Rainbow Trout

Oncorhynchus mykiss

United States

Freshwater net pen | Outdoor flowthrough raceway | Ponds

Seafood Watch Consulting Researcher

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Seafood Watch Standard used in this assessment: Aquaculture Standard v4

Disclaimer

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Table of Contents

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-water body 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: Are well managed and caught or farmed in environmentally friendly ways.

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

Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Raceways/Ponds

Criterion	Score	Rank	Critical?
C1 Data	7.73	GREEN	
C2 Effluent	7.00	GREEN	NO
C3 Habitat	9.33	GREEN	NO
C4 Chemical Use	6.00	YELLOW	NO
C5 Feed	6.15	YELLOW	NO
C6 Escapes	7.00	GREEN	NO
C7 Disease	5.00	YELLOW	NO
C8X Source of Stock	0.00	GREEN	NO
C9X Wildlife Mortalities	–1.00	GREEN	NO
C10X Introduction of Secondary Species	–0.40	GREEN	
Total	**46.81**		
Final score (0–10)	**6.69**		

OVERALL RANKING

Final Score	6.69
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK
GREEN

Scoring note – Scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact. Two or more red criteria, or 1 Critical criterion trigger an overall Red recommendation.

Summary

The final numerical score for rainbow trout *(Oncorhynchus mykiss)* produced in freshwater raceways and ponds production systems in the United States is 6.69 out of 10, which is in the Green range. The final recommendation is Green or Best Choice.

Freshwater Net Pens

Criterion	Score	Rank	Critical?
C1 Data	8.86	GREEN	
C2 Effluent	7.00	GREEN	NO
C3 Habitat	9.33	GREEN	NO
C4 Chemical Use	6.00	YELLOW	NO
C5 Feed	6.00	YELLOW	NO
C6 Escapes	7.00	GREEN	NO
C7 Disease	5.00	YELLOW	NO
C8X Source of Stock	0.00	GREEN	NO
C9X Wildlife Mortalities	0.00	GREEN	NO
C10X Introduction of Secondary Species	–1.00	GREEN	
Total	**48.20**		
Final score (0–10)	**6.86**		

OVERALL RANKING

Final Score	6.86
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK
GREEN

Summary

The final numerical score for rainbow trout *(Oncorhynchus mykiss)* produced in freshwater net pen systems in the United States is 6.86 out of 10, which is in the Green range. The final recommendation is Green or Best Choice.

Executive Summary

This Seafood Watch assessment involves a number of different criteria covering impacts associated with effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of nonnative organisms (other than the farmed species), disease, the source stock, and general data availability. Both freshwater raceways/ponds and freshwater net pens are assessed in the report, and all criteria except 8X—Source of Stock have been scored individually, to reflect the disparate production protocols, harvest size, and, to an extent, data availability between the two production methods.

Rainbow trout is native to many North American rivers and lakes that drain into the Pacific Ocean. It has also been introduced throughout much of North America (and the world) to establish sport fisheries. The United States produces over 20,000 metric tons (mt) of rainbow trout in freshwater systems annually, yet it is still a significant net importer of the species. The majority of imported trout are grown in saltwater systems (≈14,500 mt), with lesser imports of freshwater-reared product (≈5,300 mt). The majority of production in the U.S. occurs in flow-through (i.e., a single-pass of water that may cascade through multiple raceways before discharge, termed "serial reuse") concrete raceways and ponds, with the remainder being produced in freshwater net pens.

Data

Data availability is moderate to high for raceways/ponds. Disease, Escapes, and Chemical Use data scored poorly due to the lack of transparently available information from producers in some cases (Disease/Chemicals), and to the aggregation of production data that created uncertainty. One point of consistency was the availability of robust regulatory information governing the industry, based on ecological principles. In some cases, the aggregated production data affected the ability to clearly resolve other criteria that relied upon weighting calculations. The final numerical score for Criterion 1—Data for raceways and ponds is 7.73 out of 10.

Data availability scored highly for net pens, because this system is represented by a single operator with commendable transparency, as well as best management practices across all aspects of the operation. In several scores, the data transparency of the operation allowed higher scoring because of robust data availability with which to base the decision. Some uncertainty in Feed (due to the proprietary nature of feed formulations to feed mills) and Disease negatively affected the Data scoring for this criterion. The final numerical score for Criterion 1—Data for net pens is 8.86 out of 10.

Effluent

Raceways and ponds are represented by Idaho and North Carolina, which together make up 64% of the national production volume, and the majority (≈75%) of trout farmed in these systems. Both states have robust regulatory frameworks for setting water quality standards, issuing permits, government monitoring programs, and enforcement. The aquaculture industry has been quite successful in reducing nutrient discharge through changing feed formulations and modifying management practices. Aquaculture has outperformed the regulatory limits to nutrient loading, and authorities are working to ensure that Total Maximum Daily Loads (TMDLs) remain appropriate for receiving waters. The TMDL system is a cumulative management framework based on the biological loading capacity of the receiving waterway from contributions of all impacting industries. Monitoring and enforcement of point source discharges are in place through the National Pollution Discharge Elimination System (NPDES) permitting framework, to maintain the biological limits for the waterway set in the TMDLs. State agencies in both Idaho and North Carolina (IPDES and NCPDES, respectively) have the primary authority for enforcing the NPDES framework in each state. Waste load allocations approved by the U.S. Environmental Protection Agency (EPA) for total suspended solids (TSS) and phosphorus from fish production facilities, conservation hatcheries, and fish processors in the region of the Middle Snake River, Idaho have been in place for approximately two decades. The industry complies with extensive water quality testing to meet NPDES monitoring requirements, and the results are available to the public via the EPA's Enforcement and Compliance History Online (ECHO) database. State water quality standards are based on ecological factors (such as aquatic habitat and biological parameters in each water body) through a comprehensive monitoring and assessment process, and are reviewed every 3 years (IDEQ, 2022a). This is a robust and ecologically appropriate system to monitor degradation of the water body. Both states have farms that show rare industry exceedance of water quality standards, and such incidents are temporary and resolved promptly. But, recent reviews have indicated that the current waste load allocations in Idaho (for all industries, including aquaculture) may be too high, because the Snake River has failed to meet water quality targets and impacts persist. At this time, a precautionary approach is taken to scoring, in the absence of clarifying data from the Idaho Department of Environmental Quality (IDEQ) TMDL revision process, and given the potential for cumulative impacts at the water body or regional scale. A final intermediate score of 7 out of 10 for the evidence-based assessment is given to raceways and ponds.

Effluent regulation for net pens is comprehensive and based on ecological principles. The primary parameters reported for NPDES permitting purposes are dissolved oxygen (DO) and turbidity, which are measured on a sliding scale of an allowable discharge limit above background levels (which shift due to the river system having fluctuating DO and turbidity from seasonal flow conditions and dam operations). Water-quality data analysis is performed by a third-party laboratory to meet Tribal effluent data monitoring requirements for the parameters of dissolved gas, total gas pressure (TGP), pH, turbidity, temperature, total phosphate (P), ortho P, nitrite and nitrate, ammonia (as nitrogen), total nitrogen, total dissolved solids (TDS), and oil and grease. The Tribal water quality standards are readily available online and the monitoring procedures are more than adequate to capture any changes to the beneficial uses of the water body. The pens are in an area of high current (≈40–70 cm/s) with rare periods of low current observed. Extensive benthic mapping and current modeling have been done in the reservoir, and they support the evaluation that waste from the pens is being effectively transported and is not likely to build up underneath the pens. A probable pathway of assimilation of wastes into the food web has been demonstrated via isotopic analysis. Based on the monitoring data available in the permit renewal documents, the operation is meeting the discharge limits set in its permit requirements, and any impacts within the immediate vicinity are temporary. But, uncertainty remains about the cumulative impact potential of aquaculture in addition to all other nutrient inputs (point source and nonpoint source) at the water body scale. A final score of 7 out of 10 for the evidence-based assessment is given to net pens.

Habitat

Because of the relatively small footprint of farms (U.S. trout production in the top two states uses less than one-fifth of a square mile of land), and their locations on land of low habitat value that was previously converted for agriculture or other industries, trout farm raceways are not considered to be contributing to ongoing habitat fragmentation or a reduction in ecosystem functioning in Idaho or North Carolina. Farm siting regulation and management is robust, with evidence of cumulative management systems for assessment of habitat impacts. Future expansion is regulated through the existing processes. Permitting processes are transparent and enforcement is highly effective. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 9.33 out of 10.

The freshwater net pens that represent this system are clustered in three sites within an impounded reservoir between two dams on a river system (a modified habitat of low value). The pens are in an area of high current (≈40–70 cm/s) with rare periods of low current observed. Waste transport and a probable pathway for assimilation into the food web have been demonstrated, and the habitat is considered to be maintaining full functionality. Sites are permitted according to ecological principles and environmental considerations, though there is no area-based management plan in place to manage potential expansion. Permitting and enforcement procedures are transparent, and there have been no formal violations of the operator in the last 5 years. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 9.33 out of 10.

Chemical Use

For raceways and ponds, robust regulatory guidance is available for farmers to select appropriate chemicals, and mitigation methods are used where possible to limit the frequency and/or total use of chemicals, such as using appropriate stocking densities, disinfection of tools and equipment between production areas, vaccinations, dietary additives (e.g., probiotics), and proactive approaches to fish health. The use of antibiotics at the largest producer in the country, representing approximately 67% of total U.S. raceway and pond production, is limited to oxytetracycline at an estimated 0.37 treatments/cycle and florfenicol at 0.01 treatments/cycle, on average, both listed as highly important for human medicine by the World Health Organization (WHO). Although florfenicol is used only in animal medicine, it may meet the conditions as a highly important antimicrobial for human medicine in limited geographies for treatment of specific conditions. Although the data used represent a significant portion of the total industry, there is uncertainty as to how representative the data are of all farm scales of production in the U.S. trout industry, as well as the long-term fate of antibiotics that reach discharge waters.

Overall, the available data indicate that antibiotics are used on average less than once per production cycle (a score of 8); however, with uncertainty about the representativeness of these data, a precautionary approach is warranted. Given the flow-through nature of rainbow trout raceways and ponds and the physicochemical properties of these compounds, it is possible for bioavailable antimicrobials to be discharged and present in the receiving water body. Risk is mitigated by dilution, degradation, and intermittent judicious use with veterinary oversight. Both of the antimicrobials common to the trout industry (Aquaflor and Terramycin 200) have received Findings of No Significant Impact (FONSIs) from the EPA. Although there is some concern and evidence of developed resistance in receiving water bodies globally, there is no evidence that antibiotic use on U.S. trout farms has resulted in or contributed to resistance. Regulatory limits for chemical type and dose exist and are well enforced, though there are no legislated limits to total use. The final numerical score for Criterion 4—Chemical Use is 6 out of 10.

For net pens, reliable data were available to confirm that the frequency of antibiotic usage (oxytetracycline and florfenicol) is 0.77 treatments annually for cycles harvested in 2021 and 2022 (consistent with a score of 8). The system demonstrates a low need for chemical treatments, with zero bath treatments administered during grow-out (baths are not possible in the high-flow environment). Given the flow-through nature of rainbow trout net pens and the physicochemical properties of these compounds, it is possible for bioavailable antimicrobials to be discharged and present in the receiving water body. Risk is mitigated by dilution, degradation, and intermittent judicious use with veterinary oversight. Although there is some concern and evidence of developed resistance in receiving water bodies globally, there is no evidence that antibiotic use on U.S. trout farms has resulted in or contributed to resistance. Regulatory limits of chemical type and dose exist and are well enforced, though there are no legislated limits to total use. The final numerical score for Criterion 4—Chemical Use is 6 out of 10.

Feed

Overall, the U.S. rainbow trout industry is still reliant on fishmeal and fish oil inputs to grow fish, though significant reductions have been made with a transition to more land animal and terrestrial crop proteins and oils over recent years. Trout feeds generally use nonmarine ingredients to provide the majority of the protein composition, and some diets also supply the majority of lipids from terrestrial sources. Feed is scored separately for raceways/ponds and net pens because of the significantly larger body size that fish are grown to in net pens and the associated higher eFCR, which is not representative of raceways/ponds.

The majority of fishmeal is sourced from whole fish (94% of the fishmeal used in the average aggregated feed composition), and a lesser 67.5% of fish oil is sourced from whole fish. This reflects that the feed industry is using a greater proportion of fish oil by-products than fishmeal by-products, likely due to the complexities of sourcing fishmeal as a by-product.

For raceways and ponds, the FFER value for fishmeal is 0.8 and the FFER value for fish oil is 0.5, using an eFCR of 1.4. For diets commonly used in these systems, the sustainability of wild fish use is scored at 8, leading to an overall score for Factor 5.1 of 7.3. The net protein gain/loss is –75.531, which means that there is a net loss of protein during production, partly because of the relatively high average protein content of feeds over the entire life cycle (45.83%); this produces a score for Factor 5.2 of 2. There are 7.352 kg CO_2-eq produced per kg of farmed rainbow trout protein, scoring 8 for Factor 5.3. Factors 5.1, 5.,2 and 5.3 combine to give a final Criterion 5—Feed numerical score of 6.15 out of 10 for raceways and ponds.

For net pens, the FFER value for fishmeal is 1.0 and the FFER value for fish oil is 0.6, which reflects the higher eFCR (1.7) that is most likely related to growing the fish to a larger final body size, thus requiring a greater amount of fish products to grow each mt of trout. The sustainability of wild fish use is scored at 8, leading to an overall score for Factor 5.1 of 7. The net protein gain/loss is –79.514, which means that there is a net loss of protein during production, partly because of the relatively high average protein content of feeds over the entire life cycle (45.08%); this produces a score for Factor 5.2 of 2. There are 8.105 kg CO_2-eq produced per kg of farmed rainbow trout protein, scoring 8 for Factor 5.3. Factors 5.1, 5.2, and 5.3 combine to give a final Criterion 5—Feed numerical score of 6 out of 10 for net pens.

Escapes

Although there is low to moderate risk of escapes from well-constructed and sited facilities, escapes are occurring from raceway and pond systems, as documented in aggregated food fish and distribution production data from U.S. Department of Agriculture (USDA) Trout Surveys. All the compiled evidence suggests that the number of potential escapes from flow-through rainbow trout production facilities poses no significant risk of additional ecological impacts, when considering the volume of effectively identical fish released into the same waters over the past century by state hatcheries. Escaped farmed rainbow trout are likely to exhibit similar behavior, experience similar mortality rates, and are genetically similar (if not identical) to intentionally stocked trout. There are cases of genetically pure native trout species existing in watersheds where commercial trout aquaculture is located, which provide a nonzero potential for impact of escapees. It is known that escapes from aquaculture facilities can and do happen; although unlikely, these fish may be capable of competing, and in some cases hybridizing, with wild populations. Factors 6.1 and 6.2 combine to give a final numerical score for raceways/ponds of 7 out of 10 for Criterion 6—Escapes.

The net pen operation is an open system with a documented track record of no escapes in the last 10 years, and the farm construction and management goes beyond best management practices. The net pen operation has active procedures in place in case of a large escape event (release of 1,500 or more fish >1 kg or 3,000 or more fish <1 kg) that would trigger a recapture plan to be approved by the Tribal Fish and Wildlife Department. The farm stock is sterile, and there is no genetic risk from escapes. There is no risk to threatened species, which is provided in evidence from government reporting of critical habitat and surveys of fish populations in the waterway. But, a remote risk of competition with native salmonids exists in the event of a catastrophic escape in an open system. Restoration of the anadromous Pacific salmon corridor above the lower dam of the reservoir has been tested by using fish-passage tubing technology, and efforts are ongoing to reintroduce salmon in the Upper Columbia River Basin. If passage of anadromous salmon becomes permissible into the impounded waterway, a re-evaluation of impacts in that context will be warranted. Factors 6.1 and 6.2 combine to give a final numerical score for net pens of 7 out of 10 for Criterion 6—Escapes.

Disease

Overall, the US has a comprehensive regulatory system for disease management. Disease losses at farms may be as high as 8–15% of the anticipated harvest, though these data do not provide an entirely accurate picture because of the aggregation of hatcheries and grow-out sites. In general, farms understand what diseases are common to their stock and demonstrate best management practices for surveillance testing and rapid treatment. The presence of all common pathogens has been demonstrated in the wild where U.S. rainbow trout farming occurs. This criterion would benefit from an understanding of the overall incidence of disease at farms and any potential interaction with wild fish, which is currently lacking due to an absence of data.

The largest raceway operator (representing 67% of all rainbow trout farmed in this system) maintains fish health improvement and biosecurity plans that are updated annually following biosecurity audits, and employs a fish health team that is actively engaged in on-farm improvements as well as responding to morbidity/mortality events. Raceways and ponds have additional risk-management benefits that are not possible in open net pen systems, including the physical separation of farmed fish from wild fish and (in some cases) the sourcing of spring water. The entry of *F. columnaris* from the wild into a raceway farm site has been demonstrated via source water (vulnerability to introduction of local pathogens) as a potential means of transmission, and the persistence/shedding of pathogens from biofilms within tanks is not yet well understood. In general, farms use protocols for biosecurity and best management practices to monitor for disease. Resources are available in all states to sample and identify pathogens. Data to verify the rates of morbidity and mortality from specific diseases are not available from the industry, and the aggregated national trout data show an average annual mortality of 12.5%. Data from industry to verify the mortality rate from disease may benefit the scoring. There is little data availability to understand transmission between wild and farmed populations. The final numerical score for Criterion 7—Disease is 5 out of 10.

For net pen production, a staff veterinarian, robust biosecurity measures, and fish health best practices are in place and offer some risk reduction. As a result of fish health management measures, there are infrequent occurrences of infections or mortalities at the farm level. The mortality rate from disease is estimated to be within the national average for U.S. rainbow trout grown in all systems (12.5% 5-yr average), when considering that the farm's reported mortality (≈18% on average) includes normal attrition. All pathogens detected at the farm site are present in the water body. But, the open system is vulnerable to introductions of local pathogens and parasites (e.g., from water, broodstock, eggs, fry, feed, or local wildlife) and is also open to the discharge of pathogens, with limited data availability to understand transmission between wild and farmed populations. The final numerical score for Criterion 7—Disease for net pens is 5 out of 10.

Source of Stock

Rainbow trout were the first fish to be fully domesticated on a large scale in North America. Currently, 100% of the stock used for commercial food-fish rainbow trout farming is supplied by domesticated broodstock. No wild rainbow trout are relied upon for production. The final score for Criterion 8X—Source of Stock is –0 out of –10.

Wildlife Mortalities

Trout are lost due to predation, as evidenced by USDA industry data reporting, so there is a demonstrated potential for wildlife interactions at farms. Nonlethal control measures are part of best management practices in the U.S. trout industry, and appropriate regulations are in place to only allow lethal control of predatory birds with a permit for wildlife control (depredation) from the relevant regional Fish and Wildlife authority. The lethal take of small mammals is legally allowed under the regulations of individual state statutes; however, this is known to be a rare occurrence because of the efficacy of exclusionary structures. Wildlife mortalities at raceways and ponds are likely limited to exceptionally rare cases and do not occur at most facilities because of total exclusion structures. Populations of predatory animals are not significantly affected by the U.S. trout aquaculture industry. The final numerical score for Criterion 9X—Wildlife Mortalities is –1 out of –10 for raceway and pond systems.

Nonlethal control measures are used at the net pen facilities, and no mortalities have been reported. Because there is only one active freshwater net pen farm in the U.S. and these data reflect this entire system of farming, uncertainty in the representativeness of these data is significantly reduced. The final numerical score for Criterion 9X—Wildlife Mortalities is –0 out of –10 for net pens.

Introduction of Secondary Species

Trout genetics companies in the Pacific Northwest supply the majority of the U.S. rainbow trout industry. Farms that are located in Idaho are near to two major trout genetics suppliers, so there is less need for trans-water body shipment within this state (only an estimated 10% of trans-water body shipments are necessary). The second largest production state, North Carolina, imports an estimated 99% of eggs from the Pacific Northwest. A weighted estimation of the trans-water body shipments was created, based on the unique within-state egg production of Idaho, along with the assumption that all states outside of Idaho follow the trend of North Carolina (a necessary assumption because of the aggregation of state data, which makes it not possible to break out Washington, for example). The biosecurity of egg production facilities is high, and eggs are often certified disease-free. Thus, there is a low risk of unintentionally introducing secondary species during animal shipments. The scoring deduction for Criterion 10X—Introduction of Secondary Species is –0.40 out of –10.

For net pens, all seed stock is sourced from genetics companies within Washington. But, these companies are in distinct watersheds, meaning that all seed stock is shipped trans-water body to reach the net pen site. The biosecurity of egg production facilities is high, and eggs are often certified disease-free. Thus, there is a low risk of unintentionally introducing nonnative species (i.e., species other than the cultured trout) during animal shipments. The scoring deduction for Criterion 10X—Introduction of Secondary Species is –1 out of –10.

Introduction

Scope of the analysis and ensuing recommendation

Species
Oncorhynchus mykiss

Geographic Coverage
United States of America

Production Methods
Raceways and ponds (freshwater)
Net pens (freshwater)

Species Overview

Rainbow trout *(Oncorhynchus mykiss)* is a salmonid fish native to the North American streams, rivers, and lakes that drain to the Pacific Ocean; it ranges from Alaska to Mexico and belongs to the genus *Oncorhynchus*, which includes the closely related Pacific salmon and many Pacific trout species. It is a fast-growing, cold-water fish that typically reaches weights of 1–3 kg, and larger sea-run steelhead (anadromous *O. mykiss*) often reach 10 kg, although sizes up to 25 kg have been reported (Behnke 2002). It has a speckled body with a darker dorsal surface and silvery sides that have a pink-to-red band. This band is often iridescent, resembling a rainbow, which gives the fish its common name. Its diet in the wild is varied and includes many insects, crustaceans, other small fish, and eggs. Because of its popularity as a sport and food fish, rainbow trout has been intentionally introduced all over the world and currently inhabits all continents except Antarctica (FAO 2022a).

The rearing of rainbow trout began in the United States in the 1800s and was undertaken principally for stocking purposes. This stocking continues to this day, albeit in a more controlled manner to avoid potentially negative ecological consequences of introduction into new habitats. Rainbow trout aquaculture for the purpose of food-fish market production began in earnest in the 1960s. It has since grown amid innovations in management and feed that have resulted in more efficient and less impactful production techniques. Although steelhead trout (rainbow trout reared in saltwater) are farmed in many parts of the world, the farm sites assessed in this report are freshwater-only systems, and the ensuing recommendation covers only *O. mykiss* farmed in freshwater systems, known as rainbow trout.

Production system
The US rainbow trout industry uses four main types of production systems (Table 1), though only two systems will be assessed in this report: freshwater raceways/ponds and freshwater net pens. Anadromous rainbow trout (those with a marine component to their life cycle) are known as *steelhead* or *steelhead trout*, and will not be assessed here. In addition, rainbow trout

grown using recirculation aquaculture systems (RAS) are assessed in the Seafood Watch Global RAS report, and are not assessed here.

Table 1: Summary of differences between production systems. FW = freshwater, SW = salt water.

Method	FW/SW	Water Source	Exchange	Maximum Stocking Density
Raceways, ponds	FW	Groundwater, surface water	single-pass flow-through (open)	35 kg/m^3 (Welker et al. 2019)
RAS	FW	Groundwater	98.5% recirc.	60–80 kg/m^3 (Roque d'orbcastel et al. 2009)(Good et al. 2010)(Davidson et al. 2017)
Net Pens	FW	Surface water	open	Estimated 20–50 kg/m^3
	SW	Ocean	open	20 kg/m^3 (by proxy of Atlantic salmon from Ayer and Tyedmers 2009)

The majority of the industry uses flow-through concrete/earthen raceways or ponds (Table 2) that are spread across states throughout the U.S. There are other production methods in use (freshwater net pens, marine net pens, RAS), with the representation of each system ranging between 1 and 3 sites operated by individual companies within single states. There are three freshwater net pen sites (all in WA), two marine net pen sites (both in WA), and one RAS site (in NY). As of the last USDA Census of Aquaculture (2018), there were a total of 300 trout farms in the U.S. rearing food-size fish.

Table 2: Approximate percentage of rainbow trout farmed using each system, by metric tonnage of total production.

Production System	**Estimated Percentage of Total Production** Total U.S. Production 2022 = 19,617 mt (USDA 2023)	Reference
Raceways, ponds	76%	Based on subtraction of other values in the table from 100%
Freshwater net pen	18%	(pers. comm., Pacific Aquaculture 2022)
RAS	6%	(pers. comm., Hudson Valley Fisheries 2022)

Raceway and Pond System Descriptions

In the U.S., rainbow trout is most commonly grown in raceways (approximately 76% of production; Table 2); these flow-through tanks are usually concrete, although earth and other materials are also used (Fornshell and Hinshaw 2008). When multiple tanks are used, raceways can be arranged in series and/or in parallel with water flowing along a downhill gradient. The scale of a farm's production is limited by the amount of freshwater available, and the source of water depends on the geography of the farm site. In Idaho [the largest producer state, responsible for approximately 56% of total national production and 67% of production in raceways and ponds (USDA 2023)], groundwater is used, while in North Carolina [the second-largest producer, responsible for approximately 8% of total national production (USDA 2023)], surface water is diverted from nearby water bodies (Fornshell and Hinshaw 2008). Groundwater sources typically provide stable temperatures and a low risk of pathogen introduction, but they may be lower in dissolved oxygen and higher in gases that are deleterious to fish (e.g., carbon dioxide, nitrogen, hydrogen sulfide) compared to surface water (Hinshaw et al. 2004). Regardless of the water source, the flow-through nature of raceway systems necessitates that water exchange and turnover rates be high in order to maintain water quality, and range from four to nine system volume turnovers per hour (Fornshell et al. 2012).

Waste discharged from raceways includes high volumes of effluent that contain low concentrations of dissolved metabolites, as well as suspended particulate wastes (fecal matter and unconsumed feeds) (Fornshell and Hinshaw 2008)(Fornshell et al. 2012). The majority of wastes in effluent are dissolved metabolites, such as ammonia, nitrite, nitrate, and phosphate, and are discharged directly into receiving water bodies; however, 7–32% of total N (TN) and 30–84% total P (TP) are bound as particulate waste and captured through solids removal (Sindilariu 2007). The most common system to capture and remove solids from concrete raceways in the U.S. is a combination of quiescent (fish-free) zones and off-line settling basins, which effectively separate the majority of solids wastes from effluent discharges (Fornshell et al. 2012)(Hinshaw et al. 2004).

The second most common method used for the cultivation of rainbow trout is earthen ponds. These are created either by using soil to build embankments (i.e., dikes) for holding water, by damming low-lying areas, or by some combination of the two (Tucker et al. 2008b). Although at one time this was the predominant form of trout aquaculture, it has become much less frequent because raceways are able to produce more fish with the same amount of water (Fornshell 2002). The source of water for ponds is highly variable and includes stream water, groundwater, surface runoff from precipitation, and diverted water from watersheds (Tucker et al. 2008b). In ponds, conditions are subject to the natural processes of the environment and the water turnover rate is low (between one to four volume turnovers per hour) (Westers 2000). Thus, ponds often act as settling basins, and solids settle, resuspend, and resettle frequently; the result is a buildup of heavier, large particles, but an estimated 80% end up as fine (5–20 um) particles that remain suspended in relatively low concentrations (<10 mg/L) (Westers 2000). Therefore, it is difficult to manage effluent discharges from ponds, because settling ponds and microscreening are not effective in removing low concentrations of small particles (Westers 2000).

In both ponds and raceway flow-through production systems, water is discharged back into the water body from which it was sourced (Fornshell et al. 2012)(Fornshell and Hinshaw 2008)(Hinshaw et al. 2004), except in the case of spring water, where it is sourced from a nearby spring and discharged to a surface water body.

Net Pen System Description

U.S. trout net pen grow-out sites are constructed in a manner typical of salmonid aquaculture (Figure 1). The structures comprise square, floating net pens arranged in a grid, surrounded by raised walkways, and entirely covered in antipredator bird netting. The pens are anchored to the bottom in a way that allows some minor movement in response to currents. Net pen facilities are typically sited to take advantage of water movement to supply adequate oxygen to the animals, as well as to carry and disperse fish waste. There is open exchange with the environment, which means that any feces, dissolved nutrients, chemicals, and feeds that enter the water have the potential to cause an impact, which is minimized through the use of best management practices. Onshore facilities for hatchery and nursery production are close to the grow-out pens and readily accessible. The three sites that represent freshwater net pen production of rainbow trout are located within an impounded section of a major river (between two dams), which forms an expansive lake in an area characterized by strong currents and a maximum depth of ≈30 m.

There are 60 cages in production; 40 have dimensions of 25 m × 25 m × 12 m deep and 20 of them on a newer site constructed in 2010 are steel cages of dimensions 30 m × 30 m × 15 m deep (pers. comm., Pacific Aquaculture October 2022).

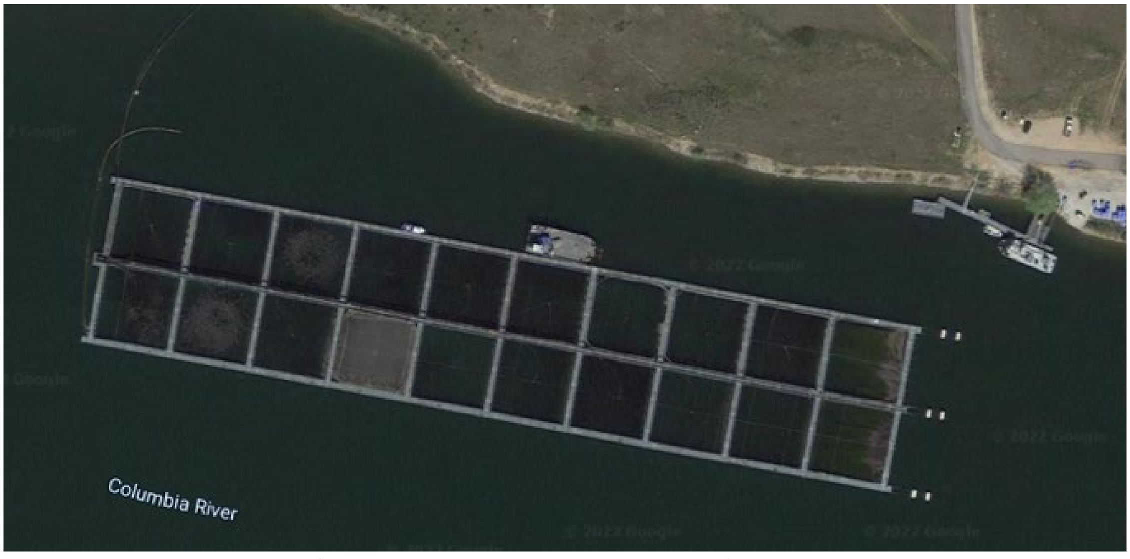


Figure 1: General layout of U.S. rainbow trout production in freshwater net pens.

Production Statistics

Global rainbow trout production in inland freshwater environments was 733,998.58 mt in 2020, with Asia leading production, followed by Europe and then the Americas (FAO FishStatJ, 2020).

A total of 19,617 mt of rainbow trout sized 12 in or longer were produced as food fish in the U.S. in 2022 (Table 3). Outside of the normal year-to-year fluctuations, it appears that production decreased and stagnated over 2020–22 (pandemic).

The majority of rainbow trout farms are small, with production from individual farms ranging from approximately 9.1 mt/year to 226.8 mt/year (Engle et al., 2019). As of 2017, the U.S. trout industry comprised 300 farms producing food-size or market-size fish (note that this number includes farms producing fish for stocking; i.e., not for direct consumption), with average sales per farm of $319,520 (USDA NASS 2019), further demonstrating that most of the industry are small producers. There are larger-scale companies in the market as well; for example, in the consolidation within the industry's largest producing state, Idaho, where 1 producer has gained ownership of 14 smaller farms (ASC, 2022). It is common for larger rainbow trout farming companies using raceways and/or ponds to feature a distribution of smaller farms rather than one large, centralized operation.

Idaho's market share trended downward between 2017 and 2021, though it appears to be increasing again (currently producing 56% of total trout in all systems). Of the states where data are withheld in the table to avoid exposing individual operations, California and Washington are also known to be in the top five trout-producing states by volume along with Idaho, North Carolina, and Pennsylvania (Engle et al., 2019). It is possible that California and/or Washington may be responsible for gaining market share from Idaho, but the data cannot clarify this because the specific areas of growth are obscured by aggregation. Note that the year 2020 is not valid for assessing market share in Idaho vs. other states because Idaho's data has been aggregated into the "Other" category.

Table 3: Total live weight (mt) of rainbow trout 12 in or longer produced in the U.S., from USDA Trout Production Surveys 2017–22 (USDA 2023).

State/Year	2017	2018	2019	2020	2021	2022
AR	0	0	0	0	0	0
CA	(D)	(D)	(D)	(D)	(D)	(D)
CO	288	268	(D)	369	323	301
GA	(D)	(D)	(D)	(D)	(D)	(D)
ID	15,238	12,245	11,338	(D)	9,841	11,020
MI	(D)	(D)	(D)	(D)	(D)	(D)
MO	301	(D)	(D)	(D)	(D)	(D)
NY	(D)	(D)	(D)	(D)	(D)	(D)
NC	1,882	1,814	(D)	(D)	1,565	1,474
OR	(D)	(D)	(D)	(D)	(D)	(D)

PA	485	544	544	526	621	612
UT	83	87	131	(D)	80	111
VA	238	232	245	310	296	289
WA	(D)	(D)	(D)	(D)	(D)	(D)
WV	234	197	186	156	(D)	(D)
WI	171	162	142	132	56	117
Other	5,518	6,014	10,524	18,695	7,542	5,693
U.S. Total	24,439	21,564	23,110	20,187	20,324	19,617

Proportion of U.S. Total Grown in Major States						
% ID	62%	57%	49%	(D)	48%	56%
% NC	8%	8%	(D)	(D)	8%	8%
% Other*	23%	28%	46%	93%	37%	29%

(D): data withheld because it would expose individual operations.

* Other: includes the data from states where data were withheld (D).

Import and Export Sources and Statistics

Exports of trout remain relatively small, with a total of 1,247 mt exported in 2021 (NOAA 2022). Although this is an increase in exports compared to 2016, when the previous Seafood Watch assessment was published, exports have largely stagnated over the previous 5 years (Table 4). The top export destination for U.S. trout continues to be Canada, which has accounted for an average of 59% of exports for the previous 5 years (NOAA 2022).

A significant volume of trout is imported to the U.S. Over the last 5 years, imports of trout have risen by 53% to a total of 19,872 mt imported in 2021 (NOAA 2022)—nearly equal to domestic production during the same period. These total import data are aggregated and include all species of trout sourced from both freshwater and saltwater rearing methods. Since 2017, the top countries for imports of trout have consistently been Chile and Norway, which provided 6,402 mt and 8,770 mt of saltwater-reared product, respectively, in 2022 (NOAA 2022). The top countries for imports of freshwater-reared trout that is most equivalent to the product produced by farms in this assessment are Chile, which sends 2,200 mt annually to the United States (SFW, 2023), and Peru and Columbia, which provided 1,599 mt and 1,491 mt, respectively, in 2022 (NOAA 2022).

Table 4: Historical import and export of trout by U.S. Data are aggregated (all species, all rearing methods) (NOAA 2022).

Volume (mt)/Year	2017	2018	2019	2020	2021	Average
Import	12,932	15,972	17,492	17,945	19,871	16,842
Export	1,742	1,571	1,852	1,560	1,248	1,595
Net	11,190	14,401	15,640	16,385	18,623	15,248

Common and Market Names

Scientific Name	*Oncorhynchus mykiss*
Common Names	Rainbow trout, steelhead trout, steelhead
United States	Rainbow trout
Spanish	Trucha arcoiris
French	Truite arcenciel
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 are commonly available.

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 (Raceways and Ponds)

C1 Data Category	Data Quality
Production	7.5
Management	10.0
Effluent	10.0
Habitat	7.5
Chemical Use	5.0
Feed	7.5
Escapes	7.5
Disease	5.0
Source of Stock	10.0
Wildlife and Mortalities	7.5
Introduction of Secondary Species	7.5
C1 Data Final Score (0–10)	**7.73**

Criterion 1 Summary (Net Pens)

C1 Data Category	Data Quality
Production	7.5
Management	10.0
Effluent	10.0
Habitat	10.0
Chemical Use	7.5
Feed	7.5
Escapes	10.0
Disease	5.0
Source of Stock	10.0
Wildlife and Mortalities	10.0
Introduction of Secondary Species	10.0
C1 Data Final Score (0–10)	**8.86**

Brief Summary

Data availability is moderate to high for raceways/ponds. The industry reflects the fact that best management practices are used across all aspects of operations to farm the majority of rainbow trout production in these systems. Disease, Escapes, and Chemical Use data scored poorly because of the lack of transparently available information from producers in some cases (Disease/Chemicals), and to the aggregation of production data that created uncertainty. One point of consistency was the availability of robust regulatory information governing the industry based on ecological principles. In some cases, the aggregated production data affected the ability to clearly resolve other criteria that relied upon weighting calculations. The final numerical score for Criterion 1—Data for raceways and ponds is 7.73 out of 10.

Data availability scored highly for net pens, because this system is represented by a single operator with commendable transparency, as well as best management practices across all aspects of the operation. In several scores, the data transparency of the operation allowed higher scoring because of robust data availability from which to base the decision. Some uncertainty in Feed (due to the proprietary nature of feed formulations to feed mills) and Disease negatively affected the Data scoring for this criterion. The final numerical score for Criterion 1—Data for net pens is 8.86 out of 10.

Justification of Rating

Production

Industry-wide production data are readily available from reliable government sources (USDA, NOAA), but in some cases, aggregation of data diminishes their usability. For example, there is no granularity about volumes grown by different production methods (raceway, net pen, RAS) or a distinction between species of trout. Production data are available by state, but in some cases, individual state production volumes are withheld for confidentiality, which creates data gaps. Data quality and availability for industry and production statistics scores 7.5 out of 10 because data are considered reliable and current, with minor gaps.

Management

Data to describe the regulations and management of trout aquaculture are readily available from relevant government sources, both federal and state. The details of effluent management measures vary in comprehensiveness by state, but are generally specific to the production systems being used and the capacities of the receiving waters. General trout aquaculture National Pollution Discharge Elimination System (NPDES) permits are readily accessed for the two largest trout production states, Idaho and North Carolina, and describe specific farm-level management and reporting requirements. Effluent reporting data and farm compliance are readily accessed on a government database (EPA's Enforcement and Compliance History Online [ECHO]), and penalties and fines for mismanagement are published; however, not all data that are required to be reported by farms are publicly accessible (e.g., chemical usage). Some data gaps were filled by speaking directly with producers. Management data quality and availability scores 10 out of 10 because it is reliable and current in all cases for the states representing the systems analyzed in the report.

Effluent

Effluent regulatory control is stringent, and enforcement is strict, with a comprehensive and publicly available permitting program through the NPDES. High-quality information regarding effluent discharge is available from Discharge Monitoring Reports (DMR) that are required as part of NPDES compliance. These periodic reports include data on chemical and biological discharge on an individual farm level and can be accessed via the ECHO Water Pollution Search data registry system (USEPA 2022a). Through ECHO, empirical monitoring data are downloadable and fully transparent to the public, and noncompliance or exceedance values are flagged. The registry can be searched by watershed, pollutant, industry (including descriptors specifically for aquaculture), and/or by using individual facilities by name. General NPDES Permits for Upper Snake River aquaculture facilities provide specific, publicly available, numerical limitations on discharge of total phosphorus (TP) and total suspended solids (TSS) for every existing aquaculture operation (with seasonal limitations placed where appropriate), based on the Total Maximum Daily Loads (TMDL) allowances for the ecological carrying capacity of the water system. The discharge limits used for compliance and enforcement are based upon the EPA's Effluent Guidelines for Concentrated Aquatic Animal Production (CAAP), which took effect in 2004 and cover U.S. aquaculture operations using flow-through, recirculating, or net pen systems (all U.S. trout aquaculture production methods) that produce more than 45 mt/year (CFR Title 40, Chapter 1, Subchapter N, Part 451).

The impacts of aquaculture effluent are difficult to determine separately from historical watershed degradation and the combined effects with other industries. But, data to determine the impairment of receiving waters where trout farming occurs in the U.S. are readily available to guide regulatory control and the necessity for remediation action. Surface waters receiving aquaculture effluents are assessed in transparent government data via the EPA's Assessment, Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS), which aggregates data reporting required by the Clean Water Act and provides a determination of the biological impairment as well as whether the waters require action to remediate. A score of 10 out of 10 for data quality is given for Effluent.

Habitat

Broad, aquaculture-specific legislation regulates the ecologically appropriate siting, construction, and discharge of aquaculture operations into habitats. The documentation for permitting and approval of aquaculture farm operations is transparent and readily accessible. Enforcement penalties exist, and there are public records for violations available from the government. Habitat data are lacking where production statistics have been aggregated in government reporting, which obscures which states are experiencing expansion, and thus the specific habitats potentially being affected. Because of aggregation of the data in the USDA Trout Survey "Other" category, it is not possible to tell what states were responsible for the large contribution to production during 2017–20, and thus the related habitat that may be affected. Because of this lack of information, a score of 7.5 out of 10 for data quality is given to Habitat.

Chemicals
Government processes control the licensing, approval, and appropriate label uses of chemicals in the U.S. Publicly available lists of approved animal drugs for aquaculture are available from the FDA, and of other agricultural chemicals from the EPA. Impacts of chemical discharge from semi-open and open systems are somewhat understood, and reliable government analyses related to all FDA-approved aquaculture chemicals have resulted in Findings of No Significant Impact (FONSIs), with transparent information relating to impacts. There is regular use of a deferred regulatory status chemical that has not been assessed by the FDA, so there is less confidence in the potential impact. Antibiotics are discharged, but use data are not made public. Some antibiotic use data were available upon request from producers. Questions or uncertainties remain in key information relating to the fate of antibiotics in the environment. A score of 5 out of 10 for data quality is given to Chemicals.

Feed
Exact feed composition data are closely guarded by feed companies, so there is uncertainty in the exact inclusion percentages used in the feed analysis. Two feed producers provided composition information with ranges for each ingredient, which was essential to inform the scoring in this category. More composition information would increase the confidence that the formulation evaluated in this report is representative of the majority of trout feed manufacturers. Information about the sources and stock used for fishmeal and fish oil in rainbow trout feeds was available from ASC certification reports associated with one large producer (public information—ASC, 2022). Two feed producers confirmed the source and stock of the fishmeal and fish oil used in their diets by direct communication. Estimated eFCR data were provided by reliable contacts, though not by farms themselves. A score of 7.5 out of 10 for data quality is given to Feed.

Escapes
There are no provisions for reporting escapes in either the Idaho or North Carolina General Permits. There are no published papers on total escapes of farmed rainbow trout in the U.S., despite the risk of flooding and loss of fish. Losses due to flooding (a form of escape) is a specific classification on USDA annual government reporting from rainbow trout farms; however, all size classes of fish are aggregated, which limits the usefulness of the data. Though the availability and thoroughness of escape data are limited, it is imperative to consider that the release of essentially genetically identical fish is happening on a routine basis in waters throughout North America, and the world, via restocking and fishery enhancement programs. Thus, there is little incentive for monitoring escapes when fish have been intentionally introduced to nonnative ranges for hundreds of years. A score of 7.5 out of 10 for data quality is given to Escapes.

Disease
Estimates of disease occurrence and mortality on rainbow trout farms are from peer-reviewed research, government reports, and personal communications with experts. These are considered reasonably robust; however, the reported losses in government data are not pathogen-specific, and disease occurrence on grow-out sites and hatcheries is aggregated,

which causes a loss of relevant information. Information regarding pathogen type, transmission, and treatment is well documented, though lacking in terms of established evidence (or lack thereof) of transmission to wild populations and the associated impacts. Operators were generally willing to provide the names of pathogens, but not specific information related to morbidity and mortality rates from each pathogen, which left gaps in understanding that can only be somewhat addressed from the literature. The U.S. Fish & Wildlife Service National Wild Fish Health Survey Database provides some data on pathogen occurrence in wild fish in waters throughout the country, but does not fill the data gap of transmission from farm to wild or vice versa. US FWS opportunistically samples disease presence in wild salmonids, but sampling bias is present, which limits the usefulness of the data. There is no comprehensive testing program to monitor disease transfer from wild-farmed fish or vice versa. US FWS samples fish on a sporadic basis to answer management questions, which leaves an incomplete and biased data set for the purposes of this assessment that cannot be used for any discussion of disease intensity or distribution. Information regarding biosecurity management measures is robust and well documented. A score of 5 out of 10 for data quality is given to Disease.

Source of Stock

Reliable data sources confirmed the source of stock used across the U.S. trout industry is all from broodstock programs and not from the wild. A score of 10 out of 10 is given for data quality for Source of Stock.

Wildlife Mortalities

Reliable data sources were available in the form of industry experts and producers to verify wildlife deterrence methods and the general use of nonlethal control methods. Robust population data and statuses are available on all species that are likely to interact with farms. Lastly, regulations at the state and federal levels are strict, often specific to agriculture/aquaculture facilities, and restrict the use of lethal methods to only those approved by permit (a significant change from last reporting). Because there is no public database on the issuance or use of legally approved wildlife take permits related to raceway and pond aquaculture, minor gaps exist in understanding how often this process is used by operators, though it is considered minimal based on information provided by industry contacts. A score of 7.5 out of 10 is given for data quality for Wildlife Mortalities.

Escape of Secondary Species

Estimations of trans-water body egg transport were available from industry contacts in Idaho and North Carolina. There is some inherent uncertainty in estimating an entire state’s seed stock origin, which is reflected in the scoring of this category. In addition, a condition of 99% trans-water body shipments had to be made about the origin of seed stock for raceways and ponds in Washington due to the aggregated industry production data (which are not provided for Washington to protect individual operators). It could not be treated separately from other states in the estimation of trans-water body shipments, because the calculation depended on having a value for total production that was unavailable—even though it is likely that a larger proportion of seed stock is available without significant transport because of proximity to genetics companies in the state. A score of 7.5 out of 10 for data quality is given to Introduction of Secondary Species.

Conclusions and final score

Overall, data availability was good for raceways/ponds. Disease, Escapes, and Chemical Use data scored poorly because of the lack of transparently available information from producers in some cases (Disease/Chemicals), and to the aggregation of production data that created uncertainty. One point of consistency was the availability of robust regulatory information governing the industry, based on ecological principles. In some cases, the aggregated production data affected the ability to clearly resolve other criteria that relied upon weighting calculations. The final numerical score for Criterion 1—Data for raceways and ponds is 7.727 out of 10.

Data Scores (Net Pens, where different from above)

Production

Same as raceways and ponds, above.

Effluent

Transparently available regulatory documents for the relevant agencies governing discharge are the same as in raceways/ponds. Discharge requirements for the specific net pen sites evaluated are readily available in the permitting documents for the operation. Routine data collection requirements are in place for water quality samples, and process documents provided by the operation demonstrate that their internal collection methods meet the Federal and Tribal effluent monitoring requirements. Raw monitoring data (over the years 2015–19) were publicly available as part of the permit renewal process, which showed robust triplicate data collection for each measurement date and demonstrated adherence to the regulations. Overall, the data is up to date within reason, complete, and collected using appropriate and transparent methods. A score of 10 out of 10 for data quality is given to Effluent.

Habitat

There is a comprehensive understanding of the water body that the net pens are sited in, based upon publicly available reports that detail the columnar flow characteristics around the pens, and the benthic environment and ecosystem at the net pen locations and downstream of the sites. These are available from either government agencies (Army Corps of Engineers [ACOE]) or funded by Tribal authorities related to permitting the net pen operation and the expansion of new sites. The hydrological interests in the waterway (dam operations) also have public resources available to understand the habitat of the reservoir the pens are sited in. Because it is a single operator, the data available provide confidence that the entirety of freshwater net pen culture of rainbow trout in the U.S. is accurately represented. A score of 10 out of 10 for data quality is given to Habitat.

Chemical Use
The strict regulations and control measures for chemicals are identical to those in raceways and ponds, with one additional layer of regulatory control at the net pen site by the Tribe. The producer was able to openly share high-quality chemical use data representative of the system. There is a demonstrably low need for chemical application in grow-out, and the only chemicals of potential concern are antibiotics, which are only used in limited quantities. The producer transparently provided comprehensive antibiotic usage data (type and size of medicated feeds administered, labelled by cohort reference numbers) for all pens harvested in 2022, for the purposes of calculating frequency data that were essential to scoring. The environmental fate of antibiotics in the waterway is the only key uncertainty, because the degradation processes and the adsorption and transport of antibiotics with feces and other organic matter has not been studied in situ. A conservative approach had to be taken to scoring because of this gap in knowledge. A score of 7.5 out of 10 for data quality is given to Chemical Use.

Feed
Composition data are the same as for raceways and ponds. eFCR data were transparently available from the operator, thus removing uncertainty in this value that exists with raceways and ponds. A score of 7.5 out of 10 for data quality is given to Feed.

Escapes
Complete and up-to-date information regarding escapes was available from the farm. A robust prevention plan was shared that demonstrates a comprehensive understanding of mitigating the risk of escapes specific to the net pen construction and the environment the pens are sited in. Protocols are in place in the event of an escape in the future, and they include cooperative procedures with the Tribe to recover any escapees. The information provided by the farm addressed all questions relevant to the assessment. The location of the farm is within an impounded reservoir waterway between two dams, which provides a greater understanding of the potential risk of escapes than systems with greater connectedness to other rivers or water bodies. A score of 10 out of 10 for data quality is given to Escapes.

Disease
Disease prevention protocols, as well as routine monitoring methods, were readily available from the operator. Data were shared about the types of disease common to the farm, and morbidity and mortality data were available as an annual aggregation of all types of disease. There are robust records of wild salmonid disease presence/absence in the waterway from U.S. Fish and Wildlife and Tribal sources, which demonstrate with confidence that all disease affecting the culture fish is present in the wild, and that disease likely transfers from wild to farmed fish when they enter the net pens. Although there is considerable information available from reliable sources, it does not provide the resolution necessary to use an evidence-based assessment (e.g., no data to resolve whether pathogens or parasite numbers on wild species are amplified above background levels, or the morbidity rates of wild species due to wild-origin pathogens or parasites). As a result, a score of 5 out of 10 for data quality is given to Disease.

Source of Stock
Same as for raceways and ponds.

Wildlife Mortalities
Information that confirmed no wildlife mortalities and no use of lethal action to deter wildlife was available from the operator. In addition, best management practices for the complete coverage of the systems in bird netting for nonlethal avian control are in place, as well as protocols for storing feed to minimize wildlife interactions. A score of 10 out of 10 for data quality is given to Wildlife Mortalities.

Introduction of Secondary Species
Complete information was available from the operator about the origin locations of eggs used at the farm site. No averaging or aggregation obscures the data. A score of 10 out of 10 for data quality is given to Introduction of Secondary Species.

Conclusion and Final Score
Overall, data availability was quite good for net pens, because this system is represented by a single operator with commendable transparency, as well as best management practices across all aspects of the operation. In several scores, the data transparency of the operation allowed higher scoring because of robust data availability with which to base the decision. Some uncertainty in Feed (due to the proprietary nature of feed formulations to feed mills) and Disease negatively affected the Data scoring for this criterion. The final numerical score for Criterion 1—Data for net pens is 8.864 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

Raceways and Ponds

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)	**7**	**Green**

Net Pens

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)	**7**	**Green**

Brief Summary

Raceways and Ponds

Raceways and ponds are represented by Idaho and North Carolina, which together make up 64% of the national production volume, and the majority (≈75%) of trout farmed in these systems. Both states have robust regulatory frameworks for setting water quality standards, issuing permits, government monitoring programs, and enforcement. The aquaculture industry has been quite successful in reducing nutrient discharge through changing feed formulations and modifying management practices. Aquaculture has outperformed the regulatory limits to nutrient loading and authorities are working to ensure that TMDLs remain appropriate for receiving waters. The TMDL system is a cumulative management framework based on biological loading capacity of the receiving waterway from contributions of all impacting industries. Monitoring and enforcement of point source discharges are in place through the NPDES permitting framework, to maintain the biological limits for the waterway set in the TMDLs. State agencies in both Idaho and North Carolina have the primary authority for enforcing the NPDES framework in each state (IPDES and NCPDES). Waste load allocations approved by the EPA for TSS and phosphorus for fish production facilities, conservation hatcheries, and fish processors in the region of the Middle Snake River have been in place for approximately two decades. The industry complies with extensive water quality testing to meet NPDES monitoring requirements, and results are available to the public via the ECHO database. State water quality standards are based on ecological factors (such as aquatic habitat and biological parameters in each water body) through a comprehensive monitoring and assessment process and are reviewed every 3 years (IDEQ, 2022a). This is a robust and ecologically appropriate system to monitor degradation of the water body. Both states have farms that show rare industry exceedance of water quality standards, and such incidents are temporary and resolved promptly. But, recent reviews have indicated that the current waste load allocations in Idaho (for all industries, including aquaculture) may be too high, because the Snake River has failed to meet water quality targets, and impacts persist. At this time, a precautionary approach is taken to scoring in the absence of clarifying data from the IDEQ TMDL revision process, and given the potential for cumulative impacts at the water body or regional scale. A final intermediate score of 7 out of 10 for the evidence-based assessment is given to raceways and ponds.

Effluent regulation for net pens is comprehensive and based on ecological principles. The primary parameters reported for NPDES permitting purposes are DO and turbidity, which are measured on a sliding scale of an allowable discharge limit above background levels (which shift due to the river system having fluctuating DO and turbidity from seasonal flow conditions and dam operations). Water-quality data analysis is performed by a third-party laboratory to meet Tribal effluent data monitoring requirements for the parameters of dissolved gas, TGP, pH, turbidity, temperature, total P, ortho P, nitrite and nitrate, ammonia (as nitrogen), total nitrogen, TDS, and oil and grease. The Tribal water quality standards are readily available online, and the monitoring procedures are more than adequate to capture any changes to the beneficial uses of the water body. The pens are in an area of high current (≈40–70 cm/s) with rare periods of low current observed. Extensive benthic mapping and current modeling have been done in the reservoir, and they support the evaluation that waste from the pens is being effectively transported and is not likely to build up underneath the pens. A probable pathway of assimilation of wastes into the food web has been demonstrated via isotopic analysis. Based on the monitoring data available in the permit renewal documents, the operation is meeting the discharge limits set in its permit requirements, and any impacts within the immediate vicinity are temporary. But, uncertainty remains about the cumulative impact potential of aquaculture in addition to all other nutrient inputs (point source and nonpoint source) at the water body scale. A final intermediate score of 7 out of 10 for the evidence-based assessment is given to net pens.

Justification of Rating

Evidence-based assessment

Because the effluent data quality and availability are good (i.e., Criterion 1 score of 7.5 or 10 of 10 for the effluent category), the evidence-based assessment was used. The discharge of effluents containing particulate and dissolved wastes remains one of the most persistent environmental concerns associated with aquaculture worldwide, especially for salmonid species reared in freshwater environments, such as rainbow trout (Bureau and Hua 2010)(Tello et al. 2010).

The nutrients ultimately contained in the effluent first enter the water as aquafeeds. As they pass through the aquaculture system, they can be divided into three fractions: the first fraction is those nutrients that are digested and retained in the body of the fish; the second fraction is passed through the body of the fish and released as solid and dissolved wastes; and the final fraction is in uneaten feed [typically about 5% or less; see (Aubin et al. 2011)(Hinshaw and Fornshell 2002)]. It is the last two fractions (wastes and uneaten feed) that flow into downstream environments as effluent if they are not captured and removed.

Nutrient-rich effluents can affect the receiving ecosystem because they are a source of nutrients that may otherwise be limiting (nitrogen in seawater and phosphorus in freshwater) or may be discharged at a rate that does not allow for adequate assimilation, and can lead to increases in phytoplankton growth, biological oxygen demand, and total suspended solids (Tucker et al. 2008a). If discharges are inappropriate for the receiving waters, the consequences of these changes may alter the structure and function of downstream ecosystems by contributing to eutrophication, hypoxia, changes in species composition, water turbidity, the accumulation of sediments on the benthos, and direct toxic effects (Sindilariu 2007).

Flow-through trout farm effluents are typically high volumes of dilute dissolved and particulate wastes. The total production and composition of waste within a trout farm system will vary, depending on major variables such as stocking density and feed choice. Some of the measurable waste variables at trout farms are total suspended solids (TSS), nitrogen in the forms of particulate, ammonia, and urea, and phosphorus in the forms of particulate and orthophosphate (Roque d'Orbcastel et al. 2008). Particulate wastes are typically managed by settling (in quiescent zones at the bottom of raceways, and in settling ponds), whereas nonparticulate (i.e., dissolved) wastes can be managed through treatment or, to an extent, feed composition (e.g., low-phosphorus trout diets). The particulate (i.e., solid) wastes, which may include 30–84% of total phosphorus and 7–32% of total nitrogen wastes, can be partly captured and removed before discharging the effluent from aquaculture facilities (Sindilariu 2007)(True et al. 2004). This is commonly done by solids filtration.

Solids filtration is used to ensure compliance with federal and state laws that govern effluent discharges and protect water quality. This is done using various technologies, including microscreens, separators, flocculation, mobile screen (e.g., drum, belt) filters, and media (e.g., sand, bead) filters (Fornshell and Hinshaw 2008)(Sindilariu 2007). Because of the higher economic cost of many of these technologies, the most common treatment used at rainbow trout farms in the U.S. is sedimentation of solids in a settling basin downstream of production raceways or ponds (Engle et al. 2005)(Fornshell and Hinshaw 2008) (Hinshaw and Fornshell 2002). Some smaller production systems often employ filtration alongside sedimentation, but the majority of operations (approximately 95%) use sedimentation only (pers. comm., Dr. Jacob Bledsoe February 2023). All farms in North Carolina are using gravitational settling in ponds, with some facilities using a vacuum system to remove and compost solids for an additional farm income stream (pers. comm., Jeff Hinshaw October 2022). Some farms in Idaho are also using vacuum systems (pers. comm., Tasha Owens, IDEQ 2023). The percentage of settleable solids removed by settling basins can vary based on construction (e.g., baffling, shape, substrate), and efficacy can be managed through factors such as the overflow rate to improve settling efficiency (Wong and Piedrahita 2000). Farms with raceway construction may also employ quiescent zones (areas for settling of solids in the downstream portion of each raceway tank) to reduce waste before reaching the farm's settling ponds; however, this is not economically feasible for all farm locations (Engle et al. 2005). As of the current reporting, quiescent zones are being used in the great majority, if not all, raceways in Idaho (pers. comm., Dr. Jacob Bledsoe February 2023) and over 90% of farms in North Carolina (pers. comm., Jeff Hinshaw February 2023).

The settling properties of solid waste are directly related to fecal density (Unger and Brinker 2013), which can be manipulated via feed composition. In addition, manufacturing technology can increase the water stability of feed pellets and reduce the loss of solids from feed into the culture water, and thus reduce the potential for unrecoverable feed waste to be discharged in effluent water (Welker et al. 2018). Extruded pellets reduce the unrecoverable feed waste, compared to expansion-compression pellets that quickly break down in the water column, and the use of extruded floating and semifloating pellets is standard practice in U.S. trout aquaculture (pers. comm., Jeff Hinshaw October 2022)(pers. comm., Dr. Jacob Bledsoe November 2022).

Context for Setting and Enforcing Allowable Impacts for Trout Aquaculture

In the U.S., point-source effluent discharge from aquaculture operations is regulated at the federal level by the Environmental Protection Agency (EPA), using the Clean Water Act (CWA). The CWA mandates that a state designate specific uses of its water bodies, such as aquatic life, fishing, and swimming, and assign site-specific water quality standards that will maintain those uses (CWA Section 303). If the water quality of a given water body is not meeting quality standards, the water body must be designated as "water quality limited," and specific total maximum daily loads (TMDL) are put in place to restore water quality to a level that achieves state water quality standards (CWA Section 303(d)). TMDLs are calculated by summing the waste load allocations (WLAs) for point-source discharges with load allocations for nonpoint-source discharges, and then adding a margin of safety. By setting a TMDL, the overseeing agency is defining the maximum amount of a pollutant that a water body can receive, such as nitrogen or phosphorus, without exceeding the state water quality standard for the pollutant (USEPA 2021). Individual waste load allocations are assigned to each major water-using industry discharging into a given impaired-status water body, and these specify exactly how much of each pollutant is permissible to be discharged within a margin of safety to maintain the status of the impaired waterway. The specific agency or government department responsible for regulating and enforcing TMDLs varies by state. In Idaho, for example, regulation is carried out by the Idaho Department of Environmental Quality's Water Quality Division, and all aquaculture development must conform to the TMDL limits that are in place (IDEQ 2022a).

The EPA enforces aquaculture discharges via permitting through the National Pollutant Discharge Elimination System (NPDES) (CWA Section 402), of which Concentrated Aquatic Animal Production Facilities (CAAP) have specific regulations. Trout farms that discharge water more than 30 days per year must have an NPDES permit, unless they produce less than 9,090 kg of trout per year and use less than 2,272 kg of feed per month (USEPA 2022b). These permits regulate discharges with either technology-based (TBEL) or water quality-based (WQBEL) effluent limitations, which are required where TMDLs are in place. TBELs require a "minimum level of treatment of pollutants for point source discharges based on available treatment technologies," such as filters, whereas WQBELs are set based on the water quality standards of the receiving water and are often included in NPDES permits when TMDLs are not in place, as is the case in North Carolina (USEPA 2022c). It must be noted that state-specific variations exist with stricter standards, because NPDES permits are written state by state; for example, Idaho has stricter standards than West Virginia (Viadero et al. 2005). Compliance with discharge permitting is ubiquitous in the industry, and may also include further regulations, such as requirements for best management practice plans for discharge along with the permit, as are in place in North Carolina (pers. comm., Jeff Hinshaw October 2022) and Idaho.

Compliance with these regulations must occur throughout production, including times of peak biomass (pers. comm., Gary Fornshell March 2013). The EPA actively enforces effluent restrictions in cooperation with various state-level departments. In instances where farms are in violation of their NPDES permit, they are first subject to an informal "Notice of Violation," which provides instruction for coming into compliance before any penalties are put in place (Boyd et al., 2008). Enforcement may vary by state; in Idaho, IDEQ begins permit violation responses with informal enforcement that does not include a Notice of Violation as a first step (IDEQ 2020). Penalties have been and are implemented, and these can be quite severe; the EPA has the authority to administer civil penalties of up to $27,500 per day per violation (CWA Section 309(d)). Information on infractions and penalties is readily available through the Enforcement and Compliance History Online (ECHO) database (USEPA 2022a). Because of the gravity of the potential penalties, compliance with NPDES permits is almost 100%; the last trout food-fish farm CWA violation was in 2010, when a producer in Idaho was assessed and paid a fine of $98,002 for NPDES permit violations (USEPA 2022d). Two trout farms in North Carolina received corrective action after failing to reapply for permits within the 180-day window before expiration of their current NPDES permits (no fine issued). Further evidence of regulation compliance in U.S. trout farming is the recognized burden of regulatory costs in trout food-fish farm economics (Engle et al. 2019).

Snake River, Idaho

Idaho, the largest producer state, is responsible for approximately 56% of national trout production (USDA 2023), 98% of which is concentrated in the counties of Twin Falls, Gooding, and Jerome, with the highest density (70 farms) in Magic Valley (Engle et al. 2021). Generally, Idaho trout farms use spring water or (less commonly) surface water in single-pass flow-through raceways. The intake/receiving watershed of farms in the Magic Valley is the Middle Snake River Basin. The majority (>90%) of trout farming occurs along a 92-mile stretch of the Snake River from Milner Dam to King Hill, known as the Upper Snake Rock/Middle Snake River (pers. comm., Gary Fornshell June 2016).

The EPA currently lists the reaches of Snake River (Twin Falls to Rock Creek) and Rock Creek [river mile 25 (T11S, R18E, Sec. 36) to mouth] as impaired to cold-water aquatic life (CWAL) on the Watershed Assessment, Tracking & Environmental Results System (WATERS) database; with the reach of Rock Creek being additionally impaired to salmonid spawning (because of flow regime modification, temperature, and TSS) and secondary contact recreation (because of fecal coliform), of which aquaculture may be associated with TSS (USEPA 2022e). CWAL assessments are conducted using a standardized regimen that includes the presence of indicator macroinvertebrate species, fish assemblages, and the seasonal presence of bull trout (IDEQ 2016); but, note that bull trout are not present in the Middle Snake River, where the majority of trout production takes place in Idaho (pers. comm., Tasha Owens IDEQ 2023).

The segment of the Snake River that supports most of the state's trout production has been considered "water-quality limited," and TMDLs were written for total phosphorus (TP) and total suspended solids (TSS), covered together under two Watershed Management Plans (WMPs): the Middle Snake River WMP in 1998 (IDEQ 1998) and the Upper Snake Rock WMP in 1999 (IDEQ 1999). A TMDL was not written for nitrogen because data did not show that nitrogen was exceeding water quality standards or affecting beneficial uses, though data are under continuous review by the Idaho DEQ (IDEQ 2022b). The goal of the 1998 WMP is "to improve water quality in the Middle Snake River by reducing pollution loadings from all sources including tributaries and agricultural returns, so as to restore the beneficial uses" over the course of 10 years (IDEQ, 1998). The Snake River receives pollution from a number of industries in addition to aquaculture, including irrigated crop production, rangeland, animal holding areas and feedlots, hydropower, and urban runoff (IDEQ 2022b). Reduction targets for TP and TSS were set to achieve instream water quality goals (which were linked to the attainment of state water quality standards for support of cold-water biota such as native trout) by year 10. This year 10 monitoring report was provided by IDEQ in 2010 (IDEQ 2010). Temperature and ammonia are potentially going to be reviewed for TMDL approval by the EPA in the future, which may apply to specific reaches of the watershed, as necessary (IDEQ 2022b).

Preliminary aquaculture waste load allocations (WLAs) for TP and TSS were set in 1999 for the 13 largest facilities and were required to be re-evaluated and set after 3 years for all facilities; the preliminary WLA for the aquaculture industry required a 40% reduction from measured 1991 TP loadings (IDEQ 1998). Data were collected and reviewed over 3 years, and overall WLAs were subsequently modified to include aquaculture WLAs, set to the 40% reduction, in 2004–05 (IDEQ 2022a). The last available 5-year review, conducted in 2010, in conjunction with discharge monitoring report (DMR) data provided by industry and considered in the previous SFW assessment, revealed that the aquaculture industry reduced TP loadings by 62% relative to 1991 levels, thus exceeding their required reduction levels and discharging less TP than maximally allowed by NPDES permits (IDEQ 2010). Aquaculture was allocated 987.9 lb/day TP out of a total 7,464.3 lb/day (13.2%), yet only contributed 616.7 lb/day, which was 8.26% of the total TP loading (including all other industries and nonpoint sources) into the Snake River (IDEQ 2010)(aggregated DMR data, unpublished). There is publicly available discharge information transparently published on the EPA ECHO database, which states the permit limits and average monthly measurements for each individual operation.

The last available IDEQ analysis from 2010 demonstrated that the aquaculture industry was performing well within its allocations at that time. But, a full revision of the TMDLs in the

Middle Snake River was initiated following that 5-year review, because of the failure of the Middle Snake River to meet TMDL targets, and recognition that the TMDLs were initially set based on a streamflow assumption 1.5–3 times greater than actual flows measured in the river (pers. comm., IDEQ September 2022). The streamflow assumption error caused the loads being allowed in the river to exceed the apparent carrying capacity for the system. To correct this, the EPA and IDEQ are, as of February 2023, working through the science, modeling, and watershed advisory input, along with coordinating a 30-year historical streamflow assessment, to serve as the basis of new TMDLs that will be set for the Middle Snake River. The TMDL revision process may have repercussions for industry WLAs (i.e., lowering of allowable discharge concentrations). The exact reductions that will be made are not yet known. This has been a highly contentious process, which has now extended for over 10 years and is expected to be ongoing until at least December 2023 (pers. comm., IDEQ September 2022). Thus, despite the successful efforts made by the aquaculture industry to lower discharge of TP and TSS, and the industry outperforming the required effluent limitations as of the last 5-year report, at this time there is no updated IDEQ dataset to assess whether aquaculture effluent discharges differ significantly than in the last report from 2010. The relevant authorities are actively working to ensure that the TMDLs remain appropriate for the receiving waters, and the present assessment will be made on the existing TMDLs and regulations in place.

In lieu of a more up-to-date IDEQ report, there is little other current information available to assess the cumulative impacts of phosphorus and TSS contributions of aquaculture relative to WLAs. The phosphorus contribution of aquaculture is not possible to determine in relation to the other industries that are involved in the phosphorus budget for the Middle Snake River. Contributing variables to the phosphorus vulnerability of the Magic Valley of Snake River are: manure and synthetic fertilizer application, crop types, septic systems, hydroelectric dams, food processors, aquaculture, confined animal feeding operations, accumulation and waste holding capacity of the system, and hydric soil (a sink, not a source) (Martinez, 2021). The colocation of nonpoint-source contributors with aquaculture makes it challenging to determine the individual impact of phosphorus loading from any one industry, and the same challenge exists with TSS.

Trout aquaculture facilities covered by the Idaho General NPDES permit (USEPA 2019) must implement best management practices that are consistent with federal and state legislation within 90 days of being authorized to discharge [Pollution Prevention Act of 1990, 42 U.S.C. § 13101, and Effluent Limitations Guidelines for Concentrated Aquatic Animal Production Point Source Category 69 Federal Register 51892-51930 (August 23, 2004), and 40 CFR §122.44(k)]. This is a requirement to minimize pollutants at the source before treating or discharge, including typical practices such as regular quiescent zone cleaning, attention to the application of feed to reduce wastage, and prompt removal and disposal of dead fish.

An area-based industry management initiative is in place that includes multiple industries that discharge water in Southern Idaho (SIWQC 2022). The Southern Idaho Water Quality Coalition brings together stakeholders from a variety of industries that discharge into the watershed and conducts projects to proactively improve water quality. Their mission is:

“The Southern Idaho Water Quality Coalition (SIWQC) strives to bring about water quality improvement to the Middle Snake River through collaboration with a wide range of stakeholders. We recognize that water quality is a result of a variety of factors and to improve the quality of water in our local river, we must consider those factors and more. While education and awareness are critical to our success, we also take action by working to secure funding to support projects and studies that will inform decision-making and address point and non-point pollutant sources. We believe a watershed perspective is imperative to finding creative solutions that benefit the river and the communities it supports. In short, our mission is to proactively improve Middle Snake River water quality.” (SIWQC, 2022)

The NPDES reporting required from aquaculture operations (published to the general public on the ECHO data registry, search NAICS code 112511) includes effluent measurements of total suspended solids (TSS), temperature, phosphorus, pH, flow, ammonia (as N), total suspended solids removal (must be 90%), as well as hardness ($CaCO_3$) and copper in cases where an operation is using chelated copper compounds (which the trout industry does not use). Rainbow trout farms located on the Snake River have occasionally exceeded the regulatory limits for temporary periods. Commercial trout farms have temporarily exceeded allowances in the last 5 years, including two farms exceeding their phosphorus limits in 2017 and 2020, and one farm that twice exceeded TSS allowance in 2017 and 2018 (USEPA 2022d, search Idaho using NAICS code 112511). Exceedance of regulatory limits occurs in significantly less than 10% of the measurements within a year (thus, considered to be rare) and is not considered to have any lasting impact beyond the exceedance period.

North Carolina

In North Carolina, trout farming occurs in the western part of the state in the Appalachian Mountains region, primarily in two watersheds: the Little Tennessee River Basin (accounting for approximately two-thirds of the state’s production volume) and the French Broad River Basin. Freshwater ecosystems in the Southern Blue Ridge Ecoregion have been historically affected by polluted runoff from agriculture and silviculture (i.e., forestry), home building, road construction, and mining, as well as point-source pollution from industrial and municipal waste (TNC and SAFC 2000). Generally, North Carolina trout farms divert surface water to supply single-pass flow-through raceways, with the effluent returning to the source waterway after passing through settling ponds.

The Little Tennessee River Basin has a low amount of impaired stream reaches that are associated with wastewater treatment and high fecal coliform counts (NCDEQ 2018a). Overall, the Little Tennessee River Basin is considered to be in “relatively pristine condition” because of a high proportion of intact riparian forest buffer and protected land in the watershed, and macroinvertebrate study sites are generally rated “Excellent” (NCDEQ 2012). Within the watershed, only one active TMDL is in place, regarding low pH in a subsection within Great Smoky Mountains National Park that is unrelated to any aquaculture activities.

The French Broad River Basin is not considered water-quality limited with respect to nutrient levels by the EPA, so no TMDLs for nutrient-loading pollutants (particularly TSS and TP) are in place (USEPA 2016b). For example, normal ambient TP in the French Broad River averaged 0.063 mg/L, with reservoirs frequently measuring <0.02 mg/L, with neither TP nor TSS considered to be parameters of concern (pers. comm., Jeff Hinshaw July 2016)(NCDEQ 2022)(NCDEQ 2018b). TSS levels in the French Broad River averaged 29.8 mg/L over 2019–20 (NCDEQ 2022), with the requirement for trout farms under the general NPDES permit being a 60 mg/L daily maximum and 30 mg/L monthly average (NCDEQ 2021). In addition, the section of the French Broad River that flows through a North Carolina trout farming region has "Good" water quality to support both aquatic life and recreation, as measured and reported on the EPA's WATERS system (USEPA 2022e). Water quality is consistently monitored with monthly measurements in watersheds throughout the state via the Ambient Monitoring System (NCDEQ 2022).

All of the 33 trout farms actively operating in North Carolina are permitted through an NPDES general permit or individual permit administered by the North Carolina Department of Environmental Quality (DEQ). Individual permit holders are not covered by the general permit because they do not meet the general requirements (due to size or location) and receive individual permits to operate and discharge (pers. comm., Jeff Hinshaw July 2016). Specific effluent parameter maximums are stipulated in permitting conditions.

The content of the general permit includes water-quality-based effluent limitations for TSS, settleable solids (SS), and dissolved oxygen (DO); these limitations are not exclusive to aquaculture and are found in other industries' NPDES throughout the state (pers. comm., Jeff Hinshaw July 2016). These limits were set after long-term monitoring and data collection in the 1990s; they are protective of the water quality standards of the receiving waters and provide the NCDEQ with the regulatory authority to manage trout farm effluents, if the water quality of the receiving waters begins to degrade (USEPA 2016a)(pers. comm., Jeff Hinshaw July 2016). The general permit only sets specific maximums for TSS, but because of constant ambient watershed monitoring, management of state water quality standards is functional and complies with EPA regulation (pers. comm., Jeff Hinshaw July 2016). Quarterly monitoring is required for flow, temperature, pH, TSS, TAN, TP, DO, and turbidity, and a weekly visual observation is required for the receiving stream condition 100 ft downstream of the outflow (NCDEQ 2021).

Commercial rainbow trout farm water quality data provided for this assessment demonstrate that the use of settling ponds in North Carolina farms can remediate water quality parameters of TSS, inorganic N, nitrate, ammonia, and phosphorus to near (or in some cases, below) intake levels (Table 5) (pers. comm., Jeff Hinshaw November 2022). In two cases, a farm's effluent TSS value was reduced below the farm's water supply TSS intake value by the use of settling ponds—returning water of improved turbidity to the discharge body. The study was conducted over 2018–20 at four farms in North Carolina to inform best management practices. The farms were selected in consultation with the North Carolina Division of Environmental Quality and to provide examples of the waste treatment systems used on North Carolina trout farms. The farm sizes range from just over 90 mt (200,000 lb) annually to approximately 272 mt (600,000 lb) annually. This effort was focused on characterization of the farm effluent and did not attempt to measure the effects of dilution in the receiving stream or any other receiving stream characteristics (pers. comm., Jeff Hinshaw November 2022).

Table 5: Water quality parameter analysis at four rainbow trout farms in North Carolina (2018–20) demonstrating the net change with the use of various water treatment systems before discharge.

Farm	Sampling Location	Water Quality Parameters, as averages in mg/L					Description of Farm Discharge System
		TS	Inorganic N	Ammonia – N	Nitrate – N	Phosphorus	
1 (n = 8)	Head (inflow)	1.85	0.73	0.45	0.3	0.04	A vacuum system is used to remove solids from the quiescent zone of each raceway. Solids are allowed to settle in larger tanks. Excess water can be decanted. Solids are removed by auger and land applied. The full flow of the farm is discharged through an artificial wetland lined with 40 mm pond liner (series of five holding basins with a drop below each).
	Tail (bottom of all raceways)	2.27	1.25	0.97	0.29	0.15	
	Bottom (at point of discharge)	1.87	1.03	0.71	0.35	0.1	
	Average net change from inflow	**0.02**	**0.3**	**0.26**	**0.04**	**0.06**	
2 (n = 4)	Head (inflow)	1.35	1	0.66	0.35	0.06	Settling pond constructed below farm—takes full flow of farm before return to creek.
	Tail (bottom of all raceways)	2.2	1.18	0.84	0.34	0.12	
	Bottom (at point of discharge)	1.85	1.11	0.84	0.28	0.1	
	Average net change from inflow	**–0.5**	**0.11**	**0.18**	**–0.07**	**0.04**	
3 (n = 4)	Head (inflow)	4.95	0.57	0.4	0.18	0.05	Settling pond improvements made, including diverting road runoff from entering into the settling pond, which was causing short-circuiting.
	Tail (bottom of all raceways)	5.35	0.74	0.56	0.18	0.12	
	Bottom (at point of discharge)	4.75	0.88	0.68	0.2	0.11	
	Average net	**–0.2**	**0.31**	**0.29**	**0.02**	**0.07**	

	change from inflow						
4 (n = 4)	Head (inflow)	2.03	0.65	0.39	0.26	0.05	Vacuum system installed to remove solids from quiescent zone. Solids pumped to holding pond, then land applied on nearby pasture.
	Tail (bottom of all raceways)	2.35	0.69	0.52	0.18	0.07	
	Bottom (at point of discharge)	4.1	0.96	0.72	0.24	0.06	
	Average net change from inflow	**2.1**	**0.31**	**0.33**	**–0.02**	**0.01**	

Samples were all analyzed as 24-hr composite samples.
Farm 1 sample dates: 3/19/2018–12/16/2020 (n = 8)
Farm 2 sample dates: 8/28/2019–9/16/2020 (n = 4)
Farm 3 sample dates: 3/24/2020–12/18/2020 (n = 4)
Farm 4 sample dates: 3/10/2020–12/17/2020 (n = 4)

In addition, effluent best management practices in North Carolina farms may include vacuum systems in quiescent zones and settling ponds to collect waste solids for land or compost applications (pers. comm., Jeff Hinshaw November 2022), a practice that has an economic incentive from the additional income opportunity, which further demonstrates the processes to minimize effluent discharge in the state.

Enforcement of water quality standards is strict, although no monetary penalties have been applied. In at least one instance, a farm was issued a notice to develop a plan to reduce effluent loads after the macrobiotic community in the receiving water body began to indicate eutrophication (pers. comm., Jeff Hinshaw July 2016). Although official water quality standards were never exceeded, the farm complied and, combined with several other factors such as increased flow rates due to drought cessation, the ecological status of the receiving water body was restored (pers. comm., Jeff Hinshaw July 2016). In the past 5 years, only one exceedance of allowable discharge limits occurred ,which was a single trout farm that temporarily exceeded TSS allowance in 2020 (see USEPA 2022d, search North Carolina using NAICS code 112511). Thus, exceedance has occurred in only one rare case, but the impacts to the receiving waters are temporary and are resolved promptly.

Conclusions and Final Score (Raceways and Ponds)

Raceways and ponds are represented by Idaho and North Carolina, which together make up 64% of the national production volume, and the majority (≈75%) of trout farmed in these systems. Both states have robust regulatory frameworks for setting water quality standards, issuing permits, government monitoring programs, and enforcement. The aquaculture industry has been quite successful in reducing nutrient discharge through changing feed formulations and modifying management practices. Aquaculture has outperformed the regulatory limits to nutrient loading, and authorities are working to ensure that TMDLs remain appropriate for receiving waters. The TMDL system is a cumulative management framework based on biological loading capacity of the receiving waterway from contributions of all affecting industries. Monitoring and enforcement of point-source discharges are in place through the NPDES permitting framework, to maintain the biological limits for the waterway set in the TMDLs. State agencies in both Idaho and North Carolina have the primary authority for enforcing the NPDES framework in each state (IPDES and NCPDES). Waste load allocations approved by the US EPA for TSS and phosphorus for fish production facilities, conservation hatcheries, and fish processors in the region of the Middle Snake River have been in place for approximately two decades. The industry complies with extensive water quality testing to meet NPDES monitoring requirements, and results are available to the public via the ECHO database. State water quality standards are based on ecological factors (such as aquatic habitat and biological parameters in each water body) through a comprehensive monitoring and assessment process and are reviewed every 3 years (IDEQ, 2022a). This is a robust and ecologically appropriate system to monitor degradation of the water body. Both states have farms that show rare industry exceedance of water quality standards; these have been temporary and resolved promptly. But, recent reviews have indicated that the current waste load allocations in Idaho (for all industries, including aquaculture) may be too high, because the Snake River has failed to meet water quality targets and impacts persist. At this time, a precautionary approach is taken to scoring in the absence of clarifying data from the IDEQ TMDL revision process, given the potential for cumulative impacts at the water body or regional scale. A final intermediate score of 7 out of 10 for the evidence-based assessment is given to raceways and ponds.

Net Pens

Evidence-based assessment
Because the effluent data quality and availability are good (i.e., Criterion 1 score of 7.5 or 10 of 10 for the Effluent category), the evidence-based assessment was used. This section includes the same basic properties of trout effluent covered under raceways and ponds, above.

The net pens are grouped into three sites within in an impounded waterway (dams at both upstream and downstream ends) and all sites have high average current speeds, though there are times of seasonal low current. The water body is officially classified as a lake, with a surface area of 34 km^2, length of 82 km, and gross storage volume of 728 million cubic meters (USGS/UCUT 2017) (ACOE 2009). The high flow is characterized by an average water retention time in the lake of only 2.5 to 5 days on average—individual estimates from three sources were 2.5, 3, and <5 days (Rensel 2010)(ACOE 2009)(UCUT 2019). The average flow rate through Farm Sites 1 and 3 averages ≈40–70 cm/s (Rensel and Siegrist 2011)(Rensel 2010)(UCUT 2019).

The net pen operation facilities are located on tribal land and waters of the Confederated Tribes of the Colville Reservation (CTCR), which act as a state within their boundaries. Thus, the CTCR's environmental rules and regulations apply to all effluent discharge activities, including aquaculture. Discharge permitting is evaluated by the EPA NPDES permitting process under the Clean Water Act (CWA § 401, 33 U.S.C. § 1341) and the EPA recommends permits to be certified by CTCR. Water quality monitoring requirements are in place to provide data to satisfy both Tribal and NPDES permit reporting.

The current NPDES regulations for the site set limits for DO and turbidity (Figure 2). Specific monitoring requirements are listed in the permit documents (Figure 3) and provide confidence that the data are adequately capturing any impact that the effluent is having on the parameters. Water quality datasets submitted for the permit renewal process provided compliance data for DO and turbidity measurements from May to October for the years 2015–19 (USEPA Fact Sheet 2020). Turbidity is evaluated on a sliding scale against the background turbidity of the water body, because it can fluctuate significantly based on the river flow and upstream dam management decisions. The turbidity data show no exceedance of the instantaneous maximum limit of 5 NTU above background level, and in fact, frequently the turbidity downstream of the farm is less than the ambient upstream turbidity in the waterway. The DO data reflect no significant deviations from the DO limit of 8.0 mg/L. All data are provided in triplicate for each monthly sampling date over 2015–19 (between May and October each year), and although some measurements were below 8.0 mg/L, this was either because background DO levels were <8.0mg/L at that time or, when the measurement was averaged within its triplicate, it showed no deviation from the effluent requirement.

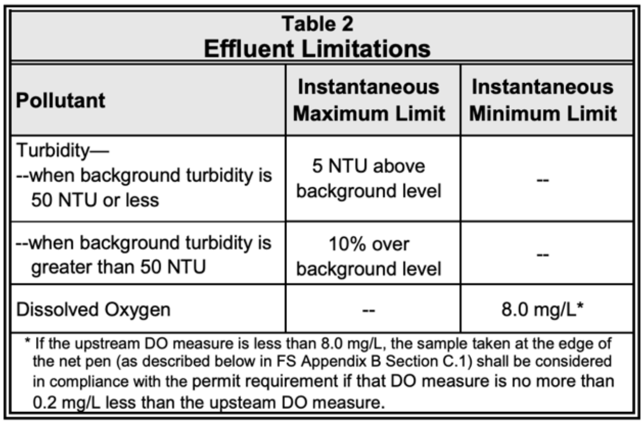


Table 2
Effluent Limitations

Pollutant	Instantaneous Maximum Limit	Instantaneous Minimum Limit
Turbidity— --when background turbidity is 50 NTU or less	5 NTU above background level	--
--when background turbidity is greater than 50 NTU	10% over background level	--
Dissolved Oxygen	--	8.0 mg/L*

* If the upstream DO measure is less than 8.0 mg/L, the sample taken at the edge of the net pen (as described below in FS Appendix B Section C.1) shall be considered in compliance with the permit requirement if that DO measure is no more than 0.2 mg/L less than the upsteam DO measure.

Figure 2: Effluent limitations placed on the net pen operation (USEPA Fact Sheet 2020).

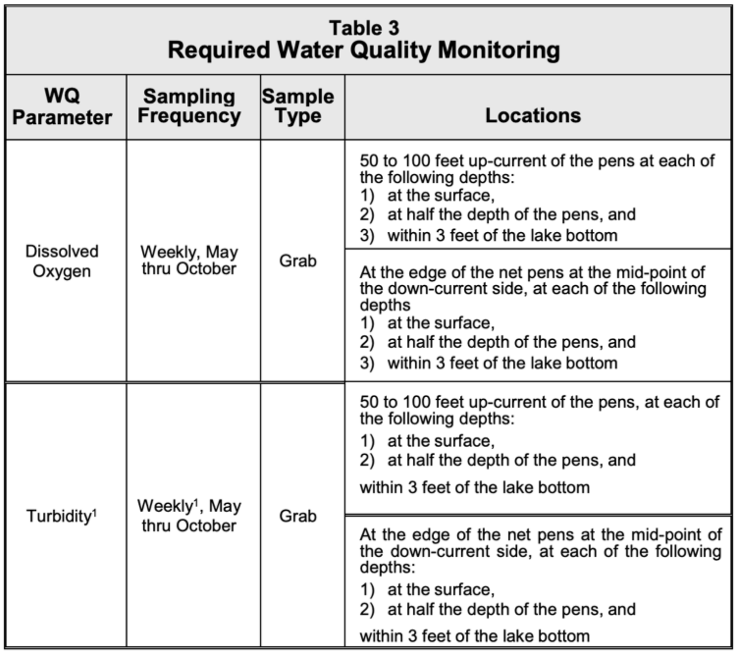


Table 3
Required Water Quality Monitoring

WQ Parameter	Sampling Frequency	Sample Type	Locations
Dissolved Oxygen	Weekly, May thru October	Grab	50 to 100 feet up-current of the pens at each of the following depths: 1) at the surface, 2) at half the depth of the pens, and 3) within 3 feet of the lake bottom
			At the edge of the net pens at the mid-point of the down-current side, at each of the following depths 1) at the surface, 2) at half the depth of the pens, and 3) within 3 feet of the lake bottom
Turbidity[1]	Weekly[1], May thru October	Grab	50 to 100 feet up-current of the pens, at each of the following depths: 1) at the surface, 2) at half the depth of the pens, and within 3 feet of the lake bottom
			At the edge of the net pens at the mid-point of the down-current side, at each of the following depths: 1) at the surface, 2) at half the depth of the pens, and within 3 feet of the lake bottom

Figure 3: Effluent monitoring sample schedule and methods for the net pen operation (USEPA Fact Sheet 2020).

Photographic surveys are also required to comply with the NPDES permit (Figure 4). Photographic surveys are completed by the operator (these involve video recording of the substrate at 15 established reference point locations around and under the net pens, covering just upstream to 150 feet downstream) and are performed twice monthly by divers between May and October. Artificial lighting is used to take 12–30 sec of video from 3 to 7 feet above the substrate at each of the 15 sites. Observations are recorded to capture the possibility for temporal or spatial trends in sediment accumulation. The farm also has three stationary continuous monitoring video feeds in locations of the highest possible impact (pers. comm., Pacific Aquaculture October 2022), which are required to be used to log daily conditions regarding feed and feces occurrence between June and December.

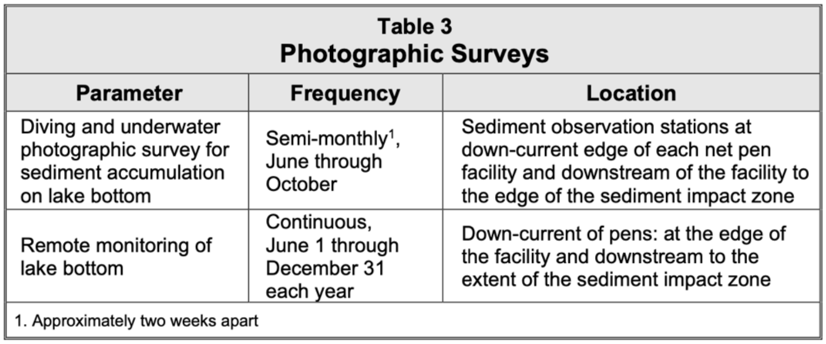


Table 3
Photographic Surveys

Parameter	Frequency	Location
Diving and underwater photographic survey for sediment accumulation on lake bottom	Semi-monthly[1], June through October	Sediment observation stations at down-current edge of each net pen facility and downstream of the facility to the edge of the sediment impact zone
Remote monitoring of lake bottom	Continuous, June 1 through December 31 each year	Down-current of pens: at the edge of the facility and downstream to the extent of the sediment impact zone

1. Approximately two weeks apart

Figure 4: Requirements for photographic surveys at the net pen sites.

Sedimentation collecting beneath structures is a primary concern to other types of net pen systems. But, the strong unidirectional flow of this river system is likely to disperse most particulate waste exiting the pens the majority of the time, except in quite low-flow scenarios. In one rare case, an accumulation of wastes highly similar in isotope composition to fish feed was found over a decade ago underneath the net pens in a seasonal low-flow period, which was explained by mismanagement of the farm before being taken over by the current owners (Rensel 2010), and this is not representative of current management practices.

The higher flows characteristic of the net pen sites facilitate the resuspension, transport, and aeration of the particulate waste leaving the pens. The critical resuspension speed of particulate wastes (average size: 2–6 mm) is modelled at 9.5 cm/s (Cromey et al. 2002), which is beyond satisfied by the measured flows in Rufus Woods Lake by Rensel and Siegrist (2011). The critical deposition speed is 4.5 cm/s (Cromey et al. 2002), which may occur during seasonally low-flow periods. Cycles of resuspension and deposition aerate waste organic matter, improving the decomposition and recycling of nutrients, which ultimately reduces the impact of particulate waste to the surrounding habitat (Torres-Beristain et al. 2006). Resuspension processes also aid in transport, which is important to the dispersion of waste—a key siting practice for net pen aquaculture to minimize impacts.

At the rainbow trout net pen site, the current meter data have demonstrated that the mean flow moves “offshore” and toward the middle of the waterway and that “most sedimentation that will occur from this site [Site 3] will be visible within a few hundred feet or less from the pens” (Rensel and Siegrist 2011), with the probable zone of effect of Site 1 pens estimated to be 400–600 ft downstream in a C and N isotope study (Rensel 2010). This transport direction, along with no-flow periods being “either very infrequent or nonexistent,” would likely prevent the buildup of particulate wastes in shallow waters on the edges of the waterway or underneath the farm structures. But, there is clear potential for a narrow pathway of distribution in the unidirectional flow model (which differs from marine systems, where waste disperses in multiple directions with changing current and tides) (Rensel and Siegrist 2011).

Stable isotope analysis prepared for the farm and CTCR in 2010 (before the company acquired the third net pen site in the lake, but when all three net pen sites were in commercial operation) indicated that wastes were being assimilated into an environment that was otherwise depleted of nitrogen and phosphorus, because of both nutrient trapping upstream and lack of transport of ocean-derived nutrients as a result of the extensive damming of the river (Rensel 2010). The benthic community in the reservoir includes small snails, crayfish, and prickly sculpins on a sand/gravel substrate, and this stable isotope analysis has indicated that fish farm wastes are being incorporated into this food web (Rensel 2010). Cumulative impacts to the habitat are considered, but in terms of particulate waste assimilation into the environment, the data presented can be limited in usefulness [e.g., it is known that sculpins assimilate some amount of fish waste, but their population was not measured to determine whether the scale on which they are capable of assimilating nutrients is meaningful, relative to the amount being discharged into the waterway (Rensel 2010)(USEPA Fact Sheet 2020)].

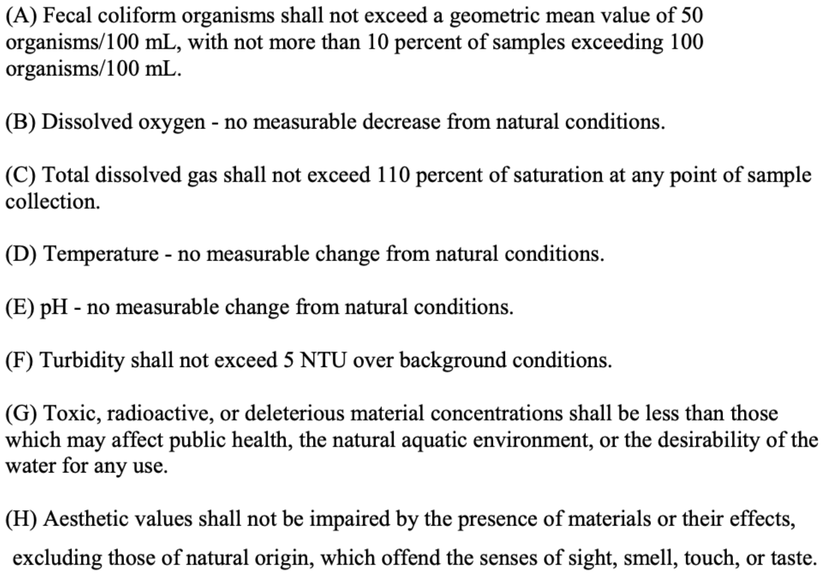
Importantly, although water quality may generally be oligotrophic in the reservoir, unstable environmental conditions can cause nutrification. Water quality deteriorated during high-flow events of 2010 and 2011 that caused shoreline flooding, erosion, and resuspension of benthic sediments (i.e., nutrients), paired with dam water discharges that caused supersaturation of gases in the water that resulted in high losses of both farmed and wild fish in the reservoir (Richards et al. 2011).

Phosphorus is not currently being measured under an NPDES permit requirement (as in the typical raceway/pond system) because the water body has not been classified as water-quality limited with respect to phosphorus, which would activate the TMDL process and impose restrictions. But, the Tribal authority monitors phosphorus in addition to a host of parameters, and has the responsibility and authority to classify the waters as water-quality limited, if necessary, in the future.

The Tribal effluent requirements for the farm include weekly water quality samples, routine twice-monthly video recording of the substrate, and oil sheen management. Tribal water quality samples are taken by farm staff once weekly and analyzed at a third-party lab for the parameters of dissolved gas, total gas pressure (TGP), pH, turbidity, temperature, total P, ortho P, nitrite and nitrate, ammonia (as nitrogen), total nitrogen, TDS, and oil and grease. The Tribal water quality standards are readily available online (Figure 5) (CTCR 2010) and include a "Lake Class" of water quality requirements to maintain beneficial uses for water supply, stock watering, fish and shellfish, wildlife habitat, ceremonial and religious use, recreation, and commerce. The applicable Tribal water quality metrics for the net pen operation are to maintain the natural condition (i.e., no deviation from the water body's ambient value) of DO, temperature, and pH, and for turbidity to be no greater than 5 NTU above background levels (CTCR 2010). The DO and turbidity requirements are being met by the farm (because they mirror NPDES requirements), and though data are unavailable to verify that the temperature and pH are maintained at natural conditions, there is no reason to suspect that farm operations would affect either of these variables. Photographic surveys are also submitted to the Tribal authority (same as those collected for NPDES).

Oil and sheen are generated from the dispersal of top-coated oils as pellets enter the water during feeding. This is managed through the use of an oil boom at the downstream end of the pens, paired with an automated fish oil skimmer device, which the farm has found to be effective in controlling sheen on the water, addressing the Tribal water quality standard that the preservation of aesthetic values of the water must not be impaired (CTCR 2010).

In addition to these monitoring requirements, the farm has established best management practices within their Pollution Prevention Plan to not wash nets (biofouling is not a problem as it is in the marine environment), to promptly remove and dispose of moribund fish on the shore (at least once weekly), and to use highly digestible feeds with minimum crumbling and fines that would affect water quality.



(A) Fecal coliform organisms shall not exceed a geometric mean value of 50 organisms/100 mL, with not more than 10 percent of samples exceeding 100 organisms/100 mL.

(B) Dissolved oxygen - no measurable decrease from natural conditions.

(C) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(D) Temperature - no measurable change from natural conditions.

(E) pH - no measurable change from natural conditions.

(F) Turbidity shall not exceed 5 NTU over background conditions.

(G) Toxic, radioactive, or deleterious material concentrations shall be less than those which may affect public health, the natural aquatic environment, or the desirability of the water for any use.

(H) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

Figure 5: Lake Class water quality criteria established by the Confederated Tribes of the Colville Reservation, which apply to the freshwater net pens sited within tribal waters. Sourced from CTCR Chapter 4-8 Water Quality Standards (CTCR 2010).

Toxic algae blooms are known to regularly occur in the lake, which are documented in a water quality monitoring report from the CTCR, the literature, and a subbasin report. Toxic algae testing is done by the Washington Department of Ecology and is transparently available online, showing ongoing exceedances of toxic algae concentration in the lake (Washington State Toxic Algae 2022). There are records within the lake of “reoccurring blooms producing anatoxin-a with a unique seasonal pattern: July and August 2011; July, August, September 2012; May through September in 2013; and May through July in 2014 (maximum 110 µg/L anatoxin-a, July 2012)” (Trainer and Hardy 2015). CTCR routinely samples the lake water, which included samples exceeding acceptable anatoxin-a and/or microcystin levels 54 out of 195 times (28%) from 2011 to 2016 (Wright 2017).

Although it is unclear whether the net pens may have any role in algae blooms within the lake (Richards et al. 2011), the evidence strongly suggests that the onset of algae blooms originates from upstream nutrient inputs, not the net pens. Using the extensive toxic bloom event of 2011 in Rufus Woods Lake as an example, a state Department of Ecology phosphorus monitoring station immediately downstream of Grand Coulee Dam (where water enters the lake in which the pens are sited) detected spikes in phosphorus entering the lake in the year, reflecting that the influx of nutrients came from upstream. Furthermore, the farm site reported not having any algae blooms appear on their farm or affect their operations in 2011 (pers. comm., Pacific Aquaculture October 2022). Regarding the ongoing blooms, there is a complex network of influences between warming water temperatures, phosphorus loading, and invasive zooplankton that has historically favored certain cyanobacteria assemblages when the environmental conditions are met to create blooms (Rose 2020). There is no research that specifically mentions any interactions between aquaculture and toxic algal blooms in the waterway. Despite the evidence suggesting that the farm is not the primary cause of algal blooms, there is a knowledge gap about the total nutrient loading capacity of the water body and the cumulative impact potential of aquaculture in addition to all other inputs (both point and nonpoint sources).

On an ongoing basis, the farm reports receiving warnings from the Army Corps when toxic algal blooms are detected in the lake (almost always in the pool behind Chief Joseph Dam on the downstream side of the impounded lake). The farm staff track these announcements and are always routinely monitoring fish health to detect any effect on the farm site. They have never seen a detrimental effect, and they do not see the matting that blooms typically make in still water, likely because of the high flow rate at the farm site (pers. comm., Pacific Aquaculture February 2023).

Conclusions and Final Score (Net Pens)

Effluent regulation for net pens is comprehensive and based on ecological principles. The primary parameters reported for NPDES permitting purposes are DO and turbidity, which are measured on a sliding scale of an allowable discharge limit above background levels (which shift due to the river system having fluctuating DO and turbidity from seasonal flow conditions and dam operations). Water quality data analysis is performed by a third-party laboratory to meet Tribal effluent data monitoring requirements for the parameters of dissolved gas, TGP, pH, turbidity, temperature, total P, ortho P, nitrite and nitrate, ammonia (as nitrogen), total nitrogen, TDS, and oil and grease. The Tribal water quality standards are readily available online and the monitoring procedures are more than adequate to capture any changes to the beneficial uses of the water body. The pens are in an area of high current (≈40–70 cm/s) with rare periods of low current observed. Extensive benthic mapping and current modeling have been done in the reservoir, which support the concept that waste from the pens is being effectively transported and is not likely to build up underneath the pens. A probable pathway of assimilation of wastes into the food web has been demonstrated via isotopic analysis. Based on the monitoring data available in the permit renewal documents, the operation is meeting the discharge limits set in its permit requirements, and any impacts within the immediate vicinity are temporary. But, uncertainty remains about the cumulative impact potential of aquaculture in addition to all other nutrient inputs (point source and nonpoint source) at the water body scale. A final intermediate score of 7 out of 10 for the evidence-based assessment is given to net pens.

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

Raceways and Ponds

C3 Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0–10)		9
F3.2a Content of habitat regulations (0–5)	5	
F3.2b Enforcement of habitat regulations (0–5)	5	
F3.2 Regulatory or management effectiveness score (0–10)		10.000
C3 Habitat Final Score (0–10)		**9.333**
Critical?	No	**Green**

Net Pens

C3 Habitat parameters	Value	Score
F3.1 Habitat conversion and function (0–10)		10
F3.2a Content of habitat regulations (0–5)	4	
F3.2b Enforcement of habitat regulations (0–5)	5	
F3.2 Regulatory or management effectiveness score (0–10)		8.000
C3 Habitat Final Score (0–10)		**9.333**
Critical?	No	**Green**

Brief Summary

Raceways and Ponds

Because of the relatively small footprint of farms (U.S. trout production in the top two states uses less than one-fifth of a square mile of land) and their locations on land of low habitat value that was previously converted for agriculture or other industries, trout farm raceways are not considered to be contributing to ongoing habitat fragmentation or a reduction in ecosystem functioning in Idaho or North Carolina. Farm siting regulation and management is robust, with evidence of cumulative management systems for assessment of habitat impacts. Future expansion is regulated through the existing processes. Permitting processes are transparent and enforcement is highly effective. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 9.333 out of 10.

Net Pens
The freshwater net pens that represent this system are clustered in three site locations within an impounded reservoir between two dams on a river system (a modified habitat that is considered low value, per the Seafood Watch Aquaculture Standard). The pens are in an area of high current (≈40–70 cm/s) with rare periods of low current observed. Waste transport and a probable pathway for assimilation into the food web have been demonstrated, and the habitat is considered to be maintaining full functionality. Sites are permitted according to ecological principles and environmental considerations, though there is no area-based management plan in place to manage potential expansion. Permitting and enforcement procedures are transparent, and there have been no formal violations of the operator in the past 5 years. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 9.333 out of 10.

Justification of Rating

Factor 3.1—Habitat Conversion and Function

Raceways and Ponds
The potential ecological impacts of land-based salmonid farms are largely rooted in the discharge of nutrients, pathogens, and chemicals from the farm as effluent (assessed in the respective criteria), rather than the conversion of habitat for initial farm siting (Tello et al. 2010). The habitat conversion that does occur for rainbow trout production results from the construction of the rearing units themselves (ponds and raceways) and any associated building structures (e.g., feed and equipment storage, offices).

The siting of flow-through raceways and ponds is dictated by the high flow and water quality requirements of rainbow trout, as well as topographical requirements of the facility to enable water to flow via gravity (Fornshell 2002). This limits rainbow trout production to areas where sufficient quantities of high-quality water are available, though these locations are increasingly rare, and "expansion of the industry will not come from additional water resources" but from increased intensity and efficiency (Fornshell 2002). The habitats where trout farming is already occurring—primarily the Magic Valley region of the Snake River in Idaho, and the Blue Ridge Mountain region in North Carolina—have maintained ecosystem function despite historic alteration from aquaculture, and both historic and continued alteration from a multitude of other industries (TNC 2014)(USEPA 2001).

Physical Site Characteristics
In Idaho, the Magic Valley region (Ecoregion 12i) naturally features arid grasslands of sagebrush and bunchgrass that have minimal ecosystem service value; in addition, over 90% of the land in this region is currently in use for irrigated and dryland agriculture (48.31%) and livestock grazing on natural rangeland (42.54%) (McGrath et al. 2002)(IDFG 2022). The Snake River flows through this region, walled by the rocky slopes of a large, 500-ft deep and 1,300-ft wide canyon. Trout

farms are either sited in these agriculture areas or along the canyon floor (pers. comm., Gary Fornshell June 2016). Impacts include land clearing and diversion of natural springs, with outflows returning to the Snake River.

In North Carolina, trout farms are primarily sited in the Appalachian Mountains along the western part of the state in three ecoregions (66d/g/j) (Griffith et al. 2002). These areas, which are dense forests on public and private lands, are currently in use primarily for timber production and mineral extraction; forests in North Carolina currently face concerns of invasive insects, disease, and drought (NCFS 2020). The watershed that supports approximately two-thirds of North Carolina trout aquaculture, the Little Tennessee River Basin, is ≈90% forested land and <5% developed or urban land (NCDEQ 2018). The ecosystem function of the Central Appalachians (North Carolina is South-Central) is primarily threatened by atmospheric deposition, deer herbivory, drought, energy development (including shale gas), fragmentation, and pests and disease (Butler et al. 2015). In addition, hydrologic construction such as canals, dams, reservoirs, and drainage and clearing for agriculture threaten floodplain and riparian forests (Butler et al. 2015). Aquaculture impacts include land clearing and diversion of surface water (in some cases up to 90%, though all water is returned) (Fornshell and Hinshaw 2008).

In general, a trout farm requires little land conversion as a result of the intensive production achievable in flow-through raceways and ponds. The most common structure used to rear trout—a 30-m long × 10-m wide × 1-m deep concrete raceway—typically produces nearly 20,000 lb (9 mt) of trout per year, roughly equal to 300 mt/hectare/year (Boyd et al. 2005). Even large farms producing 1,000 mt annually would only need roughly 3.33 ha of raceways, as well as space for support buildings (Boyd et al. 2005). Therefore, it is estimated that production in Idaho and North Carolina in 2018 (the two largest producer states at pre-pandemic production highs) required roughly 40.8 ha and 6 ha, respectively (derived from data in Table 1; USDA 2023), or less than one-fifth of a square mile.

Water Usage

In Idaho, the watershed of the Upper Snake River Basin (where the majority of the state's aquaculture occurs) was significantly altered in the late 1800s, using surface-flow diversions to support irrigated agriculture of hundreds of thousands of acres in the basin (TNC 2014). In the early 1900s, reaches of the Snake River were entirely depleted due to irrigation diversions, and dams were constructed to create reservoirs to enable present-day agricultural conditions in the region (TNC 2014). The river no longer has natural flow regimes as a result of historical damming and canal installations, which have altered the sedimentation characteristics of the river (IDEQ 2022). The use of ground water (as opposed to surface water) began in the mid-1950s to support expansion of irrigated agriculture (TNC 2014). Thus, surface and groundwater diversions, and their associated habitat impacts, have been historically present in the region. Trout farms in Idaho typically divert water from natural springs by tapping into groundwater aquifers; no fish and few small animals live in groundwater, and the impact of diverting this water has a minimal effect on natural habitat (pers. comm., Gary Fornshell October 2013).

In North Carolina, because of the nonconsumptive water-use nature of flow-through raceways and ponds, even operations that divert up to 90% of streamflow are considered to have minimal impact: the diversion occurs on a scale of several tens to several hundred feet, and all water is returned to the stream (Fornshell and Hinshaw 2008). In addition, farms on sites that require surface water, such as in North Carolina, will tend to be smaller in size than those based on groundwater, because of limitations to withdrawal and seasonal flow (Fornshell et al. 2012)

Industry Expansion/Contraction

By production volume, the U.S. trout industry is not actively expanding. Overall, U.S. trout production declined in 2020 and stagnated in 2021 and 2022 (see Table 1), which can be largely attributed to the COVID-19 pandemic. The volatility of the seafood market during the pandemic has not entirely resolved in the data, so production volumes that changed dramatically in 2020–21 are not considered long-term trends.

In Idaho, where 56% of U.S. trout were grown in 2022, production decreased from 2017 to 2021, with a pre-pandemic drop from 12,562 mt in 2017 to 11,338 mt in 2019. After a low point of 9,841 mt in 2021, Idaho reported a slight increase in production to 11,020 mt in 2022. Overall, the Idaho trout industry has not surpassed the 2017 production levels in the past 5 years, which suggests that the trout industry is not currently actively expanding in Idaho. In Magic Valley, where 98% of Idaho's trout production occurs (Engle et al. 2021), there are approximately 70–75 trout farms in operation, and of these farms, 55–60 sites are known to be raising trout for sale in human food markets (pers. comm., Dr. Jacob Bledsoe November 2022).

Production in Pennsylvania, Virginia, and North Carolina has remained relatively level over the previous 5 years, again suggesting that no active expansion is happening in these largest producing states. In North Carolina, the industry has been fairly static, with only one small facility being developed within the past 5 years (pers. comm., Jeff Hinshaw October 2022). There are currently 33 farms in operation in the state, which is a change from the 35 farms in operation at the time of the last SFW assessment (2016).

An interesting area of change in production has been the contribution of what the USDA classifies as "Other" states. These include production numbers for states that are not listed by name in Table 1 and for the states where data were withheld to avoid exposing individual operators. Because of the aggregation, there is a gap in understanding exactly where trout production is happening in the "Other" group. These aggregated data also include production of fish for distribution (i.e., stock enhancement or sales to private ponds) in the food-size class, which further obscures whether farms are being developed in the "Other" states or if there was an increase in fish reared for stocking purposes. This group nearly doubled production volume during 2017–19 from 5,518 mt to 10,524 mt. It also represented nearly all U.S. trout production during 2020, then fell precipitously in 2021, with a continued downward trend in 2022.

There is strong federal and state regulation over any development in watersheds and riparian areas, which indicates good management to ensure that active expansion in "Other" states is of marginal concern. Based on the 1,000 mt/3.33 ha production footprint estimate above, it is expected that the production in “Other” states would require ≈35 ha of additional land to be converted over a maximum of 42 states aggregated in this category, thus further justifying a marginal concern.

Net Pens

The freshwater net pens representative of this production system are submerged in a freshwater river, within an impounded reservoir lake between two dams. This fits the classification as a modified habitat, and the value is scored as “low” in accordance with the Seafood Watch Standard for Aquaculture. The net pens are situated within a reservoir, called Rufus Woods Lake, between two dams (Grand Coulee Dam and Chief Joseph Dam). The volume (gross storage capacity) of the lake that the net pens are situated in is a substantial 728 million cubic meters (ACOE 2009).

The high flow characteristics of the lake are more similar to a river than one might typically imagine in a lake. For example, water retention time in the lake averages 2.5 to 5 days; individual estimates from three sources were 2.5, 3, and <5 days (Rensel 2010)(ACOE 2009)(UCUT 2019), and the average flow rate through Farm Sites 1 and 3 averages ≈40–70cm/s (Rensel and Siegrist 2011).

The siting of net pens has some physical impact (anchors) that is likely negligible, especially given that the benthos in the river reservoir under the net pens is mainly sand and gravel (Rensel 2010). The pens are anchored with a grid arrangement of 20 ft × 0.5 ft (≈6 m × 0.15 m) rolled steel anchoring pins driven into the substrate (pers. comm., Pacific Aquaculture October 2022). The structural complexity of net pens in a river system likely provides some novel habitat that did not previously exist around the anchors and lines, which may be a benefit. The pens are located in a historically modified habitat (a reservoir lake impounded by two dams) that is considered to be maintaining full functionality of ecosystem services.

3.1 Summary

Because of the relatively small footprint of farms (U.S. trout production in the top two states uses less than one-fifth of a square mile of land) and their location on land that was typically previously converted for agriculture or other industries, trout farm raceways are not considered to be contributing to ongoing habitat fragmentation or a reduction in ecosystem functioning in Idaho or North Carolina. Because of the site characteristics that are required for siting raceway operations, it is reasonable that the increased production in “Other” states is not affecting any moderate- or high-value habitats, as classified in the Seafood Watch Standard. The impact of water usage on the physical habitat is considered minimal. In North Carolina, hydrological diversion of surface waters is a physical habitat alteration of stream flow movement. But, the farm sizes are relatively small, the movement of water is over short distances, and all water is returned to the source body, so the physical impact is considered minimal. In Idaho, the historically modified agricultural waterscape of dams, reservoirs, and canals is considered to be maintaining the current level of ecosystem services. There are minimal impacts associated with historic land-use change, including wild animals no longer being able to use converted land, and in the case of North Carolina, small-scale alteration of stream flow. For raceways and ponds, the score for Factor 3.1 is 9 out of 10.

The freshwater net pens are sited in a modified habitat (low value) consisting of a reservoir lake impounded by dams at both the upstream and downstream ends, with the lower dam not allowing fish passage up into the reservoir. There are efforts to restore fish passage above the lower dam, and the associated impacts are discussed in Criterion 6 (Factor 6.2). The benthos that the pens are anchored to is gravel and sand, with a small benthic community assemblage of snails, crayfish, and sculpins. Thus, the modified habitat (due to construction of dams) is considered to be maintaining full functionality. For net pens, the score for Factor 3.1 is 10 out of 10.

Factor 3.2. Farm Siting Regulation and Management

Factor 3.2a: Content of habitat management measures

Site selection is important in trout production, both to ensure that appropriate conditions exist for maintaining optimum fish health and to reduce environmental impacts (Fornshell and Hinshaw 2008). The construction of an aquaculture site is strongly regulated in the United States through multiple federal, state, and local agencies. The major federal permit required for freshwater rainbow trout aquaculture farm siting is issued by the U.S. Army Corps of Engineers. For raceway and pond sites, additional permits governing siting are issued by each state’s Department of Environmental Quality and Department of Agriculture.

Raceways and Ponds

In both Idaho and North Carolina, the process to apply to construct an aquaculture facility is transparent, readily accessible, and specific to the relevant habitat considerations of aquaculture operations. In Idaho, the constrained availability of water rights severely limits the expansion potential of the trout aquaculture industry. Because of the competition and cost of water rights, it is unlikely that any new traditional raceway construction can be done in Idaho’s most productive trout region (pers. comm., Dr. Jacob Bledsoe September 2022).

Water quality permitting under federally regulated TMDLs (covered in Criterion 2—Effluent) effectively rate-limits the flow-through volume of farms and increases the incentives for efficiency in production practices (pers. comm., Dr. Jacob Bledsoe September 2022). It may also, to a lesser extent than water quality rights, actually manage farm siting densities because of its comprehensive consideration of the relative impact of all other industries on the receiving habitat and the carrying capacity for additional operations (e.g., farms may not be able to site in places where there are no waste load allocations available within the TMDLs available to the aquaculture industry). For siting in the Upper Snake River basin, operators must apply under the General NPDES permit of the EPA and receive approval by the IDEQ, with the allowance for additional state regulations and monitoring to be put in place as ecologically appropriate (USEPA 2019). There are stipulations specific to aquaculture discharge to maintain the “beneficial uses” of the receiving water, which include wildlife habitat. The regulatory coordination for permitting and ecological review represents a robust cumulative management system in Idaho, with regulatory safeguards in place to manage any future expansion. An area-based, industry management initiative is in place that includes multiple industries that discharge water in southern Idaho (SIWQC 2022).

In North Carolina, a General NPDES permit must be applied for (NCG530000) with approval from the North Carolina Department of Water Quality, which involves a consideration of appropriate siting similar to the Idaho process.

The U.S. Army Corps of Engineers (Corps) regulates compliance with the Clean Water Act (CWA) by issuing Section 404 permits, thus ensuring that dredge and fill activities that result in the discharge of pollutants to the navigable waters of the United States (such as the construction of an aquaculture facility) will not violate applicable state water quality standards (CWA, Section 401). State water quality standards are enforced through the NPDES program, as detailed in Criterion 2—Effluent. In addition, the Corps may regulate trout farm construction via the issuance of Nationwide Permit #7 (NWP), which ensures that outfall structures and associated intake structures comply with the NPDES program (i.e., consideration of ecological concerns). Section 404 permits do not apply in Idaho, where trout facility construction does not require dredging because water is received from springs and not diverted surface waters; instead, a “stream channel alteration permit” is required and is administered by the Department of Environmental Quality (DEQ) (pers. comm., Gary Fornshell June 2016). In North Carolina, a Section 404 permit is required for construction of the water intake structure (NCDACS 2001). In addition, in North Carolina, the Army Corps permit process will investigate potential trout aquaculture sites to determine if they will affect wetland habitat (thus satisfying the relevance of regulation to appropriate ecological considerations).

On the state level, both the Department of Environmental Quality and Department of Agriculture in Idaho and North Carolina ensure that all trout facilities are constructed and operating according to state code, by licensing and permitting elements of the construction and operation (e.g., intake structure specifications and waste disposal methods) (Idaho Statutes 2022) (NCGS 2022a). Both state codes include conditions based on the maintenance of habitat functionality—specifically stating that the construction of facilities and the water diversions to supply said facilities shall not impede fish passage or damage natural habitat (Idaho Statutes 2022) (NCGS 2022a).

There are no provisions for restoration of former high-value habitats; however, this does not negatively affect the overall score, because it is highly unlikely that high-value habitats would be affected in Idaho and North Carolina. This is partly due to the location (e.g., Idaho trout aquaculture is in grassland that is not a high-value habitat anyway), and partly to the highly regulated permitting environment (relevant agencies evaluate the site and do not issue permits if there could be impacts). If, for example, by negligence of an operator, an unpermitted farm was affecting a wetland habitat in North Carolina, penalties and fines would be assessed against the operator in a judicial case that would include ceasing operation and mandatory, court-ordered restoration of the affected habitat. Therefore, for raceways and ponds, the score for Factor 3.2a is 5 out of 5.

Net Pens

The US freshwater net pen aquaculture industry is represented by just one producer. Thus, this discussion is focused on the content of habitat management measures specific to the location of one operator.

The overall legislation regulating land conversion to aquaculture installations in the U.S. is robust and covers the siting and operation of freshwater net pens. Site approval is regulated on federal, tribal, state, and city/country levels. Agencies that set the relevant laws covering aquaculture permitting in their jurisdiction are described below.

Federal

The Army Corps of Engineers (ACOE) uses the Section 10 permit for installation of structures within navigable waters of the U.S. and regulates the installation and maintenance of navigation lights at the farm site. Any discharge of dredge or fill for the proposed activities is governed by Section 404 of the Clean Water Act. Standard Individual Permits typically have a 10-year term. The Corps/EPA Mitigation Rule (33 CFR 325 & 332, April 10, 2008) requires an effort for minimization be made by the operator to reduce impacts of the farm to the surrounding environment in order to reduce the need for compensatory mitigation, which will be required by law in instances where appropriate. In addition, cultural resource surveys must be undertaken for review by ACOE because they pertain to the Section 106 National Historic Preservation Act.

Farms must have an NPDES permit to discharge waste. Within the NPDES permits are requirements for photographic surveys, which pertain to habitat management because of their focus on monitoring for possible sedimentation under the pens (discussed in detail in Criterion 2—Effluent).

Tribal

The freshwater net pens are located within Tribal boundaries. Federal permit applications receive final review and approval by the Tribal government, which has formal status to act as a State. The Tribe also holds responsibility for assessing waters for impairment and setting TMDLs. Authorities from the Tribal departments of History and Archaeology, Environmental Trust, and Planning periodically visit to verify that operational activities are in accordance with permitting (pers. comm., Pacific Aquaculture October 2022). The benthic photographic surveys conducted by the operator (described in Criterion 2) are also required to be submitted to the Tribe.

State

In Washington, the state Department of Land and Natural Resources issues aquatic land use leases. The state Department of Ecology issues 401 water quality certification as it relates to its responsibility under the Clean Water Act, which has overlapping elements to an NPDES permit review, just at a state level of authority. There is a blanket 401 water quality certification for federal facilities and those located on tribal lands within the state of Washington that is current as of December 5, 2002 (WA DOE 2022). Local representatives of the U.S. Fish and Wildlife Service (USFWS) have jurisdiction over the protection of freshwater animals as it pertains to the Endangered Species Act, and are tasked with evaluating whether the proposed activity is in critical habitat for the species and if there is potential for impact.

Maintaining the current level of ecosystem functionality and not allowing negative impacts to the habitats of listed species is, to an extent, built into the permitting review process. The permitting process includes ecological considerations to the habitat such as the Endangered Species Act evaluation (by USFWS), which determines the habitat values of the areas being permitted. For example, the ESA evaluation process found that the farm sites in Rufus Woods Lake are not in critical habitat areas for spawning of bull trout (threatened species), and the agency presented the distance from spawning areas and other life-history characteristics to explain its reasoning. Thus, the present regulatory framework should adequately reveal whether negative impacts to ecosystem functioning are likely, and halt the permitting process before farm permit approvals.

In the permitting process, there are multiple regulatory levels managing the potential cumulative impacts to the waterway (e.g., ESA evaluation by USFWS, ACOE permits, Tribal permits). The unique location of the freshwater pens in an impounded lake lends itself to an area-based management strategy, because of its discrete segmentation within the river system. The pens are located within a Tribal jurisdiction that values preservation of ecosystem services and functionality (under the authorities of their Watershed Management and Fish and Wildlife Departments) and is likely to consider any additional growth in the reservoir lake in the context of maintaining the habitat. Careful consideration of future expansion within Tribal boundaries is likely under this structure of management.

Importantly, the permitting and management systems are different on the Tribal side of the reservoir and the other side. The Tribe acts with the authority of a state on its side of the reservoir, and the State of Washington Department of Ecology and other relevant agencies act on the other side (each governing roughly half the water body). There are no published documents outlining an overall coordination for an area-based management of aquaculture and/or other industries discharging into the reservoir; however, the overall regulatory framework of aquaculture in the farm location does comprehensively consider all types of impacts.

All sites are permitted according to ecological principles and environmental considerations. For net pens, the score for Factor 3.2a is 4 out of 5.

Factor 3.2b: Enforcement of habitat management measures

Raceways and Ponds
Enforcement of these laws is strict; operators who construct and operate an aquaculture facility without the proper permits are subject to significant fines and penalties, including possible imprisonment (USEPA 2016e). For example: the EPA, which is tasked with enforcing the Clean

Water Act (which operators are required to comply with through the permits detailed above), has the authority to charge a maximum of $27,500 per day in civil penalties for violation of a Section 404 permit (CWA, Section 309(d)).

Likewise, at the state level, penalties for noncompliance with the state code range from civil penalties to criminal offenses, based on the degree of noncompliance. In both Idaho and North Carolina, the administrator also has the authority to suspend or revoke an aquaculture license in lieu of or in addition to any penalties levied (Idaho Statutes 2022) (NCGS 2022a).

For the most part, penalties for noncompliance are rare because noncompliance is rare. If an operator is found to be out of compliance, the EPA will generally issue a civil administrative action (notice of violation or order to come into compliance) before taking judicial action (lawsuits), with criminal actions being sought for only the most egregious violations (USEPA 2022f). The same course of action is taken on the state level, with civil administrative action being the preferred method of enforcing compliance.

Permitting and licensing of aquaculture operations through federal processes requires a public comment period, and issuance of permits is in the public record, which provides a transparent process for compliance enforcement. Penalties for violations of the CWA are publicly reported through the ECHO Enforcement Case Search tool (USEPA 2022d). There are records of formal administrative action being taken against three trout farms in North Carolina in the last 10 years (all in 2014), all of which were due to failure to renew the permits within the 180-day window before expiration, not because of violations of the discharge to the receiving habitat. The last record of assessed penalties from the EPA for violations of the CWA were against two commercial aquaculture operations (catfish, tilapia) in Idaho in 2012 and 2013 that resulted in fines of $15,000 and $25,000 and an order to become compliant (USEPA 2022d).

The scale of enforcement is appropriate to the scale of the industry. Permit reporting requirements are strict, and maximums are enforced. Suspected violations of the CWA can be reported by the public in the ECHO system (USEPA 2022g). Violations to Army Corps permits are handled in alignment with their enforcement guidelines (33 CFR Part 326), which include surveillance procedures by public reporting and coordination of state, local, and federal agencies to detect violations. Civil penalties can be assessed for $10,000 per violation by the ACOE.

The score for Factor 3.2b is 5 out of 5. Combined with the Factor 3.2a score of 5 out of 5, the final Factor 3.2 score is 10 out of 10 for raceways and ponds.

Net Pens

Permitting and licensing of freshwater net pen operations is done through the same transparent processes as for raceways and ponds and provides public comment periods. Final authorization for the permits to become effective is done through the relevant Tribal processes. All Tribal requirements are included in the permits published for public comment. The net pen operator is subject to surprise inspections by the EPA, CTCR Environmental Trust, and CTCR Fish and Wildlife per their permits, and an audit was performed in 2009 by EPA (pers. comm., Pacific Aquaculture October 2022), which demonstrates the capacity for enforcement of the rules.

ACOE has the responsibility to investigate complaints about potential violations of Section 404 and Section 10 permits issued under its authority and is also responsible for inspecting permitted activities for compliance. Legal action may be taken, as appropriate. Penalties for violating a permit under the Rivers and Harbors Act include a criminal misdemeanor imprisonment and fines up to $100,000 for individuals and $200,000 for corporations (33 U.S.C. 401).

Penalties for violating the Clean Water Act are the same as listed for raceways and ponds above. No formal enforcement actions have been taken against the freshwater net pen operator in the past 5 years, as reported on the EPA's ECHO database. Evidence of penalties or infringements would be available publicly if they had occurred. There is capacity for enforcement of allowable discharge via the routine water quality analysis required by CTCR and EPA to satisfy permit requirements.

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 Factor 3.2 score is 8 out of 10 for net pens.

Conclusions and Final Score

Raceways and Ponds

Because of the relatively small footprint of farms (U.S. trout production in the top two states uses less than one-fifth of a square mile of land), and their locations on land of low habitat value that was previously converted for agriculture or other industries, trout farm raceways are not considered to be contributing to ongoing habitat fragmentation or a reduction in ecosystem functioning in Idaho or North Carolina. Farm siting regulation and management is robust, with evidence of cumulative management systems for assessment of habitat impacts. Future expansion is regulated through the existing processes. Permitting processes are transparent and enforcement is highly effective. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 9.333 out of 10.

Net Pens

The freshwater net pens that represent this system are clustered in three site locations within an impounded reservoir between two dams on a river system (a modified habitat of low value). The pens are in an area of high current (≈40–70 cm/s) with rare periods of low current observed. Waste transport and a probable pathway for assimilation into the food web have been demonstrated, and the habitat is considered to be maintaining full functionality. Sites are permitted according to ecological principles and environmental considerations, though there is no area-based management plan in place to manage potential expansion. Permitting and enforcement procedures are transparent, and there have been no formal violations of the operator in the past 5 years. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 9.333 out of 10.

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

Raceways and Ponds

Chemical Use parameters	**Score**	
C4 Chemical Use Score (0–10)	**6**	
Critical?	NO	**YELLOW**

Net Pens

Chemical Use parameters	**Score**	
C4 Chemical Use Score (0–10)	**6**	
Critical?	NO	**YELLOW**

Brief Summary

Raceways and Ponds

Robust regulatory guidance is available for farmers to select appropriate chemicals, and mitigation methods are used where possible to limit the frequency and/or total use of chemicals, such as using appropriate stocking densities, disinfection of tools and equipment between production areas, vaccinations, dietary additives (e.g., probiotics), and proactive approaches to fish health. The use of antibiotics at the largest producer in the country, which accounts for approximately 67% of total U.S. raceway and pond production, is limited to oxytetracycline at an estimated 0.37 treatments/cycle and florfenicol at 0.01 treatments/cycle, on average; both are listed as highly important for human medicine by the WHO. Although florfenicol is used only in animal medicine, it may meet the conditions as a highly important antimicrobial for human medicine in limited geographies for treatment of specific conditions. Although the data used represent a significant portion of the total industry, there is uncertainty about how representative the data are of all farm scales of production in the U.S. trout industry, as well as the long-term fate of antibiotics that reach discharge waters.

Overall, the available data indicate that antibiotics are used on average less than once per production cycle (a score of 8); however, with uncertainty as to the representativeness of these data, a precautionary approach is warranted. Given the flow-through nature of rainbow trout raceways and ponds and the physicochemical properties of these compounds, it is possible for bioavailable antimicrobials to be discharged and present in the receiving water body. Risk is mitigated by dilution, degradation, and intermittent judicious use with veterinary oversight. Both of the antimicrobials common to the trout industry (Aquaflor and Terramycin 200) have received Findings of No Significant Impact (FONSIs) from the EPA. Although there is some concern and evidence of developed resistance in receiving water bodies globally, there is no evidence that antibiotic use on U.S. trout farms has resulted in or contributed to resistance. Regulatory limits of chemical type and dose exist and are well enforced, though there are no legislated limits to total use. The final numerical score for Criterion 4—Chemical Use is 6 out of 10 for raceways and ponds.

Net Pens

Reliable data were available to confirm that the frequency of antibiotic usage (oxytetracycline and florfenicol) is 0.77 treatments annually for cycles harvested in 2021 and 2022 (consistent with a score of 8). The system demonstrates a low need for chemical treatments, with zero bath treatments administered during grow-out (baths are not possible in the high-flow environment). Given the flow-through nature of rainbow trout net pens and the physicochemical properties of these compounds, it is possible for bioavailable antimicrobials to be discharged and present in the receiving water body. Risk is mitigated by dilution, degradation, and intermittent judicious use with veterinary oversight; although there is some concern and evidence of developed resistance in receiving water bodies globally, there is no evidence that antibiotic use on U.S. trout farms has resulted in or contributed to resistance. Regulatory limits of chemical type and dose exist and are well enforced, though there are no legislated limits to total use. The final numerical score for Criterion 4Chemical Use is 6 out of 10 for net pens.

Justification of Rating

A variety of chemicals are used in rainbow trout aquaculture for animal husbandry (therapeutants, anesthetics) and cleaning (disinfection). Chemicals add cost to production, and it is in the best interest of producers to minimize chemical use because of this. The majority of U.S. trout aquaculture operations discharge effluent to natural systems (which may or may not be mediated by settling ponds); thus, there is risk for chemicals to enter the environment.

Chemical Use Regulation and Management

In the U.S., animal drugs are regulated under the Federal Food, Drug, and Cosmetic Act (FFDCA) by the Food and Drug Administration (FDA) Center for Veterinary Medicine. For a drug to be approved by the FDA for use in flow-through salmonid systems, an environmental assessment (EA) is often conducted to determine the potential for environmental impact resulting from use and/or discharge. If there is a potential impact found in the EA process, the FDA will write an environmental impact statement; otherwise, a summary of the findings of the EA is written, called a Finding of No Significant Impact (FONSI) (USFDA 2022). To date, none of the drugs currently used in freshwater rainbow trout aquaculture in the United States has had an environmental impact statement written for its use, and all the FONSIs are available online

(USFDA 2022). It is important to note that these assessments effectively studied environmental impacts of repeated one-time applications of a drug from single point-source discharges, whereas the cumulative environmental impact of potentially continuous drug application (i.e., multiple farms with simultaneous production cycles at different stages) and discharge into the environment is not certain. The impacts can also be limited in scope (e.g., species, geographical regions) and may not be specific to the ecological concerns of all potential receiving waters.

Medicated feed, which is a common way to administer antibiotics to large cohorts of fish, is regulated by the FDA's Veterinary Feed Directive (VFD), which only permits using VFD drugs intended for use in animal feeds under the supervision of a licensed veterinarian (USFDA 2022b). This makes it illegal to use antimicrobials for production purposes (i.e., growth promotion). It is a misconception in the first place that antibiotics promote growth in finfish, which has been clarified in the literature (Trushenski et al. 2018). Nevertheless, it is regulated under the authority of the FDA to prohibit the practice entirely. Legal restrictions on dosage and species are in place under the blanket requirement that the label usage must be adhered to for immersion and injectable drugs, and under the guidance of a veterinarian for medicated feeds or any extra-label usage.

Table 6 outlines the chemicals regulated by the FDA and their approved uses in aquaculture. The FDA also uses a designation of low regulatory priority (LRP) drugs, which are not approved, but the agency deems that exposing food fish to them is "unlikely to result in a risk to human health if people consume the fish" (USFDA 2022c). Their usage may need to be reported, based on individual state permit stipulations (e.g., Idaho and Washington NPDES permits for rainbow trout facilities have requirements for this, whereas North Carolina does not).

Table 6: Chemicals currently approved by the FDA for use in aquaculture, and their uses in freshwater-reared salmonid spp. (USFDA 2022d).

Delivery Method	Chemical	Approved Brands	For the Control Of	First Approved	Use Conditions
Immersion	Chloramine-T	HALAMID® AQUA	Bacterial gill disease (*Flavobacterium* spp.)	2014	Label Use Only, unless approved for Investigational New Animal Drug (INAD) study, or extra-label use by written prescription from a licensed veterinarian
	Formalin	FORMALIN-F®, FORMACIDE-B, PARASITE-S	External parasites [protozoa: *Ichthyophthirius* spp., *Chilodonella* spp., *Costia* spp., *Scyphidia* spp., *Epistylis* spp., and *Trichodina* spp. and monogenetic trematodes: *Cleidodiscus* spp., *Gyrodactylus* spp., and *Dactylogyrus* spp.] and as a fungicide for eggs	1986	
	Hydrogen Peroxide	35% PEROX-AID ®	Bacterial gill disease (*Flavobacterium branchiophilum*), external columnaris disease (*Flavobacterium columnare*)(*Flexibacter columnaris*), saprolegniasis associated with fungi in the family Saprolegniaceae,	2007	

			treatment and control of *Gyrodactylus* spp.		
	Oxytetracycline hydrochloride	OXY Marine™, Tetroxy® 343, Pennox 343®, Terramycin 343®, TETROXY® Aquatic	Skeletal marking for subsequent identification (primarily done in hatchery restocking)	2003	
	Tricaine methanesulfonate	SYNCAINE	Temporary immobilization (anesthetic)	1997	
Injectable	Chorionic gonadotropin	CHORULON®	Aid in spawning broodstock	1999	
Medicated Feeds	Florfenicol	Aquaflor®	Coldwater disease (*Flavobacterium psychrophilum*), furunculosis (*Aeromonas salmonicida*), columnaris disease (*Flavobacterium columnare*), streptococcal septicemia (*Streptococcus iniae*)	2005	Only under supervision of a licensed veterinarian
	Oxytetracycline dihydrate	Terramycin® 100 for Fish, Terramycin® 200 for Fish	Ulcer disease caused (*Hemophilus piscium*), furunculosis (*Aeromonas salmonicida*), bacterial hemorrhagic septicemia (*Aeromonas liquefaciens*—updated to *A. hydrophila* 07.16.2018) and pseudomonas disease, gaffkemia (*Aerococcus viridans*), coldwater disease (*Flavobacterium psychrophilum*), columnaris (*Flavobacterium columnare*), skeletal marking	1970	
	Sulfadimethoxine/ormetoprim	Romet®-30	Furunculosis (*Aeromonas salmonicida*)	1984	

In addition to those listed in the table, drugs with deferred regulatory status (DRS, those for which no regulatory action exists until further study is completed), and those with low regulatory priority (LRP, unapproved drugs that are considered low risk by FDA when used in fish destined for human consumption; see USFDA 2021) are in use for U.S. rainbow trout production. These include potassium permanganate and povidone iodine. More on these is described in the relevant category of "Other Treatments for Bacteria (not Antibiotics)" later in this criterion. Chemicals that are allowed to be used under Investigational New Animal Drug (INAD) exemption authorizations may also be applied on farms. There is evidence of a limited amount of approved INAD use of Slice® (Emamectin Benzoate) happening in Idaho at a frequency of 0.01 times/cycle (Table 7).

Agricultural pesticides are regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) by the EPA. The EPA reviews and licenses all pesticides distributed or sold in the U.S. and verifies that when used according to their label, "will not generally cause unreasonable adverse effects on the environment" (USEPA 2022h). Chemicals associated with cleaning must have their FDA-approved labels followed, and any limits to allowable discharge are regulated by individual states.

Although there is a strong regulatory structure for use of chemicals in the U.S. rainbow trout industry, public data reporting by farms is essentially nonexistent. Records of VFDs are handled the same as other livestock industries, with logs being maintained by the operator, veterinarian, and feed mill producing the medicated feed. These records are subject to regulatory compliance activities such as inspections by FDA at any time. But, these are not public information. Data were made available from farms contacted directly for this assessment. As an example of the lack of public data transparency from the state that leads U.S. trout production (Idaho), the forms to record the frequency and type of medicated feeds used on farms are only done on a voluntary basis; these reports are only made available to DEQ during inspections, and the data are not required to be submitted with a farm's routine DMR reporting (pers. comm., IDEQ September 2022). Thus, these data are not publicly available, and the limited amount that may be collected from DEQ via the inspections process is only available through a formal Public Records Request.

On-Farm Chemical Use (Raceways and ponds)

In trout raceway and pond aquaculture, the primary chemicals of concern are therapeutants (antibiotics and pesticides). Cleaning chemicals are frequently used as well to disinfect and upkeep biosecurity at the farm site. In Idaho, an analysis of the annual NPDES chemical usage reporting from aquaculture farms concluded that the most likely chemicals to be discharged from trout aquaculture in the region are potassium permanganate, povidone iodine, formalin, and chloramine-T (USEPA Fact Sheet 2019). Following a biological evaluation to assess the ecological risk of drugs and chemicals discharged from Idaho facilities, the EPA concluded that, "concentrations in the discharges were below toxicity concentrations and not likely to adversely affect all species evaluated: bull trout, chinook salmon, sockeye salmon, and steelhead" (USEPA Fact Sheet 2019). Although fish are a species of concern in the waters receiving discharge, this does not address the potential for accumulation in sediment or impacts to other nontarget organisms. The North Carolina general permit does not specify chemical types and thresholds in the same manner or provide likely chemical discharges from the industry (likely because of its relatively smaller scale). Both Idaho and North Carolina general permits require that label directions for drugs and pesticides be followed in accordance with the FIFRA and FDA, except when conducting an Investigational New Animal Drug (INAD) study, or as prescribed in writing by a veterinarian.

The chemicals currently in use for raceway and pond rainbow trout production in the U.S. are listed in Table 7 and expanded upon in the following text.

Table 7: Chemicals used for grow-out rainbow trout aquaculture (from receipt of eggs to harvest) in raceways and ponds.

Delivery Method	Chemical	Approved Brands	Dosage	Frequency	Regulations
Immersion	Chloramine-T	HALAMID® AQUA	12–20 ppm for 60 min/d for 3 (alternate or consecutive) d	Primarily cleaning only	Label Use Only, unless INAD study or extra-label vet prescription
	Formalin	FORMALIN-F®, FORMACIDE-B, PARASITE-S	250 uL/L for 1 hr in tanks and raceways, and 15–25 uL/L indefinitely in earthen ponds (USEPA 2022)	0.02 times/cycle	Label Use Only, unless INAD study or extra-label vet prescription
	Potassium permanganate		0.5–2 ppm immersion for 30 min/d for 3 (alternate or consecutive) d	2.69 times/cycle	Deferred Regulatory Status drug
	Providone iodine		100 ppm for 10 min upon receipt of eyed eggs	N/A	Low Regulatory Priority drug
	Tricaine methanesulfonate	SYNCAINE	Calculated by fish weight	Extremely limited usage	Label Use Only, unless INAD study or extra-label vet prescription
Medicated Feeds	Florfenicol	Aquaflor®	15 mg/kg fish/d for 10 d	0.01 times/cycle	Only under supervision of a licensed veterinarian
	Oxytetracycline dihydrate	Terramycin® 100 for Fish, Terramycin® 200 for Fish	3.75 g/100 lb fish/d for 10 d	0.37 times/cycle	Only under supervision of a licensed veterinarian
Cleaning	Quaternary ammonia	Virex	Variable	N/A	Label Use Only, general purpose cleaner
	Disinfectant mixture	Virkon Aquatic	Variable	N/A	Label Use Only, limited use for biosecurity between systems

Antibiotics

Bacterial outbreaks requiring intervention with antibiotics occur periodically in hatchery and grow-out facilities. Antibiotics are typically administered using medicated feed, which must be done under the supervision of a licensed veterinarian. Raceways and ponds discharge effluent to the environment, which may release antibiotics to natural systems.

Some common reasons to use antibiotics in trout aquaculture are for bacterial cold-water disease (BCWD) and columnaris disease, which often affect juveniles of cold-water fish species. The bacteria responsible for columnaris disease (*Flavobacterium columnare*) was found to be continually delivered into at least one Idaho trout facility via a natural spring water source (Testerman et al. 2022), making it a constant pathogen risk. There are currently no commercially available vaccines for BCWD. But, a live-attenuated vaccine is in development for use in the U.S. (Ma et al. 2019)(Sudheesh and Cain 2016)(LaFrentz et al. 2008), which may reduce the need for antibiotics in the future. A complete list of diseases of cold-water fish that may be legally treated with approved antibiotics in the U.S. is found in Table 6.

FDA-approved antibiotics that may be incorporated into trout feeds are florfenicol, oxytetracycline dihydrate, and sulfadimethoxine/ormetoprim (Table 6). Sulfonamides (sulfadimethoxine) and oxytetracycline are both highly important for human medicine, and florfenicol is a highly important antimicrobial that is only used in animals (WHO 2019). The antibiotics in use by the U.S. trout industry are primarily oxytetracycline dihydrate and, in a distant second, florfenicol. Publicly available data from the ASC certification of a large operator in Idaho that controls 14 farms within the state were used to evaluate antimicrobial usage. Although these data are a subset of total U.S. trout production, public information indicates that this operator produces approximately 10,000 mt annually (ASC 2022b), which represents ≈90% of Idaho production volume and ≈67% of total U.S. raceway and pond production volume in 2022. Therefore, these data points are considered representative of total U.S. raceway and pond culture (ASC 2022). Using the published data on the number of production units and the number of times each chemical was used per year, calculations were made on the estimated frequency of use per cycle.

In raceways and ponds, the use of florfenicol is estimated to be 0.01 treatments/cycle on average, and the use of oxytetracycline is 0.37 treatments/cycle on average. In North Carolina, antibiotics are most often required in the hatchery to treat BCWD on fish <5 g, and often, when fish reach the grow-out tanks, they will not need to be treated again (pers. comm., Jeff Hinshaw October 2022).

The greatest concern from the use of antibiotics is their potential to contribute to antimicrobial resistance (AMR), a condition whereby bacteria develop the capacity to survive an antibiotic drug(s) as the result of an accumulation of adaptions over long-term exposure to the drug, such as what happens with overuse or misuse of antibiotics (Lomazzi et al. 2019). Antimicrobial resistance is a critical global health concern, and its association with trout aquaculture farm operations has been demonstrated elsewhere globally (Duman et al. 2018)(Dadar et al. 2016)(Schmidt et al. 2000)(Naviner et al. 2011); including confirmation of AMR genes for tetracycline, florfenicol, and/or sulfamethoxazole in bacteria isolated from rainbow trout individuals or within farm systems in France, Turkey, and Spain (Capkin et al. 2017)(Duman et al. 2017)(Duman et al. 2018)(Naviner et al. 2011)(Del Cerro et al, 2010). Though many existing and emerging bacterial pathogens to trout aquaculture remain sensitive to commonly approved antibiotics (Saticioglu et al. 2018) (Calvez et al. 2014)(Del Cerro et al. 2010)(Schmidt et al. 2000), it does not preclude the imperative to be judicious about the application of antibiotics. Other measures for disease prevention that could reduce the use of antibiotics must be encouraged as a first option whenever and wherever available, such as vaccines, probiotics, or bacteriophages, if/when the technologies become available and approved for use in the U.S. (Cabello et al. 2016)(Ghosh et al. 2016)(Burbank et al. 2012).

Association does not mean there is a causative relationship in all cases of AMR being detected at aquaculture farms. Attributing the source of AMR in the environment remains complicated, with routine antibiotic introductions from several industries (including wastewater, agriculture, and aquaculture) that affect the baseline bacterial communities in any given source water. What is clear is that AMR is developed over time from the routine release of antibiotics into the environment, that aquaculture can be a source of antibiotic release into the environment, and that the trout aquaculture industry in the U.S. cannot be ignored as a potential contributor in the absence of data to clarify otherwise—which is unlikely to be resolved, given the complicated network of various industries sharing waterways. Aquaculture facilities can be ideal settings for AMR to develop (presence of hosts, suitable environmental conditions, exposure to antibiotics over time), which is mitigated by the judicious use of antibiotics by responsible operators (Trushenski et al, 2020). AMR studies at U.S. commercial rainbow trout grow-out raceway facilities are nonexistent in the literature; however, longitudinal sampling of bacteria and antibiotic susceptibility testing in state-run fish hatcheries does exist. At hatcheries operated by Idaho Fish and Game (IDFG), the use of medicated feeds—including oxytetracycline and florfenicol—has not significantly altered the susceptibility of three common bacterial species isolated from the facilities (*F. psychrophilum*, *A. salmonicida*, and other *Aeromonas* spp.) over the course of 20 years, as measured by semiquantitative disk diffusion methods (Trushenski et al. 2020). This is currently the best baseline from which to understand the long-term development of AMR in the U.S. trout industry, and it suggests that. under the common use practices and regulatory structure for aquaculture antibiotics in the U.S., there is a low risk for development of AMR.

The environmental impact of discharged antibiotics will vary, based on the volume and frequency of use. As much as 70–80% of oxytetracycline (OTC) that is ingested by fish is excreted unmetabolized (Schmidt et al, 2007)(Romero et al. 2012)(Daghrir and Drogui 2013). Risk exists for impacts to nontarget organisms when OTC is in low concentrations in controlled laboratory exposure analyses (Zounkova et al. 2011); however, its behavior when passing through farm discharge systems (e.g., quiescent zones, settling ponds) and natural environments includes important degradation processes that are not adequately replicated in many exposure studies. OTC is poorly to moderately absorbed by ingestion, but when it is excreted, natural processes such as photodegradation and/or formation of molecular complexes (mostly with calcium and magnesium ions) generally reduce the bioavailability of OTC in the environment (Leal et al. 2018).

OTC is known to sorb to dissolved organic matter and biosolids, such as suspended aquaculture solids (i.e., uneaten fish feed and excrement), and become largely biologically unavailable (Schmidt et al. 2007). Given the requirement of trout farms to limit their discharge of suspended solids and the widespread use of settling ponds, the majority of applied OTC (>80%) is expected to be captured and properly disposed of (applied as fertilizer, composted, or buried in compliance with state law) before discharge into the receiving water body (Schmidt et al. 2007). OTC that is discharged, both in solution and bound to sediments, is then subject to dilution as well as biotic and abiotic degradation in the receiving water body, further mitigating its impact (Schmidt et al. 2007). The three main abiotic degradation processes of OTC in natural environments when OTC is associated with dissolved organic matter (DOM) are photolysis, hydrolysis, and biodegradation (Leal et al. 2018). As an example, 90% degradation of OTC (breakdown to products that no longer have antimicrobial activity) in brackish discharge water was demonstrated by photodegradation at a simulated 40 °N latitude in midwinter in <1 hr of experimental sunlight exposure (Leal et al, 2016)—a likely breakdown process happening within settling ponds, which are used as a best management practice by nearly all U.S. trout farms. Limitations in applying this information to commercial discharge include the absence of dissolved salts that may catalyze photodegradation, and that performance has not been evaluated at a farm site to validate any experimental results. Indications from the literature are that the photoproducts of OTC photodegradation do not maintain antibacterial activity that would contribute to AMR (Lunestad et al. 1995)(Pereira et al. 2013)(Leal et al. 2017).

There is some evidence of OTC desorbing from sediments into a bioavailable form (Schmidt et al. 2007), which remains an uncertainty in assessing the impact of antibiotic use in commercial fish farms. Given the regulatory restrictions on the use of antibiotics and the low usage demonstrated by U.S. trout farms, the potential impact is likely low.

There is a low risk of acute toxicity of OTC to nontarget organisms in receiving waters at the application rates assessed (Leal et al. 2018). For example, the 48h LC50 acute toxicity of OTC to the invertebrate *Artemia parthenogenetica* is 806 mg/L (Ferreira et al. 2007), which is quite unlikely to occur due to the considerable dilution and generally low application rates of antibiotics under U.S. regulatory controls and industry best management practices. Chronic toxicity (e.g., low exposure over longer periods) remains an unresolved concern that is a unique consideration to each receiving system (e.g., specific water chemistry, intermixing of discharges from other industries.). For instance, there is some concern for chronic toxicity to cause negative impacts to invertebrate (*Daphnia magna*) reproduction (Wollenberger et al. 2000), based on laboratory study.

Florfenicol is more likely to persist in the water column, with a much lower affinity for binding to particles, and the “fate of this antibiotic will be to a greater extent related to hydrodynamic processes such as dispersion and water mass transport by currents” (Jara et al. 2022). The medicated feed Aquaflor® is the FDA-approved method for delivery of florfenicol. Toxicity studies published within the FONSI conclude only transient effects to nontarget organisms (an algae, duckweed, and cyanobacterium) as a result of pond and flow-through raceway discharge, and no anticipated risk to other representative ecological species (USFDA 2012). It has been estimated that 70–80% of florfenicol antibiotic from medicated feed can enter the receiving environment, either via excretion or as a result of uneaten feed (Rico et al. 2012)(Romero et al. 2012)(Boyd & McNevin 2015). In an experimental setting using pure water at 8 °C, only 16 ± 8% of dissolved florfenicol was complexed (i.e., bound to ions) (Jara et al. 2022). The Aquaflor® FONSI reports that 33% will be “transiently bound to solids and feces under optimal conditions” (USFDA 2012). Despite disagreement in the amount of florfenicol likely to bind, a higher proportion of florfenicol relative to the amount administered to culture fish is likely to be discharged compared with OTC. It is important to keep in mind that florfenicol is used much less often in the U.S. rainbow trout industry than OTC (0.01 times per cycle compared to 0.37 times per cycle; see Table 7).

The environmental impacts of sulfadimethoxine/ormetoprim are much less clear; the 1984 environmental assessment that approved this drug states, “there appears to be no information available for predicting the effects [of Romet-30] on sediment (or soil) bacteria, protozoans, fungi, benthic crustaceans, worms, clams, snails or rooted aquatic macrophytic plants” (USFDA 1984). Still today, there is little information available for reliably predicting the effects of Romet-30® on bacterial and algal communities, though the literature is in congruence that the majority of Romet-30 discharged is mobile and bioavailable (Bakal 2001) (Sanders 2007). The original assessment concludes that any impacts to benthic fauna and microbial communities are likely to be short-term and intermittent (USFDA 1984). Based on the farms surveyed for this assessment, sulfadimethoxine/ormetoprim are rarely being used in the U.S. rainbow trout industry.

Three main uncertainties severely limit our understanding of antibiotic fate in the environment. Firstly, the literature of antibiotic toxicity in environments is limited primarily to the study of freshwater microalgae [with 60% of papers focusing on *Raphidocelis subcapitata* (Sharma et al. 2021)], which does not provide a holistic understanding of ecosystem impacts. Secondly, the systems of degradation present in natural environments are not accounted for in lab studies and limit the usefulness of extrapolating information. Thirdly, on-farm discharge concentrations of antibiotics during regimens of treated feed are not known, and any average based on annual usage of treated feed would not account for peaks in antibiotic discharge that result from targeted treatment regimens. Together, these uncertainties leave knowledge gaps in the fate of antibiotics discharged into the environment.

Short-term inhibitory effects will result in the repopulation of unaffected bacteria and algae, possibly including those that carry resistant/resistance genes. The occurrence of antibiotic resistance to all three of these drugs in water and sediments near aquaculture farms/industries has been well documented in various locations globally, and evidence of resistance is becoming more robust for freshwater systems (Cabello et al. 2013)(Gildemeister 2012)(Miranda 2012)(Sanders 2007)(Schmidt et al. 2000) (Stamm 1989). But, importantly, there is no evidence that the discharge of antibiotics or their residues from U.S. rainbow trout farms has resulted in the development of antibiotic-resistant bacteria or mobile resistant genes. Further to this, the trout industry has anecdotally made significant reductions in the application of antibiotics since last reporting, as a result of market acceptance and availability (i.e., only possible to be used now with a VFD), though no specific data are available to confirm this (pers. comm., Jeff Hinshaw October 2022). Farmers are aware that excessive or negligent use of antimicrobials/antibiotics is ineffective, expensive, wasteful, and can have deleterious effects on the farm microbiome; these factors have led to antimicrobials/antibiotics use only when required for serious disease (pers. comm., Dr. Jacob Bledsoe November 2022).

The total volumes of active ingredient applied at a subset of 14 farms in Idaho during 2021 (representing approximately 10,000 mt or 67% of production in raceways) are estimated to be

716.9 kg of oxytetracycline active ingredient (at an inclusion rate of 1.6 g/lb of active ingredient in medicated Terramycin 200® feed, as reported in USFWS 2019) and 8.26 kg of florfenicol (at an inclusion rate of 2.724 g/kg of active ingredient in medicated Aquaflor® feed, which is a precautionary estimation using the upper dosage indication for veterinary usage, as reported by Merck 2023). Using the known volumes of medicated feed supplied (ASC 2022), the label use requirements for each drug (Syndel 2023)(MerckUSA 2023), the literature cited above, and the publicly reported production volume of the farms, the relative usage of OTC is 71.7 g/mt rainbow trout harvested, and the relative usage of florfenicol is 0.83 g/mt harvest. Given that these data are from a single operator, there is some uncertainty as to the representativeness of this information across the industry, despite it being attributable to the majority of all raceway and pond trout production.

Other Treatments for Bacteria (not Antibiotics)

Immersion baths of select therapeutants (Chloramine-T and hydrogen peroxide; see Table 6) are also approved to treat disease related to bacterial infection. Chloramine-T degrades to chlorine that may be discharged in effluent. In Idaho, chlorine discharge concentration is regulated by WQBELs in place under the general NPDES permit system with an AML of 9 ug/L and MDL of 18 ug/L, which is a reduction from the 11 ug/L and 19 ug/L in previous issuances of the general permit (USEPA 2019—Idaho General Permit). It is worth noting that Chloramine-T is also used as a disinfectant that is then allowed to dry (similar to chlorine, below), in which case it is not likely to enter effluent and discharge. Hydrogen peroxide decomposes into oxygen and water, and its discharge is not required to be reported under general permit conditions in Idaho or North Carolina. But, the NPDES FONSI stipulates an acute benchmark of 0.7 mg/L, which local NPDES authorities can use at any time to place discharge limits on individual facilities if environmental conditions require it (e.g., receiving waters do not have adequate flow for dilution) (USFDA 2022). Chloramine-T (Halamid®) is occasionally used in a production cycle (0–2 times, depending on the occurrence of disease—varies from cycle to cycle and across life-stage) to treat bacterial gill disease (*Flavobacterium sp.*) via bath/immersion treatment (once-daily, 60-minute treatments for 3 days consecutively or alternating days), and hydrogen-peroxide is utilized on some farms in a similar fashion to Halamid® (pers. comm., Dr. Jacob Bledsoe November 2022).

Potassium permanganate ($KMnO_4$), a strong oxidizing agent, is used to treat bacterial gill disease (caused by *F. branchiophilum*) and external parasites, and is recognized in the Idaho General Permit as a likely discharge substance. Notably, it is not on the list of approved aquaculture drugs published by the FDA; however, it has “deferred regulatory status,” meaning that there is currently no regulatory action for the drug until further study is completed. It can be toxic to invertebrates living within ponds during treatment at concentrations that could potentially be met by operators using the recommended dosage of 2.5 times the potassium permanganate demand of their water (the estimated reducing agents present, which varies based on water chemistry) (Hobbs et al. 2006a). But, in an experimental mesocosm setting (i.e., simulated aquaculture pond), the effects of potassium permanganate to pond ecology at the recommended dosage were temporary and only lasted approximately 48 hrs (Hobbs et al. 2006b). In the U.S. rainbow trout industry, potassium permanganate is a commonly used treatment at an average application of 2.69 times/cycle (see Table 7). A flow-through concentration of 0.5–2 ppm (≈0.5–2 mg/L) in the treatment pond/raceway is diluted with a high volume of water from the rest of the farm into a settling pond(s) before discharge, which would greatly reduce the concentration in the effluent to likely below detection levels. The invertebrate species, *Daphnia magna*, has a 96 hr mean LC50 of 1.98 ± 0.12 mg/L in pond water treated with potassium permanganate, and other nontarget indicator species have higher values, ranging from an average of 2.39 to 13.55 mg/L (Hobbs et al. 2006a). It is unlikely that effluent entering receiving waters could reach acute toxicity concentrations for even the most sensitive indicator species (*D. magna*), given the amount of dilution before discharge.

Povidone iodine is a low-regulatory-priority drug used to treat incoming eyed eggs in static baths. It is used in such limited quantities within high volume flow-through of the overall operation that it is likely effectively diluted below detection.

Anti-parasites

Copper (a deferred regulatory status drug) is an anti-parasitic therapeutant for removal of ectoparasites delivered in an immersion bath. It can also be used as an anti-fouling agent, although this is not known to be done in raceways. It is not especially effective at reducing bacterial growth in trout raceways, and it is a serious ecological concern for toxicity in effluent or sediment disposal (Tom-Peterson et al. 2011). Complete prohibition of copper in aquaculture effluent is now in place in Idaho, based on the latest general permit update, which came into effect in 2019, and it is not in use in the trout industry in North Carolina (pers. comm., Jeff Hinshaw October 2022).

Formalin is approved for treatment of protozoa and trematode parasite species (see Table 6) in cold-water finfish at concentrations of 250 uL/L for 1 hr in tanks and raceways, and 15-25 uL/L indefinitely in earthen ponds (USEPA 2022). The FONSI requires tenfold dilution of finfish treatment water, not to exceed a formalin concentration of 25 ppm where effluent enters the environment (USEPA 2022). In raceways and ponds, the use of formalin is low and averages 0.02 times/cycle.

Herbicide/Pesticide Use

Chlorine is quite frequently used for general cleaning of supplies and equipment, and disinfection of holding facilities between cohorts. But typically, tanks and equipment are left to dry completely (further disinfection) before being used, which makes it quite unlikely for chlorine to be discharged in effluent (USEPA 2019—Idaho General Permit). Operators contacted for this report also listed branded cleaning and disinfection agents in their chemical lists, which are used according to label directions and in compliance with state discharge regulations.

Herbicide/pesticide application around earthen ponds may take place, although the federally regulated FIFRA label instructions are required to be followed, which correspond to EA evaluations done by federal authorities on the appropriate use of the chemical.

On-Farm Chemical Use (Net Pens)

Net pen construction uses Dyneema® and nylon, removing any concern for chemical release from the nets themselves as would be the case with copper mesh. A robust spill prevention and response plan is in place for the accidental release of chemicals or petroleum products associated with farm vessels.

Antibiotics are used only when prescribed by a veterinarian, and in accordance with all FDA requirements. All medicated feed is to be stored in labeled, leak-proof containers to minimize accidental use or leaching, as outlined in the farm's Pollution Prevention Plan. The antibiotics applied are the same as for raceways and ponds—oxytetracycline and florfenicol—both are listed as highly important for human medicine by the WHO (WHO 2019). Although florfenicol is used only in animal medicine, it may meet the conditions as a highly important antimicrobial for human medicine in limited geographies for treatment of specific conditions. Based on the average cycle length of 16–18 months (>1 year) for rainbow trout in net pens, a yearly metric for frequency is used. Antibiotic use was reported at 29.85 g/mt of harvested fish averaged over harvests for 2021 and 2022. The frequency of antibiotic treatments is 0.77 treatments annually (reflecting that some cohorts require zero antibiotics during grow-out) (pers. comm., Pacific Aquaculture March 2023).

In this open system, antibiotics excreted by fish enter the surrounding environment readily. The semi-closed nature of raceways and ponds that provide opportunities for settling is suggested to have a fundamental role in decreasing the discharge of chemicals (Rico et al. 2014). Natural processes such as photodegradation are likely important in the deactivation of antibiotics released into the water column from net pens (see discussion re: Leal et al. 2018 above, under Antibiotics), which is supported by the low turbidity in the waterway. But, light attenuation at depth in the system is not understood well enough to make any conclusion about the extent of photodegradation. Antibiotics sorbed to fecal or other organic matter in the water are expected to be dispersed downstream by the strong current and subjected to biological degradation (the processes of which are discussed in Antibiotics, above), though their final fate is unknown.

Strict requirements are in place for chemical usage and reporting through the farm's permits. The use of any Low Regulatory Priority (LRP) drugs (not appearing in the FDA Table 6) or potassium permanganate (deferred regulatory status) must be reported orally and in writing to the EPA and CCT Environmental Trust Department (USEP, 2020), and no use of either category was reported for this assessment.

No bath treatments are used during grow-out in the net pens, and there is no use of Chloramine T, Formalin, or potassium permanganate, as in raceways and ponds. Other chemical use during grow-out is limited to cleaning and anesthetic purposes. Tricaine methane-sulfonate (MS-222) is used for the temporary immobilization of fish to take sample weights. It is used per label instructions and at a frequency of approximately 60 times/year to track growth on various cohorts of fish (0.3–1.5 kg) at the farm sites, totaling only 0.75 kg of product use annually (pers. comm., Pacific Aquaculture October 2022). The Tribe has set restrictions that do not allow the use of either anesthetic or cleaning chemicals over the water in case of spillage, which removes the risk for these chemicals entering the environment.

Conclusions and Final Score

Raceways and Ponds

Robust regulatory guidance is available for farmers to select appropriate chemicals, and mitigation methods are used where possible to limit the frequency and/or total use of chemicals, such as using appropriate stocking densities, disinfection of tools and equipment between production areas, vaccinations, dietary additives (e.g., probiotics), and proactive approaches to fish health. The use of antibiotics at the largest producer in the country, which represents approximately 67% of total U.S. raceway and pond production, is limited to oxytetracycline at an estimated 0.37 treatments/cycle and florfenicol at 0.01 treatments/cycle, on average, and both are listed as highly important for human medicine by the WHO. Although florfenicol is used only in animal medicine, it may meet the conditions as a highly important antimicrobial for human medicine in limited geographies for treatment of specific conditions. Although the data used represent a significant portion of the total industry, there is uncertainty about how representative the data are of all farm scales of production in the U.S. trout industry, as well as the long-term fate of antibiotics that reach discharge waters.

Overall, the available data indicate that antibiotics are used on average less than once per production cycle (a score of 8); however, with uncertainty about the representativeness of these data, a precautionary approach is warranted. Given the flow-through nature of rainbow trout raceways and ponds and the physicochemical properties of these compounds, it is possible for bioavailable antimicrobials to be discharged and present in the receiving water body. Risk is mitigated by dilution, degradation, and intermittent judicious use with veterinary oversight. Both of the antimicrobials common to the trout industry (Aquaflor and Terramycin 200) have received Findings of No Significant Impact (FONSIs) from the EPA. Although there is some concern and evidence of developed resistance in receiving water bodies globally, there is no evidence that antibiotic use on U.S. trout farms has resulted in or contributed to resistance. Regulatory limits of chemical type and dose exist and are well enforced, though there are no legislated limits to total use. The final numerical score for Criterion 4—Chemical Use is 6 out of 10 for raceways and ponds.

Net Pens

Reliable data were available to confirm that the frequency of antibiotic usage (oxytetracycline and florfenicol) is 0.77 treatments annually for cycles harvested in 2021 and 2022 (consistent with a score of 8). The system demonstrates a low need for chemical treatments, with zero bath treatments administered during grow-out (baths are not possible in the high-flow environment). Given the flow-through nature of rainbow trout net pens and the physicochemical properties of these compounds, it is possible for bioavailable antimicrobials to be discharged and present in the receiving water body. Risk is mitigated by dilution, degradation, and intermittent judicious use with veterinary oversight; although there is some concern and evidence of developed resistance in receiving water bodies globally, there is no evidence that antibiotic use on U.S. trout farms has resulted in or contributed to resistance. Regulatory limits of chemical type and dose exist and are well enforced, though there are no legislated limits to total use. The final numerical score for Criterion 4—Chemical Use is 6 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

Raceways and Ponds

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	**0.849**	
F5.1b Source fishery sustainability score (0–10)		**8**
F5.1: Wild fish use score (0–10)		**7**
F5.2a Protein INPUT (kg/100 kg fish harvested)	**64.162**	
F5.2b Protein OUT (kg/100 kg fish harvested)	**15.700**	
F5.2: Net Protein Gain or Loss (%)	**–75.531**	**2.000**
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	**7.352**	**8.000**
C5 Feed Final Score (0–10)		**6.150**
Critical?	**No**	**Yellow**

Net Pens

C5 Feed parameters	Value	Score
F5.1a Forage Fish Efficiency Ratio	**1.031**	
F5.1b Source fishery sustainability score (0–10)		**8**
F5.1: Wild fish use score (0–10)		**7**
F5.2a Protein INPUT (kg/100 kg fish harvested)	**76.636**	
F5.2b Protein OUT (kg/100 kg fish harvested)	**15.700**	
F5.2: Net Protein Gain or Loss (%)	**–79.514**	**2.000**
F5.3: Species-specific kg CO_2-eq kg^{-1} farmed seafood protein	**8.105**	**8.000**
C5 Feed Final Score (0-10)		**6.000**
Critical?	**No**	**Yellow**

Brief Summary

Overall, the U.S. rainbow trout industry is still reliant on fishmeal and fish oil inputs to grow fish, though significant reductions have been made with a transition to more land animal and terrestrial crop proteins and oils over recent years. Trout feeds generally use nonmarine ingredients to provide the majority of the protein composition, and some diets also supply the majority of lipids from terrestrial sources. Feed is scored separately for raceways/ponds and net pens because of the significantly larger size that fish are grown to in net pens, and the associated higher eFCR, which is not representative of raceways/ponds.

The majority of fishmeal is sourced from whole fish (94% of the fishmeal used in the average aggregated feed composition), and a lesser 67.5% of fish oil is sourced from whole fish. This reflects that the feed industry is using a greater proportion of fish oil by-products than fishmeal by-products, likely the result of the complexities of sourcing fishmeal as a by-product.

For raceways and ponds, the FFER value for fishmeal is 0.8 and the FFER value for fish oil is 0.5, using an eFCR of 1.4. For diets that are commonly used in these systems, the sustainability of wild fish use is scored at 8, leading to an overall score for Factor 5.1 of 7.3. The net protein gain/loss is –75.531, which means that there is a net loss of protein during production, partly because of the relatively high average protein content of feeds over the entire life cycle (45.83%); this produces a score for Factor 5.2 of 2. There are 7.352 kg CO_2-eq produced per kg of farmed rainbow trout protein, scoring 8 for Factor 5.3. Factors 5.1, 5.2, and 5.3 combine to give a final Criterion 5—Feed numerical score of 6.15 out of 10 for raceways and ponds.

For net pens, the FFER value for fishmeal is 1.0 and the FFER value for fish oil is 0.6, which reflects the higher eFCR (1.7) that is most likely related to growing the fish to a larger final body size, thus requiring a greater amount of fish products to grow each mt of trout. The sustainability of wild fish use is scored at 8, which leads to an overall score for Factor 5.1 of 7. The net protein gain/loss is –79.514, which means that there is a net loss of protein during production, partly because of the relatively high average protein content of feeds over the entire life cycle (45.08%); this produces a score for Factor 5.2 of 2. There are 8.105 kg CO_2-eq produced per kg of farmed rainbow trout protein, scoring 8 for Factor 5.3. Factors 5.1, 5.2, and 5.3 combine to give a final Criterion 5—Feed numerical score of 6 out of 10 for net pens.

Justification of Rating

The specific ingredients used in aquaculture feeds—particularly their inclusion levels in each feed—and growth performance measures (e.g., feed conversion ratio) are seldom publicly available, because feed manufacturers and producers consider this information proprietary. Two feed companies that produce grow-out feeds for rainbow trout in the United States provided data for this assessment. For reasons of anonymity, these data have been aggregated and used as necessary in the calculations below; i.e., without attribution to any one feed company. The data, which are variable in completeness, included a list of feed ingredients used and the inclusion levels, and the sources of the marine ingredients (fishmeal and oil). Information from the literature and from publicly available certification audits was also used where appropriate.

Feed ingredients and inclusion levels

The data used to determine a representative feed composition were provided by two U.S. trout feed manufacturers for their standard trout grow-out diet. The ingredients and inclusion percentages have been aggregated to provide the best-fit feed formulation in Table 8. A weighted average was not possible due to the considerable uncertainty in market share representation, so a 50:50 average was used. The source fisheries for marine ingredients (fishmeal and fish oil) were obtained directly from two feed manufacturers as well as publicly available trout feed-composition information (ASC, 2022). The fishmeal and fish oil inclusion rates were derived from ranges provided by two feed manufacturers, which resulted in an average fishmeal inclusion of 14.5% and an average fish oil inclusion of 5%. By-product inclusion levels were provided directly from the manufacturers and were again aggregated and averaged between the two diets, providing an average fishmeal by-product inclusion of 0.91% and an average fish oil by-product inclusion of 3.4%.

Table 8: Best-fit feed formulation based on data provided by two trout feed manufacturers in the United States, averaged between the two because of considerable uncertainty in market share that precluded weighting by market share.

Ingredient	Aggregated or estimated inclusion level (%)
Fishmeal (from whole fish)	13.6
Fishmeal (from by-products)	0.9
Fish oil (from whole fish)	1.6
Fish oil (from by-products)	3.4
Corn gluten	16.8
Whole wheat	10.0
Corn: dried distillers grains	2.8
Soy oil	5.3
Wheat flour	12.5
Soybean meal	4.1
Poultry meal	17.5
Hydrolyzed feather meal	5.0
Poultry blood meal	3.0
Poultry fat	2.3
Vitamins and minerals/other	3.0
Total	**101.8**

Economic Feed Conversion Ratio (eFCR)

The feed conversion ratio is the ratio of feed given to an animal per weight gained, measured in mass (e.g., an FCR of 1.4:1 means that 1.4 kg of feed is required to produce 1 kg of fish). It can be reported as either biological FCR, which is the straightforward comparison of feed given to weight gained, or economic FCR (eFCR), which is the amount of feed given per weight harvested (i.e., accounting for mortalities, escapes, and other losses of otherwise-gained harvestable fish).

Raceways/Ponds

The use of a single FCR value to represent all raceways and ponds is challenging. The difficulty is rooted in the differences in fish genetics, feed formulations, farm practices, occurrence of disease, and more. Trout production globally has historically seen eFCRs in the range of 0.7 to 2.0, with the United States falling at the global average of 1.3 (Tacon and Metian 2008).

There is considerable advancement occurring in the feed formulation of trout diets. Leaders in the industry are incorporating emerging plant-based protein and oil ingredients that reduce the reliance on wild-forage fisheries for feed ingredients. Higher inclusions of plant-based proteins have been made possible through innovations in processing techniques that reduce anti-nutritional factors that previously limited the inclusion of proteins like soybean meal. Experimental diets tested in laboratory settings have achieved FCR values at or below 1:1. But, experimental formulations do not always translate to commercially successful diets.

Literature describing feed experiments that have tested the growth of rainbow trout on various permutations of ingredients, including those resembling the average feed composition used in the industry, is widely available—though it offers limited insight to commercial grow-out applications. Numerous studies have achieved eFCRs less than or equal to 1:1 (Choi et al. 2020)(Craft et al. 2016)(Tomás-Almenar et al. 2020)(Pirali et al. 2014)(Gaylord et al. 2018). But, such experiments typically use juvenile fish and are limited to a few weeks in duration. Juvenile fish have lower FCR than later adult stages; thus, a representative industry eFCR must consider information from the entire growth cycle, not only the juvenile stages. On-farm data are the most reliable source, though no raceway operators contacted for the assessment provided this information.

The experimental data that most closely describe the eFCR of adult fish during grow-out in the U.S. rainbow trout industry are provided in Voorhees et al. (2018). For the purpose of this report, the eFCRs of two individual diets tested in the study are averaged, because each has attributes resembling the average feed composition used in the U.S. rainbow trout industry. From a starting weight of ≈800 g, the fish were grown to 2.5–3 kg, with eFCRs of 1.30 ± 0.04 and 1.14 ± 0.03, averaging 1.22 ± 0.04. The final weight of 2.5–3 kg (5.5–6.6 lb) is a larger body size than the average harvest weight of 1.6 lb across the entire trout industry (USDA 2023), and this is considered in the final determination of a representative eFCR, which follows.

Typical farm eFCR ranges of 1.1 to 1.3 (North Carolina) and 1.2 to 1.8 (Idaho) were provided for the states that are representative of raceways and ponds in this assessment, with the majority in Idaho falling between 1.4 and 1.6 (pers. comm., Jeff Hinshaw November 2022)(pers. comm., Dr. Jacob Bledsoe November 2022). The final harvest size is a major factor in the eFCR, along with culture parameters and mortality events.

With an average estimated eFCR for Idaho of 1.5 (representing 67% of all raceways and pond production by volume) and an average for all other states at 1.2 (using the North Carolina estimate to represent the remaining fraction), the overall average eFCR for raceways and ponds is approximately 1.4. Therefore, based on all available information, an eFCR of 1.4 is used for raceways and ponds in this assessment.

Net Pens

The eFCR for net pens is 1.7. This was provided directly by the operator and likely reflects its product being grown to an average of 1.7 kg, a significantly larger size than the average U.S. rainbow trout grown in raceways and ponds.

Factor 5.1—Wild Fish Use

Factor 5.1 combines an estimate of the quantity of wild fish used to produce farmed rainbow trout with a measure of the sustainability of the source fisheries. Table 9 shows the data used and the calculated Fish Feed Equivalency Ratio (FFER) for fishmeal and fish oil.

Factor 5.1a: Forage Fish Efficiency Ratio (FFER)

The Forage Fish Efficiency Ratio (FFER) ratio for aquaculture systems is driven by the feed conversion ratio (eFCR), the amount of fish used in feeds, and the source of the marine ingredients (i.e., do the fishmeal and fish oil come from processing by-products or from whole fish targeted by wild capture fisheries).

Fishmeal and Fish Oil Inclusion

Fishmeal and fish oil inclusion levels (including the fraction of by-products) were obtained from information provided by two major U.S. feed manufacturers for their standard rainbow trout grow-out diets and are considered representative of the industry at large. Tables 9 and 10 (raceways/ponds and net pens, respectively) show the weighted average values (averaged 50:50 between companies, due to unknown market share). By using the standard yield values for fishmeal and fish oil from wild fish (22.5% and 5%, respectively, from Tacon and Metian (2008)), in addition to the eFCR for each system, the FFER values are calculated.

Table 9: Parameters used and their calculated values to determine the use of wild fish in feeding U.S. farmed rainbow trout in raceways and ponds.

Parameter	Data
Fishmeal inclusion level (total)	14.5%
Fishmeal inclusion level from whole fish	13.6%
Fishmeal inclusion level from by-product[2]	0.9%
Fishmeal yield	22.5%
Fish oil inclusion level (total)	5.0%
Fish oil inclusion level from whole fish	1.6%

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[2] Note that 5% of the by-product fishmeal inclusion (i.e., inclusion level × 0.05) is included in the FFER calculations.

Fish oil inclusion level from by-product[3]	3.4%
Fish oil yield	5.0%
Economic Feed Conversion Ratio	**1.4**
FFER fishmeal	0.8
FFER fish oil	0.5
Assessed FFER	**0.8**

Overall, from the eFCR and by-product inclusion rates discussed, the calculated FFER score is 0.8 for fishmeal and 0.5 for fish oil. The SFW methodology applies the higher of these two scores (in this case, fish oil), and it means that, from first principles, 0.8 mt of wild fish are required to produce 1 mt of cultured rainbow trout. This results in a final score for Factor 5.1a—Forage Fish Efficiency Ratio of 0.8 for raceways and ponds.

Table 10: Parameters used and their calculated values to determine the use of wild fish in feeding U.S. farmed rainbow trout in net pens.

Parameter	Data
Fishmeal inclusion level (total)	14.5%
Fishmeal inclusion level from whole fish	13.6%
Fishmeal inclusion level from by-product[2]	0.9%
Fishmeal yield	22.5%
Fish oil inclusion level (total)	5.0%
Fish oil inclusion level from whole fish	1.6%
Fish oil inclusion level from by-product[3]	3.4%
Fish oil yield	5.0%
Economic Feed Conversion Ratio	**1.7**
FFER fishmeal	1.0
FFER fish oil	0.6
Assessed FFER	**1.0**

Overall, from the eFCR and by-product inclusion rates discussed, the calculated FFER score is 1.0 for fishmeal and 0.6 for fish oil. The SFW methodology applies the higher of these two scores (in this case, fish oil), and it means that, from first principles, 1.0 mt of wild fish are required to produce 1 mt of cultured rainbow trout. This results in a final score for Factor 5.1a—Forage Fish Efficiency Ratio of 1 for net pens.

Factor 5.1b: Sustainability of the Source of Wild Fish

The data for sources of wild fish were collected from publicly available reports from trout industry operators (ASC 2022) and direct responses from two trout feed companies. All FishSource scores were obtained from its website on March 23, 2023. All source fisheries

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[3] Note that 5% of the by-product fish oil inclusion (i.e., inclusion level x 0.05) is included in the FFER calculations.

known to be used in these diets are listed in Table 11, along with the relevant scoring for this factor and the rationale behind the applied score.

Table 11: Important capture fisheries supplying U.S. rainbow trout feeds. FishSource scores are for management strategy, management compliance, fisher's compliance, current stock health, and future stock health, from left to right.

Target	Stock	Fish Source Scores	Stock Health Score	Fishery Certifications	SW Score	SW Score Rationale
North Pacific hake	NE Pacific	10, 10, 10	10, 9.7	MSC certified	10	MSC Platinum: fishery exceeds all reference points and has no significant concerns
NW Atlantic menhaden	NW Atlantic	≥8, ≥6, 9.7	9.1, 8.6	MSC certified, Certificates of Conformity provided by mill	8	FishSource scores all >8, SFW recommendation is to buy certified product; MSC Bronze: "Conditions have not been met as scheduled by MSC"
Gulf menhaden	Gulf of Mexico	≥6, ≥8, ≥6	8.7, 9.7	MSC certified	7	All FishSource scores at least ≥6 and ≥8 on "Stock Health"; MSC Bronze
Anchoveta	Southern Peru/ Northern Chile	<6, 6, 10	10, 10	No certifications	6	All FishSource scores ≥6, No MSC certification of SFW recommendation
Monterey sardine (South American pilchard)	FAO 77, Gulf of CA specifically	≥6, ≥6, ≥6	≥8, 6	MSC certified	8	All FishSource scores at least ≥6 and ≥8 on "Stock Health"; MSC Gold: "No conditions have been set at the time of the certification or all conditions have been met and closed during the surveillance audits."
Alaskan pollock oil and meal by-products	FAO 67, Gulf AK and Bering Sea	10, 10, 10	9.5, 10	MSC certified	10	MSC Platinum: fishery exceeds all reference points.

Note that not all these fishery sources appear in the representative composition. For some feed manufacturers that did not contribute to the total composition data, fishery sources were publicly available. Only the fishery sources that contribute to the representative composition appear in the scoring.

The score for Factor 5.1b—Sustainability of the Source of Wild Fish is 8 out of 10 for both raceways/ponds and net pens. Overall, this reflects that the fishery products used in U.S. trout feeds are generally sourced from well-managed stocks.

For raceways and ponds, when combined, the Factor 5.1a and Factor 5.1b scores result in a final Factor 5.1 score of 7.30 out of 10. For net pens, when combined, the Factor 5.1a and Factor 5.1b scores result in a final Factor 5.1 score of 7 out of 10.

Factor 5.2—Net Protein Gain or Loss

Data on the total feed protein content provided by two feed companies (supplemented by information available on their websites) show a range of protein contents across different types and sizes of feed, from 44% to 55% (Rangen 2023)(Skretting 2023). Starter feeds (used in low quantities for small fish) have the highest protein levels compared to the larger grow-out feeds that represent the bulk of the total feed to harvest. These feed company data, combined with estimated feeding schedules (e.g., starter feed for 2 months, grow-out feed for 10+ months), allow the calculation of a weighted average feed protein content for 2022 (across both feed companies and all feed sizes) of 45.8% for raceways and ponds, and 45.1% for net pens (see Appendix 3 of the Seafood Watch Standard for Aquaculture for details).

In a study of the body composition of rainbow trout, Dumas et al. (2007) reported a whole-body protein content of fish weighing <1,580 g of 15.7%. This is similar to the value of 15.6 reported by Boyd et al. (2007). The value 15.7% is used here.

Therefore (as displayed in Table 12), 1 mt of feed contains 458 kg of protein, and 1.4 mt of feed is used to produce 1.0 mt of farmed rainbow trout in raceways and ponds; therefore, the net protein input per mt of farmed rainbow trout production is 641.6 kg. With only 157 kg of protein in 1 mt of harvested whole rainbow trout, there is a net loss of 75.5% protein. This results in a score of 2 out of 10 for Factor 5.2 for raceways and ponds.

Table 12: Values used to calculate net protein gain or loss in raceways and ponds.

Parameter	Data
Protein content of feed (%)	45.8
Protein content of whole harvested rainbow trout (%)	15.7
Economic Feed Conversion Ratio	1.4
Total protein INPUT per mt of farmed rainbow trout (kg)	641.6
Total protein OUTPUT per mt of farmed rainbow trout (kg)	157.0
Net protein gain or loss (%)	**–75.5% loss**
Seafood Watch Score (0–10)	2

For net pens, 1 mt of feed contains 451 kg of protein, and 1.7 mt of feed is used to produce 1.0 mt of farmed rainbow trout in net pens; therefore, the net protein input per mt of farmed rainbow trout production is 766.7 kg. With only 156 kg of protein in 1 mt of harvest whole rainbow trout, there is a net loss of 79.0% protein. This results in a score of 2 out of 10 for Factor 5.2 for net pens.

Table 13: Values used to calculate net protein gain or loss for net pens.

Parameter	Data
Protein content of feed (%)	45.1
Protein content of whole harvested rainbow trout (%)	15.7
Economic Feed Conversion Ratio	1.7
Total protein INPUT per mt of farmed rainbow trout (kg)	766.7
Total protein OUTPUT per mt of farmed rainbow trout (kg)	157.0
Net protein gain or loss (%)	**–79.0% loss**
Seafood Watch Score (0–10)	2

Factor 5.3—Feed Footprint

This factor is an approximation of 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[4] to estimate the global warming potential (GWP) of 1 mt of feed, followed by multiplying this value by the eFCR and the protein content of whole harvested seafood. To get a single value that is representative of all three feed types, a weighted average based on the percentage of feed use is then calculated. The detailed calculation methodology can be found in Appendix 3 of the Seafood Watch Aquaculture Standard.

Table 14 shows the ingredient categories selected from the GFLI database according to the above methodology. 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.

Table 14: Estimated embedded global warming potential of 1 mt of a typical U.S. rainbow trout feed.

Feed ingredients (≥2% inclusion)	GWP (incl. LUC) Value (kg CO_2-eq/ton product)	Ingredient inclusion %	kg CO_2-eq/mt feed
Fishmeal from whole fish	Fishmeal, from Atlantic menhaden, at processing/US Economic S	7.25%	**58.50**
	Fishmeal, from South American pilchard (sardine), at processing/US Economic S	6.35%	**77.76**
Fishmeal from by-products	Alaskan pollock meal by-product	0.90%	**9.12**
Fish oil from whole fish	Fish oil, from South American pilchard (sardine), at processing/US Economic S	1.63%	**19.92**
Fish oil from by-products	Alaskan pollock oil by-product	3.38%	**39.84**
Vegetable/crop ingredient(s)	Maize gluten meal, dried, at processing/US Economic S	16.75%	**137.81**
	Wheat grain, dried, at storage/US Economic S	10.00%	**60.06**

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[4] http://globalfeedlca.org/gfli-database/gfli-database-tool/

	Maize distillers grains, dried, at processing/US Economic S	2.75%	**18.44**
	Crude soybean oil (pressing), at processing/US Economic S	5.25%	**45.46**
	Wheat flour (USA)	12.50%	**93.04**
	Soybean meal (solvent), at processing/US Economic S	4.13%	**22.28**
Land Animal Ingredients	Animal meal, poultry, at processing/RER Economic S	17.50%	**141.85**
	Feather meal, from dry rendering, at processing/RER Economic S	5.00%	**38.30**
	Blood meal, from poultry, at processing/RER Economic S	3.00%	**28.64**
	Poultry fat, from dry rendering, at processing/RER Economic S	2.25%	**20.63**
Alternative Ingredients	None used in significant enough quantities to score.	0.00%	**0.00**
Other	Total minerals, additives, vitamins, at plant/RER Economic S	3.00%	**26.71**
Sum of Total		**101.62%**	**838.36**

As can be seen in Table 14, the estimated embedded GWP of 1 mt of a typical rainbow trout feed is 838.36 kg CO_2-eq.

For raceways and ponds, considering a whole fish protein content of 15.7% and an eFCR of 1.4, it is estimated that the feed-related GWP of 1 kg farmed rainbow trout protein grown in raceways and ponds is 7.352 kg CO_2-eq. This results in a score of 8 out of 10 for Factor 5.3—Feed Footprint for raceways and ponds.

For net pens, considering a whole fish protein content of 15.7% and an eFCR of 1.7, it is estimated that the feed-related GWP of 1 kg farmed rainbow trout protein grown in raceways and ponds is 8.105 kg CO_2-eq. This results in a score of 8 out of 10 for Factor 5.3—Feed Footprint for net pens.

Conclusions and Final Score

Overall, the U.S. rainbow trout industry is still reliant on fishmeal and fish oil inputs to grow fish, though significant reductions have been made with a transition to more land animal and terrestrial crop proteins and oils over recent years. Trout feeds generally use nonmarine ingredients to provide the majority of the protein composition, and some diets also supply the majority of lipids from terrestrial sources. Feed is scored separately for raceways/ponds and net pens because of the significantly larger size that fish are grown to in net pens, and the associated higher eFCR, which is not representative of raceways/ponds.

The majority of fishmeal is sourced from whole fish (94% of the fishmeal used in the average aggregated feed composition), and a lesser 67.5% of fish oil is sourced from whole fish. This reflects that the feed industry is using a greater proportion of fish oil by-products than fishmeal by-products, likely because of the complexities of sourcing fishmeal as a by-product.

For raceways and ponds, the FFER value for fishmeal is 0.8 and the FFER value for fish oil is 0.5, using an eFCR of 1.4. For diets commonly used in these systems, the sustainability of wild fish use is scored at 8, which leads to an overall score for Factor 5.1 of 7.3. The net protein gain/loss is –75.531, which means that there is a net loss of protein during production, partly because of the relatively high average protein content of feeds over the entire life cycle (45.83%); this produces a score for Factor 5.2 of 2. There are 7.352 kg CO_2-eq produced per kg of farmed rainbow trout protein, scoring 8 for Factor 5.3. Factors 5.1, 5.2, and 5.3 combine to give a final Criterion 5—Feed numerical score of 6.15 out of 10 for raceways and ponds.

For net pens, the FFER value for fishmeal is 1.0 and the FFER value for fish oil is 0.6, which reflects the higher eFCR (1.7) that is most likely related to growing the fish to a larger final size, thus requiring a greater amount of fish products to grow each mt of trout. The sustainability of wild fish use is scored at 8, leading to an overall score for Factor 5.1 of 7. The net protein gain/loss is –79.514, which means that there is a net loss of protein during production, partly because of the relatively high average protein content of feeds over the entire life cycle (45.08%); this produces a score for Factor 5.2 of 2. There are 8.105 kg CO_2-eq produced per kg of farmed rainbow trout protein, scoring 8 for Factor 5.3. Factors 5.1, 5.2, and 5.3 combine to give a final Criterion 5—Feed numerical score of 6 out of 10 for net pens.

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

Raceways and Ponds

Escape parameters	Value	Score
F6.1 System escape risk (0–10)	6	
F6.1 Recapture adjustment (0–10)	0	
F6.1 Final escape risk score (0–10)		6
F6.2 Competitive and genetic interactions (0–10)		9
C6 Escape Final Score (0–10)		**7**
Critical?	NO	**GREEN**

Net Pens

Escape parameters	Value	Score
F6.1 System escape risk (0–10)	6	
F6.1 Recapture adjustment (0–10)	0	
F6.1 Final escape risk score (0–10)		6
F6.2 Competitive and genetic interactions (0–10)		9
C6 Escape Final Score (0–10)		**7**
Critical?	NO	**GREEN**

Brief Summary

Raceways and Ponds

Although there is low to moderate risk of escapes from well-constructed and sited facilities, escapes are occurring from raceway and pond systems, as documented in aggregated food fish and distribution production data from USDA Trout Surveys. All the compiled evidence suggests that the number of potential escapes from flow-through rainbow trout production facilities poses no significant risk of additional ecological impacts, when considering the volume of effectively identical fish released into the same waters over the past century by state hatcheries. Escaped farmed rainbow trout are likely to exhibit similar behavior, experience similar mortality rates, and are genetically similar (if not identical) to intentionally stocked trout. There are cases of genetically pure native trout species existing in watersheds where commercial trout aquaculture is located, which provides a nonzero potential for impact of escapees. It is known that escapes from aquaculture facilities can and do happen; although unlikely, these fish may be capable of competing, and in some cases hybridizing, with wild populations. Factors 6.1 and 6.2 combine to give a final numerical score for raceways/ponds of 7 out of 10 for Criterion 6—Escapes.

Net Pens

The net pen operation is an open system with a documented track record of no escapes in the past 10 years, and the farm construction and management goes beyond best management practices. The net pen operation has active procedures in place in case of a large escape event (release of 1,500 or more fish >1 kg or 3,000 or more fish <1 kg), which would trigger a recapture plan to be approved by the Tribal Fish and Wildlife Department. The farm stock is sterile, and there is no genetic risk from escapes. There is no risk to threatened species, as provided in evidence from government reporting of critical habitat and surveys of fish populations in the waterway. But, a remote risk of competition with native salmonids exists in the event of a catastrophic escape in an open system. Restoration of the anadromous Pacific salmon corridor above the lower dam of the reservoir has been tested by using fish-passage tubing technology, and efforts are ongoing to reintroduce salmon to the Upper Columbia River Basin. If passage of anadromous salmon becomes permissible into the impounded waterway, a re-evaluation of impacts in that context will be warranted. Factors 6.1 and 6.2 combine to give a final numerical score for net pens of 7 out of 10 for Criterion 6—Escapes.

Justification of Rating

Factor 6.1. Escape risk

Escape records (Raceways/Ponds)

There is no requirement in either the Idaho or North Carolina General NPDES Permits for the monitoring or reporting of escaped fish by self-report or by government agent, and there is no searchable public government database for commercial escape events. But, self-reported "flood" and "other" loss data from producers are collected by the USDA in its annual Trout Production survey (Table 15) and can be used for a worst-case estimation. In instances of losses due to flood, it is possible that individuals survive and find their way into nearby water bodies. The "other" losses may include some unknown proportion of escapes, though a significant proportion of "other" losses are likely actually due to other losses, such as dam failure (pers. comm., Gary Fornshell August 2016). In addition, because of the difficulty in estimating actual stocking rates, it is possible that the number of fish is overestimated at the time of stocking; therefore, the number of true losses is smaller than what is reported and is known as "disappearing inventory" (pers. comm., Gary Fornshell August 2016). These USDA data have limitations in that they are aggregated to all size classes, so the number of fish estimated to escape will be higher than what may have occurred, because the values not only are for commercial food fish, but also include losses from hatcheries of fish intended for distribution programs. Also, because of limitations in the available data, the ultimate fate of these fish and the precise number of escapes is unknown. For these reasons, the actual percentage of escapes is likely a great deal less than the estimation presented here.

Anecdotally, flooding losses occur rarely in Idaho, where roughly 67% of U.S. raceway and pond production takes place. Though major producers have not seen catastrophic escape losses in over 25 years, some farms in the state had their lowest raceways inundated during a historic 100-year flood event in 1997 (pers. comm., Gary Fornshell August 2016) (pers. comm., Randy MacMillan August 2016). There have been no notable escape events in Idaho in recent history (pers. comm., Dr. Jacob Bledsoe November 2022).

Table 15: Estimated losses (mt) in U.S. trout industry due to flooding and other causes (all production methods aggregated). Data from (USDA 2023).

Year / mt of Fish	2018	2019	2020	2021	2022	5-Year Avg.
Trout lost to flooding (aggregated, all size classes)	69	108	178	186	65	121
Trout lost to other (aggregated, all size classes)	29	296	244	1,034	669	454
Total lost to flooding or other	98	404	421	1,220	734	575
Total Production (mt)						
Total fish sold (mt; food-fish size class)	21,564	23,110	20,187	20,324	19,617	20,960
Total losses (mt; all causes)	3,434	4,639	4,222	3,579	4,348	4,044
Grand Total (mt; harvest + loss due to all causes)	24,998	27,749	24,410	23,902	23,965	25,005
Estimated* percentage loss due to flooding + other of total annual production	0.4%	1.5%	1.7%	5.1%	3.1%	2.3%

*Percentage loss is conservatively inflated because the data for flood and other loss are aggregated (all size classes in one value), whereas the annual production is only of the food-fish size class.

The 5-year average losses due to flooding and other causes is 2.3% (or 1,513,000 fish, as reported by USDA, based on a 5-year annual production average), which represents a worst-case escape rate. This number is affected by heavy losses in 2019–22, which are again not all necessarily attributable to escapes, but it is not possible to resolve due to limitations in the data. The significantly higher "Other" losses value in 2021 may be a result of fish donated from farms that were not able to be sold during the pandemic (pers. comm., Anonymous (industry) 2023); however, USDA NASS (the collector and publisher of the annual Trout Survey data) declined to provide any analysis of the data when contacted to resolve this high value. Over the past 10 years, similar or higher losses have been recorded in these categories, and the values over 2019–22 do not indicate an escalating trend at the present time.

Escape records (Net Pens)

For net pens, no escape events have been recorded in the past 10 years, as provided by self-reported farm records. In the event of an escape, immediate reporting to the relevant environmental authorities is required (Tribal Departments of Fish and Wildlife, Environmental Trust, and Police, as well as the state Department of Health if medicated fish are released). This provides a reliable system of data collection and accountability.

Management Practices to Prevent Escapes (Raceways/Ponds)

U.S. trout farms have multiple fail-safe procedures to prevent escapes from raceways, and it is in their best business interests to prevent escapes. This generally includes screens: one screen separating production tanks from quiescent zones, and a second screen separating any quiescent zone from the settling pond. The settling pond effectively acts as a final capture site for any escapes, though it is highly unlikely that fish would reach that point, given the routine monitoring best management practices (BMP) for checking quiescent zones, promptly removing any fish, and repairing any damaged screens. Additional BMPs provided by farms in the preparation of this report included the ubiquitous presence of bird netting to minimize escapes from avian predation attempts, and harvest procedures that minimize any risk of escape (use of appropriately sized nets, crowders, and other gear that is kept in working order).

In Idaho, Department of Agriculture authorities inspect the upstream and downstream exclusions (i.e., structures designed to prevent fish movement in/out of farm) to make sure there are no ways for wild fish to enter farms, and no ways for fish to exit with discharge into receiving waters (pers. comm., Dr. Jacob Bledsoe September 2022). This is part of the Idaho State Department of Agriculture’s fish-rearing license process (applicable to all farms regardless of size), which stipulates that there must be an inspection by a livestock investigator to minimize the risk of escapes [authorized by the Idaho Department of Fish and Game (Title 36 “Fish and Game”) and ISDA (Title 22, Chapter 46 “Fish Farms”)]. Each farm’s Commercial Fish Farm license must be renewed every other year, and all new and/or renewing facilities are investigated by an ISDA Livestock Investigator (pers. comm., Dr. Jacob Bledsoe February 2023), thus providing a frequency of inspection of at least once every other year.

Management Practices to Prevent Escapes (Net Pens)

The net pen operation goes beyond best management practices in farm construction and operations, to minimize escape events. Construction includes the use of top netting on the fish pens, double paneling around the bottom perimeter of the nets, lines that extend from the surface of nets to anchor points on the opposite side to stabilize them, and a double net around the water line 0.5 m above and below the surface to protect against floating debris strikes. Special attention is given to the scheduled replacement of upstream mooring lines, an upstream debris barrier is in place, and the staff conducts daily visual inspection of the upstream netting for debris that could damage the netting or lines. Operational procedures are in place to minimize escapes during juvenile transfers, swim overs (movement of fish between pens with minimal handling), grading, counting, and harvesting. These operational procedures include only conducting such events with suitable weather/water conditions, constant supervision, testing of all transfer hoses before events, and final inspections to ensure the containment of fish. On-farm monitoring for escapes takes place daily, and records are maintained for a minimum of 5 years.

A significant fish escape and response plan is in place to 1) minimize the extent of any potential escape event, 2) properly notify relevant authorities, and 3) recapture the fish in compliance with relevant regulations. This includes having divers available for emergency repairs in the event that any net breach is discovered that could result in escapes (preventative), as well as procedures to minimize losses without divers in the event of an emergency (i.e., blocking fish passage using available netting materials and/or altering the pen shape to prevent fish access to the hole).

Fish recapture would be done in coordination with the Tribal Department of Fish and Wildlife, which would develop a recovery plan if a significant escape event were to occur, and the farm would be required to provide a recovery report within 5 days of completing their recapture efforts. There have been no escape/recapture events at the farm site in the past 10 years to determine a recapture adjustment, so none is applied.

Susceptibility to Flooding (Raceways and Ponds)

Flooding events are the greatest concern for escapes in raceways and ponds because they are generally constructed near water sources, where less pumping and discharge infrastructure is required. In the absence of extreme external forces (e.g., flooding), ponds and raceways have a low inherent risk of escapement because they are separated from natural water bodies by barriers and screens (Fornshell and Hinshaw 2008). As seen in Figure 6, an aerial image of a large trout farm in Idaho, the entire production system is separated from the receiving water body by concrete, which leaves the discharge outflows as the only realistic pathway to escape and survive (in the absence of extreme external forces).

Figure 6: Aerial image of a large trout farm in the Hagerman Valley, Idaho. Note the discharges (whitewater) into the Snake River, whereas the raceways are surrounded by concrete.

Not all waterways used for production of trout are prone to the levels of flooding that would allow escapes, so the threat is not equal for all facilities. In Twin Falls County, Idaho, flooding is ranked as a “medium” hazard that happens to some extent every 1 to 2 years, and it can be incited by natural activity (e.g., heavy rainfall, snowmelt, ice jams) or human activity (e.g., dam, canal, or levee failure; clearing vegetation), but it is most often caused by spring snowmelt (TFC 2020). Several Idaho trout farms are close to the boundary of the 100-year floodplain of the Snake River, although no county-specific discussion to the threat to any commercial industries (aquaculture or other) is made in the Hazard Mitigation Plan (TFC 2020), suggesting minimal risk. The severity of flooding can be variable, based on factors like topography, soils, and vegetation; depth, rate, and velocity of water; and the construction of developed areas (TFC 2020). The county estimates that, “based on past events, the probability that significant flooding will occur in a given year is 30% and can be expected to occur every 3.3 years” (TFC 2020). That said, no large escape events from Idaho raceways have been documented publicly, and a large proportion of U.S. trout farms have been evaluated to be in areas not prone to flooding.

In North Carolina, rivers are prone to large flooding events. In 2021, there was a catastrophic flooding event on the Pigeon River (from a tropical storm) that resulted in operator-reported losses of ≈70,000 lb of trout from a pond facility (Hodge 2021), as well as from a state wildlife hatchery. The commercial pond facility was not rebuilt, and because there are now no longer any pond facilities in operation in North Carolina (pers. comm., Jeff Hinshaw October 2022), the potential for flood losses has been reduced to raceway facilities, which take higher water levels to flood out because of their higher walls (thus, they are less likely to flood).

Based on the typical system design of raceways (i.e., single-pass flow-through) and the possibility of escape from pond and raceway systems associated with flooding and other events, rainbow trout farms are considered to be moderate risk systems. But, escape prevention measures are in place and escape events appear to be exceptionally rare. Water discharged from farms typically passes through multiple screens and grates (at the beginning and end of every raceway and settlement basin) in Idaho (≈56% of all U.S. production and 67% of raceway and pond production), and every raceway is fully covered in bird netting (Fornshell and Hinshaw 2008) (pers. comm., Dr. Jacob Bledsoe November 2022) (pers. comm., Randy MacMillan August 2016). Also, all settlement basins in Idaho are required to be fish-free by the EPA, so these are generally fenced in addition to having grates at the influent to prevent fish from entering, and these are regularly monitored (USEPA 2007) (pers. comm., Randy MacMillan August 2016). These escape prevention methods significantly mitigate the risk of escape, resulting in the low worst-case scenario escape percentage estimations detailed above.

Factor 6.1 Summary and Scoring

Raceways and Ponds

Raceways are a “moderate” concern system, according to the Seafood Watch Standard for Aquaculture. Ponds with low daily exchange exist that discharge at harvest into settling ponds (a best management practice), with some locations in the U.S. assumed to have vulnerability to flooding events because of the need for proximity to water sources. Thus, ponds are consistent with a “moderate” concern system as well. Both raceways and ponds have multiple or fail-safe escape prevention methods, or active best management practices for design, construction, and management of escape prevention (biosecurity) in place. Escapes of raceway and pond farmed rainbow trout because of flooding have occurred within the past 5 years, which are published in the annual USDA trout survey data. The score for raceways and ponds Factor 6.1 is 6 out of 10.

Net Pens

The net pens are an open system with a documented track record of no escapes in the past 10 years. The operation goes beyond best management practices and is considered a “moderate” concern system. The net pen operation has protocols in place in case of a large escape event (release of 1,500 or more fish >1 kg or 3,000 or more fish <1 kg) that would trigger a recapture plan to be approved by the Tribal Fish and Wildlife Department; however, because no escape events have occurred, no such recaptures have either, so no adjustment is applied. Robust data on escape records, while not independently verified, indicate that escapes (catastrophic or trickle) have not occurred in the past 10 years, and that this “moderate” concern system uses active BMPs for design, construction, and management of escape prevention (biosecurity). The score for net pens for Factor 6.1 is 6 out of 10.

Factor 6.2. Competitive and Genetic Interactions

Trout genetics programs have been in operation for many decades in the U.S., with prominent U.S. commercial suppliers selling trout eggs both domestically and globally. For example, one of the previous leaders of trout genetics in the U.S., Troutlodge (whose leading position has since been overtaken by Riverence Brood), has been in operation since 1945 (roughly 80 years). Assuming a generation every 2 years since their inception, commercial aquaculture trout genetics from the facility are now about 40 generations domesticated. Phenotypically, domesticated rainbow trout exhibit many of the same basic traits as wild fish, though it may be possible to tell differences in coloration from differences in diet, and to tell differences in body shape and fat distribution from the selection for growth characteristics and the feed regimen of commercial fish.

Many seed stock providers are certified disease-free or, if not officially certified, are taking extreme efforts to ensure that all broodstock are free of major pathogens, such as infectious hematopoietic necrosis virus (IHNV), to reduce or eliminate vertical transmission. There are also regulatory checks that differ by state. For example, in Idaho, any facilities that export eggs across state lines (i.e., most hatcheries) are required to pass mandatory broodstock disease testing (pers. comm., Dr. Jacob Bledsoe November 2022). The requirements for importing fish into Idaho are outlined in IDAPA 02.04.21—Rules for Governing Importation of Animals. In addition, as provided by personal communication with Dr. Jacob Bledsoe (February 2023):

> *All fish or viable hatching eggs imported into the state of Idaho requires (1) an authorization permit from the Idaho State Department of Agriculture, (2) permitting and certification from the Idaho Dept. of Fish and Game, (3) an invoice or bill of lading describing the origin, species, inventory, lot number and destinations of the fish/egg shipment, as well as (4) one of the following certifications listed below.*
>
> - *Certificate of Veterinary Inspection from the state of origin:*
> - *US Fish and Wildlife Title 50 Certification: "Oncorhynchus masou virus (OMV), and the viruses causing viral hemorrhagic septicemia (VHS), infectious hematopoietic necrosis (IHN), and infectious pancreatic necrosis (IPN) have not been detected in viral assays of fish lot(s) of origin of eggs or fish."*
> - *American Fisheries Society Certified Fish Health Inspector Certification:*
>
> *In addition, no fish or viable eggs may be imported from areas known for VHSV (viral hemorrhagic septicemia virus) positive area, without additional authorization and permitting from the IDFG.*
>
> *Any live fish or eggs produced in Idaho and shipped to other US states would be subject to the respective states' importation permitting, which typically follow a similar set of regulations, if not more stringent, as described above for importation into ID.*

Native Classification and Stocking of Conspecifics

Rainbow trout is considered a native species for the purposes of this report; the majority of U.S. trout production occurs in states where it is native, such as Idaho, Washington, and California. Also, rainbow trout has been purposefully (and successfully) introduced all over the world (FAO

2016a)(Okumus 2002) and is now fully ecologically established and/or maintained by stocking throughout much of the U.S. (Fuller et al. 2013) (Fausch 2008). Beginning in the 1870s, rainbow trout has been continuously introduced throughout North America by stocking programs to enhance recreational fishing, and it has since become naturalized in large swaths of its nonnative range east of the Rocky Mountains, around the Great Lakes region, and through most of the Appalachian Mountains (Fausch 2008), including present-day commercial production regions in North Carolina.

The Idaho Department of Fish and Game (IDFG) keeps historical records of restocking events that include 20,544 rainbow trout stocking events (ranging from a few hundred fish to thousands of fish released in each event) in the Magic Valley alone, which do not include the additional stocking by IDFG of selectively bred strains and hybrids like Yellow or Golden Rainbow Trout, Rainbow x Cutthroat Triploids, and Rainbow-Hayspur Triploids (IDFG, 2022b). In North Carolina, rainbow trout are stocked annually in natural water bodies, mainly from April to July, though the stocking event totals are less accessible than the data available from IDFG (NCWRC 2022). In Idaho, Rufus Woods Lake in the Columbia River has been, and continues to be, intentionally stocked with hatchery-reared rainbow trout, with ≈40,000 stocked last year (pers. comm., Pacific Aquaculture October 2022). In the context of a farm escape comparison, a significant fish escape event that would trigger the farm response plan and recapture efforts in coordination with the Tribal Fish and Wildlife would be a release of only 1,500 or more fish >1 kg or 3,000 or more fish <1 kg (pers. comm., Pacific Aquaculture October 2022).

In fact, the total number of trout distributed (released alive for the purposes of conservation, stocking, and recreation) in 2023 totaled 115,610,000 (USDA 2023), which dwarfs the maximum possible number of escapes from commercial food-fish trout farms. The USDA database that this information is sourced from only includes private, for-profit businesses that are producing fish for stocking, and does not capture fish distributed by public agencies. The amount of rainbow trout distributed by public agencies is likely many times greater than that reported from private businesses by USDA, based on an analysis of past public agency distribution activities (Halverson 2008). The worst-case scenario of escapes on the last 5-year average, 1,513,000 fish, represents roughly 1% of total trout distributed in the USDA dataset. Thus, it is crucial to consider the risk of ecological impact within the scope of impacts already caused by intentionally released hatchery fish.

Typically, hatchery fish are “more aggressive, use less energetically profitable holding and feeding positions, consume less food, and are less wary of predators” as a result of selective factors in captive environments (Meyer et al. 2012). These factors are likely to put hatchery trout at a competitive disadvantage relative to wild trout; multiple studies have shown hatchery trout survival to be low, with up to 85% mortality within 30 days and near 95% mortality within 1 year (High and Meyer 2011). In one study within North Carolina state park streams, of 163 trout marked with an adipose fin clip in October 2008, only a single marked fish was recaptured in April 2009 surveys, representing <1% survival (Wallace 2010). More recent work in Southern Appalachian streams has described less mortality of stocked rainbow trout (proportions as low as 0.01 from October to June) and suggested that a greater proportion of loss is due to emigration from the release point, based on field measurements and computer modeling; however, the authors acknowledge the considerable sampling limitations of detecting PIT-tags of dead trout that were crucial to logging the mortalities (Flowers et al. 2019). The overwhelming majority of evidence suggests quite low survival of hatchery-reared trout. Escapees from commercial operations are raised in effectively identical conditions to trout that are distributed, and are likely to experience similar mortality in receiving waters.

Historically, stocked rainbow trout have been fertile, diploid fish. It was only relatively recently (late 1990s) that state programs in Idaho and North Carolina began stocking sterile, triploid adult fish into water bodies, to mitigate the potential genetic impacts of fertile hatchery fish interbreeding with wild populations (IDFG 2019)(NCWRC 2013). California, the third-largest producer of farmed rainbow trout, only began stocking triploid rainbow trout for recreation in 2013 (CDFG 2021). Many states still stock fertile rainbow trout (WDFW 2022)(ODFW 2022), including Idaho, where younger fertile trout (<10 in) will be stocked when “no genetic risk to native trout” is determined (IDFG 2019). Historic stocking practices have resulted in the widespread introgression of hatchery rainbow trout genetics into wild populations via inter- and intra-specific breeding (McKelvey et al. 2016)(Meyer et al. 2014)(Kozfkay et al. 2011).

In their efforts to stock only sterile fish, state hatcheries often produce triploid eggs from in-house broodstock, but they will also purchase triploid eggs from the same suppliers that supply commercial food-fish producers (IDFG 2019)(NCWRC 2013) (pers. comm., Gary Fornshell August 2016) (pers. comm., Jeff Hinshaw August 2016). There is little, if any, genetic difference between eggs purchased from private suppliers by commercial producers and state hatcheries; for example, Idaho has historically stocked strains identical to those used in commercial production and has a history of purchasing private triploid eggs based on availability, regardless of genetic strain (Kozfkay et al. 2011) (pers. comm., Gary Fornshell August 2016) (pers. comm., Jeff Dillon August 2016). Genetics from a state’s own rainbow trout broodstock (i.e., not from a private supplier) may not be subjected to intentional selective breeding for performance characteristics, and thus may be genetically different than those grown for commercial culture. It is important to note that inducing triploidy, either by heat or pressure treatment, is not 100% effective; often, it results in <1–4% fertile fish being distributed (i.e., released into the wild) (IDFG 2019). The number of worst-case fertile escapes (estimated to be 1,513,000 fish on average in the past 5 years, or 1% of total distributed trout) falls within this range, so it is possible that distribution programs are already releasing an equal or higher volume of fertile trout. In addition, private commercial farms in Idaho have donated fertile fingerlings to state stocking programs (pers. comm., Randy MacMillan August 2016). It is clear that fertile rainbow trout of similar genetics are being released into watersheds in the U.S. in potentially larger volumes than a worst-case scenario estimate of escaped farmed rainbow trout.

Presence of escapes in the wild (raceways/ponds)

There are no public records of U.S. rainbow trout farm escapes from raceways or ponds being found in the wild. Hatchery-reared rainbow trout have been stocked in natural environments in North America since the early 19th century for recreational purposes. These individuals are essentially genetically identical to those being grown out to market size in commercial aquaculture facilities. The continuation of historical stocking of hatchery-raised rainbow trout that are essentially genetically identical to those being farmed in waters across North America precludes any sound reason for there to be monitoring programs or other data collection efforts directed toward escapees.

Presence of escapes in the wild (net pens)

There is a popular rainbow trout sport fishery in Rufus Woods Lake, which is routinely stocked with a triploid steelhead strain (historically from genetics of Troutlodge and the Spokane Tribal Hatchery) that is likely identical to the fish sourced by the net pen operation, and the Coleville Tribe stocks rainbow trout to both supplement subsistence and provide recreational opportunities (LeCaire 2000). There is some dated anecdotal indication of escaped fish of net-pen origin in Rufus Woods Lake that was reported by anglers because the fish were of “large size and high weight to length ratios” (Richards et al. 2011). A dated government survey of fish species in Rufus Woods Lake documented rainbow trout determined to be of net-pen origin, “based on body shapes and fin condition,” which represented 14% of their catch during a 2-year sampling period of 8,325 fishes by electrofishing and beach seines during 1998–99 (Gadmonski et al. 2003). But, the origin of the fish as being from the net pens may not signify that they have escaped, because fish from the net pen operation have historically been purchased and released into the surrounding waters by the Tribe to supplement the fishery, with records that state, “large (>10 lb) rainbow trout have been present in the reservoir since net-pen aquaculture began in 1989,” and research showing that the fish are most likely to be found adjacent to the net pens or in the pool above Chief Joseph Dam (Brown et al. 2012). All of these records predate the present ownership and best management practices of the net pen operation, and must be taken in context with the routine stocking of genetically identical fish into Rufus Woods Lake through enhancement programs.

Establishment in the wild

There is historical evidence of introduced trout becoming ecologically established throughout North America as a result of stocking programs that began in the late 1800s (Fuller et al. 2022). No established populations have been linked to commercial trout farm escapees.

Potential impacts: competitive/genetic risks

When fish escape from aquaculture sites into the environment, they can have both ecological and genetic impacts on resident organisms. Our closest understanding of how escapes might affect their release environments comes from studies that focus on the stocking of hatchery-reared trout for conservation enhancement purposes. The outcomes of introducing rainbow trout on wild salmonids have been moderately studied in the U.S., which leaves some gaps in understanding but provides evidence of the potential for impact.

Ecological impacts are rooted in competition for resources, such as food and space. Hatchery strains of rainbow trout can outcompete native cutthroat trout in Idaho for food and feeding territories (habitat) (Seiler and Keeley 2007). Habitat competition was observed between hatchery rainbow trout and wild salmonids in the Yakima River, Washington—an effect made worse if the released fish were larger than the wild salmonids (McMichael et al. 1997a).

Hatchery rainbow trout that become residual (do not leave their release point) reduce the growth of wild rainbow trout (McMichael et al. 1997b), and residual steelhead from stocking in Rufus Woods Lake are predators of juvenile salmonids and eggs, which can cause impacts to resident species (USGA/UCUT 2017).

In other cases, competition between hatchery-reared fish and wild fish may not be an issue. For example, prey composition differed between wild and hatchery-reared steelhead in California, as evidenced in stomach content analyses (Boles 1990). Also, stocking catchable-sized trout through Idaho distribution programs has been demonstrated to not have population-level effects to conspecifics in receiving waters. Stocking this size of trout did not affect the recruitment to age 1, growth, survival, or abundance of wild conspecific rainbow trout compared to control streams with no stocking; this was attributed to the "high short-term mortality and socially and physiologically naïve behavior typically exhibited by hatchery catchables stocked in lotic systems" (Meyer et al. 2012). This "catchables" size group is similar to what might escape from commercial aquaculture facilities.

Genetic introgression is a paramount concern with escapees, and impacts can result from hybridization and the introgression of selectively bred genotypes into those of their wild counterparts. This introgression may have further ecological impacts, because the hybrid offspring are often associated with lower overall fitness and may cause a wide variety of ecological impacts, including negatively affecting wild conspecifics, reducing local species abundance and biodiversity, and habitat alteration (Cucherousset and Olden 2011)(Muhlfeld et al. 2009)(Myrick 2002). Hatchery-reared fish may lose fitness at a rate of 20% per generation compared to wild fish (Araki et al. 2007), which raises concern for survival and fitness if hybridization with wild species occurs. A study of the repeated release of brook trout hatchery cohorts demonstrated limited, though not zero, introgression with wild brook trout populations (White et al. 2018). Environmental factors (i.e., habitat) may play an important role in the resilience of certain wild populations to repeated stocking activities, when others have demonstrated dramatic genetic homogenization (Bruce et al. 2020).

Although the reproductive success of hatchery-reared trout can be variable, in some cases the reproductive success of hatchery fish does not meet the requirements to perpetuate hatchery populations in the wild (McLean et al. 2007)(McLean et al. 2003). But, the risk for hybridization with wild salmonids exists, and introgressive impacts to wild stocks have been demonstrated (Araki and Schmid 2010). Rainbow trout historically stocked throughout North America have affected the genetic integrity of rarer trout species through hybridization, such as Lahontan cutthroat trout, golden trout, and redband trout in California, westslope cutthroat trout in Montana, Alvord cutthroat trout in Nevada, and Gila trout and Apache trout in Arizona (Fuller et al. 2022 and references therein). Stocking patterns (repeated releases of large numbers of fish) are likely different than escapes from farms (potentially rare large escape events, or ongoing trickle losses), and escapees are expected to have low fitness. A precautionary approach is taken because there is the rare potential impact that escapees may compete for breeding partners with wild species.

The fish cultured in the U.S. rainbow trout industry are largely all-female, diploid fish (i.e., not sterile)(pers. comm., Dr. Trushenski, 2023). There is quite a low risk that fertilized gametes would be released from all-female stock, because this would require the presence of a precocious male, which does not occur due to the duration (spawn timing, pre-maturation) and density (trout typically will not spawn at production densities) in the culture environment (pers. comm., Dr. Jacob Bledsoe November 2022). Given this consideration, the risk of genetic introgression from aquaculture escapes is low compared to the damage caused by the widespread stocking of fertile trout through historical programs throughout North America. Thus, there is a quite minute risk of genetic impacts from the operations using nonsterile stock, and there is a risk of potential competitive impacts if a large escape event were to occur.

Risk to native or threatened populations

In exceptional cases, there are native trout species that remain genetically pure in their watersheds. For example, native redband trout is estimated to remain genetically pure in ≈68% of the Upper Snake River Basin (Meyer et al. 2014). The current range of redband trout covers watersheds in Idaho, Washington, Oregon, and to a lesser extent, California, Nevada, and Montana, with a rigorous multistate conservation strategy in place to protect the species (USFWS 2016). Only ≈18% of redband trout have been genetically tested to determine hybridization. The best estimation with this limitation is that this species remains nonhybridized in 46% of currently occupied streams, and it has no imminent risk of extinction because it is widely distributed, isolated by physical barriers, and protected by active conservation management (Muhlfeld et al 2015). Both the legacy of stocking rainbow trout into the wild and habitat degradation are expected to have increasingly negative impacts on redband trout in Idaho in the context of climate change (Muhlfeld et al. 2017). Southern Appalachian brook trout in North Carolina are estimated to be ≈38% pure origin, and their populations are planned to be supported by stocking hatchery-reared Southern Appalachian brook trout only in streams being renovated to manage the species (NCWRC 2013). Impacts to native or threatened populations are evaluated in the literature in the context of stocking events (i.e., intentional and repeated release of large amounts of fish) and not at the scale of incidental escapes from aquaculture. But, this is useful in understanding the population status of wild conspecifics and, in turn, the potential competitive or genetic impacts from escaped farmed individuals.

The net pens are in Rufus Woods Lake, which has dams upstream and downstream and no fish passage for fish to enter the lake at the downstream side, so all fish in the lake are resident or dispersed from upstream. A note of exception is that there are ongoing efforts to restore the anadromous Pacific salmon corridor above the lower dam (CBB 2019)(LM Tribune 2019)(UCUT 2019 and 2022), though there does not currently appear to be any permanent fish passage solution in place. A demonstration of fish passage technology has been completed, with fish being transported up to the height of the dam and returned back down without being moved over the dam itself (i.e., this demonstrated that the technology could move fish to the proper height to clear the dam, but did not actually transport them over it)(CBB 2019). If the passage of wild Pacific salmon (i.e., endangered or protected species) becomes permissible in a permanently installed fish passage system, a re-evaluation of impacts in that context will be warranted. A comprehensive implementation plan has been published by the Upper Columbia

United Tribes to test the feasibility of reintroducing salmon to the Upper Columbia River (UCUT 2022). The lake has historically contained other salmonids, including kokanee (*Oncorhynchus nerka*), which have been supplemented through hatchery programs (Gadomski et al. 2003)(LeCaire 1998), as well as brown trout, Eastern brook trout, Chinook salmon (hatchery origin), bull trout (Le Caire 2000), and limited numbers of redband trout (USGS/UCUT 2017). Because some sampling is dated, it is unclear whether these fish all still persist in Rufus Woods Lake. Bull trout is listed as threatened; however, Rufus Woods Lake is not designated as critical habitat for the species (USEPA Fact Sheet 2020). It is listed as a rare species in Rufus Woods Lake in the most recently available survey data (USGS/UCUT 2017), and the most recent issuance of the NPDES permits for the net pens (which require consideration of the Endangered Species Act by USFWS) states that there is “no effect” to bull trout by the net pen operations in Rufus Woods Lake because there is no critical habitat upstream of the lower impoundment of the water body (USEPA Fact Sheet 2020). In addition, preserving the genetic integrity of native redband trout is a high priority for conservation of the species (USGS/UCUT 2017), which is unlikely to be affected by potential escapees due to the confirmed sterility of stock in the net pens. Although there have not been any studies conducted to survey for a self-sustaining population of wild rainbow trout within Rufus Woods Lake (Richards et al. 2011), this seems highly unlikely given that the recreational rainbow trout fishery has been described as largely hatchery stock (LeCair, 2000).

Considering all the available evidence and the data limitations, there is a potential for farmed trout escapees to interact and/or compete with native or threatened species only in exceptional scenarios (i.e., large, catastrophic escape events).

Conclusions and Final Score

Rainbow trout has been introduced and become ecologically established in trout production regions before commercial aquaculture farm operations began. Post-escape mortality of farmed rainbow trout is expected to occur similarly to fish released in restocking events, and it is expected that any potential escapees from raceways and ponds during exceptional flooding events likely do not survive. Competition, predation, disturbance, or other impacts to wild species, habitats, or ecosystems may occur, but are not considered likely to affect the population status of wild species. The ongoing stocking of genetically identical fish (which are in same cases fertile) into waters where trout are farmed throughout the U.S. is happening at scales that dwarf what might conservatively escape from aquaculture in a worst-case estimation from flooding or other causes. It is likely that the majority of the industry uses sterile stock, limiting the potential for genetic impacts to occur to wild species. There is a potential for farmed trout escapees to interact and/or compete with native or threatened species only in exceptional scenarios (i.e., large, catastrophic escape events). The score for Factor 6.2 for both raceways and ponds and net pens is 9 out of 10.

<u>Final Scores</u>

Although there is a low to moderate low risk of escapes from well-constructed and sited facilities, escapes are occurring from raceway and pond systems, as documented in aggregated food fish and distribution production data from USDA Trout Surveys. All the compiled evidence suggests that the number of potential escapes from flow-through rainbow trout production facilities poses no significant risk of additional ecological impacts, when considering the volume of effectively identical fish released into the same waters over the past century by state hatcheries. Escaped farmed rainbow trout are likely to exhibit similar behavior, experience similar mortality rates, and be genetically similar (if not identical) to intentionally stocked trout. There are cases of genetically pure native trout species existing in watersheds where commercial trout aquaculture is located, which provides a nonzero potential for impact of escapees. It is known that escapes from aquaculture facilities can and do happen; although unlikely, these fish may be capable of competing, and in some cases hybridizing, with wild populations. Factors 6.1 and 6.2 combine to give a final numerical score for raceways and ponds of 7 out of 10 for Criterion 6—Escapes.

The net pen operation is an open system with a documented track record of no escapes in the past 10 years, and the farm construction and management goes beyond best management practices. The net pen operation has active procedures in place in case of a large escape event (release of 1,500 or more fish >1 kg or 3,000 or more fish <1 kg) that would trigger a recapture plan to be approved by the Tribal Fish and Wildlife Department. The farm stock is sterile, and there is no genetic risk from escapes. There is no risk to threatened species, which is provided in evidence from government reporting of critical habitat and surveys of fish populations in the waterway. But, a remote risk of competition with native salmonids exists in the event of a catastrophic escape in an open system. Restoration of the anadromous Pacific salmon corridor above the lower dam of the reservoir has been tested by using fish-passage tubing technology, and efforts are ongoing to reintroduce salmon to the Upper Columbia River Basin. If passage of anadromous salmon becomes permissible into the impounded waterway, a re-evaluation of impacts in that context will be warranted. Factors 6.1 and 6.2 combine to give a final numerical score for net pens of 7 out of 10 for Criterion 6—Escapes.

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

Raceways and Ponds

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

Net Pens

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

Brief Summary

Overall, the U.S. has a comprehensive regulatory system for disease management. Disease losses at farms may be as high as 8–15% of the anticipated harvest, though these data do not provide an entirely accurate picture because of the aggregation of hatcheries and grow-out sites. In general, farms understand what diseases are common to their stock and demonstrate best management practices for surveillance testing and rapid treatment. The presence of all common pathogens has been demonstrated in the wild where U.S. rainbow trout farming occurs. This Criterion would benefit from an understanding of the overall incidence of disease at farms and any potential interaction with wild fish, which is currently lacking due to the absence of data.

The largest raceway operator (representing 67% of all rainbow trout farmed in this system) maintains fish health improvement and biosecurity plans, which are updated annually following biosecurity audits, and employs a fish health team that is actively engaged in on-farm improvements as well as responding to morbidity/mortality events. Raceways and ponds have additional risk-management benefits that are not possible in open net pen systems, including the physical separation of farmed fish from wild fish, and (in some cases) the sourcing of spring water. Entry of *F. columnaris* from the wild into a raceway farm site has been demonstrated via source water (i.e., vulnerability to introduction of local pathogens) as a potential means of transmission, and the persistence/shedding of pathogens from biofilms within tanks is not yet well understood. In general, farms use protocols for biosecurity and use best management practices to monitor for disease. Resources are available in all states to sample and identify pathogens. Data to verify the rates of morbidity and mortality from specific diseases are not available from the industry, and the aggregated national trout data show an average annual mortality rate of 12.5%. Data from industry to verify the mortality rate from disease may benefit the scoring. There is little data availability to understand transmission between wild and farmed populations. The final numerical score for Criterion 7—Disease for raceways and ponds is 5 out of 10.

For net pen production, a staff veterinarian, robust biosecurity measures, and fish-health best practices are in place and offer some risk reduction. As a result of fish-health management measures, there are infrequent occurrences of infections or mortalities at the farm level. The mortality rate from disease is estimated to be within the national average for U.S. rainbow trout grown in all systems (12.5% 5-year average) ,when considering that the farm's reported mortality (≈18% on average) includes normal attrition. All pathogens detected at the farm site are present in the water body. But, the open system is vulnerable to introductions of local pathogens and parasites (e.g., from water, broodstock, eggs, fry, feed, and local wildlife) and is also open to the discharge of pathogens, with limited data availability to understand transmission between wild and farmed populations. The final numerical score for Criterion 7—Disease for net pens is 5 out of 10.

Justification of Rating

Because the disease data quality and availability are moderate to low (i.e., a Criterion 1 score of 5 or lower for the Disease category), the Seafood Watch Risk-Based Assessment was utilized.

<u>On-farm protocols (all systems)</u>

It is in the best interest of farm operations to engage in preventative vaccines, to routinely monitor for disease, and to treat any diseased fish quickly. All indications are that operators of raceways, ponds, and net pens are engaging in best management practices (or beyond) to maintain the biosecurity of farm sites and to vaccinate or treat fish when necessary. A proactive approach to health management using vaccines to mitigate disease is also a preference in the market. For example, the top four producers of trout in Idaho are either ASC (Aquaculture Stewardship Council) certified and/or contracted with relatively large retailers that require high standards of husbandry practices (pers. comm., Dr. Jacob Bledsoe November 2022).

Biosecurity protocols provided by U.S. rainbow trout farms for preparation of this report included the robust analysis of disease vectors, prevention, and containment, as well as awareness of the procedures for reportable diseases to inform the relevant state, national [U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS)], and global organizations [World Organization for Animal Health (OIE)].

To prevent disease from entering farm sites, operations will typically use visitor protocols that include not permitting entry to individuals who have recently visited other farm sites and requiring a disinfection procedure for employees moving between facilities. Controlling for any potential disease spread within farms is generally done using foot baths and strict equipment sanitization procedures (or having dedicated equipment for use in one segment of the farm only). To stop any potential transfer of disease offsite, similar disinfection protocols for employees are used. The net pen operation also minimizes (and plans to eliminate) transfer of any fish between their three sites within the same water body (pers. comm., Pacific Aquaculture October 2022).

Larger farm operations typically have an in-house veterinarian responsible for continual disease surveillance and testing, who can identify clinical signs of disease, conduct sampling, test sensitivity to appropriate treatments, and prescribe rapid treatment to control outbreaks. Throughout the U.S., there are generally resources provided through the USDA or other extension services to provide similar support to small farms that do not have the financial capability to have veterinarians in-house.

Mortality/morbidity from disease

Loss from disease continues to be the greatest production loss nationwide, with the loss of anticipated harvest (harvest + loss) ranging between 8 and 15% over the past 5 years, and USDA gathers self-reported producer records of loss from disease (Table 16) (USDA 2023).

Table 16: Total U.S. trout producer loss from disease. Data from (USDA 2023).

Year / mt of Fish	2018	2019	2020	2021	2022	5-Year Avg.
Trout lost to disease (aggregated, all size classes)	3,033	3,849	3,547	1,984	3,180	3,119
Total Production (mt)						
Total fish sold (mt; food-fish size class)	21,564	23,110	20,187	20,324	19,617	20,960
Total losses (mt; all causes)	3,434	4,639	4,222	3,579	4,348	4,044
Grand total (mt; harvest + loss from all causes)	24,998	27,749	24,410	23,902	23,965	25,005
Estimated* percentage loss from disease + other of total annual production	12.1%	13.9%	14.5%	8.3%	13.3%	12.5%

* Percentage loss is conservatively inflated because the data for disease loss are aggregated (all size classes in one value), whereas the annual production is only of the food-fish size class.

Pathogens and parasites common to rainbow trout aquaculture are listed in Table 17. Mortality is approximate and depends on variables like age, density, health status, water temperature, and stress, among others.

The pathogens of greatest concern to raceways and ponds are infectious hematopoietic necrosis virus (IHNV) and *Flavobacterium psychrophilum* (bacterial cold-water disease—BCWD), because the diseases caused by these pathogens can lead to large mortality events (pers. comm., Dr. Jacob Bledsoe November 2022).

For net pens, the annual mortality rate for all causes (including pathogens/parasites, and normal attrition) is ≈18%, with a morbidity rate at any time of ≈0.5% (pers. comm., Pacific Aquaculture October 2022). The farm does not classify all its mortalities in a way that would provide a total percentage lost to only disease causes (pers. comm., Pacific Aquaculture February 2023). Of the pathogens listed as common to raceways and ponds (Table 17), only three are common to freshwater net pens: *Flavobacterium columnare*, *Flavobacterium psychrophilium*, *Aeromonas hydrophila*. One additional disease that is common to net pens is not listed: proliferative kidney disease, which is caused by a myxozoan parasite called *Tetracapsuloides bryosalmonae*; it is included in the parasite discussion that follows.

Table 17: Pathogens and parasites common to U.S. rainbow trout raceways and pond aquaculture and their primary control measures.

Pathogen	Condition Name	Cause	Mortality Rate for Naïve Fish or with Vaccine (if known)	Control Measure(s)
Bacterial	Bacterial cold-water disease (BCWD)	*Flavobacterium psychrophilum*	49.5 ± 15.2% (LaFrentz et al. 2012), 30–50% in sac fry (Holt et al. 1993)	No approved U.S. trout vaccine, antibiotics, iodophore bath (for eggs), selective breeding (Wiens et al. 2018)(Avila et al. 2022)
	Enteric redmouth disease	*Yersinia ruckeri*	Up to 70% (Furones et al. 1993), 0% with commercial vaccine or experimental bacterin (Villumsen et al., 2014). Vaccination for nonmotile strain is not as effective.	Vaccination
	Aeromonas infections, Furunculosis	*Aeromonas* spp.	8% or 95%, respectively, for low-dose and high-dose exposures in a small experimental setting (LaPatra et al. 2010)	Vaccination, antibiotics, selective breeding for resistance (Marana et al. 2021), dietary (Ji et al. 2017)
	Columnaris	*F. columnare*	40–100% (LaFrentz et al. 2012)	No approved U.S. trout vaccine, antibiotics, bath treatment (hydrogen peroxide), experimental phage therapy in development (Kunttu et al. 2021)
	Bacterial gill disease (BGD)	*F. branchiophilum*	Mortality rate when treated with Chloramine-T can be reduced to 5.7% vs. 25.8% for untreated (Bowker et al. 2008)	Bath treatment (Chloramine-T, hydrogen peroxide, potassium permanganate)

Viral	Infectious hematopoietic necrosis virus (IHNV)	*Rhabdoviridae*	65–100% in 1 g fish, 33–90% in 8 g fish, 10–85% in 25 g fish (Kasai et al. 1993). 60–90% mortality in hatcheries (Ahmadivand et al. 2016). Reduced to 2.5% with live-attenuated vaccination (Salinas et al. 2015)	Vaccination (DNA), experimental antiviral therapies (Hu et al. 2019)(Liu et al. 2021), selective breeding for resistance, management techniques (e.g., ponding)
	Infectious pancreatic necrosis virus (IPNV)	*Birnaviridae*	Up to 100% (Zhu et al. 2017) without vaccine. With experimental DNA vaccine ≈15% mortality (Ballasteros et al. 2014)	Any farms positive for IPN are depopulated (pers. comm., Dr. Trushenski 2023)
Parasitic Diseases	White spot, Ich	*Ichthyophthirius mulifiliis*	Up to 100% when untreated (Pieters et al. 2008). Experimental theront vaccine greatly reduces mortality in catfish to ≈5%, no testing yet done in trout (Xu et al. 2018)	Bath treatments (Formalin, potassium permanganate), experimental dietary probiotics (Pieters et al. 2008), experimental theront vaccines (Xu et al. 2018) not yet approved for use in trout
	Whirling Disease	*Myxobolus cerebralis*	41.7 ± 7.6% or higher with additional stressors such as elevated water temperature (Schisler and Bergersen 2000)	No known treatment, selective breeding for resistance (Schisler et al. 2006)(Fetherman et al. 2011)
	Freshwater copepods	*Salmincola californiensis*	Limited presence in raceways and ponds. Generally does not cause mortality.	SLICE (via National INAD Program)
	Monogenean worm	*Gyrodactylus salmonis*	Impairs olfactory function (Lari and Pyle 2017), generally does not lead to mortality	Bath treatment (potassium permanganate)
Fungi	Saprolegniasis	*Saprolegnia* spp.	Generally life-stage specific to hatchery and does not commonly affect grow-out	Bath treatment (Formalin)

Viral Pathogens

The primary viral pathogen, infectious hematopoietic necrosis virus (IHNV), was first detected in North America in the 1950s. It exists in both wild and cultured salmonids throughout the Pacific Northwest (Idaho, Oregon, Washington, and Alaska, and British Columbia, Canada) (Kurath et al. 2003). IHNV still has no known, commercially available treatment in the U.S. (only one vaccine has been approved for use, in Canada) (ADFG 2016) (Gudding et al. 2014). IHNV has been detected in wild salmonid populations, and fish may carry the virus with no detectable clinical signs of disease (Dixon et al. 2016 and sources within). The disease is transmitted horizontally from fish to fish via waterborne virus, as well as vertically (through ovarian fluid), although all eggs used in production are certified IHNV-free (pers. comm., Gary Fornshell July 2016) (Troyer and Kurath 2003).

The mechanisms by which IHNV enters rainbow trout farms in Idaho are still unknown; there is evidence that IHNV is present in open water sources, like the Snake River, where it was detected in a wild spawning adult Chinook salmon in 2002 (USGS-MEAP-IHNV 2016). Wild sampling is sporadic due to limitations of funding and sample collection during spawning season. Thus, there is quite little data collection happening, and no spatial or temporal trends are possible to understand the movement of IHNV among wild fish. IHNV has been shown to survive without a host in freshwater for at least 1 month in cooler water, and longer if organic material is present. Farms generally source water from fishless underground springs (that may not be enclosed), and the disease has manifested in hatcheries with enclosed pipes that run directly from the source spring, which implies that other transmission vectors, such as birds or aerosols (e.g., mist), may be involved (OIE 2016) (pers. comm., Gary Fornshell July 2016) (Breyta et al. 2016 (Troyer and Kurath 2003). The culture environment may enable increased rounds of virus replication per year, which has unknown impacts on the ongoing evolution of IHNV (Kurath et al. 2003). Although mortality from IHNV is high [up to 90% in some cases (Kassai et al. 1993)(Ahmadivand et al. 2016)], it primarily affects young fish, with mortality decreasing with age/weight. Clinical disease is uncommon in adults; however, there is a significant lack of data regarding the impacts in near-to-market-size fish, and subclinical infection is generally not considered in completed studies (Dixon et al. 2016)(Breyta et al. 2016).

Infectious Pancreatic Necrosis Virus (IPNV) has been detected in global rainbow trout production regions, causing mortality of fry at up to 100% (Zhu et al, 2017). In the U.S., IPNV was first isolated in the 1960s and has since been found in a variety of fish, crustacean, and mollusk species (Alonso et al. 2003). It is elusive in sporadic wild sampling data; however, it is present and persistent in the natural environment unrelated to aquaculture operations, with government sampling of a creek and its tributaries in Northern Idaho detecting the virus when water temperatures allow viral replication (pers. comm., USFWS August 2022). There is uncertainty about how IPNV enters farm systems, similar to the IHNV discussion above. It is not currently an issue in the Idaho trout industry (pers. comm., Dr. Trushenski 2023).

Bacterial pathogens

Both Idaho and North Carolina (54% of U.S. rainbow trout production) are affected by bacterial cold-water disease (*F. psychrophilum*), enteric redmouth disease (*Y. ruckeri*), Aeromonas infections (*Aeromonas* spp.), and columnaris (*F. columnare*) (Starliper 2010)(Kumar et al. 2015)(Austin and Austin 2012)(Evenhuis et al. 2014)(Testerman et al. 2022) (pers. comm., Dr. Jacob Bledsoe September 2022) (pers. comm., Jeff Hinshaw October 2022).

Bacterial cold-water disease (BCWD) is the most significant bacterial pathogen in terms of occurrence in both states, though it rarely occurs in fish larger than 10 g (around which size fish are stocked into grow-out raceways) and is effectively treated with Terramycin® 200 (oxytetracycline) and Aquaflor® (florfenicol) (see Criterion 4—Chemicals for details regarding the usage of these drugs). Because of the common co-occurrence of BCWD with infectious hematopoietic necrosis virus (IHNV), the use of Aquaflor® to treat BCWD is uncommon because of the high cost and likely loss of fish to IHNV despite treatment for BCWD (pers. comm., Gary Fornshell July 2016).

Enteric redmouth disease (*Y. ruckeri*) has two biotypes of concern to trout aquaculture. Biotype 1 is motile, readily understood, and treated with vaccines, and Biotype 2 (nonmotile) is capable of causing outbreaks in vaccinated trout (Arias et al. 2007)(Hauang et al. 2015). Biotype 2 is of emerging concern in the U.S., with the first known detection in South Carolina in 2007 (Arias et al. 2007). In Idaho, farms are vaccinating against *Y. ruckeri*, but there have been few occurrences, which are attributed to source water that has been contaminated by wild fish that host the pathogen (pers. comm., Dr. Jacob Bledsoe September 2022). In North Carolina, *Y. ruckeri* has not been a concern for some time because of widespread vaccination (pers. comm. Jeff Hinshaw October 2022).

Aeromonas infections—furunculosis (*A. salmonicida*) in Idaho and motile aeromonas septicemia (MAS, *A. sobria* and/or *A. hydrophila*) in North Carolina—are rarely seen in both states (on the order of several farms less than annually), though outbreaks do occur (pers. comm., Gary Fornshell July 2016), which coincide with higher water temperatures (pers. comm., Jeff Hinshaw July 2016).

Columnaris is of concern in Idaho but quite rare in North Carolina, where outbreaks are generally limited to the summer season when surface water temperatures rise (pers. comm., Gary Fornshell July 2016) (pers. comm., Jeff Hinshaw July 2016). The bacteria responsible for columnaris disease (*F. columnare*) was detected in a natural spring water source over several years of sampling at one Idaho trout facility, thus demonstrating a means for continual introduction of the pathogen into farms (Testerman et al. 2022). It is anticipated that columnaris will become a greater concern to trout aquaculture if water temperatures in groundwater springs that feed the operations rise in association with climate change. That rise would make *F. columnare* more virulent; however, that is a trade-off because higher water temperature decreases the virulence of *F. psychrophilium*—currently the most significant bacterial pathogen (pers. comm. Dr. Jacob Bledsoe September 2022).

Bacterial gill disease (BGD, *F. branchiophilum*) occurs in Idaho, but not North Carolina. Although there is no commercially available vaccine for this disease in the U.S. at the time of writing, autogenous vaccines may be utilized, and BGD does not appear to be a significant concern in trout aquaculture.

Weissellosis has been detected in the U.S. trout farming industry but has since been controlled with vaccination. Weissellosis is caused by the bacteria *Weissella ceti* (recently renamed *Weissella tructae*) and was detected at two farms in North Carolina in 2011–12, demonstrating the ability of the bacteria to persist in the environment over winter and potentially become a lasting disease problem without intervention (Welch and Good 2013). Clinical signs include darkening of the skin, lethargic swimming, and internal hemorrhaging, and outbreaks on rainbow trout farms in China and Brazil have caused severe mortality events. The source of this disease in the U.S. and its relation to Brazilian and Chinese outbreaks is unknown (Welch and Good 2013). To date, there is no indication that it has been found in wild species (pers. comm., Tim Welch September 2022), although continued research and monitoring are imperative. A bivalent injection vaccine (effective against *Weissella* and *Yersinia ruckeri*) was rapidly developed in 2014 and continues to be used at almost all farms in North Carolina (pers. comm., Jeff Hinshaw October 2022). The vaccine has been quite effective in control of the disease in North Carolina, and farmers have demonstrated a commitment to prevent recurrence of the disease with their continued use of the vaccine (pers. comm., Tim Welch September 2022). In addition, other U.S. trout aquaculture sites have showed interest in pre-exposure vaccination against Weissella before any detections occur in their region (pers. comm., Tim Welch September 2022), which demonstrates an industry-initiated disease management effort in the U.S. Since the vaccine went into use in North Carolina, Weissellosis has only been detected again a few times in sick fish, with minimal associated losses; each case was in fish held for unusually long times because of the reduced demand during the COVID pandemic, which was a length of holding time that may have exceeded the protection provided by the vaccine (pers. comm., Tim Welch September 2022).

Parasites

A commercially important parasitic disease of the trout industry is white spot disease (Ich) caused by infestations of the parasite *Ichthyophthirius mulifiliis.* Although some research has been done to understand the life cycle and distribution of Ich strains in freshwater aquaculture globally and in the U.S., vaccines that have been trialed largely offer only partial protection, and there is no commercial vaccine available in the U.S. for prevention of outbreaks as of November 2021 (MacColl et al. 2015)(USDA NOP 2014)(Shivam et al. 2021)(USDA APHIS 2021). U.S.-specific data on the prevalence or commercial impact of Ich are not available. Losses associated with Ich would be reported under the aggregated category of disease in the USDA Trout Production survey.

Freshwater net pens report that proliferative kidney disease (PKD) can affect their stock. This is caused by a myxozoan parasite, *Tetracapsuloides bryosalmonae*, and is known to cause significant economic losses to rainbow trout farms elsewhere globally, with a complex disease model that is not yet well understood (Bailey et al. 2020). The parasite has a life cycle that uses two hosts: freshwater bryzoans and salmonid fish. The parasite has been known to persist in wild environments for long periods without causing wild fish kills (up to 25 years) and may go unnoticed or undetected until large fish kills occur, as in the case of a massive wild outbreak of PKD in the Yellowstone River, Montana in 2016 (Hutchins et al., 2021). The transfer of the parasite to the net pen operation is almost certainly from wild freshwater bryzoan hosts existing in the Columbia River to fish that have moved out of their biosecure hatchery environment into the open-system net pens.

Treatment / Control Measures

There is continuous innovation in control measures to treat existing and emerging pathogens in trout aquaculture. The most desirable way to mitigate disease is through development of effective vaccines that can be delivered to juvenile fish to prevent future outbreaks; the next way is through selective breeding traits to increase resistance. Preventing disease is preferred by far, when possible, to responding with reactive protocols at later stages of disease. Control measures for disease can be grouped into the categories of baths, antibiotic feeds, vaccines, and disease management (animal husbandry, breeding techniques, dietary measures).

Baths

- Iodophore baths are used to disinfect incoming eggs
- Chloramine-T, hydrogen peroxide, or potassium permanganate baths are used to treat bacterial gill disease

Antibiotic Feeds (see Criterion 4—Chemical Use, Table 6, for a complete discussion of conditions that can be treated with antibiotics)

- Terramycin® 200 is used to treat Furunculosis (*A. salmonicida*, *A. hydrophila*) in Idaho through a veterinary feed directive (10-day feeding period, 21-day withdrawal). Terramycin® 200 is also readily used to treat columnaris (Evenhuis et al. 2014)(Evenhuis et al. 2015)(Evenhuis et al. 2016) (pers. comm., Gary Fornshell July 2016) (pers. comm., Jeff Hinshaw July 2016).
- Romet®-30 is used to treat MAS in North Carolina (pers. comm., Jeff Hinshaw July 2016), although Romet®-30 is not utilized in Idaho as often as Terramycin and AQUAFLOR® (pers. Comm., Dr. Jacob Bledsoe November 2022).
- Florfenicol (AQUAFLOR®) is used with a veterinary feed directive for treatment of bacterial cold-water disease/rainbow trout fry syndrome (*F. psychrophilum*), furunculosis (*A. salmonicida*), and columnaris (*F. columnare*) (pers. comm., Dr. Jacob Bledsoe November 2022).

Vaccines (Immersion or Injection)

- Effective vaccines (commercial and experimental bacterins) are available for ERM disease that can reduce mortality to 0% for *Y. ruckeri* Biotype 1 (Villumsen et al. 2014). In both Idaho and North Carolina, the vaccine is administered when fish are young (<10 grams) and can contribute to resistance to ERM later in life (pers. comm., Jeff Hinshaw July 2016) (pers. Comm., Dr. Jacob Bledsoe November 2022) (Evenhuis et al. 2013). In Idaho, some smaller farms also utilize autogenous vaccines (ERM and furunculosis), although they update the autogenous less frequently than larger operations (pers. comm., Dr. Jacob Bledsoe November 2022).

- Neither columnaris disease (CD) nor BCWD (both *Flavobacterium* diseases) has a commercially available trout vaccine for treatment in the U.S. There is an approved U.S. vaccine for CD in catfish, and live-attenuated vaccines are in development for future treatment of BCWD (Ma et al. 2019a)(Sudheesh and Cain 2016)(LaFrentz et al. 2008).
- DNA vaccines have been developed to manage IHNV, and are licensed for use in the U.S., but are generally not used because they must be injected (pers. comm., Dr. Trushenski 2023). HNV live-attenuated vaccine can reduce mortality to 2.5% (Salinas et al. 2015). Autogenous (site-specific) vaccines have also been developed and used at larger farms that can afford to create them (pers. comm., Gary Fornshell July 2016); however, this has been discontinued because injection is not a viable method of delivery (pers. comm., Dr. Trushenski 2023). Management of IHNV in U.S. rainbow trout aquaculture may be limited to the delay of "ponding," or stocking, into outdoor raceways from relatively more biosecure hatcheries, or factoring in expected mortality into production projections (pers. comm., Gary Fornshell July 2016) (Breyta et al. 2016).

Disease Management

- Animal Husbandry: Adhering to appropriate stocking densities and water quality parameters (temperature, total ammonia nitrogen, dissolved oxygen, pH) to manage disease was described in the best management practices provided by the largest raceway operator in Idaho. At the net pan facility, reduced handling procedures are in place to reduce stress—an important element of disease management (e.g., "swim overs" where fish transfer between sections within the net pen site in a low-stress handling event).
- Breeding Techniques: Selective breeding techniques to minimize disease are used by major trout genetics companies that supply eggs to the U.S. rainbow trout industry. Examples of successful selective breeding for disease resistance from the literature include greater performance of selected stock when challenged with *Aeromonas salmonicida* (Marana et al. 2021) or *F. psychrophilum* (BCWD) (Weins et al. 2018).
- Dietary Measures: Larger farms using high volumes of feed may be able to modify their trout diets to include proprietary blends that support immunity and reduce disease. In addition, because of the growing benefits of dietary approaches to proactive animal health, standard commercial diets from some mills may also include ingredients to improve fish health and reduce disease. Some examples of dietary ingredients that may improve farm performance are:
    - β-glucan, which can significantly increase survival against *Aeromonas salmonicida* by activating stress- and immune-related factors, and initiating the immune response to bacterial infection (Ji et al. 2017)
    - Nucleotides, which have been experimentally demonstrated to provide protection from IPNV challenge (Leonardi et al. 2003)
    - Probiotics, which have been shown to improve the survival of rainbow trout when challenged with Ich parasites in an experimental feeding trial (Pieters et al. 2008)

Emerging but not yet commercially applied control measures like antiviral therapies have been experimentally demonstrated for treatment of IHNV (Hu et al. 2019)(Liu et al. 2021). In the treatment of bacterial disease, research on phage therapy (viruses of bacteria) suggests that it could possibly be used in the future to control *F. columnaris* (Kunttu et al. 2021). A theront vaccine to prevent the parasitic disease of Ich has been demonstrated in freshwater catfish (an industry being challenged by Ich in the U.S.) but is not yet commercially available for use in trout (Xu et al., 2018).

Impact on wild species

All of these pathogens, except for *Weissella*, are naturally occurring in the water bodies where trout farms are sited. Importantly, *Weissella* has not been redetected since its first discovery, thus rendering it of low concern that has likely been controlled through widespread vaccination. Some pathogens are seen exclusively or primarily in salmonid hosts (IHN, BGD, Weissellosis); some are more ubiquitous and found among freshwater and/or marine fish of various genera (BCWD, ERM, Aeromonas infections) (Austin and Austin 2012)(Dixon et al. 2016)(OIE 2016). But the presence of pathogens in influent water and wild populations does not necessarily cause disease on a farm; often, outbreaks occur due to immunosuppressive conditions within the farm, such as high stocking density, poor water quality, and/or insufficient nutrition, rendering farmed fish more susceptible to the present pathogen(s) (LaPatra and MacMillan 2008) (pers. comm., Gary Fornshell July 2016) (pers. comm., Jeff Hinshaw July 2016). Similarly, healthy farmed and wild fish may act as pathogen reservoirs, show no symptoms of disease, and transmit the pathogen to susceptible fish (LaPatra and MacMillan 2008) (pers. comm., Gary Fornshell July 2016) (pers. comm., Jeff Hinshaw July 2016). Literature suggests that, even though bacteria and viruses are present in wild fish populations, almost all clinical disease related to these agents occurs in the farm environment (Loch and Faisal 2015)(Austin and Austin 2012)(Kunttu 2010)(Starliper 2010).

Of the bacterial diseases of concern to net pens, all are present in wild salmonids in the Columbia River Basin (USGS/UCUT, 2017, p. 70). Seasonal outbreaks of *Y. ruckeri* in wild populations happen with high water temperatures, both globally (Huang et al. 2015) and in the Pacific Northwest (pers. comm., USFWS 2022), which suggests that the greatest threat of disease to wild fish may be related to environmental stressors that increase favorable conditions for bacterial outbreaks of established/persistent wild pathogens—unrelated to any influence from trout aquaculture operations.

Pathogen tests conducted by USFWS were analyzed to determine the presence of pathogens in wild fish populations. There is sampling bias present in the opportunistic FWS sample collections, which limit the usefulness of the data. There is no comprehensive testing program to monitor disease transfer from wild-farmed fish or vice versa. USFWS samples fish on a sporadic basis to answer management questions, leaving an incomplete and biased data set for the purposes of this assessment that cannot be used for any discussion of disease intensity or distribution. The presence of *Y. ruckeri, Aeromonas salmonicidia*, and Whirling disease (*Myxobolus cerebralis*) can be confirmed in wild salmonids from sampling done between 2017 and 2018 above the Grand Coulee Dam in Washington, which are waters upstream of the net pen operation (pers. comm., USFWS September 2022).

Myxobolus cerebralis has not been detected in any trout farms, but has been present in wild salmonids in North Carolina and Tennessee since it was first discovered in the U.S. in 2015, including most recently in the French Broad River during 2018–19 sampling (Ksepka et al. 2020). It also has been detected in opportunistic wild samples in the Upper Columbia River, Washington (pers. comm., USFWS August 2022). *M. cerebralis* may potentially have a means of horizontal transmission for dispersal (Ksepka et al. 2020) and is known to be viable after passage through avian piscivores, thus enabling it to spread into even highly protected waters (Koel et al. 2010). In addition to its presence in these main commercial rainbow trout production regions, it has been detected in a total of 25 states (Bartholomew and Reno 2002)(Ksepka et al. 2020)(Koel et al. 2010), demonstrating widespread wild establishment. It has not yet been reported on any U.S. trout farms. In North Carolina, the wild detections have not been in proximity to farming operations, and the State Department of Agriculture conducts inspections for any movement or transfer of trout that would detect its presence (pers. comm., Jeff Hinshaw October 2022).

Another pathogen that is present in the wild but not yet detected on trout farms is the wild salmonid pathogen, *Ceratonova shasta* (CMS/enteronecrosis/ceratomyoxosis/"gut rot"). It is closely monitored for at some, but not all, farm sites in Idaho, without any farm detections yet reported. *C. shasta* distribution is limited to the Pacific Northwest (Stinson et al. 2018).

Wild to farm transmission and vice versa

There is evidence for the transmission of pathogens from wild environments to farms. One published example is of the bacteria responsible for columnaris disease (*Flavobacterium columnare*) being continually delivered into at least one Idaho trout facility via a natural spring water source over several years of sampling (Testerman et al. 2022), which made it a constant pathogen risk. The same study found that "every microbial class detected within the hatchery environment was present within the inflowing water community," which indicates a likelihood that source water is seeding microbial community inflow into trout farm raceways, and a microbial subset successfully forms biofilms from which it can amplify and potentially shed into the water outflow from the biofilms or infect culture fish (Testerman et al. 2022). No comparable work has been done in wild environments to understand the contribution of natural system biofilms to the same pathogen persistence in wild fish, though it is certain that the persistence of pathogens among wild fish would happen independently of aquaculture. In addition, there is anecdotal information of an Idaho state trout hatchery using fine filtration and UV light to manage *Flavobacterium psychrophilum* that was suspected to be entering the facility from natural spring water.

Strain analyses of *Yersinia ruckeri* across multiple trout raceway farm sites in Germany indicated no strains of a common type between farms in the same river system and that farms with no history of *Y. ruckeri* outbreaks are colocated on river systems with *Y. ruckeri*-positive farms; together, these indicate that there is not transfer of *Y. ruckeri* between farms via discharge water, so it is not likely that transmission to wild conspecifics is occurring (Huang et al. 2015). The study revealed that trout farm outbreaks of *Y. ruckeri* were associated with distinct genetic groups characteristic to each farm, which supports the view that there may be persistent *Y. ruckeri* within the farm sites tested that reaches clinical outbreak levels when conditions are appropriate.

To date, there is no literature demonstrating that rainbow trout farming in the U.S. has caused any amplification or increased virulence of these pathogens in the receiving water body, though literature does demonstrate on-farm increases in virulence of diseases such as columnaris and IHNV, sometimes as a result of management practices such as vaccination (Kurath and Winton 2011)(Sundberg et al. 2016)(Kennedy et al. 2015). Untreated effluent during disease outbreaks can contain amplified levels of shed viruses or bacteria. There are few documented cases of pathogen transmission from freshwater flow-through rainbow trout farms to wild fish resulting in disease outbreaks in Europe (Kurath and Winton 2011) (LaPatra and MacMillan 2008). The lack of information regarding wild disease outbreaks and aquaculture's contribution to them is largely due to uncertainties in biological, pathogenic, geographic, and anthropogenic factors (Kurath and Winton 2011)(LaPatra and MacMillan 2008). But, "uncertain risk of disease transmission is never an argument against developing and employing risk-reduction measures," and strong biosecurity measures are implemented throughout the U.S. farmed rainbow trout industry (LaPatra and MacMillan 2008).

Legislation and government regulation

The U.S. has a National Aquatic Animal Health Plan (USDA APHIS 2021) that is the responsibility of the USDA to implement as the lead agency. Recent accomplishments have included the development of a National Aquatic Animal Pathogen Testing Network that verifies the health status of animals being moved within the country, to control the potential for disease transport.

The World Organization for Animal Health (OIE) requires the U.S. to notify if any pathogens on a specific list (Reportable Aquatic Animal Pathogens—RAAPs) are detected. Best management practices provided by farms demonstrate a comprehensive understanding of this list of OIE-reportable pathogens by U.S. rainbow trout farms. The U.S. follows the OIE guidelines for basic biosecurity conditions, which require mandatory reporting of the disease to the competent authority, an internal early detection system, and a system to prevent transporting any of the pathogens (USDA APHIS 2021).

Many states have diagnostic laboratories for testing diseases and pathogens, and farms shared protocols that demonstrate their understanding of collecting and processing samples with available laboratories in their region. USDA APHIS (2021) also manages laboratory standards for testing.

The international movement of live fish is regulated by the USDA Animal and Plant Health Inspection Service. To import live fish, fertilized eggs, or gametes to the U.S., they must be accompanied by a USDA import permit, a veterinary health export certificate from the exporting country, and must undergo veterinary inspection at a designated U.S. port. There is no indication that the U.S. rainbow trout industry has any remaining reliance on the import of eggs from international destinations.

In addition to the above measures to manage disease at U.S. trout farms, the net pen operation has an additional measure of accountability, whereby if more than 5% of the total farm biomass is lost to disease within 5 days, it must be reported to the relevant Tribal authorities.

Conclusions and Final Score

Overall, the U.S. has a comprehensive regulatory system for disease management. Disease losses at farms may be as high as 8–15% of anticipated harvest, though these data do not provide an entirely accurate picture because of the aggregation of hatcheries and grow-out sites. In general, farms understand which diseases are common to their stock and demonstrate best management practices for surveillance testing and rapid treatment. The presence of all common pathogens has been demonstrated in the wild where U.S. rainbow trout farming occurs. This criterion would benefit from an understanding of the overall incidence of disease at farms and any potential interaction with wild fish, which is currently lacking due to an absence of data.

The largest raceway operator (representing 67% of all rainbow trout farmed in this system) maintains fish health improvement and biosecurity plans, which are updated annually following biosecurity audits, and employs a fish-health team that is actively engaged in on-farm improvements as well as responding to morbidity/mortality events. Raceways and ponds have additional risk-management benefits that are not possible in open net pen systems, including the physical separation of farmed fish from wild fish, and (in some cases) the sourcing of spring water. Entry of *F. columnaris* from the wild into a raceway farm site has been demonstrated via source water (i.e., vulnerability to introduction of local pathogens) as a potential means of transmission, and the persistence/shedding of pathogens from biofilms within tanks are not yet well understood. In general, farms use protocols for biosecurity and use best management practices to monitor for disease. Resources are available in all states to sample and identify pathogens. Data to verify the rates of morbidity and mortality from specific diseases are not available from the industry, and the aggregated national trout data show an average annual mortality rate of 12.5%. Data from industry to verify the mortality rate from disease may benefit the scoring. There is little data availability to understand the transmission between wild and farmed populations. The final numerical score for Criterion 7—Disease for raceways and ponds is 5 out of 10.

For net pen production, a staff veterinarian, robust biosecurity measures, and fish-health best practices are in place and offer some risk reduction. As a result of fish-health management measures, there are infrequent occurrences of infections or mortalities at the farm level. The mortality rate from disease is estimated to be within the national average for U.S. rainbow trout grown in all systems (12.5% 5-year average), when considering that the farm's reported mortality (≈18% on average) includes normal attrition. All pathogens detected at the farm site are present in the water body. But, the open system is vulnerable to introductions of local pathogens and parasites (e.g., from water, broodstock, eggs, fry, feed, and local wildlife) and is also open to the discharge of pathogens, with limited data availability to understand the transmission between wild and farmed populations. The final numerical score for Criterion 7—Disease for net pens is 5 out of 10.

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

C8X Source of Stock – Independence from wild fish stocks	Value	Score
Percent of production dependent on wild sources (%)	0.0	0
Use of ETP or SFW "Red" fishery sources	No	
Lowest score if multiple species farmed (0-10)		n/a
C8X Source of stock Final Score (0-10)		**0**
Critical?	No	Green

Brief Summary

Rainbow trout was the first fish species to be fully domesticated on a large scale in North America. Currently, 100% of the stock used for commercial food-fish rainbow trout farming is supplied by domesticated broodstock. No wild rainbow trout are relied upon for production. The final score for Criterion 8X—Source of Stock is –0 out of –10.

Justification of Rating

The U.S. trout aquaculture industry is reliant on selective breeding for performance traits. See Factor 6.2 for the discussion of selective breeding programs and the history of domestication. Because most U.S. trout producers are small farms, many do not have built-in broodstock programs, so they source eggs from one of the major trout genetics companies established in the country.

Rainbow trout has been cultured successfully for over 100 years, and today, 100% of the stock for commercial trout aquaculture is supplied by domesticated broodstock in hatcheries around the U.S. (Fornshell 2002). This demonstrates an independence of farming practices from wild stocks.

This is further confirmed at the time of reporting for both Idaho and North Carolina (pers. comm., Dr. Jacob Bledsoe September 2022) (pers. comm., Jeff Hinshaw October 2022) as it pertains to raceways and ponds, and also for the freshwater net pen operation, which uses only sterile triploids produced in hatchery settings (pers. comm., Pacific Aquaculture September 2022).

Conclusions and Final Score

Because there is 0% reliance of the U.S. commercial rainbow trout aquaculture industry on wild-caught juveniles, broodstock, or other actively stocked species, the final numerical score for Criterion 8X—Source of Stock is a deduction of –0 out of –10.

Criterion 9X: Wildlife 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

Raceways and Ponds

C9X Wildlife Mortality parameters		Score
Single species wildlife mortality score		–1
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score		**–1**
Critical?	No	Green

Net Pens

C9X Wildlife Mortality parameters		Score
Single species wildlife mortality score		0
System score if multiple species assessed together		n/a
C9X Wildlife Mortality Final Score		**0**
Critical?	No	Green

Brief Summary

Rainbow trout are lost due to predation, as evidenced by USDA industry data reporting, so there is a demonstrated potential for wildlife interactions at farms. Nonlethal control measures are part of best management practices in the U.S. trout industry, and appropriate regulations are in place to allow lethal control of predatory birds only with a permit for wildlife control (depredation) from the relevant regional Fish and Wildlife authority. Lethal take of small mammals is legally allowed under the regulations of individual state statutes; however, this is known to be a rare occurrence because of the efficacy of exclusionary structures. Wildlife mortalities at raceways and ponds are likely limited to exceptionally rare cases and do not occur at most facilities, as a result of total exclusion structures. Populations of predatory animals are not significantly affected by the U.S. trout aquaculture industry. The final numerical score for Criterion 9X—Wildlife Mortalities is –1 out of –10 for raceway and pond systems.

Nonlethal control measures are used at the net pen facilities, and no mortalities have been reported. Because there is only one active freshwater net pen farm in the U.S. and these data reflect this entire system of farming, uncertainty in the representativeness of these data is significantly reduced. The final numerical score for Criterion 9X—Wildlife Mortalities is –0 out of –10 for net pens.

Justification of Rating

Predation has historically and presently resulted in substantial economic losses to trout farm operators (Belle and Nash 2008)(Glahn et al. 1999), and is responsible for an average of 1.2% loss of anticipated harvest over the past 5 years (Table 18). For this reason, it is in the best interest of trout farmers to install exclusionary and deterrent devices, to mitigate interaction and predation. When properly implemented, these defenses are usually inexpensive and effective, and reduce the impact on the fish and other wildlife (Belle and Nash 2008) (pers. comm., Steve Naylor March 2013).

Table 18: Total U.S. trout producer losses from predation. Data from (USDA 2023).

Year / mt of Fish	2018	2019	2020	2021	2022	5-Year Avg.
Trout lost to predation (aggregated, all size classes)	277	321	217	333	328	295
Total Production (mt)						
Total fish sold (mt; food-fish size class)	21,564	23,110	20,187	20,324	19,617	20,960
Total losses (mt; all causes)	3,434	4,639	4,222	3,579	4,348	4,044
Grand total (mt; harvest + loss from all causes)	24,998	27,749	24,410	23,902	23,965	25,005
Estimated* percentage loss from predation + other of total annual production	1.1%	1.2%	0.9%	1.4%	1.4%	1.2%

* Percentage loss is conservatively inflated because the data for predation loss are aggregated (all size classes in one value), whereas the annual production is only of the food-fish size class.

Raceways and Ponds

Throughout the U.S., there are several wildlife species that may interact with rainbow trout farm infrastructure and stocked fish. Birds (e.g., cormorant, pelican, heron, osprey, California gull, common grackle, and mallard) attempting to prey on fish account for the most common wildlife interactions at trout farms, although contacts with other predators such as mink, skunk, and raccoon also occur (Fornshell and Hinshaw 2008)(Pitt and Conover 1996).

There are dated studies that have shown that lethal control of common piscivorous birds such as herons, cormorants, gulls, and egrets on trout and catfish farms [a significantly larger industry with significantly more predator interactions (Dorr et al. 2012)] has had negligible effects on migratory and resident populations (Blackwell et al. 2000)(Belant et al. 2000). More-recent studies have shown that populations of American white pelicans and double-breasted cormorants have dramatically increased since the early 1990s throughout the U.S. (Meyer et al. 2016)(Adkins et al. 2014). Other predators, such as mink, striped skunk, and raccoon, are all listed as "Species of Least Concern" by the International Union for the Conservation of Nature (IUCN) and are actively hunted year-round in areas where trout farming regularly occurs, for reasons not associated with aquaculture (IUCN 2022).

In Idaho, there are four IUCN Red List species (all in the phylum Mollusca; shown here with status and population trend) that potentially overlap with trout farming operations:

- Ashy pebblesnail (*Fluminicola fuscus*): "Near Threatened," decreasing
- Desert valvata (*Valvata utahensis*): "Vulnerable," unknown population trend
- Shortface lanx (*Fisherola nuttalli*): "Endangered," decreasing
- Western ridged mussel (*Gonidea angulata*): "Vulnerable," decreasing

The threats to their populations center around historical hydrological alteration, competition with invasive species, degraded water quality, and habitat fragmentation. Of these, water quality is the only overlap with aquaculture, and all discharge is done in compliance with requirements to maintain the beneficial uses of the Snake River, which are enforced through the Idaho Department of Water Quality's Idaho Pollutant Discharge Elimination System (IDPES) permits. Aquaculture is not considered to be a threat to their populations.

In North Carolina, there is a critically endangered mollusk species in the general region where aquaculture farms are located [Appalachian elktoe (*Alasmidonta raveneliana*): "Critically Endangered," decreasing], but its critical habitat of inland wetlands does not likely overlap with aquaculture siting, so aquaculture is not considered a threat.

There is also a species of skunk in North Carolina, the eastern spotted skunk (*Spilogale putorius*), which overlaps in range with the primary trout aquaculture region of North Carolina and is listed as "Vulnerable" as of 2016 with a decreasing population (IUCN 2022). Threats to the species include incidental fur trapping, synthetic pesticides, habitat change associated with row-crop agriculture, changing predator dynamics, and disease (IUCN 2022). Interactions with trout aquaculture are not listed in association with the species. The interaction of trout aquaculture with animals such as skunks is quite rare, because they often only attempt to prey on diseased or moribund fish and have little impact on production (Fornshell and Hinshaw 2008)(Pitt and Conover 1996). Furthermore, aquaculture is not a known source of interactions with eastern spotted skunk in North Carolina.

The majority of predator protections for rainbow trout raceways are nonlethal (Fornshell and Hinshaw 2008). Fencing and netting are the two most commonly used methods, and effective implementation of these completely excludes predators. Also, it is in the best interest of aquaculture businesses to exclude predators. Total exclusion structures are employed at nearly all commercial aquaculture sites in Idaho (Fornshell and Hinshaw 2008) (pers. comm., Gary Fornshell August 2016).

Net Pens

Colonial waterbirds (Caspian tern, California gull, ring-billed gull, double-crested cormorant) are known to be significant predators of steelhead smolts in the Upper Columbia River (Evans et al. 2019), so they are likely nuisance predators that would attempt predation at the net pen operation in the Upper Columbia River. Total exclusion avian bird netting is in place at the facility for nonlethal management of avian predators.

IUCN status and population trend of these species:

- Caspian tern: “Least Concern,” increasing
- California gull: “Least Concern,” decreasing
- Ring-billed gull: “Least Concern,” increasing
- Double-crested cormorant: “Least Concern,” increasing

The farm also has interactions with black bear, musk rat, and river otter. All these species have stable or increasing populations of “Least Concern” on the IUCN Red List. Mammal interactions are managed with nonlethal control methods only (netting, noise cannons), best management practices for feed storage, and trapping and relocation by Tribal Fish and Wildlife services (pers. comm., Pacific Aquaculture October 2022).

Governance

Almost all birds (including all those implicated in trout farm predation) are protected by the Migratory Bird Treaty Act (MBTA), and the killing of such birds is prohibited by federal law without a “Federal Migratory Bird Depredation Permit,” which is issued by the U.S. Fish and Wildlife Service (USFWS 2020). An Aquaculture Depredation Order was in place as of the last assessment, which allowed the take of specific species of birds (such as double-crested cormorant) in certain locations for the protection of aquaculture interests without a permit; however, the order was vacated by court order in May 2016 and is no longer in effect (Federal Register 50 CFR Part 21). The use of lethal force is only authorized by permit and in conjunction with enacted nonlethal measures, which must be attempted before a permit application. Any legal lethal control taken under a permit is required to be recorded and submitted annually to the regional Fish and Wildlife Service office. Because of the efficacy of total exclusion structures in Idaho, there have been no depredation permits issued; similarly, there are no depredation permits in use in North Carolina (pers. comm., Dr. Jacob Bledsoe November 2022)(pers. comm., Jeff Hinshaw August 2016). There are no indications that endangered or protected species are experiencing mortality, especially considering the lack of interaction among endangered species and fish farms (pers. comm., Gary Fornshell October 2013).

Small predatory mammals such as mink, skunk, and raccoon can be legally killed without a permit in most places where commercial trout aquaculture occurs, such as Idaho and North Carolina, by following state regulations (IDAC 2022)(NCGS 2022). But again, the interaction with these animals is quite rare, because they often only attempt to prey on diseased or moribund fish and have little impact on production (Fornshell and Hinshaw 2008)(Pitt and Conover 1996). Exclusionary structures, such as fencing, are highly effective in limiting predator access, and small predatory mammals are generally not of concern, especially compared to birds (Fornshell and Hinshaw 2008) (pers. comm., Randy MacMillan August 2016).

Conclusions and Final Score

Rainbow trout are lost because of predation, as evidenced by USDA industry data reporting, so there is a demonstrated potential for wildlife interactions at farms. Nonlethal control measures are part of best management practices in the U.S. trout industry, and appropriate regulations are in place to allow lethal control of predatory birds only with a permit for wildlife control (depredation) from the relevant regional Fish and Wildlife authority. The lethal take of small mammals is legally allowed under the regulations of individual state statutes; however, this is known to be a rare occurrence as a result of the efficacy of exclusionary structures. Wildlife mortalities at raceways and ponds are likely limited to exceptionally rare cases and do not occur at most facilities because of total exclusion structures. Populations of predatory animals are not significantly affected by the U.S. trout aquaculture industry. The final numerical score for Criterion 9X—Wildlife Mortalities is –1 out of –10 for raceway and pond systems.

Nonlethal control measures are used at the net pen facilities, and no mortalities have been reported. Because there is only one active freshwater net pen farm in the U.S. and these data reflect this entire system of farming, uncertainty in the representativeness of these data is significantly reduced. The final numerical score for Criterion 9X—Wildlife Mortalities is –0 out of –10 for net pens.

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

Raceways and Ponds

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on trans-waterbody movements (%)	39.4	6
Biosecurity score of the source of animal movements (0–10)		9
Biosecurity score of the farm destination of animal movements (0–10)		7
Species-specific score 10X Score		–0.400
Multispecies assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**–0.400**
Critical?	No	**Green**

Net Pens

C10X Introduction of Secondary Species parameters	Value	Score
F10Xa Percent of production reliant on trans-waterbody movements (%)	100.0	0
Biosecurity score of the source of animal movements (0–10)		9
Biosecurity score of the farm destination of animal movements (0–10)		6
Species-specific score 10X Score		–1.000
Multispecies assessment score if applicable		n/a
C10X Introduction of Secondary Species Final Score		**–1.000**
Critical?	No	**Green**

Brief Summary

Trout genetics companies in the Pacific Northwest supply the majority of the U.S. rainbow trout industry. Farms that are located in Idaho are in proximity to two major trout genetics suppliers, so there is less need for trans-waterbody shipment within this state (only an estimated 10% of trans-waterbody shipments are necessary). The second largest production state, North Carolina, imports an estimated 99% of eggs from the Pacific Northwest. A weighted estimation of the trans-waterbody shipments was created, based on the unique within-state egg production of the state of Idaho, along with the assumption that all states outside of Idaho follow the trend of North Carolina (a necessary assumption due to the aggregation of state data not making it possible to break out Washington State, for example). The biosecurity of egg production facilities is high, and eggs are often certified disease-free. Thus, there is a low risk of unintentionally introducing secondary species during animal shipments. The scoring deduction for Criterion 10X—Introduction of Secondary Species is –0.40 out of –10.

For net pens, all seed stock is sourced from genetics companies within Washington State. But, these companies are in distinct watersheds, meaning that all seed stock is shipped trans-waterbody to reach the net pen site. The biosecurity of egg production facilities is high, and eggs are often certified disease-free. Thus, there is a low risk of unintentionally introducing nonnative species (i.e., species other than the cultured trout) during animal shipments. The scoring deduction for Criterion 10X—Introduction of Secondary Species is –1 out of –10.

Justification of Rating

Factor 10Xa—International or Trans-Waterbody Live Animal Shipments

The U.S. rainbow trout industry is reliant on selective breeding for performance traits, and there are a handful of trout genetics companies that likely supply nearly all seed stock to the U.S. The major supplier of rainbow trout eggs in the U.S. is Riverence Brood, with another source of stock being Troutlodge (both with facilities in Washington State and Idaho). It is economically necessary for all but the largest farm operations to purchase eggs from genetics companies rather than attempt to maintain competitive in-house broodstock programs, which are cost prohibitive. For example, the average-sized rainbow trout farm generates $319,520 in sales per year (USDA NASS 2019), which is well below the consideration for upkeep of a competitive broodstock program.

In Idaho, there are two major suppliers of trout genetics colocated with production facilities. The market share of these companies is not transparent. It is also not known if, or in what quantities, the seed stock originating from broodstock facilities of the largest farm operation in Idaho are being sold to other farms in the vicinity. An estimated 90% or more of eggs used in Idaho are locally sourced, with the majority coming from major genetics suppliers in the region, and some smaller operations doing their own spawning with broodstock held on their farms (pers. comm., Dr. Jacob Bledsoe November 2022). With this information, an estimate of 90% is used (as a precaution with the uncertainty in the >90% estimate) for seed stock sourced from within the Magic Valley region to supply the local industry. A precautionary assumption had to be made that the other 10% of stock is transported from trout genetics companies in Washington State. Trout companies from Washington State that supply seed stock to farms in Idaho are considered trans-waterbody shipments based on their locations in different watersheds (i.e., trans-waterbody), as delineated by the Region 17 Pacific Northwest USGS watershed boundary map (https://water.usgs.gov/wsc/reg/17.html). Only farms near trout genetics companies would not have trans-waterbody shipments of eggs.

In North Carolina, almost all eggs [estimated at up to 99% (pers. comm., Jeff Hinshaw October 2022)] are imported from the Pacific Northwest. Thus, 99% of eggs for all other states except Idaho are estimated to be shipped trans-waterbody. Because of the aggregation of USDA production data, Washington State had to be treated the same as all other states, even though it is where major trout genetics companies are located, and some farms there may not have to ship eggs trans-waterbody.

Raceways and Ponds

An estimated 10% of eggs in Idaho are shipped trans-waterbody. Idaho production makes up 67% of the total estimated raceway and pond production (calculated by subtracting net-pen production volume from total U.S. production, then calculating the Idaho share). In all other states, 99% of eggs move trans-waterbody, and these make up 33% of the total estimated raceway and pond production.

$$\text{Idaho} + \text{All Other States} = \text{Total Raceways and Ponds Trans-Waterbody Shipments}$$
$$(67\% \times 0.1) + (33\% \times 0.99) = 39.4\%$$

For raceways and ponds, because 39.4% of production is reliant on international/trans-waterbody animal movements, the score for Factor 10Xa is 6 out of 10.

Net Pens

Eggs at the net pen facilities travel from trout genetics companies within the same state, though in different watersheds, as delineated by the Region 17 Pacific Northwest USGS watershed boundary map (https://water.usgs.gov/wsc/reg/17.html) (pers. comm., Pacific Aquaculture October 2022). Thus, for net pens, because 100% of production is reliant on international/trans-waterbody animal movements, the score for Factor 10Xa is 0 out of 10.

Factor 10Xb—Biosecurity of Source/Destination

The sites of trout genetics facilities are typically chosen for superior biosecurity and isolation from wild-source pathogens. Some of the seed facilities are recirculation aquaculture systems (RAS), though not all. Transfer of biological material is generally from large egg producers in the Pacific Northwest to small farm operations throughout the country. The only pathogen of concern to culture that is not considered widespread and established in the wild across trout farming regions is Weissella (only detected in North Carolina; see Criterion 7—Disease). Because North Carolina is not a production hub for out-of-state exports of eggs and/or live fish, the risk of Weissella transport is not relevant, and does not contribute to the scoring in this category.

Furthermore, the major egg suppliers used by the U.S. trout industry are certified disease-free by facility or, if not officially certified, are taking extreme efforts to ensure that all broodstock are free of IHNV, to reduce and /or eliminate vertical transmission (pers. comm., Dr. Jacob Bledsoe November 2022). There are also regulatory checks, which differ by state, to ensure no disease transfer. For example, in Idaho, any facilities that export eggs across state lines (i.e., most hatcheries) are required to pass mandatory broodstock disease testing (pers. comm., Dr. Jacob Bledsoe November 2022).

The shipment system for trout eggs requires essentially no movement of source water. The eggs are shipped moist, but are not submerged in water, and require a rehydration upon arrival at their farm destination. In addition to not moving water with transport, OIE regulations require disinfection of the eggs upon arrival at the farm site, which would kill any pathogens capable of transferring on the egg surface. Bath treatments (e.g., povidone iodine) applied upon receipt of eggs minimize the risk of pathogen transmission to the lowest extent possible. For example, 99.9% of IHNV is inactivated within 7.5 seconds of a low-dose iodine bath (Batts et al. 1991).

Destination farm facilities are less biosecure. Raceways and ponds are a flow-through (moderate risk) system with multiple BMPs in place for design, construction, and biosecurity management, which scores a 6. Net pens are an open (high risk) system with multiple BMPs in place for design, construction, and biosecurity management, which scores a 2. Only the highest scoring location (the source facilities, not the destinations in this case) is considered in the final numerical score.

Because of the combination of protocols used in source facilities, it is highly unlikely that pathogens transport with eggs. Most source systems are RAS (consistent with a score of 8) and there are some systems that are fully biosecure (consistent with a score of 10). Some uncertainty exists about the robustness of biosecurity in RAS systems, and there are also non-RAS facilities with good biosecurity (consistent with a score of 6). Overall, considering these elements along with the certified disease-free and disinfection steps, the final score is 9 out of 10 for Factor 10Xb.

Conclusions and Final Score

Trout genetics companies in the Pacific Northwest supply the majority of the U.S. rainbow trout industry. Farms that are located in Idaho are in proximity to two major trout genetics suppliers, so there is less need for trans-waterbody shipment within this state (only an estimated 10% of trans-waterbody shipments are necessary). The second largest production state, North Carolina, imports an estimated 99% of eggs from the Pacific Northwest. A weighted estimation of the trans-waterbody shipments was created, based on the unique within-state egg production of the state of Idaho, along with the assumption that all states outside of Idaho follow the trend of North Carolina (a necessary assumption because of the aggregation of state data not making it possible to break out Washington State, for example). The biosecurity of egg production facilities is high, and eggs are often certified disease-free. Thus, there is a low risk of unintentionally introducing secondary species during animal shipments. The scoring deduction for Criterion 10X—Introduction of Secondary Species is –0.40 out of –10.

For net pens, all seed stock is sourced from genetics companies within Washington State. But, these companies are in distinct watersheds, which means that all seed stock is shipped trans-waterbody to reach the net pen site. The biosecurity of egg production facilities is high, and eggs are often certified disease-free. Thus, there is a low risk of unintentionally introducing nonnative species (i.e., species other than the cultured trout) during animal shipments. The scoring deduction for Criterion 10X—Introduction of Secondary Species is –1 out of –10.

Overall Recommendation

The overall recommendation is as follows:

The overall final score is the average of the individual criterion scores (after the two exceptional scores have been deducted from the total). The overall ranking is decided according to the final score, the number of red criteria, and the number of critical scores as follows:

- **Best Choice** = Final score ≥6.6 AND no individual criterion is Red (i.e., <3.3)
- **Good Alternative** = Final score ≥3.3 AND <6.6, OR Final score ≥6.6 and there is one individual "Red" criterion.
- **Red** = Final score <3.3, OR there is more than one individual Red criterion, OR there is one or more Critical score.

Raceways/Ponds

Criterion	Score	Rank	Critical?
C1 Data	7.73	GREEN	
C2 Effluent	7.00	GREEN	NO
C3 Habitat	9.33	GREEN	NO
C4 Chemicals	6.00	YELLOW	NO
C5 Feed	6.15	YELLOW	NO
C6 Escapes	7.00	GREEN	NO
C7 Disease	5.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife	–1.00	GREEN	NO
C10X Introduction of Secondary Species	–0.40	GREEN	
Total	**46.81**		
Final score (0–10)	**6.69**		

OVERALL RANKING

Final Score	6.69
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK

GREEN

Freshwater Net Pens

Criterion	Score	Rank	Critical?
C1 Data	8.86	GREEN	
C2 Effluent	7.00	GREEN	NO
C3 Habitat	9.33	GREEN	NO
C4 Chemicals	6.00	YELLOW	NO
C5 Feed	6.00	YELLOW	NO
C6 Escapes	7.00	GREEN	NO
C7 Disease	5.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife	0.00	GREEN	NO
C10X Introduction of Secondary Species	–1.00	GREEN	
Total	**48.20**		
Final score (0–10)	**6.86**		

OVERALL RANKING

Final Score	6.86
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK
GREEN

Acknowledgements

Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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Appendix 1: Data Points and all Scoring Calculations

Raceways and ponds

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	10.0
Effluent	10.0
Habitat	7.5
Chemical Use	5.0
Feed	7.5
Escapes	7.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	7.5
Escape of secondary species	7.5
C1 Data Final Score (0–10)	**7.727**
	Green

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

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0–10)	9
F3.2 – Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	5
3.2b Enforcement of habitat management measures	5
3.2 Habitat management effectiveness	10.000
C3 Habitat Final Score (0–10)	**9.333**
Critical?	No

Criterion 4: Chemical Use	
Single species assessment	Data and Scores

Chemical use initial score (0–10)	6.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0–10)	**6.0**
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 %	13.595
Fishmeal from by-products, weighted inclusion %	0.905
By-product fishmeal inclusion (@ 5%)	0.045
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	1.625
Fish oil from by-products, weighted inclusion %	3.375
By-product fish oil inclusion (@ 5%)	0.169
Fish oil yield value, weighted %	5.000
eFCR	1.400
FFER Fishmeal value	**0.849**
FFER Fish oil value	**0.502**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	8.081
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	**7.300**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	45.830
Protein INPUT kg/100 kg harvest	64.162
Whole body harvested fish protein content	15.700
Net protein gain or loss	–75.531
Species-specific Factor 5.2 score	**2**
Critical (Score = 0)?	No
Critical (FFER > 3 and 5.2 score < 2)?	No

5.3 Feed Footprint	**Data and Scores**
GWP (kg CO_2-eq kg^{-1} farmed seafood protein)	**7.352**
Contribution (%) from fishmeal from whole fish	16.293

Contribution (%) from fish oil from whole fish	2.381
Contribution (%) from fishmeal from by-products	1.090
Contribution (%) from fish oil from by-products	4.764
Contribution (%) from crop ingredients	44.848
Contribution (%) from land animal ingredients	27.431
Contribution (%) from other ingredients	3.193
Factor 5.3 score	**8**
C5 Final Feed Criterion Score	**6.2**
Critical?	**No**

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	6
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	6.000
F6.2 Invasiveness score	9
C6 Escape Final Score (0–10)	**7.0**
Critical?	No

Criterion 7: Disease	**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	**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
Lowest score if multiple species farmed (0–10)	n/a
C8X Source of Stock Final Score (0–10)	**0**
Critical?	No

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	–1
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**–1**
Critical?	No

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on trans-waterbody movements (%)	39.4
Factor 10Xa score	6
Biosecurity of the source of movements (0–10)	9
Biosecurity of the farm destination of movements (0–10)	7
Species-specific score 10X score	–0.400
Multispecies assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–0.400**
Critical?	n/a

Net pens

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	10.0
Effluent	10.0
Habitat	10.0
Chemical Use	7.5
Feed	7.5
Escapes	10.0
Disease	5.0
Source of stock	10.0
Wildlife mortalities	10.0
Escape of secondary species	10.0
C1 Data Final Score (0–10)	**8.864**
	Green

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

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0–10)	10
F3.2 – Management of farm-level and cumulative habitat impacts	

3.2a Content of habitat management measure	4
3.2b Enforcement of habitat management measures	5
3.2 Habitat management effectiveness	8.000
C3 Habitat Final Score (0–10)	**9.333**
Critical?	No

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0–10)	6.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0–10)	**6.0**
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 %	13.595
Fishmeal from by-products, weighted inclusion %	0.905
By-product fishmeal inclusion (@ 5%)	0.045
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	1.625
Fish oil from by-products, weighted inclusion %	3.375
By-product fish oil inclusion (@ 5%)	0.169
Fish oil yield value, weighted %	5.000
eFCR	1.700
FFER Fishmeal value	**1.031**
FFER Fish oil value	**0.610**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	**Data and Scores**
Source fishery sustainability score	8.050
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	**7.000**

5.2 Net Protein Gain or Loss (%)	**Data and Scores**
Weighted total feed protein content	45.080
Protein INPUT kg/100 kg harvest	76.636
Whole body harvested fish protein content	15.700

Net protein gain or loss	–79.514
Species-specific Factor 5.2 score	**2**
Critical (Score = 0)?	No
Critical (FFER > 3 and 5.2 score < 2)?	No

5.3 Feed Footprint	**Data and Scores**
GWP (kg CO_2-eq kg^{-1} farmed seafood protein)	**8.105**
Contribution (%) from fishmeal from whole fish	17.922
Contribution (%) from fish oil from whole fish	2.619
Contribution (%) from fishmeal from by-products	1.199
Contribution (%) from fish oil from by-products	5.240
Contribution (%) from crop ingredients	49.331
Contribution (%) from land animal ingredients	21.880
Contribution (%) from other ingredients	1.809
Factor 5.3 score	**8**
C5 Final Feed Criterion Score	**6.0**
Critical?	**No**

Criterion 6: Escapes	**Data and Scores**
F6.1 System escape risk	6
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	6.000
F6.2 Invasiveness score	9
C6 Escape Final Score (0–10)	**7.0**
Critical?	No

Criterion 7: Disease	**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	**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
Lowest score if multiple species farmed (0–10)	n/a
C8X Source of Stock Final Score (0–10)	**0**
Critical?	No

Criterion 9X Wildlife Mortality parameters	**Data and Scores**
Single species wildlife mortality score	0
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**0**
Critical?	No

Criterion 10X: Introduction of Secondary Species	**Data and Scores**
Production reliant on trans-waterbody movements (%)	100
Factor 10Xa score	0
Biosecurity of the source of movements (0–10)	9
Biosecurity of the farm destination of movements (0–10)	6
Species-specific score 10X score	–1.000
Multispecies assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–1.000**
Critical?	n/a