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Implementation of True Cost of Food Accounting in selected Swiss Agricultural Value Chains: the Case of Farmed Atlantic Salmon

Consumption Trends in Switzerland and abroad

The Blue Transformation Roadmap 2022-2030, published by the FAO, recognizes the need to support the UN Sustainable Development Goals through more efficient and sustainable aquatic food systems for better production, better nutrition, and a better life, leaving no one behind. Aquatic food systems in general and aquaculture in particular are also intended to relieve pressure on wild fisheries; almost 90% of commercially exploited fish stocks in the world's oceans are considered to be overfished.

In 2022, fisheries and aquaculture production reached an all-time high of 223.2 million tons, with over 57% originating from aquaculture systems. Global fish consumption per capita has reached an estimated 20.7 kg per capita of aquatic animal foods, constituting about 15% of the animal protein supply, reaching over 50% in several countries in Asia and Africa. With about 8.3 kg per capita, Swiss average consumption of fish and seafood in 2023 is relatively low, even though it grew over the past two decades by roughly 15%. This amounts to a total annual Swiss consumption of 75,000 tons. As a land-locked country, Switzerland imports 96% of its aquatic animal foods. Out of the 4% from domestic sources, wild-caught fish accounts for little more than 1% of Swiss consumption, while the rests originates from aquaculture. Rainbow trout is by far the most popular domestically produced fish consumed in Switzerland (1200 t/year), but farmed Atlantic salmon (240 t/year) has experienced the fastest growth rates.

Challenges and opportunities of sustainable salmon farming in Switzerland

With annual average growth rates of +10% in the past few years there are great economic opportunities to increase domestic fish farming in Switzerland and retailers are eager to offer domestically produced fish to Swiss consumers, provided that they are raised in a sustainable way. Despite the high demand, there are also several challenges in obtaining a permit for the construction of aquaculture facilities. For example, the use of net-cages in aquaculture is not allowed in Switzerland. At the same time, land-based recirculating aquaculture systems (RAS) cannot be certified as 'organic' farmed. As a consequence, certified organic Atlantic salmon (salmo salar) that is available in Swiss retail stores is imported from Irland and other places where they are raised in net-pens. An additional challenge for RAS systems in Switzerland are the high construction, land and labor costs in Switzerland.

Recirculating Aquaculture Systems (RAS)

https://www.zhaw.ch/de/lsfm/institute-zentren/iunr/oekotechnologien-energiesysteme/aquakultursysteme/

RAS are land-based aquaculture production systems that grow fish in a highly controlled indoor environment and have a low dependence on the surrounding environmental system. This allows producers to reduce fish mortality rates to an absolute minimum by protecting fish from pathogens and predators. Thanks to the internal water treatment and reuse, a RAS consumes less water and generates a fraction of the waste of common salmon farming systems. In return, a RAS-based production is more capital and energy intensive, and there are concerns about fish welfare in case of technical malfunctions or wrong management.

The Swiss company 'Blue Salmon has convinced many investors as well as Swiss retailers that the new generation of RAS Systems can manage such risks and is able to meet the growing domestic demand for sustainably produced domestic salmon in Switzerland. The company will be located in Mollis in the Canton of Glaris, at the shore of Lake Walen. Its operations will run on 100% renewable energy, use the latest water treatment technologies and reuse waste as part of the circular strategy.

The company known under the brand Swisslachs[1] based in Lostallo in the canton of Graubünden is so far the only major producer of farmed atlantic salmon taking advantage of RAS technology. RAS are resource efficient and intensive fish farming systems. As land-based recirculating systems, they minimize adverse environmental impacts, such as habitat destruction, water pollution and eutrophication, and aquatic biodiversity loss due to captive fish and exotic species escape, disease outbreaks, and parasite transmission. Moreover, RAS operate in a controlled indoor environment, and are therefore only minimally affected by climatic factors as rainfall variation, floods, droughts, global warming, cyclones, salinity fluctuations, ocean acidification, and sea level rise. This also protects animal health and welfare explaining the very low mortality rates of farmed fish in RAS. However, high stock densities and the potential risk of mass mortality in the event of technical failures remain an animal welfare concern associated with RAS.

Overall, RAS may have several sustainability advantages compared to the farmed salmon imported to Switzerland from Norway, Scotland or Ireland where salmon, especially if the salmon was raised in net-cages..

Environmental and animal welfare costs of farmed salmon

As a carnivorous fish, salmon is typically fed with pellets containing 20-30% fishmeal from small wild-caught fish or trimmings. This increases the overall environmental footprint. However, increasing proportion of fish meal and fish oil used in salmon feed is made from trimmings, i.e. seafood processing by-products. Moreover, substantial efforts have been made in recent years to improve the feed conversion rates and to increase the share of proteins from alternative sources such as soy bean and insects. The volume of live fish extracted from the sea needed to produce one kg of liveweight salmon in each supply chain is calculated by the Fish-in-Fish- Out Ratio (FIFO), which improved substantially over time. If feed from trimmings is discounted, it amounts to a net-FIFO of 1.8 for fish oil, and 0.7 for fish meal for Atlantic salmon. Another indicator is Forage Fish Dependency Ratio (FFDR). It takes into account the amount of fishmeal and fish oil in the feed that originates from wild stock. It is calculated on a site specific basis. The FFDR for Atlantic salmon improved from 2.57 in the year 2000 to 0.68 in 2020[2].

Almost 80% of the salmon produced worldwide is farmed salmon, of which around 99% is raised in net cages at seashores. These net-cages are densely packed and expose salmon to viruses and pathogens. This affects animal welfare and generates undesirable effluences into the surrounding aquatic environment, such as salmon waste and chemicals used to treat fish infections, such as sea lice. The excrements of farmed salmon may be collected and recycled to some extent, but it can also lead to eutrophication reducing oxygen levels and biodiversity in the respective habitats. In addition, salmon that escape from their underwater cages pose a threat to their wild counterparts, as they can spread diseases and breed with wild fish to the detriment of the natural ecosystem. As a result, 40% of the salmon found in Norwegian rivers originates from salmon farms.

[1] https://swisslachs.ch/

[2] https://www.iffo.com/ffdr-data

Value chain perspective of fish different production methods

Interview with Fridolin Tschudi (FT), Head of Recirculating Aquaculture Systems ZHAW Wädenswil and Co-Founder of the Koordinationsstelle Aquakultur, July 17, 2024

Question: Where do you see the major animal welfare and environmental challenges of aquaculture?

FT: Fish farming has become subject to scrutiny in view of unsustainable practices associated with net-cages. Studies from Norway show that average mortality rates are close to 20% when salmon is farmed in net-cages. Reasons are different, for example sea lice, viruses, bacterial infections, algae blooms and more. Net-cage farming is also a threat to the local environment and aquatic biodiversity due to environmental pollution and escapes of farmed fish into the wild. Switzerland addresses these challenges through strict animal welfare guidelines and water protection laws. It is a good legal framework that makes RAS-based salmon farming attractive.

Question: Do you see a gap between public perception and facts in the aquaculture debate?

FT: There are problems in aquaculture, but popular documentaries such as seaspiracy tend to make use of outdated numbers about the use of fishmeal to feed salmon and do not mention any progress over the past decades in minimizing the negative externalities. The discussion often ignores possible trade offs between specific aspects of animal welfare end environmental pollution. For example, farming fish on land requires the construction of tank infrastructure. The lower the stocking density chosen, the higher the environmental impact of the construction (concrete, land use etc).

A recent study published by Wild Fish (2023[3]) revealed systemic failure of net-caged based systems to improve environmental, animal welfare standards, which would also apply to the most widely recognized farmed salmon certification schemes in Scotland such as Aquaculture Stewardship Council (ASC), RSPCA Assured and Soil Association's Organic standards. The report denounces third-party certification schemes for open-net farmed salmon as greenwashing that mainly allows retailers to command a premium price. It is however important to take into account that there is a wide range of net-cage based management practices, some of which have invested substantially in the latest technology to reduce their negative impact on animal welfare and the environment, while others failed to do so.

How does the footprint of wild salmon compare with farmed salmon?

Roughly 20% of salmon consumed worldwide is labeled as wild salmon (pink, sockey, coho, chinook salmon) mainly originating from North America/Alaska, and to a lesser extent from Japan, Russia and Norway. Even though wild salmon enjoys a better image and is less exposed to public scrutiny, the term 'wild' would only apply to the tiny share of recreational fisheries, if taken literally. Instead, the term 'ranged' rather than 'wild' would better apply to the significant share of salmon that are raised in professionally managed hatcheries before being released and later caught as 'wild' in purse seines or gill nets as the fish return to spawn. Troll fisheries are primarily used to target chinook and coho salmon. Despite numerous techniques to avoid by-catch, it is inevitable that other fishes end up in the nets. Due to the short duration of the fish harvesting period (June/July) the fish catch is processed quickly on site and then exported as 'fresh' salmon for further processing to third countries. Fish by-products on-site therefore tend to be grounded up and dumped rather than recycled as secondary products such as fish oil or fish meal. 60% of the harvest of Alaska-based wild salmon is exported to China, often for further processing and re-export, which tends to increase carbon emissions.

Overall, the constrained nature of wild salmon production makes the system more extensive, which tends to lower the negative impact on the environment. But processing and transportation to remote destinations can still result in high carbon emissions, especially when salmon is exported fresh via airfreight.

Upstream Sustainability Challenges and Opportunities

Apart from fish feed, a sustainability challenge described earlier, a salmon farm buys either smolts (young salmon) or fish eggs. The quality of these inputs depends to a great extent on fish genetics.

Fish genetics

Selective breeding programs have led to significant improvements in terrestrial livestock production. In farmed aquatic species, genetic improvement is still in its infancy, but recent advances in the

[3] https://wildfish.org/wp-content/uploads/2023/09/Responsibly-Farmed-Investigating-the-certification-of-Scottish-farmed-salmon.pdf

Value chain perspective of fish different production methods

Question: How did new technologies help reduce the environmental footprint?

FT: There were at least three major technologies: a) the extrusion process, which renders fish feed easier for fish to digest and absorb. This allowed to increase feed conversion rates and increase the share of plant-based feed ingredients also for carnivorous salmon. This is valid for all types of production systems, not only RAS. b) Advances in genetics research combined with new fish vaccines have massively improved fish resilience and health, which again helped to reduce the use of antibiotics and increase survival rates. Indirectly this improves the overall feed efficiency as well. c) recirculating aquaculture systems (RAS) have become an alternative to net-cages ensuring emissions from fish farming activities can be controlled and kept to an absolute minimum and finite resources like phosphorus can be recycled.

Question: True Cost Food (TCF) aims to internalize the external costs of fish production. Would that be in the interest of Swiss producers of farmed salmon and would other players in the value chain support it?

FT: The TCF concept could be interesting, but it needs to involve all players in the value chain. In Switzerland, the 'Koordinationsstelle Aquakultur' fosters dialogue across the value chain and beyond. The challenge is however that the value chain is focused to a great extent on the processing and marketing of imported fish rather than the products from a relatively small number of domestic producers.

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understanding of fish genetics and novel breeding techniques have greatly increased the potential to address economic as well as environmental and animal health challenges. As one of the most prominent and commercially valuable fish species, Atlantic salmon can be considered as one of the few aquatic animals that has been properly domesticated by humans to better suit the conditions of fish farming, be it in net cages or RAS. Bred Atlantic salmon tends to grow faster, has better feed conversion rates, is more disease resistant and produces more of the valuable consumable parts compared to its wild counterparts.

Sterile eggs

In order to minimize the risk of bred salmon to interbreed with wild salmon in case they manage to escape from net cages, certain companies already sell sterile eggs based on the triploidy technique. Triploidy generates a set of three rather than two chromosomes in salmon, inhibiting the second meiotic division, yielding sterile fish. The technique has been successfully applied three decades ago. However, it still faces little acceptance in the market as the mortality of sterile salmon is higher. In this context, the use of advanced breeding techniques has a great potential to address such constraints effectively. In addition, genome editing holds significant potential to further improve desirable traits that also benefit animal health and well-being while reducing the environmental impact of farmed salmon through reproductive confinement. The advantage of using genome editing in fish breeding is the fact that eggs are relatively large compared to those of mammals, and the fact that they are external makes them easily amenable to microinjection, electroporation, or other protocols to introduce DNA constructs.

Smoltification

There are also several challenges related to the upstream business: the so-called parr-to-smolt transition (PST), otherwise known as smoltification. Smolts are raised in hatcheries that are in most cases 'closed fresh water tanks'. Later on, they are transported to net cages at seashores or dropped in rivers close to the sea waiting for their return to freshwater rivers to spawn. Hatcheries represent a critical life stage for salmon involving large physiological, morphological, and behavioral changes required for successful transition from freshwater (FW) to seawater (SW). In the case of farmed salmon, in particular, the initial procedures of gathering together, counting, capturing, sorting, crowding, pumping, vaccinating and loading smolts can be very stressful leading to an elevation of plasma cortisol in juvenile (10–14 months) salmonid species. Animal welfare concerns are raised due to injuries that may easily happen during life transport over longer distances that later on may lead to higher mortality rates.

Downstream Sustainability Challenges and Opportunities

A differentiated life cycle assessment of farmed salmon downstream should consider four major areas: 1) use of by-products for secondary products; 2) use of energy source (renewable/non-renewable) in the cold chain; 3) amount and type of refrigerants used to keep product

Value chain perspective of fish different production methods

Question: Is it safe for consumers to simply rely on labels in their desire to pick the sustainable fish product?

FT: I think many of the sustainability labels conceal more than they reveal. One example is imported certified of organic salmon from Ireland or Scotland. It relies on net cage technology and the phosphorus in fish feces continue to be an undesirable source of emissions.

In terms of animal welfare, Swiss Aquaculture Association requires today that fishes must spent 90% of their life in Switzerland in order to obtain the label Suisse Garantie. This generates additional costs for fish producers while encouraging abuse. For example, there were cases where companies imported fish alive and subsequently raised and sold them as 'Swiss' fish.

Question: Would it make sense to replace or complement labels with a sustainability score based on concrete output measurements for each actor in the fish value chain?

FT: I am very confident that Swiss-based companies that produce fish in recirculating aquaculture systems (RAS) would obtain a very high score. But they would probably only take the effort to enter all their data to obtain a score, if there is a return on investment. In this context, the TCF concept could indeed make it more attractive.

fresh/frozen); 4) means of transportation and type of packaging in logistical chain for fresh/frozen farmed salmon. In each area, there are potential trade-offs between sustainability and profit that may or may not be successfully addressed through innovation in technology and management practices. Sustainability solutions may entail climate neutral refrigerants, hydropower-generated electricity and full utilization of by-products through state-of-the art facilities near the production site. The best combination may also depend on the respective species, the production method, the origin and the product form.

Product Waste: Why frozen fish deserves a better image

The main aspect to consider in the downstream part is product waste that may be substantially reduced by making use of the latest technologies to upgrade by-products from primary and secondary processing to create additional food products and ingredients. Generating more food products out of the biomass harvested would also substantially reduce carbon emissions. This would also require a shift in the demand from fresh to frozen products. However, recent trend go into the opposite direction due to the low consumer esteem for frozen products; in view of the higher margins for fresh fish, industry marketing campaigns, and sometimes even governmental policies tend to neglect the raising of consumer awareness about the positive external benefits of frozen seafood products. They include reduced transport emissions and lower product losses. Alternatively, airfreight of fresh salmon can be avoided when making use of sub-chilling (a technology that cools fresh fish down extremely fast to just above the freezing point. It may more than double the shelf life of fresh salmon, especially when combined with modified atmosphere packaging, where oxygen is replaced with nitrogen and carbon dioxide to further reduce microbial growth. As a consequence, fresh salmon can be transported by ship across long distances.

Socioeconomic and public health benefits of domestically produced salmon

Aquaculture in general and RAS in particular may contribute to local economic development and the creation of off-farm employment in rural regions where land use is more affordable, which also encourages the processing of fish and its by-products on site. Increased local aquaculture-based fish production also improves the accessibility and availability of nutritious foods. Salmon consumption is considered to be healthy due to its high content of protein and omega-3 fatty acids. It is also a good source of minerals, iodine and vitamins.

Trade-offs between economic and environmental sustainability

The potential trade-offs between economic viability and sustainability in aquaculture production systems may, at least in principle, be addressed through innovation in management and technology. The case of the company Swiss Blue Salmon illustrates this well. It has the ambitious objective to not merely reduce dependence of imported farmed salmon, which often originates from problematic net-cage rearing, but to create one of the most advanced and sustainable land-based RAS systems.

Producer Perspective (Blue Salmon)

Interview with Rudolf Ryf (RR), CEO of Blue Salmon, July 10, 2024

Question: The concept 'True Cost of Food' (TCF) aims to internalize the negative environmental and social externalities generated in the production of a particular food product. How would Blue Salmon fare in a TCF Assessment?

RR: More than 99% of the farmed salmon we import originates from net-cage farming systems, including certified organic. A TCF assessment would have to differentiate between different systems of salmon production. Our planned recirculating aquaculture system (RAS) will use the latest technologies to improve animal health and welfare and to minimize the impact on the environment. Moreover, it would be based on 100% renewable energy. In addition, by buying eggs rather than smolts we ensure that the salmon goes through all the development stages in-house. We guarantee the best water quality for the fish resulting in 100% parasite free fish and the lowest mortality rates in the industry.
Realizing such a production facility in Switzerland would be a milestone in lowering the external costs of salmon production. Currently, there is however no label or score that acknowledges the sustainability of such high-tech facilities; sustainability scores could give consumers a more accurate and transparent picture of production methods.

This may be financially risky because it requires a lot of investment and the build-up of an entire economic ecosystem in the region to meet the high sustainability standards and make use of all possible by-products in the respective region. However, as the case of Swiss Shrimps illustrated, the revenues from sales may not cover the costs of operating an advanced RAS system on the long run. Blue Salmon may however be different since it will be able to produce higher volumes due to the size of its facilities. A lot may however depend on the willingness of Swiss consumers to value a sustainable domestic Swiss salmon production. Once the company has obtained the construction permit it may count on a lot of political support from the local authorities who recognize the economic potential.

Sustainability Labels and Scores

There is not yet a label that adequately recognizes the sustainability performance of such a RAS. At the same time, there is skepticism about existing sustainability labels in aquaculture, including organic ones that are also based on net-cage farming. Moreover, these labels often benefit the certifiers rather than the producers and many of them have credibility issues. There are attempts to address this by calculating more concrete sustainability scores. Ecoscore[4], for example, relies on the assessment of different production systems and transport methods made by organizations such as WWF. It integrates firm-level data if available. But detailed data on the firm level is rarely available, unless the respective company has published a sustainability. Since small- and medium-sized companies rarely have the means to collect environmental and social data and publish such a report, they are likely to obtain less favorable rating. This may explain why Salmon from a small-sized alpine Swiss production site using a RAS system (Schweizer Alpenlachs) obtained a low 'E+' score (14 out of 100 points) in Coop retail stores in 2024 - compared to a relatively high B- (62 out of 100 points) for wild salmon imported from Alaska. Obtaining a sustainability score based on independently verifiable data provided by the company itself would be a more accurate and fair way of estimating the real sustainability performance; especially when scores are comparable among peers through a calibrated benchmarking system.

True Cost of Food Assessment of Fish

Over the past five decades, the aquaculture sector responded to economic opportunities in response to the growing global demand for seafood by expanding and intensifying production. This trend also led to environmental costs such as destruction of critical natural habitats, nutrient pollution, and the use of wild fish in feed production. Emerging awareness of these risks and subsequent regulation forced the sector to respond to these environmental challenges through investment in innovation in technology and management practices. In addition, sustainability labels and scores have been developed to increase transparency and orientation for consumers – even though they often lack differentiation.

Perspective of Blue Salmon (continued)

Question: Are there also disadvantages of a RAS that is based on 100% renewables?

R.R.: There is the environmental footprint resulting from animal feed and there are concerns about animal welfare due to the relatively high stock densities and possible technical failures that could have a lethal impact on the farmed fish. As for animal feed, we have already obtained the assurance of several Swiss-based companies that could provide us with insect- and fungi-based rather than fish-based proteins.

Concerning animal welfare, Swiss regulation does not allow fish stock densities that exceed 80kg/m^3. This 30-40% lower than the industry standard abroad. Despite this strict animal welfare standard, we will be able to produce economically thanks to size of our facility and the advanced technologies we use to control animal health and welfare parameters. As for system failure, this is highly unlikely considering the dependable infrastructure in Switzerland.

Question: Many would consider 'wild salmon' to be the best choice because it seems more close to nature, would you agree?

R.R.: Salmon that is labeled as 'wild' stems from 'ranged' salmon production imported from remote regions such as Alaska. In my view, its claim to be natural and sustainable has to be challenged. The documentary „Artifishal" from Patagonia illustrates these unsustainable practices well. It does not fit the romantic story of pricy 'wild' salmon in retail stores.

[4] https://beelong.ch/en/

Assessing farmed Swiss Atlantic Salmon in a RAS

The trend can be well-illustrated in the case of Atlantic salmon, a high value seafood product that has experienced steep growth rates due to strong consumer demand. The demand for Atlantic salmon may not just be related to its taste but also to its nutritional value. Salmon contains essential nutrients that are harder to come by in terrestrial animal-sourced foods, such as certain essential fatty acids, but also due to low sodium and saturated fat content. As such, it belongs to the seafood products that have the best balance of nutrient density to GHG emissions, if sustainably managed, according to a recent study by Bianchi et al. Land-based recirculating aquaculture systems (RAS), such as the one planned by Blue Salmon to increase the offer of sustainably produced domestic salmon in Switzerland illustrates this well. It is taking advantage of almost all opportunities to reduce GHG emissions by using low-emission technologies or inputs (e.g. renewable energy sources, feed inputs), relying on a circular economy approach to water and waste management and by minimizing its impact on the local environment through advanced containment technologies. At the same time, extremely low mortality rates of farmed salmon in RAS indicate that such systems perform better in terms of animal health and welfare than net-cage based systems from which all the imported farmed salmon in Switzerland originates. In return, a RAS-based production tend to be more capital and energy intensive, and there are concerns about fish welfare in case of technical malfunctions or wrong management.

Minding the Gap

However, neither current Sustainability Labels and Scores, nor existing True Cost of Food assessments of salmon production currently take into account how innovation in technology and management are able to effectively address tradeoffs. Instead, sustainability assessments tend to rely on publicly available data on product- or method-based footprint assessments that do not really capture the actual sustainability performance of a particular producer. There is also an ongoing discussion whether True Cost of Food Assessments tend to focus too much on the so-called 'green shift', which tends to assume that a transition from meat-based to plant-based diet is not just good for the environment but human health, despite the fact that certain nutrients are missing in an exclusive plant-based diet. Since salmonids have some of the highest nutrient density and are very complementary to a plant-based diet, some scholars like Golden et al., Gephart et al and Bianchi et al., argue in favor of a 'blue shift' rather than a 'green shift'.

Perspective of Blue Salmon (continued)

Question: Will sustainable production of farmed salmon in Switzerland also be economically viable?

R.R: Yes, it may be expensive to operate such facilities in Switzerland, but we will be able to produce relatively large volumes of high margin salmon that meet a great demand from Swiss-based retailers. Moreover, we save a lot of resources thanks to making smart use of surrounding environmental resources. For example, our RAS has the great advantage of being close to Lake of Walen, which allows to cool our facilities with lake water without having an impact on the temperature in the lake. Despite all this, it would greatly help to make the business succeed if its sustainability performance would also be acknowledged by retailers and the Swiss government.

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Consumption, Production and Trade of Fish

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Labels for Sustainable Aquaculture

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https://www.youtube.com/watch?v=XdNJ0JAwT7I

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