow trout stocking from 2020 to September 2023 (blue dots are rainbow trout, grey dots are other stocked species), and an analysis of the data shows an average of more than half a million fish (501,955) were stocked annually over this period. Note that a single blue dot represents all the fish stocked into Lake Huron. The same data are available in a different format at Ontario's Fish On-line website.[86]

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[83] https://nas.er.usgs.gov/queries/greatLakes/FactSheet.aspx?Species_ID=910&Potential=N&Type=0&HUCNumber=DGreatLakes

[84] https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=910

[85] https://geohub.lio.gov.on.ca/

[86] https://www.lioapplications.lrc.gov.on.ca/fishonline/Index.html?viewer=FishONLine.FishONLine&locale=en-CA

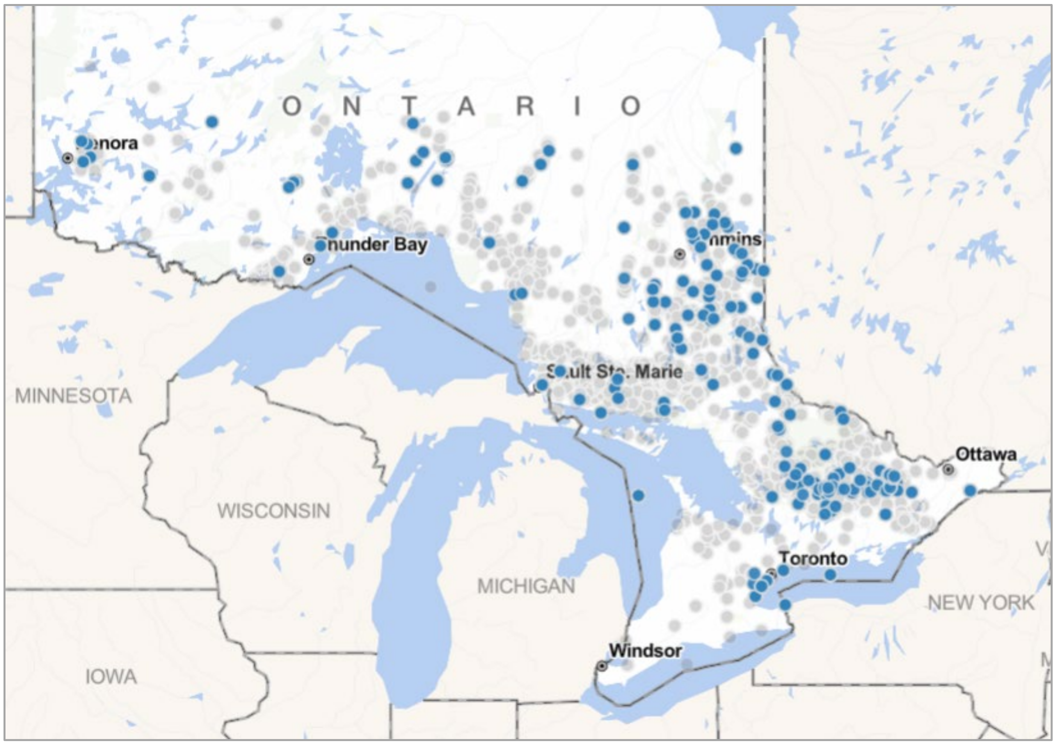

Figure 32: Rainbow trout stocking events (blue dots) between 2020 and September 2023. Grey dots indicate other stocked species. Image reproduced from the Ontario GeoHub.

In Lake Huron specifically, Figure 33 shows that rainbow trout is the most commonly stocked species, with 769,163 fish stocked in the five years between 2018 and 2022, or an annual average of 153,832. This reflects a similar longer-term pattern, with the 10-year average slightly higher at 148,848 fish per year (2013–22). The Ontario MNRF noted an annual average of approximately 180,000 rainbow trout intentionally stocked into the Ontario waters of Lake Huron (pers. comm., M. Smith, OMNRF, May 2024). It is noted that these are Canadian data and that similar stocking occurs into Lake Huron from the United States shorelines; for example, the Michigan Department of Natural Resources released 671,338 rainbow trout into Lake Huron between 2018 and 2022, with a drop in 2021 to 29,999 (the 5-year annual average is 104,933). Combined, the government hatcheries in Ontario and Michigan, in addition to community hatcheries in Ontario, have released at least 1.17 million rainbow trout into Lake Huron in the five years 2018–22 (an annual average of 234,038). It is also noted that the stocking of other nonnative species—brown trout, Chinook salmon, and coho salmon—continues in Lake Huron.

Figure 34 shows that the annual stocking rate of rainbow trout is highly variable; for example, in Ontario, 283,000 rainbow trout were stocked into Lake Huron in 2019 but none in 2021. This is considered the result of limited hatchery operations in 2020 and 2021 from COVID-19 restrictions.[87] Though escapes from net pen farms may occur at any size of fish, Figure 34 also

[87] The Community Hatchery Program notes that all walleye and some rainbow trout community hatcheries could not operate in 2020 due to COVID-19 restrictions during the egg collection timeframe and some community hatcheries remained closed in 2021 due to ongoing volunteer safety concerns.

shows that a variety of fish sizes are stocked, from fry to adults, with yearling fish being the majority.

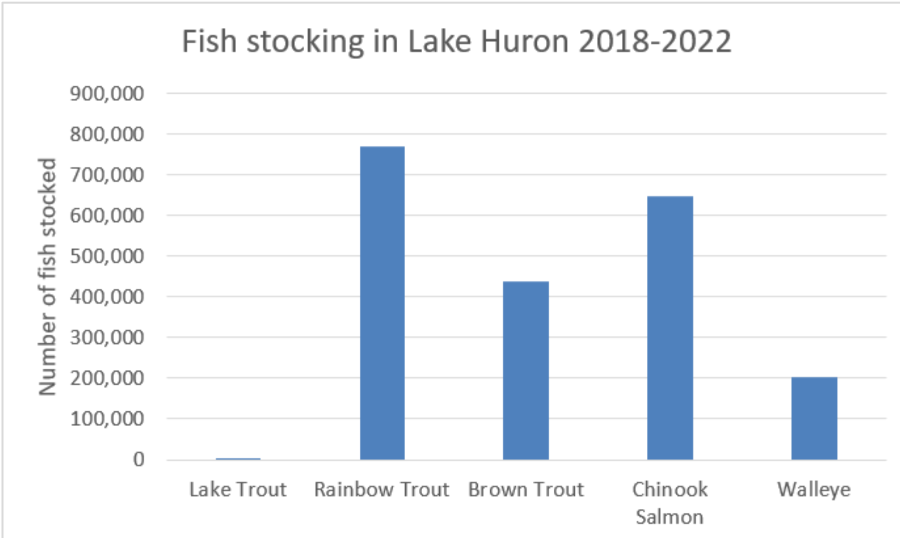

Figure 33: Species and number of fish stocked into Lake Huron from 2018 to 2022 inclusive. Data from Ontario GeoHub.

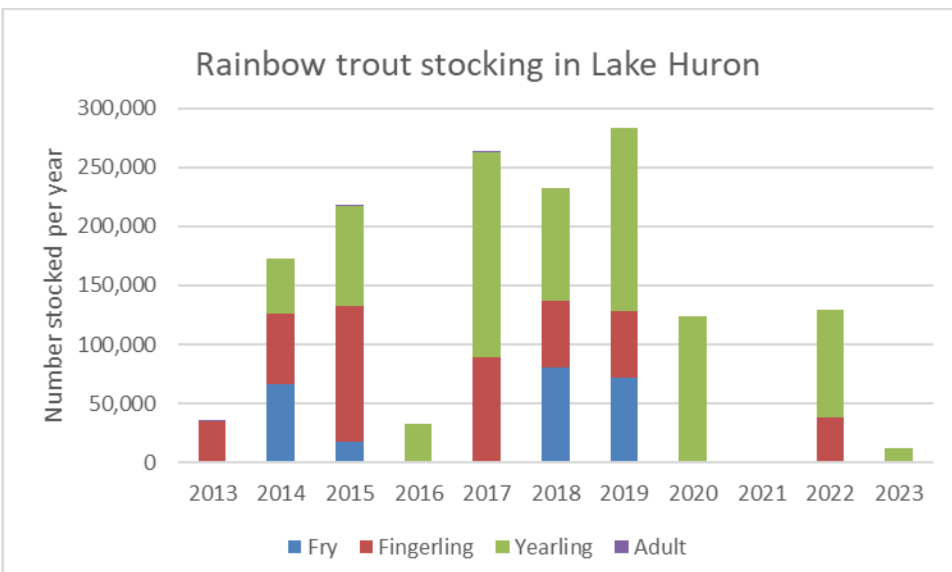

Figure 34: Characteristics of rainbow trout stocking in Lake Huron from 2013 to 2023. Note that recent years may have been affected by hatchery operations during COVID-19 restrictions.

In Lake Diefenbaker, a 2012 State of Lake Diefenbaker report (WSASk, 2012) notes that, in order to establish and maintain fish populations for angling, the Saskatchewan Ministry of Environment has stocked Lake Diefenbaker with rainbow trout from 1987 to 2005, in addition to walleye (*Sander vitreus*) (1969–present), lake whitefish (*Coregonus clupeaformis*) (1969–1972), lake trout (*Salvelinus namaycush*) (1970–75), northern pike (*Esox lucius*) (2000–03), and brown trout (*Salmon trutta*) (1987). The same report notes that the commercial net pen rainbow trout farm started in 1993 (i.e., after approximately 6 years of rainbow trout stocking), but also noted that escape events in 1994 and 2000 assisted in increasing Lake Diefenbaker's rainbow trout population. It is also interesting to note that, between 1981 and 1985 (i.e., before any stocking of rainbow trout in Lake Diefenbaker), rainbow trout was documented both by anglers and by netting as being present (albeit sparsely) throughout the lake (Young, 1989).

Similarly in Quebec, rainbow trout eggs were first imported to the province in 1893 and followed by "repeated and massive" stockings, such that the species is now captured or detected in many rivers and tributaries in the St. Lawrence River watershed, including the areas now permitted for rainbow trout aquaculture (see Figure 18 in Criterion 2—Effluent) (Thibault et al., 2010). Ongoing stocking of rainbow trout for the enhancement of sport fishing continues in Quebec, with rainbow trout and brook trout being the main species stocked under the supervision of the Ministry of Fisheries and Food.[89,90,91] Nevertheless, it is noted that authorized aquaculture and stocking activities are limited to the same areas of Quebec (Figure 18), and the government aims to restrict the stocking of rainbow trout in order to limit its impact on native populations and its spread in waterbodies; thus, stocking sterile fish is preferred and even required in some circumstances (pers. comm., ANON, MELCCFP, June 2024).

Many studies consider the potential impacts of escaping farmed fish in the wild, with relevant examples here including Fuller et al. (2023), Miller et al. (2020), Blanchfield et al. (2009), Johnston and Wilston (2014), Martens et al. (2014), and Patterson and Blanchfield (2013). For example, the GLANSIS species profile for rainbow trout[92] notes that *O. mykiss* has had a high environmental impact in the Great Lakes, with the potential to consume or displace native fishes and compete with or hybridize with rarer native salmonids. But in review, four aspects mean that a detailed analysis of potential impacts of rainbow trout escapes from farms is of limited relevance here. First, the historic establishment of rainbow trout described previously; second, the ongoing stocking also described; third, the broadly similar nature of the stocked fish to any potential aquaculture escapes; and fourth, a low conservation concern regarding potential interbreeding and genetic interactions between escaped farmed rainbow trout and naturalized rainbow trout.

Regarding the third point, approximately half of rainbow trout eggs used by the government and community hatcheries in Ontario are sourced from a local broodstock that was initially sourced from a tributary of Lake Huron (Ganaraska strain), but the remainder use domesticated breeding programs similar to those of the rainbow trout farms (pers. comm., C. Wilson, Ontario MNRF, November 2023). Although the use of domesticated eggs is focused on relatively contained waterbodies such as put-and-take trout fisheries, in a study of the comparative

[89] Consult the seeding tools | Government of Quebec
[90] Stocking - The Table filière de l'aquaculture en eau douce du Quebec inc. (TFAEDQ) (aquaculturequebec.org)
[91] Marché de l'ensemencement | Association des aquaculteurs du Quebec - AAQ (pisciculturequebec.com)
[92] Species Profile - Oncorhynchus mykiss (usgs.gov)

ecologies of domestic and naturalized rainbow trout in northern Lake Huron, Johnston and Wilson (2014) proposed that the effects of escaping domestic rainbow trout on northern Lake Huron's fish community would primarily be genetic impacts on its naturalized rainbow trout populations (as opposed to other native species). Any impacts to established nonnative species such as rainbow trout are not a conservation concern in this assessment. Similarly, in support of the restricted geographic range of aquaculture and permitted stocking in Quebec, any impacts to established nonnative species in Quebec are not a conservation concern here.

Overall, given the established nature of rainbow trout in waterbodies of relevance to this assessment, and particularly the ongoing stocking of rainbow trout and other nonnative salmonids, there is a low concern regarding the potential additional impacts of escaping rainbow trout in the areas where the farms are located. Thus, the characteristics of the receiving environment for any aquaculture escapes are considered here to mean that any escape events, if they occur, will not cause significant additional ecological impacts. The score for Factor 6.2—Competitive and genetic interactions is 10 out of 10.

Conclusions and Final Score

With a single netting barrier containing the fish in a net pen farm, there is considered to be a high risk of escape, either from catastrophic events such as storms or ice damage, or from trickle losses of small numbers of fish during routine operations. Ontario's Aquaculture Risk and Security Policy classifies net pen systems as Low Security Facilities from which losses are considered inevitable—potentially in large numbers. Although no recent data are publicly available, documented escape events in Lakes Huron and Diefenbaker support this classification. Land-based farms situated above regional flood levels and using multiple escape prevention barriers are considered (by the Ontario Ministry of Natural Resources and Forestry) to be of moderate risk of escape. The high risk of escape results in scores for Factor 6.1 of 2 out of 10 for net pens and 4 out of 10 for land-based systems. Rainbow trout is a nonnative species in the areas covered in this assessment, but was established across Canada from the late 1800s. Hundreds of millions of rainbow trout have been stocked into Lake Huron for recreational fisheries, and stocking continues; for example, between the Ontario and Michigan Departments of Natural Resources and community hatcheries in Ontario, at least 1.17 million rainbow trout have been released into Lake Huron in the last 5 years (2018–22, with an annual average of 234,038). Other nonnative salmonids such as brown trout, Chinook salmon, and coho salmon continue to be stocked into Lake Huron. In Lake Diefenbaker, rainbow trout was similarly introduced and actively stocked into the artificial reservoir (although this has now ceased). There have also been widespread introductions of rainbow trout in Quebec, but aquaculture and stocking are now restricted to limited areas of the province to reduce further spread. The historic introduction and establishment of nonnative rainbow trout has had a variety of ecological impacts, but the ongoing stocking by the government and community hatcheries of rainbow trout (and other nonnative salmonids) means that any aquaculture escapes are considered unlikely to cause significant additional ecological impacts to wild fish populations in the areas where farms operate. Potential genetic interactions of escaped farmed rainbow trout with now-naturalized rainbow trout populations are not a conservation concern in this assessment. The score for Factor 6.2—Competitive and genetic interactions is 10 out of 10. The combined scores mean that, despite the high risk of escape, the quite low risk of significant impacts results in a final score for Criterion 6—Escapes of 10 out of 10 for all production systems.

Criterion 7: Disease; Pathogen and Parasite Interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary—all production systems

C7 Disease parameters		Score
Evidence or risk-based assessment	Risk	
C7 Disease Final Score (0–10)		**5**
Critical?	No	**Yellow**

Brief Summary

Diseases in rainbow trout farms in Canada are sporadic, and mostly occur during periods of environmental stress such as unusually high surface water temperatures. The relevant pathogens are typically those that are ubiquitous in freshwater environments. But farms in Saskatchewan and Ontario have recently been affected by outbreaks of novel pathogens such as *Weissella* and *Lactococcus* (again associated with unusually high temperatures). In both cases, the industry responded rapidly with the development of vaccines and improved husbandry practices. With ongoing vaccination programs, further outbreaks have been avoided to date. Federally reported diseases have only rarely been reported in farmed rainbow trout, and the regions of relevance to this assessment are declared free from most of them (some occur in other species of salmonid and/or in marine environments). Ontario has developed a comprehensive Aquaculture Biosecurity Manual (publicly available to farms in other provinces) and overall, it can broadly be concluded that management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm. In the event of a disease outbreak on farms, there is a high likelihood that wild fish would be exposed to the pathogens from the open systems. But the risk that wild fish would succumb to those pathogens beyond the more stressful farm environment is uncertain. Therefore, the risk assessment option has been used, and while it can be argued that infections or mortalities at the "typical" farm are low, temporary, or infrequent, the recent outbreaks with mortality rates exceeding 80% in some farms indicate that the occasional outbreak of highly virulent pathogens inevitably increases the concern for potential impacts to wild fish. Therefore, the final score for Criterion 7—Disease is an intermediate score of 5 out of 10, and is applied to all production systems.

Justification of Rating

Although a substantial amount of information is available on the disease status of farmed fish and to a lesser extent in wild fish in relevant regions of Canada, as discussed in the following (in addition to examples from elsewhere), there is a limited amount of information available on the potential impacts (if any) of the transmission of pathogens from rainbow trout farms to wild fish. Thus, the risk-based assessment has been used (see the Seafood Watch Aquaculture Standard for details).

A survey of wild fish health in Quebec from 2020 to 2021, including a review of unusual fish kills, noted that most fish mortalities were associated with one-time environmental causes, such as high water temperatures and/or a lack of dissolved oxygen (Pimentel and Brisson-Bonenfant, 2023). It also appears that disease challenges in farmed rainbow trout more broadly across Canada are also closely associated with environmental stress, particularly high summer temperatures (pers. comm., RJ Taylor, OAA, October 2023).

In Ontario, the Animal Health Act of 2009 regulates aquatic and terrestrial animal health threats, including emerging pathogens and unusual diseases, although other regulations also apply (for example, the disposal of mortalities falls under the Nutrient Management Act of 2002) (pers. comm., A. Reid, OMAFRA, April 2024). The Ontario Animal Health Network (OAHN) has recently developed a comprehensive Aquaculture Biosecurity Manual covering industry coordination, disease prevention and containment, documentation, training, and monitoring (OAHN, 2022). The manual focuses on disease impacts to farm production as opposed to impacts to wild fish, but has inherent relevance to the latter.

A review of disease challenges by major rainbow trout producers in Ontario and Saskatchewan provided for this assessment (net pen producers, representing approximately 90% of current production) shows that the most common pathogen challenges are from *Flavobacterium psychrophilum*, which causes bacterial coldwater disease, and *Flavobacterium columnare*, which causes columnaris disease (pers. comm., RJ Taylor, OAA, October 2023). *F. psychrophilum* is considered one of the most important bacterial pathogens in freshwater salmonid aquaculture worldwide (Rochat et al., 2017). White spot (Ich), caused by the protozoan parasite *Ichthyophthirius multifiliis*, may also occur (pers. comm., RJ Taylor, OAA; D. Foss, WWS; N. LePage, fish veterinarian, October 2023). These pathogens also occur in hatcheries and fingerling producers, and are likely to be similar in the small number of grow-out producers in raceways, ponds, and tanks.

The reports from the industry generally reflect the Ontario Animal Health Network's (OAHN) Aquatic Animal Health Report, of which the latest version available is from 2020[93] (noting that the OAHN reports cover all aquaculture species and production systems, and typically do not specify the species affected). During the colder months, diagnoses were primarily coldwater disease and bacterial gill disease (*Flavobacterium branchiophilum*). During the warmer months,

[93] Ontario Animal Health Network (OAHN) Aquatic Animal Health Report - December 2020 - Ontario Animal Health Network

diagnoses were primarily bacterial gill disease, nodular gill disease (caused by freshwater amoeba), columnaris disease, and white spot. Bacterial kidney disease (*Renibacterium salmoninarum*) has also been detected in Ontario farmed fish, including rainbow trout.[94] The OAHN report notes that most of the concerns observed on fish farms in Ontario have been noninfectious and related to environmental conditions.

While these are mostly endemic pathogens in freshwater environments in Canada (for example, *R. salmoninarum* is a pathogen with natural reservoirs in more than 30 species in Canada; pers. comm., A. Reid, OMAFRA. April 2024), rainbow trout farms in Ontario and Saskatchewan have also recently been affected by so-called emerging or novel pathogens: namely, the bacterial *Lactococcus* species, which cause Lactococcosis, and the bacterium *Weissella tructae* (formerly *Weissella ceti*), which causes Weissellosis. *Lactococcus* was first reported in Japan in the 1950s, and the determination and naming of relevant *Lactococcus* species is still evolving (Bhat et al., 2023)(Abraham et al., 2023). Outbreaks in the Americas are a recent occurrence (Abraham et al., 2023). Weissellosis was first isolated from rainbow trout in China in 2007 (Liu et al., 2009), and has also been detected in rainbow trout farms in the United States, China, Brazil, Japan, Colombia, and Peru, and has caused severe mortality events (Medina et al., 2020)(Welch and Good 2013)(Vásquez-Machado et al., 2020). Thus, the emerging/novel nature of these pathogens refers to their occurrence in new locations or populations. It has been suggested that *Lactococcus* caused disease problems in Ontario in the 1990s, but without modern diagnostic techniques at that time, this cannot be confirmed (pers. comm., A. Reid, Ontario Ministry of Agriculture, Food and Rural Affairs, December 2023).

In 2017, the farm in Lake Diefenbaker suffered an outbreak of Weissellosis, causing “significant losses” (pers. comm., D. Foss, WWS, September 2023). The source is unclear, but *Weissella tructae* could be an opportunistic pathogen that is part of the normal flora of rainbow trout and becomes pathogenic under certain conditions, thereby causing secondary infections associated with the stress of high summer water temperatures (Vásquez-Machado et al., 2020)(Kim et al., 2023). In response to the Lake Diefenbaker outbreak, an autogenous vaccine was developed (i.e., using a killed strain of the bacterium isolated from the fish) and first administered in September 2018. With ongoing vaccination, the pathogen has not been detected in the last 3 years (pers. comm., D. Foss, WWS, September 2023). This is a similar process and outcome that followed a Weissellosis outbreak in the U.S. in 2011–12 (Welch and Good 2013).

The *Lactococcus* outbreak in Ontario is extensively described by Nikki LePage in an OAHN video (referenced here as OAHN, 2023). In brief summary, *Lactococcus* spp. were first detected in rainbow trout farms in Ontario in the late summer of 2020, then in multiple sites (open water and hatchery) during the summer of 2021. Mortality rates varied from 35% to over 80%. Similar to the responses described previously, the industry rapidly developed an autogenous vaccine that was first administered in 2022. In addition, the industry introduced a variety of management practices to reduce stress during unusually high temperatures (e.g., aerated upwellers to improve coldwater mixing, changes to stocking times and stocking sizes, adjusted

[94] Bacterial kidney disease (BKD) in rainbow trout (*Oncorhynchus mykiss*) | Animal Health Laboratory (uoguelph.ca)

feeding regimes, and improvements to fingerling quality). The industry has since recovered from the outbreak, and a province-wide vaccination program continues (pers. comm., RJ Taylor, OAA, October 2023). Nevertheless, knowledge of the disease continues to evolve; for example, Heckman et al. (2024) note that, historically, the disease was attributed to the gram-positive pathogen *Lactococcus garvieae*. But recent work has revealed three distinct lactococcosis-causing bacteria (LCB): *L. garvieae*, *L. petauri*, and *L. formosensis*, which are phenotypically and genetically similar, leading to widespread misidentification. OAHN and OMNRF have ongoing surveillance for piscine lactococcosis,[95] and as discussed in Criterion 10X, fingerling producers conduct pathogen screening assessments twice per year, and this now includes tests for two strains of *Lactococcus* (*L. petauri* and *L. garvieae*) (pers. comm., M. Chiasson, University of Guelph, December 2023).

The source of these pathogens on farms is unclear. As noted, *Weissella* may be a natural part of the flora of rainbow trout and its pathogenicity is increasingly expressed at higher water temperatures. Disease outbreaks by piscine *Lactococcus* species are one of the major concerns in aquaculture production worldwide, and have affected freshwater and marine fish species in Europe, South America, North America, and Asia (Soltani et al., 2021)(Abraham et al., 2023). Horizontal transmission is possible (i.e., from wild fish to farmed fish), in addition to mechanical transmission through migratory birds, people, or equipment (Abraham et al., 2023)(OAHN, 2023). Wild fish infected with *Lactococcus* (asymptomatic carriers) have been detected in areas without any aquaculture, supporting likely mechanical transmission. It is plausible that these pathogens may be introduced via infected eggs (see Criterion 10X), but this has not yet been tested (pers. comm., N. LePage, fish veterinarian, October 2023).

Regarding diseases in rainbow trout more broadly, the Canadian Food Inspection Agency (CFIA) lists the pathogens to which various aquatic species are susceptible.[96] For rainbow trout, these are listed as follows (* indicates a federally reportable disease; ^ indicates an immediately notifiable disease);[97] note that reporting requirements may vary by province: for example, all of the pathogens listed are immediately notifiable in Ontario.[98]

- Infectious pancreatic necrosis virus (IPNV)*
- Ceratomyxosis (*Ceratomyxa shasta*)*
- Epizootic haematopoietic necrosis virus (EHNV)*
- Infectious haematopoietic necrosis virus (IHN)V*
- Infectious salmon anaemia virus (ISAV)*
- Whirling disease parasite (*Myxobolus cerebralis*)*

[95] https://www.oahn.ca/resources/oahn-aquatics-network-project-baseline-survey-for-lactococcus-garvieae-group-in-ontario-salmonid-facilities/
[96] Susceptible species of aquatic animals: Susceptible species of aquatic animals - Canadian Food Inspection Agency (canada.ca)
[97] For explanation of reporting differences, see Aquatic animal diseases - Canadian Food Inspection Agency (canada.ca)
[98] https://www.ontario.ca/page/notifiable-hazards-and-reporting-guidelines-laboratories-and-veterinarians-under-animal-health-act-2009

- Viral haemorrhagic septicaemia virus (VHSV)*
- Epizootic ulcerative syndrome fungus (*Aphanomyces invadans*)^
- Gyrodactylosis parasite (*Gyrodactylus salaris*)^
- Oncorhynchus masou virus disease^
- Salmonid alphavirus

CFIA has additional annual reporting requirements for the following four diseases, but only for "laboratories":[99]

- Bacterial kidney disease (*Renibacterium salmoninarum*)
- Enteric red mouth disease (*Yersinia ruckeri*)
- Furunculosis (*Aeromonas salmonicida*)
- Streptococcosis (*Streptococcus iniae*)

The CFIA also publishes lists of confirmed cases of federally reportable diseases in Canada.[100] In the 2012–24 reporting timeframe (to June 2024), the only detections in freshwater rainbow trout are a single case of IPN in Quebec in 2014 and an outbreak of whirling disease from 2016 to 2017 in wild fish in Alberta (information on the whirling disease outbreak can be found here[101]).

According to declarations by provinces on the status of reportable finfish diseases (published by the CFIA[102]), Ontario, Saskatchewan, and Quebec are all currently considered free of whirling disease and most other reportable pathogens (Table 11). Of the "infected" pathogens in these areas, IPNV has only been reported in brook trout in Quebec in the 2013 to June 2024 dataset, ISAV has not been reported in Quebec (but is relatively common in Atlantic salmon), and VHSV has been detected in seven species in Ontario (but not rainbow trout) and in one marine species in Quebec.

Table 11: Declarations of finfish reportable diseases by province (accessed June 17, 2024). Data from the CFIA.

	Ceratomyxa shasta	**IPNV**	**ISAV**	**IHNV**	**VHSV IVa**	**VHSV IVb**	**VHSV IVc**	**Whirling Disease**
Ontario*	Free	Infected	Free	Free	Free	Infected	Free	Free
Saskatchewan	Free	Infected	Free	Free	Free	Free	Free	Free
Quebec	Free	Infected	Infected	Free	Infected	Free	Buffer	Free

* Only the Atlantic Ocean watershed is included here because the Hudson Bay watershed is not relevant to the scope of this assessment (the results are similar, but Hudson Bay is also free of VHSV IVb).

[99] https://inspection.canada.ca/en/animal-health/aquatic-animals/diseases/annually-notifiable
[100] Federally reportable aquatic animal diseases in Canada - Canadian Food Inspection Agency
[101] Whirling disease - Canadian Food Inspection Agency (canada.ca)
[102] Finfish Reportable Diseases - Canadian Food Inspection Agency (canada.ca)

Impacts to wild fish

There is a risk that wild fish will transmit pathogens to farmed fish, causing economically significant losses to producers, but pathogen transfer from farmed fish to wild fish poses a threat to biodiversity and naïve populations, thus endangering wildlife and affecting biodiversity (Abraham et al., 2023). It is noted that some land-based farms in Quebec do not discharge water into fish-bearing waterbodies (pers. comm., D. Madeiros, DFO, June 2024), but it is not known how many farms would be exempt from concern here.

While focusing on industry farm-to-farm transmission risks, the OAHN Aquaculture Biosecurity Manual (OAHN, 2022) includes a release assessment that identifies transmission routes. This would include transmission through natural waterbodies. The exposure and consequence aspects of the manual's risk assessment relate specifically to farm production, but combined, these three aspects (release, exposure, consequence) also inherently relate to the risk of release of pathogens and the exposure of wild fish in the environment beyond farms.

Except for the recent outbreaks of Weissellosis and *Lactococcus* in Saskatchewan and Ontario, respectively, the primary pathogens of concern to farmed rainbow trout (*Flavobacteria*) are considered to be endemic, consistent with broader research that shows that bacteria such as *F. psychrophilum* are ubiquitous in the aquatic environment, particularly in freshwater (e.g., Barnes and Brown, 2011). *R. salmoninarum* (which caused the BKD case in 2020) is also noted to be present in many types of fish in lakes and aquaculture in Ontario, although the disease is rarely diagnosed.[103] Further, pathogens and diseases may also be species/host specific, resulting in potential differences in risk between species groups in the wild (e.g., salmonids or cyprinids) (pers. comm., A. Reid, OMAFRA, April, 2024).

Horizontal transmission between fish occurs with *Weissella* and *Lactococcus*, but as noted, it is not known if the initial source of the outbreaks was wild fish, or if wild fish could subsequently be affected by any transmission from an infected farm. In the farm environment, with high densities of fish that were unable to move to colder water, mortality rates from *Lactococcus* were high (ranging from 25% to >80%), but it has been demonstrated that wild fish can be asymptomatic carriers of the pathogen, and it is unclear if wild fish would be vulnerable to these opportunistic pathogens in natural conditions (OAHN, 2023). After an outbreak of *Lactococcus* in farmed trout in California (species of trout unspecified), the bacteria were detected in several wild fish species in connected waterbodies, but the study noted no evidence of morbidity or mortality in any of the wild fish sampled (Abraham et al., 2023). It is noted again here that, with the rapid development of a vaccine, it appears that *Lactococcus* and *Weissella* are currently being effectively controlled by the rainbow trout industry.

Overall, though it is possible to infer a risk of transmission of pathogens from rainbow trout farms to wild fish (in any production system), the consequences are unclear, and there is no evidence of any impacts to wild fish. Given the intense interest in the potential transmission of

[103] OAHN Bacterial Kidney Disease Infosheet: Bacterial Kidney Disease Infosheet - Ontario Animal Health Network (oahn.ca)

pathogens from farmed salmon in marine net pens to important populations of wild Pacific salmon in British Columbia (and on the east coast of Canada), DFO conducted a series of risk assessments for key pathogens. While these are not relevant to rainbow trout, the basic risk assessment methodology provides a crude way to infer conclusions here. Figure 35 provides an overview of the risk assessment methodology for reference (in this case, referring to infectious hematopoietic vecrosis virus [IHNV] on Atlantic salmon farms, and the risk to Fraser River sockeye salmon).

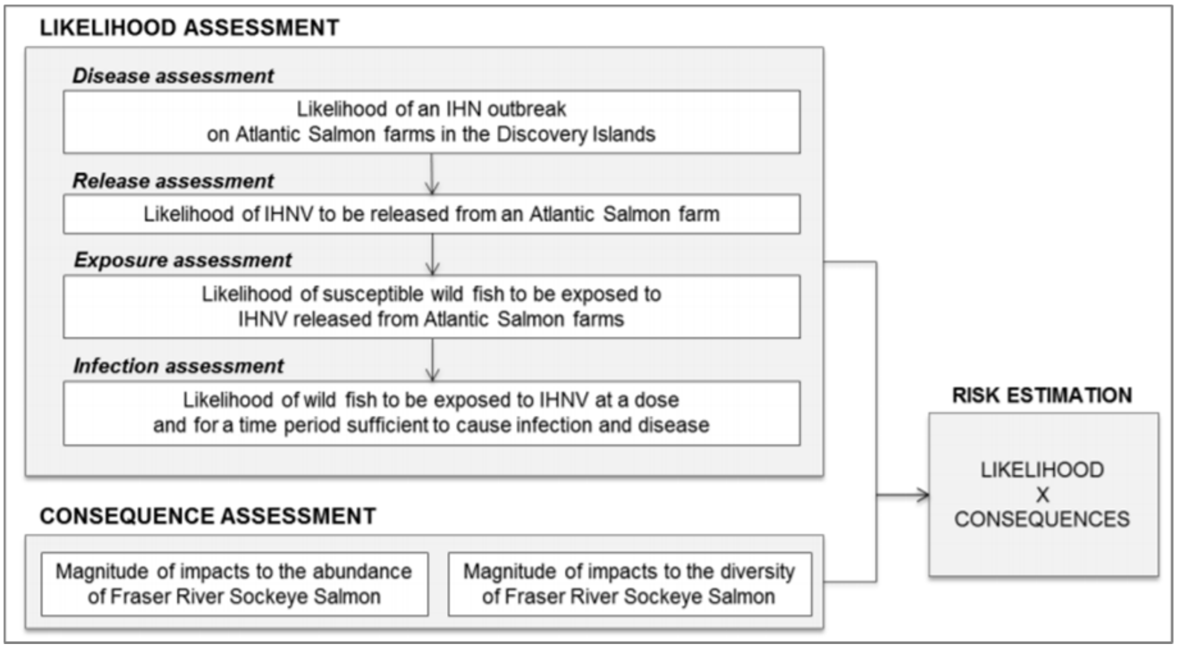

Figure 35: Conceptual model for risk assessment of IHN virus to Fraser River sockeye salmon attributable to Atlantic salmon farms located in the Discovery Islands, B.C. Image and title copied from DFO (2017b).

As noted regarding the sporadic disease occurrences and the rapid resolution of notable outbreaks of novel pathogens, it can broadly be concluded that the management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm. But if an outbreak were to occur, there is clearly a high risk of release of pathogens from the farms (either net pens or flow-through systems) and a high risk of exposure in wild fish. The challenge then becomes determining the sufficient exposure to cause infection and disease in wild fish beyond the stressful farm environment, and then the consequences to the abundance and/or diversity of relevant wild fish populations.

It is not the intent here to try to recreate a full risk assessment, but a key factor appears to be the high surface temperatures associated with most disease occurrences on farms, and the much greater ability for wild fish to avoid them (that is, rainbow trout in floating net pens are confined to surface waters with the highest temperatures—hence the development of aerated upwellers to improve coldwater circulation to reduce thermal stress in Ontario farms). Nevertheless, despite a lack of evidence for any direct impacts from farm-origin pathogens to wild fish, the risks are considered here to remain largely unknown.

Conclusions and Final Score

Diseases in rainbow trout farms in Canada are sporadic, and mostly occur during periods of environmental stress such as unusually high surface water temperatures. The relevant pathogens are typically those that are ubiquitous in freshwater environments. But farms in Saskatchewan and Ontario have recently been affected by outbreaks of novel pathogens such as *Weissella* and *Lactococcus* (again associated with unusually high temperatures). In both cases, the industry responded rapidly with the development of vaccines and improved husbandry practices. With ongoing vaccination programs, further outbreaks have been avoided to date. Federally reported diseases have only rarely been reported in farmed rainbow trout, and the regions of relevance to this assessment are declared free from most of them (some occur in other species of salmonid and/or in marine environments). Ontario has developed a comprehensive Aquaculture Biosecurity Manual (publicly available to farms in other provinces), and overall, it can broadly be concluded that management measures result in low, temporary, or infrequent occurrences of infections or mortalities at the "typical" farm. In the event of a disease outbreak on farms, there is a high likelihood that wild fish would be exposed to the pathogens from the open systems. But the risk that wild fish would succumb to those pathogens beyond the more stressful farm environment is uncertain. Therefore, the risk assessment option has been used, and while it can be argued that infections or mortalities at the "typical" farm are low, temporary, or infrequent, the recent outbreaks with mortality rates exceeding 80% in some farms indicate that the occasional outbreak of highly virulent pathogens inevitably increases the concern for potential impacts to wild fish. Therefore, the final score for Criterion 7—Disease is an intermediate score of 5 out of 10, and is applied to all production systems.

Criterion 8X: Source of Stock—Independence from Wild Fisheries

Impact, unit of sustainability and principle

- Impact: the removal of fish from wild populations for on-growing to harvest size in farms
- Sustainability unit: wild fish populations
- Principle: using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 8X Summary—all production systems

C8X Source of Stock—Independence from wild fisheries	Value	Score
Percent of production dependent on wild sources (%)	0.0	0
Use of ETP or SFW "Red" fishery sources	No	
C8X Source of Stock Final Score (0–10)		**0**
Critical?	No	Green

Brief Summary

Rainbow trout is native to western North America but has been selectively bred for decades around the world for beneficial traits such as growth rate and disease resistance. The farmed strains are now considered to be domesticated for aquaculture purposes, and there is no significant use of wild stocks for the supply of broodstock, eggs, or fingerlings. Criterion 8X—Source of Stock is a deduction of 0 out of –10.

Justification of Rating

Rainbow trout has been selectively bred for beneficial traits such as growth rate, disease resistance, and late maturity for decades throughout the world (Carcamo et al., 2015)(Janssen et al., 2015)(Reis Neto et al., 2019). Farming of the species in Canada began in the 1970s, but it has been cultivated elsewhere for more than 100 years, with the species now successfully domesticated—complete with advanced hatchery and breeding technology. As discussed in Criterion 10X, most of Canada's egg and fingerling demand is supplied from in-country breeding programs and hatcheries, but some (eggs) continue to be imported from breeding programs in the United States Thus, the culture of rainbow trout is independent of wild stocks because eggs and fingerlings are all sourced from multiple-generation, domesticated broodstock. The final score for Criterion 8X—Source of Stock is 0 out of –10.

Conclusions and Final Score

Rainbow trout is native to western North America but has been selectively bred for decades around the world for beneficial traits such as growth rate and disease resistance. The farmed strains are now considered to be domesticated for aquaculture purposes, and there is no significant use of wild stocks for the supply of broodstock, eggs, or fingerlings. Criterion 8X—Source of Stock is a deduction of 0 out of –10.

Criterion 9X: Wildlife and Predator Mortalities

Impact, unit of sustainability and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: preventing population-level impacts to predators or other species of wildlife attracted to farm sites.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

			Net Pens	Land-based
C9X Wildlife Mortality parameters			**Score**	**Score**
Wildlife mortality score			–2	–2
C9X Wildlife Mortality Final Score			**–2**	**–2**
	Critical?	No	Green	Green

Brief Summary

Wildlife mortality records provided by net pen farms in Ontario and Saskatchewan show that a variety of mammal and bird species are attracted to the fish and other farm supplies such as feed. Despite various deterrents, the records show that animals may become lethally entangled, or if persistent, require lethal control as a last resort. Mortality numbers are low, with approximately <1 animal mortalities per site per year for net pen farms, and 4.5 per year in land-based broodstock and fingerling sites (not including mice or rats). Because of the small scale of land-based grow-out production, there are no formal reporting requirements, but the available information, supported by expert opinion, indicates that they can be considered similar to the land-based systems noted. Various national and provincial wildlife regulations are in place, but most species of bird and animal (except those listed in Canada's Species at Risk Act [SARA]) can be harassed, captured, or killed (without a license) if they are doing damage to property. In 2023, the policy of the dominant broodstock fingerling producers changed, such that lethal control is now only used in exceptional life-threatening circumstances for farm workers, and mortality numbers are now considered to be low on all farms, and to be exceptional events. None of the species affected have been listed by SARA (at least between 2018 and 2023) and, given the Least Concern status from the International Union for the Conservation of Nature (IUCN) for all the affected species, there is not considered to be any significant impact at the population level. With good data availability for net pen farms, the evidence-based assessment was used, and the final score for Criterion 9X—Wildlife Mortalities is a deduction of –2 out of –10 for net pen farms. For other land-based grow-out farms, without specific data, the risk assessment must be used. But with clear similarities to the land-based broodstock and fingerling producers, and with expert support, it is also considered to be highly unlikely that wildlife interactions at land-based farms would significantly affect the health of the wild populations. The final score for Criterion 9X—Wildlife Mortalities is also a deduction of –2 out of –10 for land-based farms.

Justification of Rating

As detailed in the following, copies of predator interaction and mortality logs from rainbow trout farms in Ontario and Saskatchewan were provided for this assessment and show that the fish and other farm supplies (such as feed) attract a variety of wildlife. Farm owners confirm a commonly documented perception that the often persistent wildlife interactions with farms can cause significant economic loss because of direct or indirect fish losses and damage to infrastructure (e.g., Anderson et al. 2015). As also noted by Anderson et al., interactions have the potential to be lethal to wildlife, and the mortality logs show that various control methods (in addition to lethal control) can lead to mortalities.

Wildlife mortality logs (kept primarily as a requirement of third-party certification to schemes such as Best Aquaculture Practices [BAP]) were provided by all the net pen sites in Ontario and Saskatchewan for various timeframes between 2018 and 2023. In addition, mortality logs from the same timeframe were provided by three land-based systems in Ontario producing fingerlings and broodstock. As will be noted, because of the small scale of the land-based grow-out farms and the lack of formal reporting requirements, similar records could not be obtained from land-based systems. The records provided include 137 total mortalities from a combined 48 site-years between 2018 and 2023 (32 site-years for net pen sites and 16 site-years for land-based systems). Before analyzing the data in any way, it is important to note some characteristics of the records:

- The records from net pen sites include terrestrial animals interacting with associated shore-based sites where feed or other farm supplies are stored. These are included in the following analysis.
- Because of the characteristic winter freeze of Canadian lakes, some terrestrial animals can interact with net pens across the frozen lake surface.
- To avoid attributing "values" to different species, unless otherwise stated, all recorded mortalities are included, including species commonly referred to as vermin, such as mice and rats.
- The records include unintentional mortalities from entanglement of birds and animals in net pens, and unintentional mortalities of animals in live traps, but also include deliberate lethal control.
- As part of active predator control methods, live traps may be used to capture and relocate persistent wildlife. Some mortalities recorded in live traps are noted as being unintentional (for example, the records that were provided show numerous examples in which live-trapped animals have been released remotely from the site), but there may also be deliberate lethal control of animals caught in live traps.

- Because of company policy changes in 2023 (discussed further), the ongoing mortalities may be substantially different from the 2018 to 2023 period discussed here.

With these data, the evidence-based assessment has been used for the net pen farms. Because of the small scale of the land-based production in Quebec, there are no formal reporting requirements for wildlife interactions, so there are no specific data available. Although it is likely that wildlife interactions at land-based farms in Quebec are similar to those of land-based broodstock/fingerling producers in Ontario (discussed further), the risk-based assessment has been used for land-based systems.

Figure 36 shows the proportions of different species recorded in the mortality logs at net pen and land-based broodstock/fingerling sites. A considerable variety of species can be seen to be attracted to the fish and/or the feed, resulting in mortality from various causes. At the simplest aggregation of all sites and mortalities across all species, there were an average of approximately 3 wildlife mortalities per site per year between 2018 and 2023 (1.9 not including mice and rats). Because of easier access and smaller fish, the recorded mortalities per site-year were higher for the land-based broodstock/fingerling systems than the net pen sites, with 5.7 and 1.4 mortalities per site per year, respectively (4.5 and 0.7, respectively, not including mice and rats).

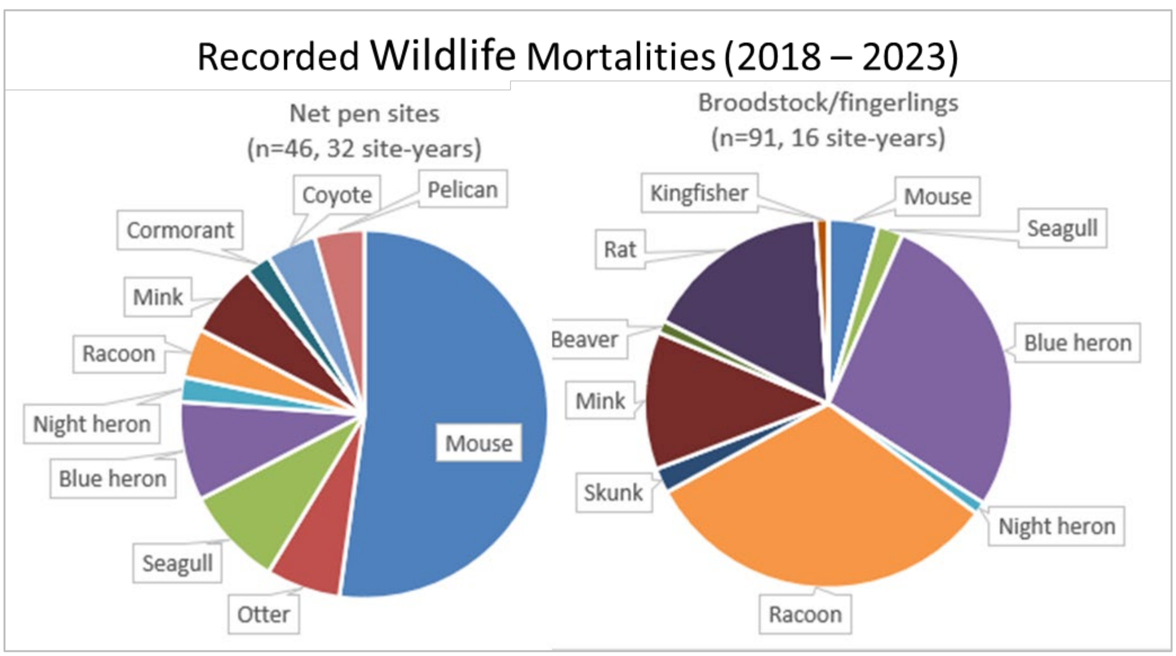

Figure 36: Species profile of all recorded mortalities at net pen farms in Ontario and Saskatchewan, and the dominant land-based broodstock/fingerling producers in Ontario, between 2018 and 2023. Data provided for this assessment from various companies. Note that the wildlife mortality policy for the dominant broodstock/fingerling producers changed in 2023, and the data presented here may not reflect ongoing activities.

Figure 37 shows an approximate profile of the causes of mortality (noting that distinguishing the specific cause of mortality from the records was not precise in some cases). The profiles of causes are different between the net pen sites and the land-based broodstock/fingerling producers. Other than mice and rats, the mortality records indicate that deliberate lethal control has been limited to four species: gulls (species not defined), great blue heron, raccoons, and mink. The companies that provided the mortality records all have wildlife management policies that require that lethal control be used only as a last resort after other measures have been exhausted (the policies were provided for this assessment), but it can be seen that (before 2023) lethal control had been used more frequently in land-based broodstock/fingerling systems.

The primary broodstock/fingerling company has reported that, since the start of 2023, lethal means of control are now only allowed under exceptional circumstances, such as a threat to human life (for example, a bear or perhaps an animal suspected of having rabies) (pers. comm., RJ Taylor, Cedar Crest, November 2023). Therefore, the data presented in Figures 36 and 37 may not represent ongoing mortality characteristics at these sites.

The records also include some notable exceptional cases through entanglement or drowning; for example, two dead coyotes were found in net pens in early 2023, having accessed the site across the frozen lake. The "other" category in Figure 37 includes a small number of cases where farm dogs have killed wildlife (raccoons), and other exceptional cases such as an otter trapped in an ice heater.

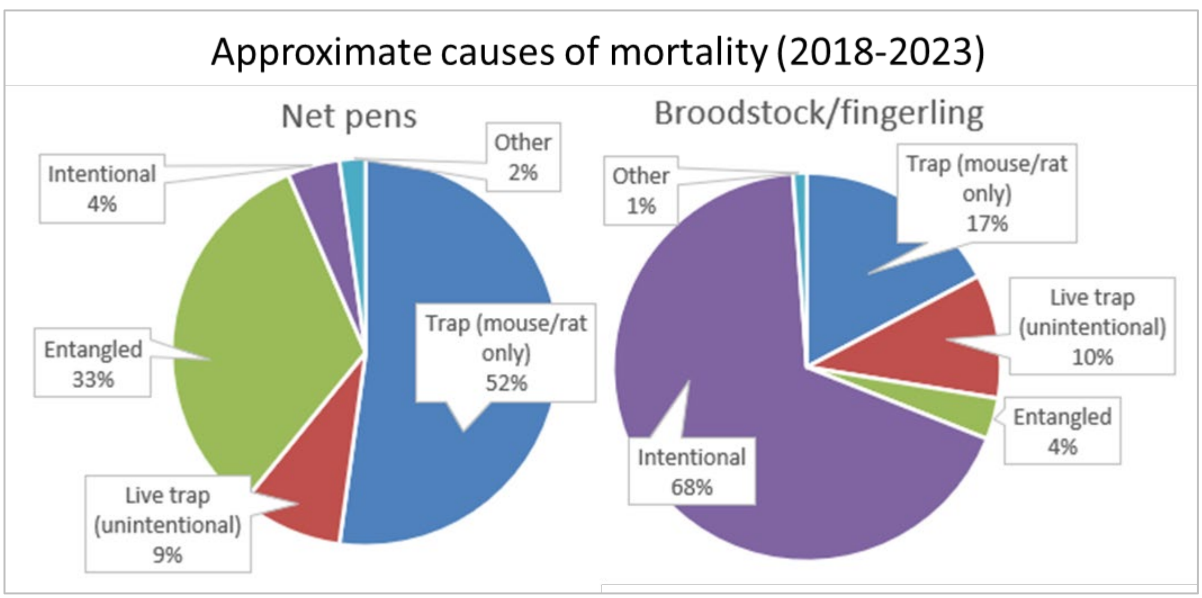

Figure 37: Approximate causes of mortality identified from mortality logs provided by all net pen companies in Ontario and Saskatchewan, and from the dominant broodstock/fingerling producers in Ontario. Data provided for this assessment by various companies. Note that the wildlife mortality policy for the dominant broodstock/fingerling producers changed in 2023, and the data presented here may not reflect ongoing activities.

Wildlife Management Plans and Regulations

Wildlife interaction plans from farms in Ontario and Saskatchewan were provided for this assessment. In addition, various regulatory measures apply. In overview, both types of measure (i.e., farm management plans and regulations) require appropriate prevention and deterrence, minimization of entanglement risks, lethal control as a last resort, and no lethal control of endangered, threatened, or at-risk species. These requirements are also instilled in the standards of certification schemes such as the BAP program, to which most large farms are certified, and it is also noted again here (as mentioned) that company policies can evolve over time.

Aquaculture license requirements for net pen sites focus on bird predation, which is commonly seen as the greatest concern to growers; for example, Figure 38 shows the license requirements for the farm in Saskatchewan.

"Bird Predation:

- ***The license holder must design and use nets and other gear or equipment in a way that reduces the risk of incidental catch of predators and causes the least amount of harm to predators.***
- ***Upon discovery of a live entangled predator, the license holder must make all reasonable attempts to free the predator without harm.***
- ***Weekly records of all incidental takes (number species and reason) must be carried out and summary included in the Annual Report."***

Figure 38: Aquaculture license requirements relating to bird predation for net pens in Saskatchewan. Image reproduced from an aquaculture license document provided for this assessment (pers. comm., D. Foss, WWS, October 2023).

Company wildlife management policies show that a variety of deterrents and barriers may be used, and indeed note that no single passive deterrent will work on its own, particularly for persistent animals. Net pen barriers are the primary line of defense to prevent entry to net pens, raceways, or other fish holding locations, although it is noted that they are less effective for heron. Appropriate secure storage of farm supplies such as feed is also important. Active deterrents include loud noises, such as yelling, fog horns, scare cannons, acoustic flares (screamers), and predator calls, in addition to dogs, decoy predators and kites, reflective tape, and scarecrows.

In Canada, all species of birds and most mammals are protected by either federal or provincial laws; for example, at the federal level, birds are protected against unregulated take by the Migratory Birds Convention Act (MBCA) of 1994.[104] The statute protects most species of birds in Canada, and regarding the species listed in Figure 36, includes great blue heron, black-crowned night heron, and various species of gull (it does not include pelican, kingfisher, or cormorant).

[104] https://www.canada.ca/en/environment-climate-change/services/birds-canada/migratory-birds-overview.html

The MBCA requires the exhaustive use of nonlethal deterrent methods, but lethal take permits could be issued under the MBCA. More broadly, under protection of property stipulations (for example, in Section 31 of Ontario's Fish and Wildlife Conservation Act), problem wildlife can be harassed, captured, or killed if there are reasonable grounds that the animal is damaging or about to damage property.[105] Various exceptions apply, of which the most relevant relate to various species of conservation concern, as follows.

Species of concern in Canada are defined and regulated by the Species at Risk Act (SARA),[106] which was updated in 2022, in addition to various provincial measures such as the Fish and Wildlife Conservation Act of Ontario or the Species at Risk in Ontario (SARO), with similar measures in other provinces. No deliberate lethal control is allowed for these species, and there are no such species listed in the mortality records provided from the farms for this assessment.

Population status of affected species and potential impacts

Regarding the species listed in the mortality records of rainbow trout farms in Ontario and Saskatchewan between 2018 and 2023 (Figure 36), Table 12 shows the population conservation status rating for each species from the International Union for the Conservation of Nature (IUCN).[107] The MCBA status for the bird species is also shown. As noted, none of the species

Table 12: IUCN and MBCA status of species recorded in rainbow trout farm mortality logs in Ontario and Saskatchewan between 2018 and 2023.

Common name	Latin name	MBCA-listed	IUCN status
River otter	*Lontra canadensis*	n/a	Least concern
Northern raccoon	*Procyon lotor*	n/a	Least concern
Striped skunk	*Mephitis mephitis*	n/a	Least concern
American beaver	*Castor canadensis*	n/a	Least concern
American mink	*Neovison vison*	n/a	Least concern
Coyote	*Canis latrans*	n/a	Least concern
Brown rat	*Rattus norvegicus*	n/a	Least concern
House mouse	*Mus musculus*	n/a	Least concern
Gull	*Laridae* spp.	Yes	Least concern
Great blue heron	*Ardea herodias*	Yes	Least concern
Black-crowned night heron	*Nycticorax nycticorax*	Yes	Least concern
Belted kingfisher	*Megaceryle alcyon*	No	Least concern
Double-crested cormorant	*Nannopterum auritum*	No	Least concern
American white pelican	*Pelecanus erythrorhynchos*	No	Least concern

[105] https://www.ontario.ca/page/harass-capture-or-kill-wild-animal-damaging-private-property
[106] https://www.canada.ca/en/environment-climate-change/services/species-risk-act-accord-funding.html
[107] https://www.iucnredlist.org/

listed are included in Canada's species at risk public registry[111] nor in Ontario's or Saskatchewan's species at risk list.[112,113]

Land-based grow-out farms

As noted, because of the small scale of the land-based grow-out production, primarily in Quebec, there are no formal reporting requirements for wildlife interactions or mortality. While this implies that mortalities are unknown, there are clear risk similarities with the land-based broodstock/fingerling producers described previously, and with the broader regulatory systems and species statuses in Canada. Further, Canadian regulators also consider this to be the case; i.e., that it is reasonable to consider that the risks to wildlife are equal across these systems (pers. comm., D. Madeiros, S. Naylor, DFO, June 2024).

With the provision of detailed wildlife interaction and mortality reports from the net pen and land-based fingerling producers, it is clear from the reported mortality numbers and the status of affected species that the interactions with wildlife at these farms in Canada will not have any significant effect on populations of the affected species at the local or national level. While no data are available from the small land-based producers (e.g., in Quebec), the available information and expert opinion indicate that it is highly unlikely that wildlife interactions at land-based farms would significantly affect the health of the wild populations.

Conclusions and Final Score

Wildlife mortality records provided by net pen farms in Ontario and Saskatchewan show that a variety of mammal and bird species are attracted to the fish and other farm supplies such as feed. Despite various deterrents, the records show that animals may become lethally entangled, or if persistent, require lethal control as a last resort. Mortality numbers are low, with approximately <1 animal mortalities per site per year for net pen farms, and 4.5 per year in land-based broodstock and fingerling sites (not including mice or rats). Because of the small scale of land-based grow-out production, there are no formal reporting requirements, but the available information, supported by expert opinion, indicates that they can be considered similar to the land-based systems noted. Various national and provincial wildlife regulations are in place, but most species of bird and animal (exception those listed in Canada's Species at Risk Act [SARA]) can be harassed, captured, or killed (without a license) if they are doing damage to property. In 2023, the policy of the dominant broodstock fingerling producers changed, such that lethal control is now only used in exceptional life-threatening circumstances for farm workers, and mortality numbers are now considered to be low on all farms and to be exceptional events. None of the species affected have been listed by SARA (at least between 2018 and 2023) and, given the Least Concern status from the International Union for the Conservation of Nature (IUCN) for all the affected species, there is not considered to be any

[111] https://species-registry.canada.ca/index-en.html#/species?taxonomyId=Birds&sortBy=commonNameSort&sortDirection=asc&pageSize=10&keywords=pelican

[112] https://www.ontario.ca/page/species-risk-ontario#section-1

[113] https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/wildlife-and-conservation/wildlife-species-at-risk

significant impact at the population level. With good data availability for net pen farms, the evidence-based assessment was used, and the final score for Criterion 9X—Wildlife Mortalities is a deduction of –2 out of –10 for net pen farms. For other land-based grow-out farms, without specific data, the risk assessment must be used. But with clear similarities to the land-based broodstock and fingerling producers, and with expert support, it is also considered to be highly unlikely that wildlife interactions at land-based farms would significantly affect the health of the wild populations. The final score for Criterion 9X—Wildlife Mortalities is also a deduction of –2 out of –10 for land-based farms.

Criterion 10X: Introduction of Secondary Species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Principle: avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals.

This is an “exceptional” criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary—all production systems

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on trans-waterbody movements (%)	41.9	5
Biosecurity score of the source of animal movements (0–10)		8
Biosecurity score of the farm destination of animal movements (0–10)		4
Species-specific 10X score		–1.0
C10X Introduction of Secondary Species Final Score		**–1.0**
Critical?	No	**Green**

Brief Summary

The OAHN Aquaculture Biosecurity Manual notes an extreme risk of the entry and exit of pathogens or other organisms during live animal movements (broodstock, juveniles, or eggs). DFO and/or provincial partners approve the intentional movements into, between, and within Canadian watershed and fish-rearing facilities of billions of aquatic organisms of hundreds of species each year for many purposes, including aquaculture and stocking purposes. The rainbow trout aquaculture industry is dependent on the movements of fertilized eyed eggs from breeding facilities to hatcheries, and the subsequent movement of fingerlings from nurseries to grow-out sites, primarily in open net pens. Considering the dominant region of production in Ontario, the movements of fingerlings are considered to be within the same Lake Huron watershed, and the majority of eggs (75% to 80%) are sourced from in-province breeding centers. These aspects vary somewhat between provinces; for example, the major producer in Saskatchewan has its own hatchery on site and does not need to ship fingerlings, but does rely on imported eggs from the United States. Overall, approximately 42% of the industry in Canada is considered dependent on trans-waterbody shipments of live trout, primarily in the form of eggs, and the score for Factor 10Xa—International or trans-waterbody animal shipments is 5 out of 10.

Across Canada, movements are authorized and licensed following the federal-provincial-territorial National Code on Introductions and Transfers of Aquatic Organisms; however, requirements vary by province. For example, in Ontario, an Aquaculture License is the only requirement for movements (in addition to the biosecurity measures described in this criterion). Introductions and Transfers Committees must apply an aquatic organism risk assessment that includes a "parasite or fellow traveler" component, and movements must be screened for key pathogens. The sources of trout eggs are considered to have the potential for high biosecurity in tank-based recirculating systems, in addition to the ability to screen and surface-disinfect eggs before shipment. Routine independent and industry screenings of hatcheries and of fingerlings before movements also substantially reduce the risk of unintentionally shipping secondary organisms during fingerling movements. The score for Factor 10Xb (based on the source of live movements) is 8 out of 10. Overall, the limited trans-waterbody movements and the potential for substantial biosecurity to reduce the risk of an organism entering shipments at the source combine for the final score for Criterion 10X—Introduction of Secondary Species of a small deduction of –1.0 out of –10.

Justification of Rating

Regarding the dominant area of rainbow trout production in Ontario, a now-dated 2014 risk assessment for the introduction or transfer of fish and associated pathogens into the Great Lakes basin prepared by the Great Lakes Fish Health Committee (GLFHC)[114] noted that the movement of fish and their gametes has been, and continues to be, the cornerstone of many fishery conservation and restoration programs within the Great Lakes. It also noted that pathogens have often invaded new geographic ranges as a result of fish importation or stocking, resulting in consequences for fish populations in those systems. While the now-dated GLFHC risk assessment focused on fish movements for stocking (note the GLFHC risk assessment is not the same as that used by the Introductions and Transfers Committees addressed in Factor 10Xb), similar concerns apply to movements of live eggs and fingerlings for aquaculture. The Aquaculture Biosecurity Manual from the Ontario Animal Health Network (OAHN, 2022) notes an extreme risk of the entry and exit of pathogens or other organisms during live animal movements (broodstock, juveniles, or eggs).

The Great Lakes in general can be considered a case study in nonnative species establishment; for example, NOAA's Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS)[115] currently lists 193 nonindigenous species, and a further 27 species that are native to some part of the basin that have expanded their ranges to other parts. The State of the Great Lakes assessment (SGL, 2022) notes that transoceanic ships (including solid ballast, packing materials, ballast water, and ballast residuals) have been the primary vector responsible for 42% of the total established, but deliberate introductions (stocking fish and agricultural/horticultural plants) have also been a significant vector (22%). Other notable vectors include hitchhikers with organisms in trade (12%) and escapes from culture (4%). It is noted that aquaculture movements were not specifically mentioned, but could be a component of the latter two categories. Currently, SGL (2022) notes that no new species have become established in the Lake Huron basin from outside the Great Lakes basin in the last decade (although they note that the spread to Lake Huron of species previously established in the

[114] GLFHC RA (Revised October 2014).pdf (glfc.org)
[115] https://www.glerl.noaa.gov/glansis/

other Great Lakes has resulted in the establishment of eight additional species in the Lake Huron basin in the past decade).

As will be discussed, DFO and provincial partners approve intentional movements into, between, and within Canadian watersheds and fish-rearing facilities of billions of aquatic organisms of hundreds of species each year for a variety of purposes (e.g., research, enhancement, aquaculture, public display or education, cultural release, and processing). This criterion provides a measure of the risk that alien species (other than the farmed species) are introduced to an ecologically distinct waterbody (one in which they are not native or present) during importations or other movements of live fish or eggs. The assessment considers the movements of eggs from breeding centers to hatcheries, and the subsequent movements of fingerlings from hatcheries to grow-out sites (in Factor 10Xa). Any biosecurity requirements, screening/testing, quarantine, etc. associated with the source and destination of live fish movements are discussed in Factor 10Xb.

Factor 10Xa—International or Trans-Waterbody Live Animal Shipments
DFO provides categorical data on introductions and transfers of aquatic organisms in Canada,[116] which show that, in 2022 (the only year available, accessed June 22, 2024), 1,005 applications were approved to intentionally move live aquatic organisms into, between, or within Canadian watersheds and fish-rearing facilities, representing more than 4 billion live aquatic organisms of 754 different species. Within the aggregated categorical DFO data, determining the specific relevance to rainbow trout aquaculture is challenging, but some simple analysis can provide some clues. For example, at the country level, Figure 39 shows that 70% of approved movements were within a province, 19% were between provinces, and 11% were for movements into Canada from another country. Also at the country level, 44% of all approved movements were aimed at aquaculture operations,[117] and 37% of all approved movements were for freshwater finfish.[118]

Provincial data from DFO are provided in the same categories and shown in Figure 40. These data also provide some useful insights, but are again limited by the diversity of the "aquaculture" category, the number of species potentially included in the "freshwater finfish" category, and differences in provincial requirements (as discussed further in Factor 10Xa). For example, in Ontario, a holder of an Aquaculture License can move the fish species listed on the license within the province with no additional permit or need to notify the government (pers. comm., S. Naylor, DFO, June 2024).

[116] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/rep-rap-eng.htm
[117] Other categorical reasons for movements include research, enhancement, public display or education, cultural release, processing, or other.
[118] Other categories include marine finfish, marine molluscs, crustaceans, echinoderms and other invertebrates, and other.

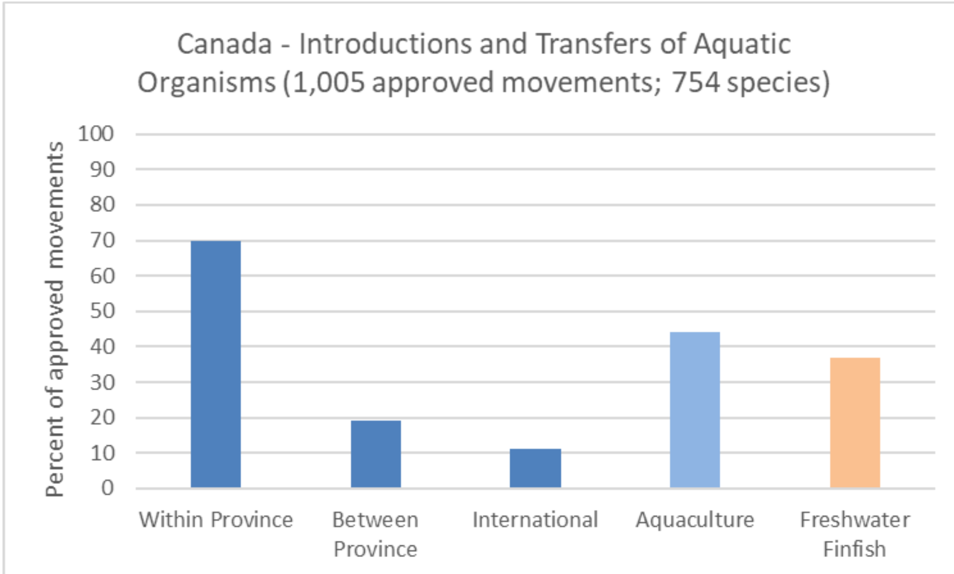

Figure 39: Categorical summary of national reporting data on introductions and transfers of aquatic organisms in Canada in 2022. Data from DFO.

With a single year of data available from DFO (i.e., 2022), it is likely that annual variations may be missed. For example, rainbow trout eggs from Troutlodge and Riverence in the United States are known to be imported into Ontario and/or Saskatchewan for aquaculture, but in 2022, there were no movements overseen by the Ontario Introductions and Transfers Committees (pers. comm., S. Rooney, DFO, June 2024).

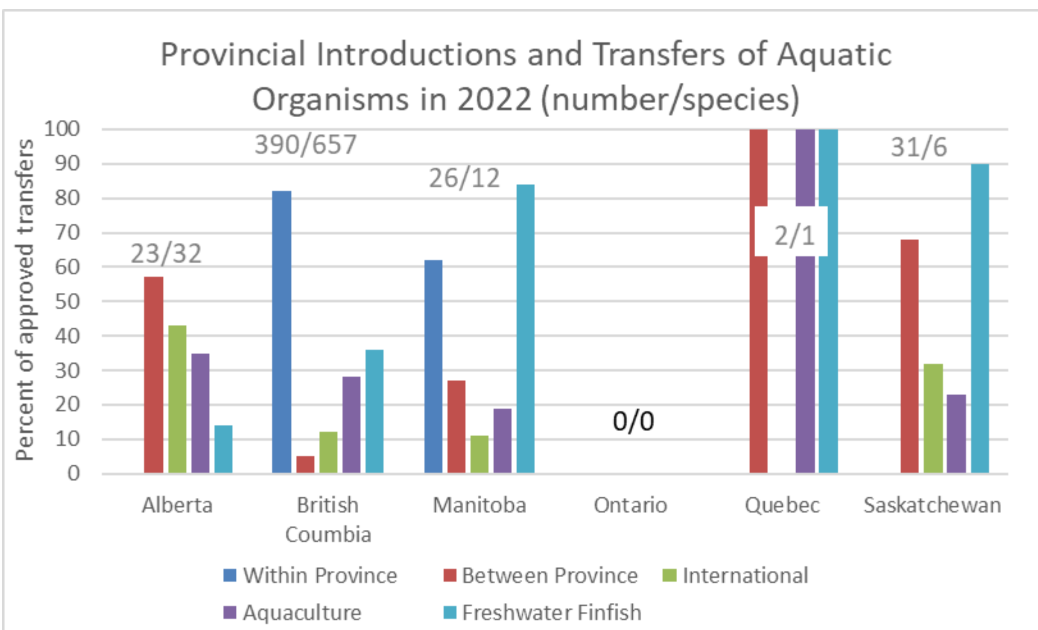

Figure 40: Provincial data from 2022 on introductions and transfers of aquatic organisms into, between, or within Canadian watersheds and fish-rearing facilities, expressed in the categories provided by DFO, and as a percentage of the total approved movement applications. The numbers included for each province state the number of approved movement applications and the number of species that they refer to.

Overall, these data provide little conclusive information about the specific movements of eggs and fingerlings for rainbow trout aquaculture, particularly in Ontario, for which no additional permit or approval is needed beyond the Aquaculture License. More broadly, it is known that breeding centers and hatcheries across Canada breed trout and supply the aquaculture industry with fertilized eyed eggs and fingerlings; for example, the OAA states that most of the rainbow trout eggs used for fish farms in Ontario are spawned from breeding stocks within the province.[119] But the OAA also notes that, when domestic production is not sufficient to meet demand, eggs are imported from international hatcheries, such as Troutlodge in the United States. It is estimated that 75% to 80% of rainbow trout in Ontario are produced from Ontario broodstock (pers. comm., RJ Taylor, OAA, October 2023); therefore, 20% to 25% of Ontario production is considered here to be reliant on imported eggs. The large net pen farm in Saskatchewan imports egg from two sources in the United States. As noted in previous criteria, stocking programs in Canada also source eggs from these U.S. suppliers.

Regarding fingerling movements, it is common for them to be transported to on-growing sites (i.e., to any on-growing farms without fingerling production on site). While the farm in Lake Diefenbaker in Saskatchewan notes that it has a fully recirculating hatchery onsite to provide its fingerlings, hatcheries in Ontario ship fingerlings over considerable distances to the large net pen growers. For example, two informational videos from the OAA[120] (now several years old) describe shipments of fingerlings from Blue Springs Trout Hatchery in Hanover (Ontario) to Manitoulin Island in Lake Huron—described as a journey of 5 to 7 hours. Less information is readily available for the hatcheries and farms in Quebec, but the salient aspects are considered likely to be similar. Some farms in Quebec are also supplied with fingerlings from Ontario (pers. comm., RJ Taylor, OAA, September 2023).

Despite the apparent distance represented by multihour fingerling deliveries, it can be seen that at least two major breeding centers and fingerling suppliers (Cedar Crest and Blue Springs) in Ontario (both located in Hanover) are in the Lake Huron watershed (Figure 41) and are considered to be the major suppliers of fingerlings to the net pen sites in the lake.

Therefore, for the purposes of this assessment, movements of eggs and fish between the large producers within the Lake Huron watershed are not considered to be trans-waterbody. This approach is supported by the findings of the SGL (2022), stated previously, that no new species have become established in the Lake Huron basin from outside the Great Lakes basin in the past decade. The remainder of production facilities in Saskatchewan and Quebec that import eggs or have inter-province fingerling movements are assumed, on a precautionary basis, to be dependent on trans-waterbody movements.

[119] https://ontarioseafoodfarmers.ca/faqs/
[120] https://ontarioseafoodfarmers.ca/trout-tour/—Loading fingerlings and transporting live fish (note this video is 8 years old).

Figure 41: Map of the Great Lakes watersheds (basins). The yellow dot represents the approximate location of major fingerling producers in Hanover, ON. Image reproduced from the Ohio Department of Natural Resources.

Considering the provincial rainbow trout production data presented in the introduction, an estimate can be made of the proportion of Canadian rainbow trout production that is dependent on international or trans-waterbody movements. The Ontario net pen farms represent approximately 75% of total Canadian production (not including the now-closed B.C. farm), and if 20% to 25% of Ontario production is dependent on imported eggs, that represents 15% to 18.8% of total Canadian production. With the remaining 25% of Canadian total production from other provinces (i.e., not including Ontario) also being dependent on international or trans-waterbody movements, it is estimated that a total of 40% to 43.8% of Canadian rainbow trout production is reliant on international or trans-waterbody movements, primarily of eggs. Because these values fall into the 40–49.9% scoring category, the score for Factor 10Xa is 5 out of 10.

Factor 10Xb—Biosecurity of Source/Destination

<u>Source of movements</u>

From a regulatory perspective, shipments of live fish or eggs involve several requirements regarding permissions and licenses, risk assessments, and screening/testing before shipment. At the Canadian level, a National Code on Introductions and Transfers of Aquatic Organisms[121]

[121] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/it-code-eng.htm#Appendix7.2

is applied by Introductions and Transfers Committees established in each province. But there are provincial variations, because the Fishery (General) Regulations, under which the federal Introductions and Transfer Licenses are made, do not apply in Ontario and the Prairie provinces (Manitoba, Saskatchewan, and Alberta) or to freshwater movements in Quebec (pers. comm., S. Rooney, DFO, June 2024). In Ontario, aspects of the Fish Licensing Regulation (664/98) apply under the Fish and Wildlife Conservation Act, and under Ontario regulation 664/98, an Aquaculture License is sufficient to transport live fish if the fish have been cultured, bought, or sold under the authority of the document.[122] That is, a holder of an Aquaculture License in Ontario can move the fish species listed on the license within the province with no additional permit or need to notify the government (pers. comm., S. Naylor, DFO, June 2024). In Quebec, there are two Introductions and Transfers Committees: one for marine applications and the other for freshwater (the marine committee is chaired by DFO and the freshwater committee is chaired by the province) (pers. comm., S. Rooney. DFO. June 2024).

Regarding disease biosecurity, the focus is on "Schedule C Fish Disease Agents" (or any other disease organism of which the Minister [or their designate] has notified the license holder), and fish cannot be stocked if these pathogens are detected. Schedule C diseases are:

- Infectious hematopoietic necrosis virus
- Viral hemmorhagic septicemia virus
- *Oncorhynchus masou* virus
- Epizootic epitheliotropic disease virus
- *Ceratomyxa shasta* (a myxosporean parasite that infects salmonid fish on the Pacific coast of North America)
- *Myxobolus cerebralis* (causative agent of whirling disease)
- Proliferative kidney disease agent

Before authorizations of live movements, the Introductions and Transfers Committees must complete an aquatic organism risk assessment, which assesses both the probability that the primary species being moved will become established and the consequences of that potential establishment. But of particular interest to this criterion is the "parasite or fellow traveler" component of the risk assessment (Appendix 7, Part 2 of the national code), which first must estimate the probability that a parasite or fellow traveler may be introduced along with the species proposed for introduction (or movement), noting that several pathways may exist through which accompanying species can enter fish habitat. The second aspect is to determine the consequence of the establishment of a parasite or fellow traveler, if it were introduced and encountered susceptible organisms or suitable habitat. These two aspects combine to give an estimate of the parasite or fellow traveler risk potential. In Ontario, the OAHN Aquaculture Biosecurity Manual (OAHN, 2022) notes that relevant risk-management measures at the source of fish movements include testing and declarations of health status before movements, inspections, and staff training.

[122] https://www.ontario.ca/page/licence-transport-live-fish

In practice, the trout breeding facilities that supply eggs—particularly the advanced genetic facilities such as Troutlodge or large producers such as Riverence (U.S.)—are primarily considered to be tank- or raceway-based systems with high water recirculation and biosecurity. Although some breeding facilities may operate as flow-through raceway systems[123], the small volumes of egg shipments (eggs are shipped moist, but are not submerged in water) and the ease of surface disinfection and screening mean that the risk of unintentionally including a secondary species is considered low. In addition, any shipping materials, including the water, ice, etc., are disinfected before disposal (pers. comm., M. Chiasson, University of Guelph, December 2023). International egg suppliers such as Troutlodge maintain an independent health certification program that meets World Organization for Animal Health (WOAH) disease-free standards. To export to Canada, this is required by both the Canadian Food Inspection Agency (CFIA)[124] and the USDA APHIS program.[125]

For movements of fingerlings within Canada, hatcheries and fingerling producers are also tank- or raceway-based and will use some recirculation,[126] particularly during the early stages, but the greater volumes of water used during production and transport mean that the potential for effective biosecurity is reduced. But several layers of screening measures are in place; for example:[127]

- Hatcheries conduct pathogen-screening panels twice annually for Notifiable Diseases and other diseases of interest (tested at designated facilities at the University of Guelph's Animal Health Laboratory or the University of Prince Edward Island's Veterinary Diagnostic Services Laboratory).
- The majority of hatcheries conduct their own screening, including gross examinations (including skin and gill wet mounts), bacteriology, and histology general screening before shipment.
- Net-pen farmers send their veterinarian to the hatcheries to conduct independent testing, including gross examinations (including skin and gill wet mounts), bacteriology, histology general screening, and qPCR for pathogens of interest before shipments.
- Gross inspections are conducted at all stages, including of individual fish during vaccination before shipment.
- Samples from each shipment are fixed in formalin to be stored on record in the event of any future findings.
- Laboratories are obligated to report results to the Ministry of Agriculture, Food and Rural Affairs under the Animal Health Act, and results more broadly are shared routinely at the provincial level with government staff via the Ontario Animal Health Network Fish group.

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[123] https://ontarioseafoodfarmers.ca/trout-tour/ - spawning and broodstock (note this video is 8 years old)
[124] https://inspection.canada.ca/eng/1297964599443/1297965645317
[125] https://www.aphis.usda.gov/aphis/home/
[126] For example, the Wild West Steelhead hatchery is noted to be a recirculation facility: https://www.wildweststeelhead.com/production-process/
[127] This list is a summary based on detailed information provided by M. Chiasson, University of Guelph, pers. comm., December 2023.

Overall, the combination of high biosecurity in the rainbow trout breeding centers (i.e., egg suppliers) with the testing and screening processes at hatcheries indicates a high potential to prevent hitchhiker species from entering live fish shipments at the source (i.e., an initial score of 8 out of 10 for Factor 10Xb—Biosecurity of source).

Destination of movements

Regarding the potential release into the wild of organisms unintentionally introduced to a farm during live animal movements, the OAHN Aquaculture Biosecurity Manual (OAHN, 2022) notes that the exit of animals from the farm through the discard of mortalities, escape, and intermediate hosts is an extreme biosecurity risk, and the discharge of water is a high risk. Relevant risk management measures at the destination regarding animals include disinfection, quarantine, monitoring/testing, and proper disposal of mortalities. For water discharges, relevant risk-management measures include water management and treatment, appropriate escape screens, disposal of wastes (e.g., filters), monitoring, and training.

For the dominant movements of rainbow trout eggs, the initial destinations are hatcheries. Noting the initial ability to surface-disinfect eggs on arrival, fry and fingerling fish are subsequently moved to increasingly open flow-through raceways and tanks before their ultimate destination in net pen farms. Without robustly knowing the uptake of the recommended biosecurity measures, the scores for Factor 10Xb—Biosecurity of the destination are 4 for the flow-through tanks and raceways during fingerling production (i.e., the destination of egg movements) and 0 out of 10 for open net pens (i.e., the primary destination of fingerling movements).

Factor 10Xb final score

Because the destinations are largely considered to be open systems (i.e., if an organism were unintentionally included in a shipment, then there is a substantial risk it would be released into the environment), the driving factor preventing unintentional introductions is the biosecurity at the source (i.e., preventing the initial entry of a secondary species before shipment). Therefore, the final score for Factor 10Xb—Biosecurity of source/destination is the higher score of 8 out of 10.

Conclusions and Final Score

The OAHN Aquaculture Biosecurity Manual notes an extreme risk of the entry and exit of pathogens or other organisms during live animal movements (broodstock, juveniles, or eggs). DFO and/or provincial partners approve the intentional movements into, between, and within Canadian watershed and fish-rearing facilities of billions of aquatic organisms of hundreds of species each year for many purposes, including aquaculture and stocking purposes. The rainbow trout aquaculture industry is dependent on the movements of fertilized eyed eggs from breeding facilities to hatcheries, and the subsequent movement of fingerlings from nurseries to grow-out sites, primarily in open net pens. Considering the dominant region of production in Ontario, movements of fingerlings are considered to be within the same Lake Huron watershed, and the majority of eggs (75% to 80%) are sourced from in-province breeding centers. These aspects vary somewhat between provinces; for example, the major producer in

Saskatchewan has its own hatchery on site and does not need to ship fingerlings, but it does rely on imported eggs from the United States. Overall, approximately 42% of the industry in Canada is considered dependent on trans-waterbody shipments of live trout, primarily in the form of eggs, and the score for Factor 10Xa—International or trans-waterbody animal shipments is 5 out of 10.

Across Canada, movements are authorized and licensed following the federal-provincial-territorial National Code on Introductions and Transfers of Aquatic Organisms. But requirements vary by province. For example, in Ontario, an Aquaculture License is the only requirement for movements (in addition to the biosecurity measures described in this criterion). Introductions and Transfers Committees must apply an aquatic organism risk assessment that includes a “parasite or fellow traveler” component, and movements must be screened for key pathogens. The sources of trout eggs are considered to have the potential for high biosecurity in tank-based recirculating systems, in addition to the ability to screen and surface disinfect eggs before shipment. Routine independent and industry screenings of hatcheries and of fingerlings before movements also substantially reduce the risk of unintentionally shipping secondary organisms during fingerling movements. The score for Factor 10Xb (based on the source of live movements) is 8 out of 10. Overall, the limited trans-waterbody movements and the potential for substantial biosecurity to reduce the risk of an organism entering shipments at the source combine for the final score for Criterion 10X—Introduction of Secondary Species of a small deduction of –1.0 out of –10.

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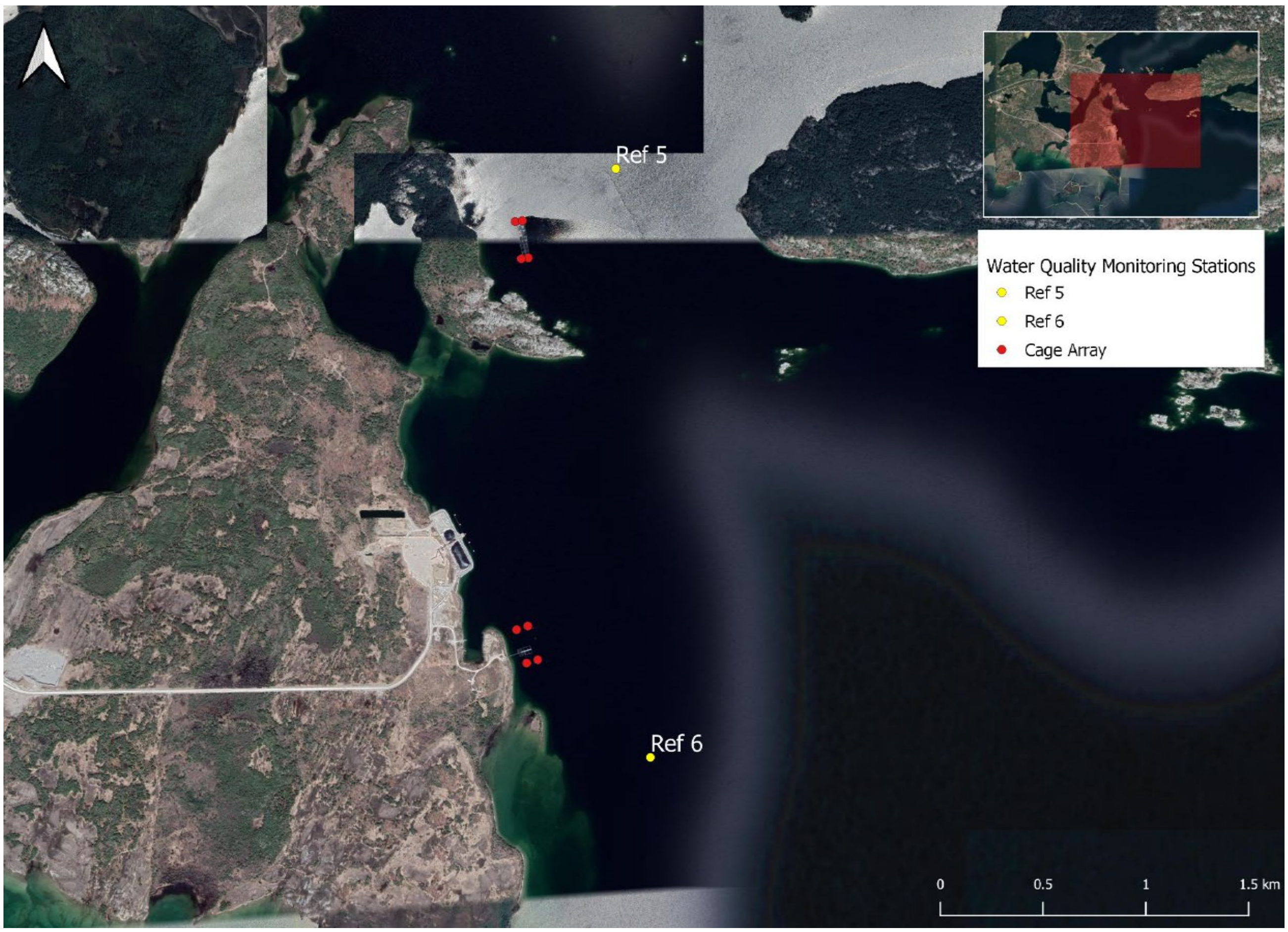
Appendix 1: Example of Net Pen Arrays and Water-Quality Monitoring Reference Points

The image shows the location of two net pen arrays (outside corners denoted by red dots) and the water-quality monitoring reference points (yellow dots) for Fisher Harbour (southern net pen array) and Eagle Rock (northern net pen array). Image provided in a Cole Munro water quality monitoring report (pers. comm., S. Higgins, Cole Munro, October 2023).



Appendix 2: Data Points and all Scoring Calculations

Criterion 1: Data	**Data Quality**	
Data Category	**Net Pens**	**Land-Based**
Production	10.0	10.0
Management	10.0	10.0
Effluent	7.5	7.5
Habitat	7.5	7.5
Chemical Use	7.5	5.0
Feed	7.5	5.0
Escapes	7.5	7.5
Disease	5.0	2.5
Source of stock	10.0	10.0
Wildlife mortalities	10.0	5.0
Escape of secondary species	7.5	7.5
C1 Data Final Score (0–10)	**8.182**	**7.045**
	Green	Yellow

Criterion 2: Effluent—Net Pens	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0–10)	**7**
Critical?	NO

Criterion 2: Effluent—Land-based systems

Risk-based assessment

2.1a Biological waste production	**Data and Scores**
Protein content of feed (%)	41.500
eFCR	1.360
Fertilizer N input (kg N/mt fish)	0.000
Protein content of harvested fish (%)	15.700
N content factor (fixed)	0.160
N input per ton of fish produced (kg)	90.304
N output in each ton of fish harvested (kg)	25.120
Waste N produced per ton of fish (kg)	65.184

2.1b Production System discharge	**Data and Scores**
Basic production system score	1.000
Adjustment 1 (if applicable)	–0.48
Adjustment 2 (if applicable)	0.000

Adjustment 3 (if applicable)	0.000
Boundary adjustment (if applicable)	0.000
Discharge (Factor 2.1b) score (0–1)	0.520
Waste discharged per ton of production (kg N mt^{-1})	33.896
Waste discharge score (0–10)	6.000

2.2 Management of farm-level and cumulative effluent impacts	
2.2a Content of effluent management measure	5
2.2b Enforcement of effluent management measures	5
2.2 Effluent management effectiveness	10.00
C2 Effluent Final Score (0–10)	**9**
Critical?	No

	Data and Scores	
Criterion 3: Habitat	**Net Pens**	**Land-Based**
F3.1 Habitat conversion and function		
F3.1 Score (0–10)	9	9
F3.2 Management of farm-level and cumulative habitat impacts		
3.2a Content of habitat management measure	4	4
3.2b Enforcement of habitat management measures	5	5
3.2 Habitat management effectiveness	6.400	8.00
C3 Habitat Final Score (0–10)	**8.667**	**8.667**
Critical?	No	No

Criterion 4: Chemical Use—all production systems	
Single species assessment	**Data and Scores**
Chemical use initial score (0–10)	8.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0–10)	**8.0**
Critical?	No

Criterion 5: Feed	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	4.800
Fishmeal from by-products, weighted inclusion %	2.200
By-product fishmeal inclusion (@ 5%)	0.110
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	4.700
Fish oil from by-products, weighted inclusion %	0.700

By-product fish oil inclusion (@ 5%)	0.035
Fish oil yield value, weighted %	5.000
eFCR	1.360
FFER Fishmeal value	**0.297**
FFER Fish oil value	**1.288**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**All Systems**
	Data and Scores
Source fishery sustainability score	5.000
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for Red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**4.840**

5.2 Net Protein Gain or Loss (%)	**All Systems**
	Data and Scores
Weighted total feed protein content	41.500
Protein INPUT kg/100 kg harvest	56.440
Whole body harvested fish protein content	15.700
Net protein gain or loss	–72.183
Species-specific Factor 5.2 score	**2**
Critical (Score = 0)?	No
Critical (FFER >3 and 5.2 score <2)?	No

5.3 Feed Footprint	**All Systems**
	Data and Scores
GWP (kg CO_2-eq kg^{-1} farmed seafood protein)	**12.752**
Contribution (%) from fishmeal from whole fish	3.640
Contribution (%) from fish oil from whole fish	2.440
Contribution (%) from fishmeal from by-products	1.668
Contribution (%) from fish oil from by-products	0.363
Contribution (%) from crop ingredients	70.575
Contribution (%) from land animal ingredients	18.577
Contribution (%) from other ingredients	2.738
Factor 5.3 score	**7**
C5 Final Feed Criterion Score	**4.7**
Critical?	**No**

Criterion 6: Escapes	Net Pens Data and Scores	Land-Based Data and Scores
F6.1 System escape risk	2	2
Percent of escapees recaptured (%)	0.000	0.000
F6.1 Recapture adjustment	0.000	0.000
F6.1 Final escape risk score	2.000	2.000
F6.2 Invasiveness score	10	10
C6 Escape Final Score (0–10)	**10.0**	**10.0**
Critical?	No	No

Criterion 7: Disease—all production systems	Data and Scores
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0–10)	**5**
Critical?	No

Criterion 8X Source of Stock—all production systems	Data and Scores
Percent of production dependent on wild sources (%)	0.0
Initial Source of Stock score (0–10)	0.0
Use of ETP or SFW “Red” fishery sources	No
C8X Source of Stock Final Score (0–10)	**0**
Critical?	No

Criterion 9X Wildlife Mortality parameters	Net Pens Data and Scores	Land-Based Data and Scores
Single species wildlife mortality score	–2	–2
System score if multiple species assessed together	n/a	n/a
C9X Wildlife Mortality Final Score	**–2**	**–2**
Critical?	No	No

Criterion 10X: Introduction of Secondary Species All production systems	Data and Scores
Production reliant on trans-waterbody movements (%)	42
Factor 10Xa score	5
Biosecurity of the source of movements (0–10)	8
Biosecurity of the farm destination of movements (0–10)	4
Species-specific score 10X score	–0.800
Multi-species assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–1.000**
Critical?	n/a