May 2020

Fish Welfare Initiative

[Figure 1. A farmed Salmon which is infested with Sea Lice. Photo: Screenshot from 'Panorama: Salmon Fishing Exposed', BBC]

Guest Report:

Welfare Issues in Farmed Atlantic Salmon

Welfare Issues in Farmed Atlantic Salmon

By Mark Borthwick, Guest Contributor

We (Fish Welfare Initiative) are very grateful to Mark for writing this report. If you are interested in being a guest contributor with Fish Welfare Initiative, we encourage you to contact us.

While Fish Welfare Initiative itself will not be focusing directly on salmon welfare in the next few years, we think it is a pressing issue nonetheless and an effective focus for animal protection organizations.

Summary

Salmon is the most valuable fish in the world, with a harvest of 2.2 million tonnes[1] of salmon (approximately 1 billion head of fish[2]) producing USD$15.4bn annually.[3] Despite a steady improvement in standards and practices in salmon aquaculture over the past two decades, innovative husbandry techniques have been accompanied by new welfare issues.

This paper outlines the main welfare issues in contemporary aquaculture of Atlantic salmon, and identifies areas where further research is required. The main findings are as follows:

- **Salmon fare particularly poorly in captivity**, and do not have a life which the Farm Animal Welfare Council (FAWC) would consider 'worth living'. Salmon are essentially kept in battery conditions, despite evidence that their quality of life is significantly impacted by current farming practices.

- **Disease**. Pesticide-resistant sea lice present an existential threat to the salmon farming industry, and represent an extinction-level threat to wild salmon populations.

- **Salmon are obligate carnivores, to which other animals are fed.** One third of all caught fish are fed to farmed fish, and salmon are increasingly fed a mixture of soy, caught fish, and poultry meal. This essay estimates that each farmed salmon is fed the equivalent of 9 herring, further compounding welfare issues for animals in the supply chain.

[1] FAO. "The State of World Fisheries and Aquaculture 2018-Meeting the sustainable development goals." (2018) p.23.
[2] Calculated by dividing gross weight by weight per head, then multiplied to include pre-harvest mortality. All in kilograms: (2,200,000,000*0.4)*1.2.
[3] International Salmon Farmers' Association, 2018 report. Available here: https://sjomatnorge.no/wp-content/uploads/2018/06/ISFA-Report-2018-FINAL-FOR-WEB.pdf.

- **Slaughter methods** have been uncritically appropriated from terrestrial animals, and not based upon the best available evidence for humane slaughter of teleost fish.
- **Species-specific research** is required to determine whether the control mechanisms for salmon's preferred behaviors can be emulated in captivity.

Contents

Why salmon?

This article will make the case that salmonid welfare is a tractable and important area of the emerging field of fish welfare ethics. Salmonids have been chosen as the focus of this article for several reasons. They are the most farmed fish in Europe, accounting for 90% of total aquaculture in the region. Scotland produced 37,000,000 salmon in aquaculture conditions in 2018,[4] and has committed to a plan to double production by 2030.[5] Norway,

[4] Marine Scotland Science. "Scottish Shellfish Farm Production Survey" (2018).
[5] Scottish aquaculture. "A view towards 2030" (2016).

the world's largest producer of salmon, has quadrupled production since 2007, and currently produces 212,000,000 salmon per annum.[6] The global market for salmon has grown by an average of 10% per year since 1976, and since 2013 salmon is the largest single fish commodity by value, constituting 18.1% of the global fish trade value, despite making up only 2.8% of global animal aquaculture.[7] [8]

Salmon occupy a unique place in the discourse of welfare in aquaculture. They are vertebrates, meaning their biology is more compatible with existing animal welfare research than molluscs and crustaceans. Additionally, several of the most prevalent welfare factors in Salmon are limiting factors in their production: sea lice infestations and high mortality threaten the economic viability of many operations. This means there is a short-term convergence of the interests of farm businesses and the welfare of their salmon crop, providing a strong economic incentive to address welfare issues on-farm. There is also a legislative propellant for innovation and reform: due to a reputation for catastrophic environmental damage, open-net salmon farms are in the process of being phased out in Washington State,[9] with Canada[10] and the EU[11] also moving towards prohibition of the practice, despite it being a significant contributor to each of these regional economies.[12]

Salmon's high farmgate value, as well as the location of salmon farms in wealthier countries, have contributed to it being amongst the most well researched husbandry systems in aquaculture. Though we are perhaps closer to understanding the welfare concerns in salmon than those of any other fish, a formidable quantity of knowledge gaps permeate the literature.

Salmon today fare particularly poorly in captivity, with high morality, a high rate of injury, and clear and present suffering at almost every stage of the production process. This article will provide an overview of the major welfare deficits, and suggest directions for further research to ameliorate their living conditions in open-net sea farms.

---

[6] EYGM. "The Norwegian Aquaculture Analysis 2017" (2017).
[7] *Supra* note 1, p.63,23.
[8] The high value/mass ratio makes salmon a promising candidate for cellular aquaculture. Indeed Tufts University began work this month on culturing salmon lines. See: https://www.gfi.org/blog-gfi-ssi-atlantic-salmon.
[9] Fisher, B. "Washington Governor Jay Inslee signs bill banning Atlantic salmon farming", *Seafood Source.* March 23 2018. Available at: https://www.seafoodsource.com/news/aquaculture/washington-governor-jay-inslee-signs-bill-banning-atlantic-salmon-farming.
[10] Smith, J, "Trudeau asks new minister to move ahead with plan to phase out BC net-pen salmon farming", *Undercurrent Magazine*. Dec 13. 2019. Available at: https://www.undercurrentnews.com/2019/12/13/trudeau-green-lights-plan-to-move-bc-salmon-farming-to-closed-containment/.
[11] Paloniitty, Tiina. "The Weser Case: Case C-461/13 Bund v Germany." *Journal of Environmental Law* 28.1 p151-158, (2018).
[12] For economic information see the FAO's National Aquaculture Sector Overviews (NASO), indexed here: http://www.fao.org/fishery/search/countrysector.

Can salmon feel pain?

A common question in fish welfare is: are these animals capable of having qualitative experiences? Until the late twentieth century it was assumed that the physiology of fish brains was too simple for them to process qualitative experience. The structure of the salmon's brain is significantly different from those of mammals: Salmon lack a neocortex, the area of the mammalian brain to which we attribute the qualitative experience of pain,[13] and fish brains are significantly smaller than their mammalian analogues.

However, salmon do possess nociceptors, afferenta which trigger the experience of pain in the human brain. The presence of these sensory neurons allow us to sidestep the philosophical dimensions of discussing the qualitative experience of pain and discuss a much simpler question: can salmon suffer?

There is a significant body of evidence supporting the claim that salmon are capable of suffering. Despite 350 million years of evolutionary divergence, teleost fish maintain a phylogenetic continuity with mammals, and the hormonal control systems of finfish is very similar to other vertebrates. Stress in fish can be measured by neuroendocrine responses through similar methods to mammals. Teleost fish have an active homologue to the hypothalamic-pituitary-adrenal stress response, which releases cortisol into the blood. Akin to mammals, reptiles, rodents, and birds, prolonged exposure to cortisol is harmful and results in loss of condition, immunosuppression, slow growth, and increased susceptibility to pathogens.[14] Pottinger states exposure to prolonged stress has "definite implications for the welfare of [fish]".[15]

Recent studies show that fish are capable of perceiving and avoiding nociceptive stimuli. They are also capable of identifying and avoiding aversive situations, such as encounters with predators.[16] These behavioural and hormonal responses to stress are sufficiently similar to mammals to indicate that fish are capable of suffering, and meet (at least) some criteria for consciousness. This allows us to conclude that aversive behavior in salmon, such as fleeing, flapping, struggling, gasping, or cortisol production, is homologous to the mammalian pain response.

---

[13] Rose, J.D. *The neurobehavioural nature of fishes and the question of awareness and pain*. "Reviews in Fisheries Science:, **10**, 1038 (2002).
[14] Wendelaar Bonga, S.E. *The stress response in fish*. "Physiology Review", **77**, 591–625. (1997).
[15] Pottinger, T., *The Stress Response in Fish -- Mechanisms, Effects, and Measurements* in "Fish Welfare", Branson Ed. , (2008).
[16] Czanyi, V. & Doka, A. *Learning interactions between prey and predator fish*. "Marine Behaviour and Physiology", **23**, 63–78. (1993).

[Figure 2. A 16-net open-net farm, home to around 3 million salmon. Photo: Inside Scottish Salmon Feedlots]

Lifecycle and mortality

Adult salmon are raised in open-net sea cages, weighted nets which dangle down into coastal waters from a buoyant ring. These nets vary in size, but it's common for them to hold 200,000 adult fish apiece. Each farm consists of multiple nets. Scotland has 211 such farms, Norway has over a thousand. Prior to this, for the first nine months of life, salmon are raised in inland tanks. Salmon are freshwater creatures until they 'smolt', a process analogous to puberty where they become adapted to saltwater conditions. Juvenile salmon are kept in inland tanks until smoltification, which can be induced as early as nine months in a controlled aquaculture setting.

Salmon have idiosyncratic needs at each stage of their lifecycle. When smolting, the salmon develop aggressive characteristics, and must be moved to saltwater quickly or the smoltification process will be interrupted, and they will adapt back to freshwater. However, parr (juvenile salmon) which are exposed to saltwater before smoltification will experience major health problems and often perish. Different members of a salmon population grow at different speeds, and not all parr in a batch will be ready to be introduced to a salt water environment at the same time. Because of this, parr are graded by size, and grouped in tanks with fish who are growing at a similar pace.

Fish find handling stressful, especially when it involves removal from the water.[17] The Humane Slaughter Association recommends the application of anaesthetic for removals of more than 15 seconds.[18] As a result, juvenile salmon are usually graded no more than four times, meaning their size groupings are imprecise.

[Figure 3. A recirculating aquaculture system, of the type used to mature juvenile salmon, Photo: Clearspan]

The school is transported into sea nets when the fish reach the approximate size to suggest they have smolted. Even when graded by size, it is common for some fish in the size group to be underdeveloped when moved into saltwater, and subsequently die. Since January 2018 The Scottish Government has published mortality rates for its salmon farms. Transfer is consistently associated with a mortality rate of ~3%.[19] A three percent loss of stock would be unacceptable in most other farming systems, and such a spike in mortality in the husbandry process is recognized as a welfare issue in terrestrial farmed animals.[20]

The Scottish Government reports that the total proportion of salmon which die before being harvested is 21%.[21] Scotland produced 37 million salmon in 2018, meaning 7.8 million salmon died during the aquaculture process.[22] The 2017 Norwegian Aquaculture Analysis reports a mortality rate of 16%, and states in its executive summary that "53 million salmon [die] inside the cage".[23]

[17] Willoughby, Stephen. *Manual of salmonid farming*. Blackwell Science Ltd, (1999).
[18] Humane Slaughter Association. "Humane Harvesting of Salmon and Trout.(Guidance notes no 5)." *HSA & CJA. Wheathampstead. UK*. (2005).
[19] These mortality reports are available at: https://www.scottishsalmon.co.uk/reports [Accessed February 2020].
[20] Blokhuis, H.J. and De Wit W.. XIX World's Poultry Congress, Amsterdam, The Netherlands, 20-24 Sept., (1992).
[21] Scottish Government FOI request 18/02806: https://www.gov.scot/publications/foi-18-02806/ (2018).
[22] Marine Scotland Science, "Scottish Fish Farm Production Survey" (2017).
[23] *Supra* note 6 .

Any practice causing such a spike in mortality in a terrestrially farmed animal would be under close scrutiny as a husbandry deficiency. A 20% standard mortality rate would raise serious concerns in any farmed mammal: pre-harvest broiler chicken mortality has been identified as problematic, at n=8%.[24] Even this is far outside the normal range of objection.

There is an additional frontier here for ethicists, however, as fish are the first vertebrates to be intensively farmed who follow an r-selection strategy.[25] Cattle, sheep, goats, poultry, *et cetera* all produce a small number of offspring and invest heavily in their survival. These animals can typically expect all or most of their offspring to survive to adulthood, without exceeding the carrying capacity of their environment.[26] Salmon operate in an entirely different way, investing very little in each of their offspring, but spawning hundreds of eggs in the expectation that the majority will die.[27] Chaput observes egg-to-smolt survival in salmon redds of <0.5%.[28] Salmon have an unusually high mortality at sea, with 65-69% of a population dying each year.[29] It is less clear that the Scottish mortality rate of 21%, which would be unacceptable for K-selection livestock, is objectionable in this context. Further research is required into acceptable mortality rates in the aquaculture of r-selection species.

Stocking density

Stocking density is somewhat more complicated in fish than in terrestrial livestock. For cattle, stocking density can be represented simply as 'heads per hectare'. The three-dimensional quality of the aquatic environment means that stocking density in fish is measured by the weight of fish per cubic metre of water. Stocking density is particularly important for fish due to the complex chemical interface between them and the water around them. If salmon have less than a bathtub's worth of water each, they begin to suffer due to the lack of available oxygen in the water. Additionally, high stocking densities lead to higher levels of disease, and increased inter-fish aggression.

[24] Yassin, Hurria, et al. "Field study on broilers' first-week mortality." *Poultry science* 88.4 (2009): 798-804.
[25] Pianka, E.R. (1970). "On r and K selection". American Naturalist. 104 (940): 592–597.
[26] This is known as 'K-selection'. *Supra* note 25.
[27] This is 'r-selection'. *Supra* note 25.
[28] Chaput G., Allard J., Caron F., Dempson J. B., Mullins C. C., O'Connell M. F.. River-specific target spawning requirements for Atlantic salmon (Salmo salar) based on a generalized smolt production model, Canadian Journal of Fisheries and Aquatic Sciences, vol. 55 pp. 246-261 (1998).
[29] Gérald Chaput, Overview of the status of Atlantic salmon (Salmo salar) in the North Atlantic and trends in marine mortality, ICES Journal of Marine Science, Volume 69, Issue 9, November 2012, Pages 1538–1548, https://doi.org/10.1093/icesjms/fss013 (2012).

[Figure 4. Stocking density in the upper layer of a sea cage in Norway. Photo: Patagonia, still from Artifishal]

High stocking densities are associated with decreased growth, diminished nutritional uptake, reduction in food conversion efficiency, fin erosion, gill damage, immunosuppression, and inter-fish aggression.[30] One 2005 study suggests that these symptoms begin to appear when salmon are stocked above 22kg/m³.[31] *Nota bene* that the current EU restrictions exceed this, allowing fish to be stocked up to 25kg/m³.[32] EU organic regulations, which aim for high welfare but are followed by a minority of salmon farmers, set salmon stocking density at 10kg/m³.[33] This more cautious stocking density is calculated in recognition that fish welfare exists in a complex web of situational factors, and other conditions (e.g. a slow tide reducing refresh rate of water in the cage) can impact the oxygen availability for individual fish.

Stocking at these lower levels mitigates, but does not solve, issues of inter-fish aggression and disease incubation. However it is not desirable to stock any lower than 10kg/m³, as many species of finfish (salmon and trout included) have a dominance hierarchy, and aggressive behaviour increases when fish are stocked at a low densities.[34] Smolts, who roam widely finding food to fuel their period of rapid growth and rarely encounter other

[30] Ashley, Paul J. "Fish welfare: current issues in aquaculture." *Applied Animal Behaviour Science* 104.3-4 (2007): 199-235. p212.
[31] Turnbull, J., Bell, A., Adams, C., Bron, J., Huntingford, F.,. Stocking density and welfare of cage farmed Atlantic salmon: application of a multivariate analysis. Aquaculture 243, 121–132. (2005).
[32] For context, 25kg/m³ is roughly equal to one salmon per ‘bathtub’s worth of water.
[33] EUR-LEX Document 32009R0710 “Commission Regulation (EC) No 710/2009 of 5 August 2009 amending Regulation (EC) No 889/2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007, as regards laying down detailed rules on organic aquaculture animal and seaweed production”.
[34] North, B. P., et al. "The impact of stocking density on the welfare of rainbow trout (Oncorhynchus mykiss)." *Aquaculture* 255.1-4 (2006): 466-479.

salmon, attack and cannibalize smaller smolts in the close confines of a sea net. Some welfare specialists, such as Juell, argue that the only reason this aggression is replaced with schooling behaviour at higher stocking densities is that the salmon are under stress, and swim together as a behavioural adaptation to that stress.[35] Juell observes that schooling behavior is not normally seen in smolts, but is common in sea farms.

From a welfare perspective the problem of stocking densities seems irreducible: the salmon school at high stocking density because they are stressed. If stocking densities are reduced in an attempt to reduce stress the salmon begin to express their naturally domineering behaviour. In the sea cage environment, smaller fish cannot flee and are harmed. Compassion in World Farming concludes that these issues mean that salmon are "fundamentally unsuitable for farming".[36]

Dissolved oxygen

As previously stated, dissolved oxygen (DO) is the most prominent water quality consideration. A sufficient DO concentration is required to facilitate passive diffusion of oxygen into the salmons' blood via the gills. Where oxygen isn't sufficiently available, fish experience hypoxia, which manifests via gasping response, anorexia, distress, unconsciousness, and death.[37] Chronic oxygen deficit in teleost fish results in a reduced capacity to convert energy into ATP, producing a measurable impact on growth.[38]

Solstorm et. al. found DO distribution is highly variable within individual cages, with a high degree of vertical, horizontal, and temporal variation. This study attached tags to salmon to record the DO they experienced, and found that fish are exposed to levels varying from 30-90% saturation in different areas of the cage.[39] Levy et. al. report that salmonids show aversive behaviour to water where oxygen levels are low,[40] but in the Solstorm study some fish remained in dangerously low DO levels for prolonged stretches, indicating that finfish cannot always effectively navigate to more oxygenated water. Salmon appear to prefer to cluster near the surface at night, and this drive supersedes the aversive instinct to low oxygen levels. The Solstorm cage was stocked at a density of 15kg/m^3, well within the advisable limit for conventional salmon farming. Overall, 25% of the recordings in this study were at DO levels proven to impact welfare.

---

[35] Juell, Jon-Erik. "The behaviour of Atlantic salmon in relation to efficient cage-rearing." *Reviews in Fish biology and Fisheries* 5.3 (1995): 320-335.
[36] Compassion in World Farming Briefing "THE WELFARE OF FARMED FISH" (2009). Available at: https://www.ciwf.org.uk/media/3818654/farmed-fish-briefing.pdf.
[37] Wedemeyer, G.A. *Physiology of Fish in Intensive Culture Systems*. Chapman & Hall, Londo (1996).
[38] Jones, D.R. (1971) The effect of hypoxia and anemia on the swimming performance of rainbow trout (*Salmo gairdneri*). *Journal of Experimental Biology*, 55, 541–51.
[39] Solstorm, David, et al. "Dissolved oxygen variability in a commercial sea-cage exposes farmed Atlantic salmon to growth limiting conditions." *Aquaculture* 486 (2018): 122-129.
[40] Levy, D.A., Northcote, T.G., Hall, K.J. & Yesaki, I. (1989) Juvenile salmon response to log storage in littoral habitats of the Fraser River estuary and Babine Lake. *Canadian Special Publication of Fisheries and Aquatic Sciences*, 105, 82–91.

Sea cages are wholly dependent on tidal motion to flush fresh water through the cages. The speed of this refresh is not controlled, and its consistency is not guaranteed. There is currently no requirement to monitor DO levels in salmon feedlots. Farmers can do nothing to prevent fish clustering in certain areas of the net. Research is required to determine the extent to which injection aerators, or other oxygen interventions, alter salmon's experience of DO exposure. As salmon prefer different areas of the cage during different times of day, aerating these coldspots could potentially have a significant impact on the DO experience of individual fish.

Sea lice

The high-density environment of sea cages leads to high rates of infectious diseases in salmon, including pancreas disease (PD), cardiomyopathy syndrome (CMS), and infectious pancreatic necrosis (IPN). At present the most prominent health condition by far is the infestation of sea lice, which is currently so severe it threatens the viability of commercial salmon farming.

Sea lice are parasites that perform extremely well in open-net farms due to the unnaturally high-density host environment. As a result, lice are able to populate in feedlots to a level far beyond what the salmon are adapted to deal with. Lice feed on the skin of the salmon, and large numbers of lice cause severe scarring, infections, fin loss, and death. Sea lice numbers are rapidly increasing in open-net farms, and it is having a huge impact on the fish within, as well as on local wild populations.[41]

In the image below taken from within a feedlot, a large number of sea lice (the brown spots) can be observed feeding on an adult salmon. It's not clear whether the skin damage is from sea lice or other environmental damage.

[Figure 5. A salmon covered in sea lice and showing significant descaling. Photo: Corin Smith]

[41] P.A., Bjørn, B. Finstad and R. Kristoffersen (2001).

Studies show that the location of open-net salmon farms strongly correlate with sea lice infestations in populations of wild fish.[42] Even a few sea lice can be fatal to juvenile salmon, which normally don't have a transmission vector for sea lice, as they don't encounter adult fish until later in their development. However, most open net farms are placed in tidal estuaries, directly in the migration routes of wild salmon parr heading to sea for the first time. No quantitative study has been done, but scholars suggest that, based on the reproductive patterns of the sea louse, open-net farms will be producing billions of sea lice larvae, which are flushed out to sea on the tide.[43]

A 2005 study shows infection pressure for sea lice was 70 times greater in proximity to salmon farms.[44] The same researchers, two years later, report that "recurrent louse infestations of wild pink juvenile salmon, all associated with salmon farms, have depressed local wild pink salmon populations and placed them on a trajectory towards rapid local extinction… results suggest that salmon farms can cause parasite outbreaks that erode the capacity of a coastal ecosystem to support wild salmon populations".[45]

These numbers may well need revision, as the Scottish Salmon Producers Organization (SSPO) report a 96% increase of sea louse count per fish in Scottish feedlots over the past year.[46] This is due in part to increased stocking densities, and also to increasing resistance in sea lice to common insecticides.[47] Wild salmon are facing extinction-level population collapse on the west coast of Scotland, with the forage of salmon dropping dramatically.[48] The Scottish government reports that the current wild catch of Salmon is the lowest on record.[49]

Salmon farms have a deleterious impact on wild fish populations. By design open nets provide no barrier to the discharge of wastes, parasites, lost food, chemicals, medicines, and disease into the surrounding waters. The industry is tackling the issue of sea lice for salmon welfare with some urgency as the issue threatens the commercial viability of Atlantic salmon farming. However, research is urgently required on the wider environmental impact of disease originating in open net farms.

---

[42] *Ibid*.
[43] Costello, Mark J. "How sea lice from salmon farms may cause wild salmonid declines in Europe and North America and be a threat to fishes elsewhere." Proceedings of the Royal Society B: Biological Sciences 276.1672 (2009): 3385-3394.
[44] Krkošek, Martin, Mark A. Lewis, and John P. Volpe. "Transmission dynamics of parasitic sea lice from farm to wild salmon." *Proceedings of the Royal Society B: Biological Sciences* 272.1564 (2005): 689-696.
[45] Krkošek, M.; Ford, J. S.; Morton, A.; Lele, S.; Myers, R. A.; Lewis, M. A. (2007). "Declining Wild Salmon Populations in Relation to Parasites from Farm Salmon". *Science*. 318 (5857): 1772–5.
[46]SSPO, Monthly Sea Lice Reports. Available at: http://scottishsalmon.co.uk/monthly-sea-lice-reports/
[47] Emamectin, the most common pesticide for sea lice, is losing efficacy.
[48] BBC News, "Scotland's wild salmon stocks 'at lowest ever level'", 24 April 2019. Available at: https://www.bbc.co.uk/news/uk-scotland-48030430.
[49] Scottish Government Salmon Fishery Statistics (2008). Available at: https://www.gov.scot/publications/salmon-fishery-statistics-2018-season/.

One possible solution is for open-net farms to operate in colder or deeper waters, nearer the salmon's conventional habitat, where sea lice are not adapted to survive. Organic salmon farms in the cold water near Orkney report minimal interference from sea lice. Thermal delousing treatments have been used with effect but are also a welfare concern. Ulcers, legions, and crush injuries are routinely reported on fish who have been been exposed to thermal delousing procedures,[50] and delayed mortality is more common in thermal delousing systems than the alternatives.[51] 175,000 salmon were killed at a Marine Harvest site in 2016 when the water was unintentionally overheated.[52] The Norwegian Food Safety Authority recently recommended a ban on Thermolicers,[53] and activists are currently petitioning for a similar ban in Scotland.[54]

'Cleaner' fish

The industry is exploring the use of several species of 'cleaner fish', such as wrasse and lumpfish, who live in the feedlots alongside salmon, and predate the sea lice, relieving the burden these lice have upon the salmon crop. These are stocked at a rate of around 1:25 wrasse:salmon. However, these fish have their own welfare concerns: wrasse in farms have been found to have their own maladaptive aggression behaviors resulting from high stocking density, and have their own bacterial and parasitic health concerns.[55] There is some evidence that cleaner fish populations incubate diseases that can then transfer to the salmon population.[56]

Open-net cages are particularly unsuitable for Wrasse, who usually live undercover on the seafloor. Wrasse are routinely predated upon by Salmon,[57] and while mortality data is currently anecdotal, reports from the British Fish Health Inspectorate routinely report 10% mortality of cleanerfish, with four reports indicating a total population death of cleaner fish within a year of them being added to the net.[58]

---

[50] Hjeltnes, B. "Fish health report 2018" *Norwegian Veterinary Institute: Norwegian*. (2019), p.32.
[51] *Ibid.,* p. 85.
[52] Patrick Sawer, *The Telegraph,* "Thousands of fish poached alive in lice treatment bungle that could hit Christmas salmon prices", 18th November 2016. Available at: https://www.telegraph.co.uk/news/2016/11/18/thousands-of-fish-poached-alive-in-lice-treatment-bungle-that-co/.
[53] Moira Kerr, *The Herald*, " Scottish Government is urged to ban 'painful' salmon delicing tech", 14th October 2019. Available at: https://www.heraldscotland.com/news/17966373.scottish-government-urged-ban-painful-salmon-delicing-tech/.
[54] Don Staniford, *Green Around the Gills*, "Video Nasty: Thermolicer - the Heated Torture Chamber for Scottish Salmon", 10th September 2019. Available here: https://donstaniford.typepad.com/my-blog/2019/10/video-exclusive-thermolicer-tortures-salmon-.html.
[55] Callaghan, A & Pering, D. Wrasse Cleanerfish Project Report. Native Marine Centre. (2016).
[56]Espen R; Basic, D; Gulla, S; Hjeltnes, B andMortensen, S. 2017. Report from the Norwegian Scientific Committee for Food and Environment (VKM) 2017:32 Risk assessment of fish health associated with the use of cleaner fish in aquaculture. Opinion of the Panel on Animal Health and Welfare of the Norwegian Scientific Committee for Food and Environment 14.12. (2017).
[57] *Supra* note 49, p. 34.
[58] Onekind, "CLEANER FISH WELFARE ON SCOTLAND'S SALMON FARMS". (2018). Available at: https://www.onekind.scot/wp-content/uploads/OneKind-Cleaner-Fish-Report.pdf.

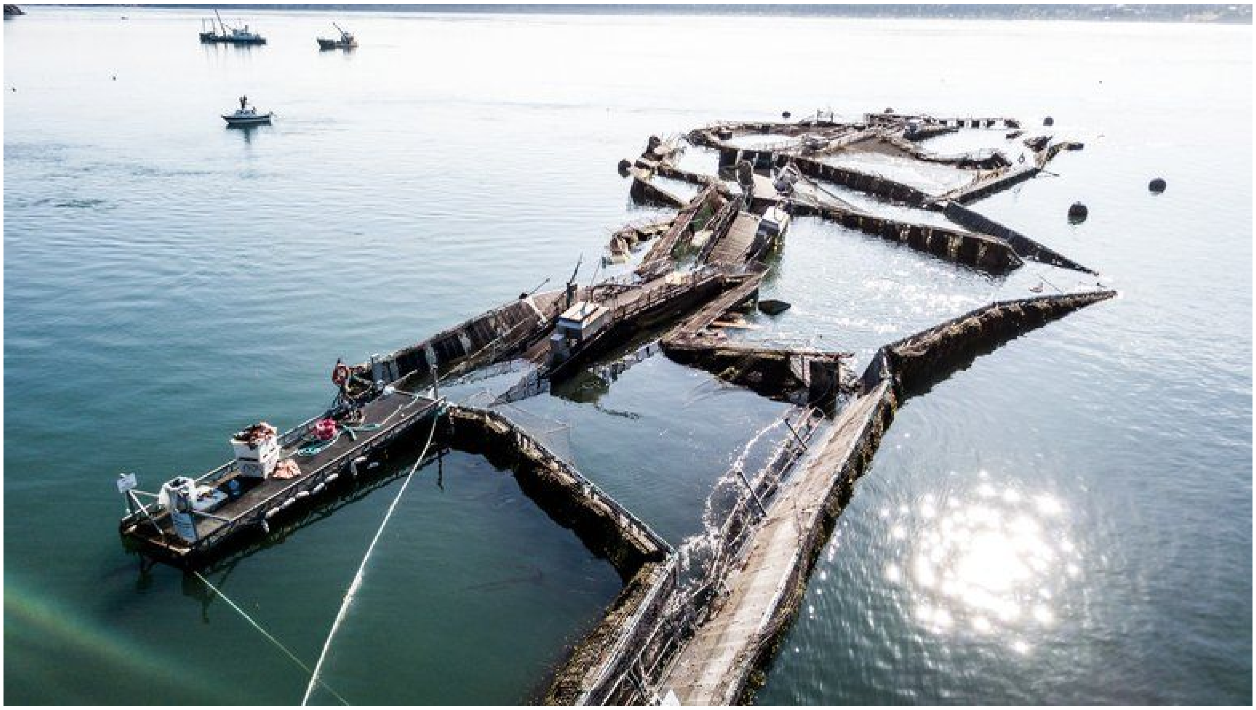
[Figure 6. A Ballan Wrasse, a common cleaner fish species. Photo: Deviantart]

Wrasse have been taken in such unsustainable numbers from their habitat that wild populations are becoming depleted.[59] New aquaculture operations are being developed in order to farm supply cleaner fish to be supplied to salmon farms. These farms will have to overcome its own unique set of welfare challenges, which are idiosyncratic to the biology of the cleaner fish. Wrasse are undomesticated carnivorous finfish, so they will share many of the same unsuitability as salmon in captivity.[60] There is an obvious logical question about the ethics of farming fish in order to alleviate the suffering of other farmed fish.

Ecosystem-level risks

If the feedlot net is breached, hundreds of thousands of salmon can escape into the wider ecosystem. Such a breach occurred in 2017 in a salmon farm near Cypress Island in Washington, where a net broke free of its mooring and released 305,000 salmon into the wild.[61] Smaller breaches are commonly caused by storms, or predator invasions (e.g. by seals).

[59]Halvorsen, Kim Tallaksen, et al. "Impact of harvesting cleaner fish for salmonid aquaculture assessed from replicated coastal marine protected areas." *Marine Biology Research* 13.4 (2017): 359-369.
[60]See: https://www.fishfarmingexpert.com/article/wrasse-breeders-reach-another-milestone/.
[61] Lee, Kessina; Windrope, Amy; Murphy, Kyle (Jan 2018). 2017 Cypress Island Atlantic Salmon Net Pen Failure: An Investigation and Review (PDF) (Report). Washington State Department of Natural Resources. pp. 1–120.



[Figure 7. The Cypress Island pen break These pens were formerly uniformly square. Photo: Beau Garreau, Children of the Setting Sun Productions]

Farmed species of Atlantic salmon are genetically different from their wild counterparts; the domestication process has genetically selected fast growth and farm suitability characteristics, and as a result their genetic stock is limited. Wild salmon, by comparison, have a much larger gene pool. Each wild population is adapted to its specific environment and has a homing instinct, which allows them to return to their natal river to spawn. Escaped farmed salmon can inter-breed with their wild counterparts leading to genetic dilution of the wild stock, leading in turn to the probability of the hybrid fish not having the genetic adaptations to survive in their specific habitat. This has been shown to result in the decline of future population resilience, population numbers, and produce further loss of genetic variation.[62]

Scotland has less than half a million wild salmon, so a single net breach has the chance to significantly alter the genetic makeup of the national population. If a whole farm was breached, releasing millions of fish at once, the wild population would be completely outperformed.

Though illegal in Norway, Scottish law still permits genetic manipulation of salmon. Environmental conditions can be used to manipulate the development of chromosomes in

[62] McGinnity, Philip, et al. "Fitness reduction and potential extinction of wild populations of Atlantic salmon, Salmo salar, as a result of interactions with escaped farm salmon." Proceedings of the Royal Society of London. Series B: Biological Sciences 270.1532 (2003): 2443-2450.

salmon roe, producing populations of all-female and triploid salmon populations. Female fish are preferred by farmers, as they mature later than males, allowing them to grow larger without decline in meat quality. As a result most aquaculture shoals are all-female. Triploid salmon contain an extra chromosome, and as such are infertile. While they are less destructive to the genetics of wild salmon if they escape, these fish are more likely to develop health problems. Spinal deformities are common in triploid salmon, and though this can be reduced with the application of mineral supplements in the feed, undercover investigations in salmon farms regularly return pictures of deformed salmon.[63]

[Figure 9. A farmed salmon with spinal deformities. Photo: Patagonia, still from Artifishal]

Other animals in the food pyramid

Finfish such as salmon, trout, and wrasse are uniquely challenging to farm as they are obligate carnivores. Indeed, finfish are the only obligate carnivores which are commercially farmed on any scale, anywhere in the world. Carnivores struggle in farm environments because of their aggressive behaviour, and farmers struggle to raise them because of the high cost of sourcing feed.

[63] Madsen, L., Arnberg, J. & Dalsgaard, I., Spinal deformities in triploid all-female rain- bow trout (*Oncorhynchus mykiss*). *Bulletin of the European Association of Fish Pathology,* (2000).

Salmon are high on the trophic pyramid, and subsist of a diet of other fish, many of whom are carnivorous themselves. Over the course of their lives, wild Atlantic salmon will eat 400kg of forage fish, converting 10kg of fish into each kilogram of bodyweight. An adult atlantic herring, a staple of the salmon's diet, will weigh around 0.5kg. Assuming, for simplicity's sake, that the salmon does not supplement its diet with any larger fish or krill, one adult salmon can eat 800 herring over the course of its life.[64]

Commercial salmon are harvested at a smaller weight, at around 5kg, depending on the production system. At a conversion ratio of 10:1,[65] this would require 100 herring to bring the salmon to harvest weight. However, a diet of feed mix can be used to create a more efficient feed-conversion ratio. Cutting-edge aquaculture feed provides a ratio of 1.2:1, requiring only five kilograms of feed to produce a harvest-weight salmon.[66] This feed contains a mix of cereals, including soybeans and wheat.[67] These feeds are rarely more than 25% fish, meaning 1.5kg of processed fishmeal is used per salmon.[68] 1kg of forage fish is turned into 0.225kg of fishmeal and around 0.08kg of fish oil,[69] meaning that 5kg of feed contains 1.5kg of fish products, composed of 4.5kg of forage, or approximately 9 herring.[70] Fish oil is mostly made from mixed catch, meaning that many smaller fish will also compose the salmon's diet. At present, 1/3 of all caught fish are used as animal feed.[71] The UNFAO reports that between 55-85% of all global fish oil production is fed to salmonids.[72] Returning to the herring standard of feed conversion, this means that 1,908,000,000 herring (or equivalent) were used to produce Norway's Salmon crop in 2017.[73]

It is also common to feed chicken and turkey to farmed salmon. Poultry meal has been found to constitute up to 30% of some commercial feeds.[74]

---

[64] Herring were selected because they are approximately the median weight for caught fish. For more information see: http://fishcount.org.uk/published/std/fishcountstudy.pdf.

[65] A feed conversion ratio of 10:1 means that for every ten kilograms of food given to a salmon, it gains one kilogram of harvest weight.

[66] Hasan, M. R., and D. Soto. "Improving feed conversion ratio and its impact on reducing greenhouse gas emissions in aquaculture." *Improving feed conversion ratio and its impact on reducing greenhouse gas emissions in aquaculture.* (2017).

[67] Pelletier, N., and P. Tyedmers. "Feeding farmed salmon: Is organic better?." *Aquaculture* 272.1-4 (2007): 399-416.

[68] *Supra* note 1, p.51.

[69] Ytrestøyl, Trine, Turid Synnøve Aas, and Torbjørn Åsgård. "Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway." *Aquaculture* 448 (2015): 365-374.

[70] Using herring is arbitrary. Global Reporting Program did a similar exercise, using anchovy instead of herring, and estimating 147 feed fish required for each salmon. Herring was chosen as it is a fish that salmon eats both in fishmeal and in the wild, and it is not itself an obligate carnivore. If anchovy was used instead of herring, my estimate would be 180 feed fish. This discrepancy might be due to us both referring to different fishmeal recipes, but Global Reporting Program does not name the fishmeal they used for this estimate. GRP's report is available here: https://globalreportingprogram.org/fishmeal/.

[71] Alder, Jacqueline, et al. "Forage fish: from ecosystems to markets." *Annual review of environment and resources* 33 (2008): 153-166.

[72] *Supra* note 1, p.58.

[73] *Supra* note 6.

[74] Steffens, W. "Replacing fish meal with poultry by-product meal in diets for rainbow trout, Oncorhynchus mykiss." *Aquaculture* 124.1-4 (1994): 27-34.

Farmed salmon are fed a mixture of farmed fish, caught fish, offcuts from human fish consumption, and meat from terrestrial animals. Some of these food sources have lower welfare concerns than others, for example using byproducts of human consumption such as feather meal, but even when using byproducts in feed the salmon's carnivorous nature means that salmon farming is ethically and economically entangled with the welfare issues of other species in the wider food production system.

Salmon, as apex carnivores, sit on top of a welfare pyramid. The production of each salmon requires the sourcing of meat for its diet. The qualitative experience of the animals salmon are fed ought to be considered, especially if this fish comes to be produced through supplementary aquaculture.

[Figure 10. Atlantic Herring, one of many wild fish caught to be fed to Salmon. ⅓ of all fish caught are used as animal feed. Photo: Marcel Painchaud]

Welfare at slaughter

Slaughter is a particularly high-risk area for animal welfare, as no matter how high standards are set, any lapse in practice can result in traumatic consequences for the animals involved. Salmon handling at slaughter is particularly delicate, as good practice requires that they be transported from the cage to a dedicated slaughter facility, that they can only be minimally handled, and that water quality must be maintained throughout.

It is conventional to starve fish for up to a month before slaughter.[75] This serves several purposes, of varying virtue. Salmon who are not fed do not create as much effluent, which

[75] Robb, DH *Welfare of fish at harvest*, in "Fish Welfare", Branson Ed. , (2008) p.219.

preserves water quality during live transport. An empty gut is preferable for avoiding contamination of the carcass during food processing, though the gut can be emptied by a fast of only 72 hours. It can take a week to empty a sea cage, and it's impossible to selectively feed fish in the cage, which means some fish will be left unfed in the cage for much longer than the evidence suggests is necessary. Starvation is also used to prolong the route to market for fish when the market is weak, allowing fish to arrive at target weight when prices are higher.

Care must be taken during live transport to prevent the buildup of carbon dioxide and ammonia in the water, as wellboats and slaughter environments usually recirculate water. This is an issue the industry has provided focus to, though welfare on wellboats is particularly poorly researched, and any lapse in practice would be extremely traumatic for the large number of fish housed within.

There are several slaughter methods that are unacceptable from a welfare point of view. Slaughter through carbonic acid cannot be recommended. In this process CO_2 is dissolved in water, acidifying it, and the salmon are released into this acid *en masse*. These fish show an immediate, strong aversive reaction to the acid,[76] and retain full brain activity until death, which takes several minutes.[77] This method allows slaughter en masse, so while its appeal in the commercial setting is understandable, the prolonged and painful nature of this death is unacceptable from a welfare point of view, especially when compared to higher-welfare alternatives.

Ambient asphyxiation kills the fish through prolonged anoxia, and also cannot be recommended, as it takes salmon over an hour to stop displaying signs of life.[78] Live chilling, essentially the same process on ice, slows gill activity in less time, but is still deficient compared to faster methods which are less likely to cause nociceptive stimuli.

The most commonly recommended slaughter method is stun-bleed. In this method the salmon are stunned, which renders them insensible, and are then immediately exsanguinated via the severance of major blood vessels in the gills. The stunning is usually percussive, where the fish is rendered insensible by a pneumatic rod, or sometimes manually pulled from the water by a worker and clubbed with a metal rod. Newer processes include fully automated percussive stun machines.

In theory, stun-bleed deprives the brain of oxygen so quickly the fish dies without regaining sensibility from the stunning. However, consistency is an issue: It is uncommon to check whether the fish has been rendered fully insensible from this stunning.

---

[76] *Ibid.*, p.232.
[77] Robb, D.H.F., Wotton, S.B., McKinstry, J.L., Sorensen, N.K. & Kestin, S.C. (2000) Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. *Veterinary Record*, **147**, 298–303.
[78] *Ibid*.

Though stun-bleed is accepted as the highest-welfare solution for most mammals, its efficacy is poorly evidenced in the context of fish.[79] Cutting the carotid artery causes death (as measured by the elimination of brain activity) in 20 seconds in sheep, and in 150 seconds in cattle.[80] However, electroencephalographic imaging of salmon brains during stun-bleed suggests it takes between 148-440 seconds for brain activity to cease in a salmons' brain following the gill cut.[81] Some studies have identified fish species that, due to divergent biology, demonstrate brain activity more than an hour after having their gills cut.[82]

Exsanguination has been uncritically appropriated from terrestrial slaughter, but species-specific research is required into the experience of slaughter for each farmed fish species. Despite salmon being subject to as much research as any fish, there are formidable gaps in the literature regarding its welfare at slaughter. Species-specific inquiries will be required for both salmon, and the other 360+ fish species currently produced in aquaculture settings.

Electrocution shows promise as a humane slaughter technique,[83] which could be done in batches and has a high stun success rate. There was interest in implementing a commercial solution in the early 2010s, and grants were made by the Humane Slaughter Association to support the development of a commercial solution,[84] but electrocution has yet to enter into widespread commercial use.

Expression of preferred behaviors

In 1979 the Farm Animal Welfare Council published the 'Five Freedoms', which are qualities of life a farmed animal must have for its experience to constitute a 'life worth living'. These freedoms are foundational to farmed animal welfare, and are ubiquitous in farm welfare standards. These were articulated as 'freedoms from', but for clarity they have also been reworded beneath as 'freedom to'.

---

[79] Soil Association, Abattoir and Slaughtering Standards (2019). Available at: https://www.soilassociation.org/media/16026/abattoir-and-slaughtering-standards.pdf.
[80] European Food Safety Authority (EFSA). "Opinion of the Scientific Panel on Animal Health and Welfare (AHAW) on a request from the Commission related to welfare aspects of the main systems of stunning and killing the main commercial species of animals." *EFSA Journal* 2.7 (2004): 45.
[81] Robb, D.H.F., Wotton, S.B., McKinstry, J.L., Sorensen, N.K. & Kestin, S.C. (2000) Commercial slaughter methods used on Atlantic salmon: determination of the onset of brain failure by electroencephalography. *Veterinary Record*, 147, 298–303.
[82] Ruff, N., et al. "Slaughtering method and dietary α-tocopheryl acetate supplementation affect rigor mortis and fillet shelf-life of turbot Scophthalmus maximus L." *Aquaculture Research* 33.9 (2002): 703-714.
[83] Humane Slaughter Association, 'Effects of Electricity". Available at: https://www.hsa.org.uk/humane-harvesting-of-fish-electrical-stunning/effects-of-electricty.
[84] Humane Slaughter Association, Media Release: Humane Slaughter Association announces two awards at International Symposium, 2011-07-12. Available at: https://www.hsa.org.uk/downloads/press/archive/2011-07-12Media%20release%20awards%20and%20symposium%202011%202.pdf.

No.	Freedom from	Freedom to
1	Hunger and thirst	Have ready access to sustenance which sustains health and vigour
2	Environmental challenge	Live in an appropriate environment which enables and does not impair wellbeing
3	Disease and injury	Live in an environment which prevents disease, does not expose to undue risk of injury, and have diseases rapidly and appropriately treated
4	Behavioural restriction	Live with sufficient space, and with such companionship and materials required to express natural behaviours
5	Mental distress	Live in conditions which avoid mental suffering

[Figure 11: The Five Freedoms rearticulated]

Is it possible to devise a farmed salmon solution which satisfies all five of these criteria? Farmed salmon are so well-fed that the first freedom is easily met. Much of this article so far has been devoted to the insufficiencies of open net farms in providing for needs 2, 3 and 5. It does seem possible to envision a farmed environment which is free from environmental challenge, free from disease, and with minimal mental distress.

However, it is freedom No. 4 that caused Compassion in World Farming to call salmon 'fundamentally unsuitable' for farming.[85] Salmon's natural behaviours seem totally incompatible with a caged environment. Atlantic salmon are migratory animals, who range over 9,000km. Some spawning sites are 300km upriver from the sea. Atlantic salmon are generally solitary animals, who are known to bully and cannibalize smaller fish. How can we reconcile the need to restrain these behaviors in intensive farming operations with the salmon's need to be free from such behavioral restriction?

We are only just becoming aware of the extraordinarily complex social lives of farm animals. For instance, recent studies show that cattle, when left to their devices in a field of sufficient size, will graze in parallel and in unison: a group will walk, several feet apart, their heads moving in perfect time with one another, up and down the field.[86] If allowed to move freely, they have lifelong relationships with their parents. Cattle prefer to be clean and will remove mud from themselves before they sleep.[87] When inspecting welfare of cattle, large plaques of dirt are an indicator that the animal either is either in a pasture so small that it

[85] *Supra* note 36.
[86] Sambraus, Hans Hinrich. "Sexualverhalten der domestizierten einheimischen Wiederkauer." (1973).
[87] Young, Rosamund. *The Secret Life of Cows*. Penguin, 2018.

cannot escape the mud, or does not have the equipment to clean itself.[88] Both constitute poor welfare. The fact that the literature is only just beginning to explore the welfare requirements of the most intensively farmed animal in history shows the formidable challenges ahead when it comes to understanding salmon welfare.

We lack sophisticated studies about the behavior of wild salmon, and empirical tests are required to understand the psychological consequences of depriving salmon of their migratory behavior.[89] This further study must determine 1) which behaviours have welfare components, and 2) whether these have control mechanisms that can be emulated in captivity.[90] A succinct reflection on this matter is provided by Paul J. Ashley:

> "If the control mechanism for migratory behaviour is based simply on continuous swimming and the search for improved feeding grounds, then supplying these things in the captive environment may reduce the motivation to migrate and avoid related suffering. However, if based on an intrinsic drive to move to new areas, confinement might well cause suffering."[91]

The alternative to open net fish farming is an extrinsic system, where salmon populations in an open ecosystem are maintained at a high enough level that an economically sustainable crop can be taken through fishing. The Veta La Palma Estate exists as a proof of concept for extensive and semi-extensive farming of marine fish, though salmon would require a far larger system including both salt and freshwater habitats.[92] As with all innovation in agriculture, a comprehensive paradigm shift in mindset and practice will be required to bring this to the mainstream.

Next steps in salmon welfare

The evidence clearly indicates that Salmon are conscious creatures deserving of the highest possible welfare conditions when kept in captivity. At present, despite great lengths taken to improve their living conditions, Atlantic salmon reared in open-net farms do not have a quality of life worth living.

There is focus in the industry on developing lifelong inland environments for salmon rearing. This would mean that, instead of releasing smolts into freshwater sea cages, they would be moved from a freshwater recirculating system into a saltwater recirculating system, and be brought to harvest weight entirely in an inland tank. Millions of dollars are being invested in developing land-based salmon aquaculture, with a dozen small-scale

---

[88] Asssurewel, "The Assurewel Manual" (2017). Available at: http://www.assurewel.org/Portals/2/Documents/AssureWel%20Manual%202018_9kb.pdf.
[89] Dawkins, M.S., 1998. Evolution and animal welfare. Q. Rev. Biol. 73, 305–328.
[90] Kiessling, A., Kadri, S., Turnbull, J., Bron, J., Brännäs, B. and Huntingford, F., 2006. Welfare of fish in European aquaculture (Cost action 867 from 2006 to 2010).
[91] Ashley, Paul J. "Fish welfare: current issues in aquaculture." *Applied Animal Behaviour Science* 104.3-4 (2007): 199-235.
[92] For more information on the Vela La Palma Estate, visit http://www.vetalapalma.es/.

proof-of-concepts in construction around the world at the time of writing.[93] Recirculating aquaculture systems (RAS) are a promising solution in terms of biosecurity, as the controlled environment can be kept free of sea lice, and prevent the farm from impacting the wider environment. The hope is that RAS systems will remove the need for cleaner fish altogether. It will also bring environmental factors such as water quality under human control, allowing for more intimate monitoring of DO levels and crowding in the pen. However, it also increases the catastrophic stock death due to potential mismanagement of water quality.

While promising, RAS systems do nothing to address the concerns listed in this article re: slaughter, preferred behaviors, or other animals in the food pyramid. It will also introduce new risks, and sufficient care must be taken to make sure that the salmon in inland systems have their welfare requirements understood.

[Figure 12. An ocean-phase sockeye salmon, at approximately commercial harvest weight. Photo: Barbara Jackson]

Salmon husbandry has emerged as the synecdoche of welfare issues in commercial finfish aquaculture, an industry which is worth USD$138.5bn globally, and set to continue to

[93] Owen Evans, *Salmon Business*, "These are the leading land-based salmon farms in the world right now". 9th May 2019. Available at: https://salmonbusiness.com/these-are-the-leading-land-based-salmon-farms-in-the-world-right-now.

expand in future years.[94] Issues identified in the salmonid context will be relevant, to a greater or lesser extent, for other farmed teleost fish. The shifting policy landscape could soon render open-net sea farms a thing of the past. However, any progress made at this juncture will have enduring relevance for the next salmon farming paradigm, as well as the welfare of other intensively farmed fish species.

This essay has highlighted that special consideration should be given to the animals used in salmon-feed. Solutions at the salmon level will have outsized welfare implications for the aquatic and terrestrial animals in its trophic chain.

Species-specific research is needed to understand salmon behaviour in captivity in order to better understand their suitability as a farmed animal. The gaps in the literature that this article has identified are extensive, and include: welfare for cleaner fish, agroecological sea lice treatments, an inquiry into control mechanisms for salmon behavior. Further study into dissolved oxygen experience of individual fish in open-sea nets is recommended, as is a further exploration of humane slaughter methods which take into account the idiosyncrasies of teleost biology.

Fig. 13: Recommended next steps in Salmon Welfare

Welfare issue	Further research recommended	Possible interventions
Sea lice infestation	Impact of sea lice on wild salmon populations, impact of net placement on sea lice population.	Agroecological alternatives to pesticides, reducing stocking densities, legislation on sea net location.
Water Quality	Whether placing DO infusers in oxygen ‘coldspots’ impacts oxygen deprivation in sea cages, DO experience in inland tanks.	Use of aerators in sea cages.
Cleaner fish	Welfare requirements of wrasse and lumpfish in sea cages.	Minimize or eliminate the use of cleaner fish by identifying and testing alternative delousing systems.
Welfare at slaughter	Electroencephalographic investigation of slaughter	Promotion of high-welfare slaughter methods according to evidence.

[94] *Supra* note 1, p.15.

	methods, further investigation of electrocution as stun-kill method.	
Expression of preferred behaviors	Identifying which behaviours have welfare components, and whether these have control mechanisms that can be emulated in captivity.	Developing extrinsic aquaculture systems. Develop salmon breeds that fare better in captivity. Transition production to more suitable species.
Stocking Density	Identify temporal and spatial distribution of fish in the sea cage. Identify how stocking density interacts with symbiotic species.	Transition to an evidence-based stocking density, probably around 10kg/m^3.
Mortality	Explore more consistent and less invasive methods of inducing smoltification, research mortality rates of cleaner fish.	Explore individual fish progression technologies for RAS systems. Eg: microchipping
Welfare in the food pyramid	Explore welfare issues for other species in the supply chain. Explore trophic interactions with terrestrial animals used for feed. Development of higher-efficiency fish feed.	Promote low-impact food standards, replace caught fish with offal.

About the author

My name is Mark Borthwick, and I am an animal welfare specialist based in the Lake District, England. I have read an MA (Hons) into intrinsic value in endangered species and an MSc (Res) into ecosystem ethics, both at the University of Edinburgh. Following this, I spent two years working on Knowledge Transfer and Innovation (KTIF) projects to improve on-farm animal welfare in Scotland. I am currently a PhD candidate, focusing on the interplay between consumer values and welfare development in aquaculture systems.

It's clear aquaculture is the next frontier for animal welfare. I'm interested in collaboration in the areas of farmed animal welfare, wild animal welfare, aquaculture, and invertebrate welfare. Please feel free to contact me at MDBorthwick@gmail.com, or reach out on Twitter or LinkedIn.