An Industry Shift Towards Environmental Enrichment in Aquaculture

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Introduction

Aquatic animals have been habitually overlooked in animal welfare research, discourse, and policy decisions. The best available contemporary evidence, such as that referred to in the Cambridge Declaration on Consciousness (2012)[1], clearly indicates that the subcortical neural networks that fish share with other vertebrates contain neural markers of qualitative feeling; neurochemically homologous to those of terrestrial mammals we associate with complex cognitive function and emotion[2].

The majority of literature on fish welfare has centred around minimizing suffering during slaughter and controlling disease[3]. Though crucially important, these issues are not the only ways fish welfare can be compromised. More recent evidence indicates that fish experience a much wider range of emotions, and are capable of more complex cognitive processes than previously thought. Some welfare concerns in captivity include stress, boredom[4], and frustration[5]. These are typical stress responses to a barren environment that can become detrimental when experienced chronically and in many cases over their entire lifetime, that are all well-documented and understood in land-based animal farming environments.

Establishing a universal definition of welfare is paramount to sustainable development for the aquaculture industry. We are being asked for the first time what good aquatic animal welfare means, and a number of seafood certifiers are in the midst of developing their very first standards for welfare in aquaculture. Incorporating environmental enrichment (EE) into this definition from the onset will place the

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[1] "The Cambridge Declaration on Consciousness* - Francis Crick ...." https://fcmconference.org/img/CambridgeDeclarationOnConsciousness.pdf.

[2]Jobling M. (2012). – Fish in aquaculture environments. In Aquaculture and behavior (F.A. Huntingford, M. Jobling & S. Kadri, eds). Wiley-Blackwell, Oxford, 36–64.

[3]Pounder, Kieran C., et al. "Does environmental enrichment promote recovery from stress in rainbow trout?." Applied Animal Behaviour Science 176 (2016): 136-142.

[4]Wemelsfelder F (1993) The concept of boredom and its rela- tionship to stereotyped behavior. In: Lawrence AB, Rushen J (eds) Stereotypic behavior: fundamentals and applications to animal welfare. CAB International, Wallingford

[5]Sánchez-Suárez, W., Franks, B., & Torgerson-White, L. (2020). From Land to Water: Taking Fish Welfare Seriously. Animals, 10(9), 1585. OR

aquatic animal welfare movement on a trajectory of higher impact[6]. It is far more efficient to include EE in standard development from the beginning, rather than having to endure long-winded and costly amendment processes down the line.

According to the United Nation Food and Agriculture Organization's State of the World Fisheries 2020 Report, there are over 600 different aquatic species being farmed across the globe, all of which undergo multiple, distinct phases during their life, each accompanied with varying needs. "Enrichment" as an element of improving animal welfare in captivity has already been demonstrated. While the scientific community will continue to discover contemporary enrichment strategies for individual species, available research reveals many promising, cost-effective interventions for most farmed species. These studies illustrate the variety of benefits that come with an enriched environment for both animals and producers.[7,8,9] A few studies suggest that some interventions (mainly structural additions for specific species) may increase aggression due to territoriality, competition, and hierarchy. However, many actions, such as dynamic water currents, favourable feeding schedules, adequate lighting/photoperiod, and preferred colours are highly unlikely to have any deleterious consequences.

Some of these changes are very easy to implement, and would require minimal capital investment and disruption to a farm's operations. While some other enrichment interventions can be more involved, the enrichment category as a whole would not be a difficult obligation for producers to fulfill. Such interventions would have multilateral positive outcomes for fish such as improved physical and psychological well being. These positive outcomes could directly translate to decreased mortality rates, enhanced growth rates, improved feed conversion ratios,

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[6] Mellor DJ, Beausoleil NJ, Littlewood KE, McLean AN, McGreevy PD, Jones B, Wilkins C. The 2020 Five Domains Model: Including Human-Animal Interactions in Assessments of Animal Welfare. Animals (Basel). 2020 Oct 14;10(10):1870. doi: 10.3390/ani10101870.

[7] Arndt, R. E., Routledge, M. D., Wagner, E. J., & Mellenthin, R. F. (2001). Influence of raceway substrate and design on fin erosion and hatchery performance of rainbow trout. North American Journal of Aquaculture, 63(4), 37–41.

[8] Soares, M. C., Oliveira, R. F., Ros, A. F. H., Grutter, A. S., & Bshary, R. (2011). Tactile stimulation lowers stress in fish. Nature Communications, 2(1), 1–5.

[9] Gerber, B., Stamer, A., Stadtlander, T., "Environmental Enrichment and its effects on Welfare in fish Autoren: Im Auftrag von: BLV-Bundesamt für Lebensmittelsicherheit und Veterinärwesen" (2015) Research Institute of Organic Agriculture.

and resistance to disease, creating a mutually beneficial situation for all beings involved. We are pleased to have analyzed and gathered enrichment interventions for 15 different species, which have been tested and shown to have favorable outcomes for both welfare and productivity. This was achieved through reviewing existing literature, and grouping types of enrichment according to their immediate surroundings. Atlantic salmon *(Salmo salar)* will be discussed as an example in this document, and information for all 15 species can be found **here**.

As we raise the profile of enrichment and promote/establish inclusive EE criteria for certification bodies, we will also accelerate industry data collection and dissemination. This in turn, will contribute to more species-specific information, leading to superior interventions. We recognize that there will be an unavoidable transition period between the installment of enrichment interventions into existing standards, the communication of said modifications to producers, and the enforcement of compliance. However, this demonstrates the importance of introducing enrichment regulations today, so we can start to observe its positive impacts tomorrow.

Through the work of our certifier campaign, several global seafood certification bodies are now incorporating enrichment as part of their upcoming standards. It is imperative that we keep pushing for all certification schemes, producers, and industry professionals to adopt EE as a fundamental necessity in this movement. The implementation of enrichment recommendations from certification schemes to producers will not only impact billions of animals currently being reared in aquaculture, currently estimated to be between 73 and 180 billion[10], but will also spur marketplace innovations, encourage the purchase of higher welfare products, and create niche opportunities for development.

[10] "Numbers of farmed fish slaughtered each year | fishcount.org.uk." http://fishcount.org.uk/fish-count-estimates-2/numbers-of-farmed-fish-slaughtered-each-year.

Goals of Enrichment

Certifiers

With more than 100 certifications of one type or another currently in use by the seafood industry, it would appear that they are here to stay; a permanent component in the welfare landscape. As consumers are becoming increasingly aware of animal welfare issues, and conscious of their purchasing decisions, certified seafood is favored, specifically in North America and Europe for the time being. However, it is not always clear what these certification schemes require in terms of positive animal welfare. There is an industry emphasis on environmental impact/sustainability, and while this is an extremely important area to consider, a connection between positive welfare and sustainability is often automatically made by consumers, which may not always be the case.

While some sectors of sustainability and welfare do indeed overlap (water quality, stocking density, etc.), up until now, certification standards have largely focused on external environmental footprints and animal health in terms of productivity, instead of overall well-being and quality of life. We seek to refine these principles through incorporating EE into certifier welfare conceptions, and encourage unambiguous communication as it relates to what “positive welfare” means for these companies. We do so in order to provide consumers with transparent, higher quality options that place a greater importance on animal welfare, and avoid humane washing in the seafood industry. Humane washing involves the use of advertising tactics to convey an admirable level of animal care and treatment that is misrepresentative of the actual conditions in which they are being farmed.

Producers

By using EE as a tool that raises the welfare bar to attain desirable certification labels, producers will ultimately be encouraged to comply to not only retain consumer appeal but to remain a competitor in the evolving seafood industry. Consumer behaviour dictates and incentivizes producer behaviour. The demand for positive welfare seafood products will lead to mindful, certified purchasing. While we recognize that the process of implementation and enforcement will not be accomplished overnight, knowing that such a change is approaching, every effort should be made by producers to stay ahead of the curve through adopting straightforward EE efforts now, while further regulations are being decided upon and put in place.

Bearing this in mind, we have identified several EE measures that could be easy to implement and would require minimal capital investment and disruption to a farm's operations. While some additional enrichment interventions can be more extensive, the enrichment category as a whole would not be a difficult obligation for producers to fulfill. Such interventions would have multidimensional, positive outcomes for aquatic animals such as physical and psychological prosperity. These positive outcomes could directly translate to decreased mortality rates, enhanced growth rates, improved feed conversion ratios, and resistance to disease.

Marketplace Innovation

As we uplift the profile of enrichment and promote and establish panoptic EE criteria, industry research, data collection, and widespread dissemination will also be accelerated. This in turn will contribute to more comprehensive species-specific information, leading to refined interventions, first-class innovations, and undeniable, effective outcomes.

A unique marketplace opportunity exists in the field of commercial EE. Presently, there are very few companies that supply and manufacture EE structures, shelters, aeration systems, feeding systems, etc. on an international scale for a variety of species and production systems. Additionally, by strengthening EE recommendations, standards, and awareness within aquaculture, we can not only improve lives and create a better space for considerate farming, but we can also pinpoint where knowledge is lacking, execute appropriate research, develop suitable remedies, and learn more about the complex lives of the most extensively farmed animals worldwide.

“Positive” Welfare

Animal welfare refers to the physical and mental state of an animal relating to the conditions in which they live[11]. In order to promote positive welfare in captive animals, it is necessary to first determine what constitutes “positive welfare” for a particular species using science-based measurements and assessment protocols. The most widely accepted paradigm is The Five Domains Model[12], a modernized version of the original Five Freedoms Model of animal welfare assessment developed in the mid 1960s[13]. The Five Domains Model is regularly updated to reflect significant developments in animal welfare science, such as the emerging interactions between the physiological (biological health) and psychological (subjective experience) aspects of animal welfare[14] and the critical importance of promoting positive experiences while reducing pain and suffering in captivity[15]. The Five Domains Model is generally considered the gold standard of holistic animal welfare assessment criterion and is extensively used to monitor welfare across a vast variety of species and contexts, including animals living in zoos, laboratories, farms, and private homes around the world[16].

The Five Domains Model is outlined as follows:

1. Nutrition - the quality, quantity, and method of delivery of the water and food available to animals.
2. Physical Environment - the affective impacts of physical, sensory, and atmospheric conditions to which animals are exposed.

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[11] Fraser, D. (2008). Understanding animal welfare. Acta Veterinaria Scandinavica, 50(1), 1-7.

[12] Mellor DJ, Beausoleil NJ, Littlewood KE, McLean AN, McGreevy PD, Jones B, Wilkins C. The 2020 Five Domains Model: Including Human-Animal Interactions in Assessments of Animal Welfare. Animals (Basel). 2020 Oct 14;10(10):1870. doi: 10.3390/ani10101870.

[13] Mellor DJ. Updating Animal Welfare Thinking: Moving beyond the "Five Freedoms" towards "A Life Worth Living". Animals (Basel). 2016;6(3):21. Published 2016 Mar 14. doi:10.3390/ani6030021

[14] Fraser, D. (2008). Understanding animal welfare. Acta Veterinaria Scandinavica, 50(1), 1-7.

[15] Fraser, D., & Duncan, I. J. (1998). ‘Pleasures’,‘pains’ and animal welfare: toward a natural history of affect.

[16] Mellor DJ, Beausoleil NJ, Littlewood KE, McLean AN, McGreevy PD, Jones B, Wilkins C. The 2020 Five Domains Model: Including Human-Animal Interactions in Assessments of Animal Welfare. Animals (Basel). 2020 Oct 14;10(10):1870. doi: 10.3390/ani10101870.

3. Health - the physiological and affective impacts of injury, disease, and varying levels of physical fitness.
4. Behavioural Interactions - behavioural evidence of hindered and/or enhanced expression of agency when animals interact with (1) their environment, (2) other non-human animals, and (3) human beings.
5. Mental State - psychological and affective consequences of domains 1-4.

The first four domains focus attention on factors that induce specific negative or positive subjective experiences, which contribute to the animal's mental state, as evaluated in the fifth domain.[17]

Defining Enrichment

The primary aim of environmental enrichment is to enhance animal well-being by providing animals with sensory and motor stimulation, through structures and resources that facilitate the expression of species-typical behaviors and promote psychological well-being through physical exercise, manipulative activities, and cognitive challenges according to species-specific characteristics[18]. Suitable enrichment could allow animals to live in good health where each of their biological systems function appropriately, while empowering them to engage in a variety of behaviours that they express in their natural habitat.

Such initial adjustments need neither be complex nor require substantial investment. Exploring potential EE interventions can begin with the development of a suitable preference test[19] for the animals (according to species, life-stage, holding environment parameters, etc.). By enriching one half of the habitat observers can then record where the animals spend the majority of their time and what behaviours they perform on each side[20]. Alternatively, EE may be added to some, but not all tanks, to

[17] Ibid.
[18] National Research Council. (2010). Guide for the care and use of laboratory animals. 8th ed. Washington, DC: National Academies Press
[19] Fraser, D. and Matthews, L. (1997). Preference and Motivation Testing Preference and Motivation Testing.
[20] Näslund, J., & Johnsson, J. I. (2016). Environmental enrichment for fish in captive environments: effects of physical structures and substrates. Fish and Fisheries, 17(1), 1-30.

compare welfare indicators such as fin condition and swimming activity. Several convergent factors relevant to both welfare and on-farm economics, such as survivability[21], access to feed for subdominant animals[22], and water quality[23] can all be positively impacted by increasing and optimizing environmental complexity.

It is the opinion of the Aquatic Life Institute that providing aquatic animals with, not only a suitable, but a *desirable* environment to live in is one of the most neglected areas of fish welfare. Many of the enrichment profiles we discuss in this document are economical and easily accessible, therefore, we presume environmental enrichment serves as a self-evident 'win-win' for animal welfare activists and producers alike.

Species and Life Stage Specificity

Aquatic animals are an incredibly diverse group of organisms, and require an equally diverse array of enrichments. As previously mentioned, every species has particular preferences and thresholds which must be carefully considered during any intervention. We must also examine the complex life cycles of each species to accommodate their needs as they fluctuate throughout development.

For example, Atlantic salmon, one of the most studied species, have a six-stage life cycle with different behaviours and environmental demands during each phase. Salmon hatchlings, known as alevin, are not free swimmers and require a gravel bed, or other substrate, to nest within. The provision of tank floor habitat as EE at this stage significantly influences growth and fish survivability[24].

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[21]Lee, Carole J., Gregory C. Paull, and Charles R. Tyler. "Effects of environmental enrichment on survivorship, growth, sex ratio and behaviour in laboratory maintained zebrafish Danio rerio." Journal of fish biology 94.1 (2019): 86-95.

[22]Huntingford, F. A., & Kadri, S. (2014). Defining, assessing and promoting the welfare of farmed fish. Revue scientifique et technique (International Office of Epizootics), 33(1), 233-244.

[23]Arechavala-Lopez, Pablo, et al. "Effects of structural environmental enrichment on welfare of juvenile seabream (Sparus aurata)." Aquaculture Reports 15 (2019): 100224.

[24]Taylor, S.G. (1984) Quality of pink salmon (Oncorhynchus gorbuscha) fry incubated from eggs in river gravel or plastic substrates. Aquaculture 42, 359–365.

However, once salmon are free-swimming fry, some studies show that shelter can hinder growth, since the high innate motivation to hide at this life stage takes dominance over food-seeking behavior, even in the absence of predators[25]. Yet, Brockmark (2007)[26] observed that sheltering structures limit the growth of large fish more than small fish. Enabling fish to grow at a similar pace might be advantageous from both a welfare and productivity perspective. Slow, consistent growth of an entire population might be preferable to uneven growth rates, since having larger fish in a confined population could lead to conspecific dominant behaviour and larger fish monopolizing food resources[27].

Once salmon smolt, their physiology adapts to salt water, and they become pelagic. At this stage, floor structures are less important from a physical perspective as they neither provide shelter nor inhibit growth, but could perhaps provide environmental variation from a naturalistic perspective. The ENRICH FISH project, executed by Nofima, in cooperation with the Institute of Marine Research and Norecopa (Norway's National Consensus Platform for the advancement of Replacement, Reduction, and Refinement in connection with animal experiments) is currently underway to evaluate the effectiveness of 2-D floor substrates on the welfare of Atlantic salmon within experimental settings. Communications of this project suggests that the 2-D provisions had the same effect as natural 3-D inclusions, perhaps indicating that as salmon develop, they respond well to the visual stimulation 2D substrate can provide[28].

At the grow-out (adult) stage for Atlantic salmon, identified forms of enrichment include lower stocking density to prevent aggression between conspecifics, variation

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[25]Griffiths, Sian Wyn, and J. D. Armstrong. "Rearing conditions influence refuge use among over-wintering Atlantic salmon juveniles." Journal of Fish Biology 60.2 (2002): 363-369.

[26]Brockmark, Sofia, et al. "Effects of rearing density and structural complexity on the pre-and postrelease performance of Atlantic salmon." Transactions of the American Fisheries Society 136.5 (2007): 1453-1462.

[27]Jobling M. (2012). – Fish in aquaculture environments. In Aquaculture and behavior (F.A. Huntingford, M. Jobling & S. Kadri, eds). Wiley-Blackwell, Oxford, 36–64.

[28] "Enrich-Fish project - Norecopa." 1 Jan. 2021, https://norecopa.no/species/fish/projects/enrich-fish.

in water current strength, and tank covers [29]. We must also acknowledge that several heavily farmed species are migratory animals, and that farming them severely restricts any opportunity to engage in typical activities. Some studies suggest fish that have evolved in environments that offer little possibility of finding better conditions (e.g. carp living in small ponds) experience less dissatisfaction in suboptimal circumstances compared to migratory species. For example, Atlantic salmon, that naturally explore the whole Northern Atlantic[30].

Compared to other aquatic species, EE interventions for Atlantic salmon are well researched. As they change from a river bed dwelling insect feeder to a tertiary migratory carnivore, environmental requirements must evolve to allow them to express rewarding behaviours. Despite the relatively high attention given to salmon welfare, knowledge gaps still persist. The same is true to a greater extent for almost every other fish species. Nevertheless, we must take advantage of existing evidence and promptly put knowledge into action, administer the most comprehensive management plans, and cultivate a life worth living for aquatic animals in aquaculture.

Fields of Enrichment

Näslund et al.[31] outlined commonly recognized spheres of enrichment that can be incorporated into farm enclosures for aquatic animals. Producers should strive to achieve enrichment inclusion in each of these areas where possible.

Social enrichment

- ➔ Animals experience the correct amount and type of contact with conspecifics. This includes sufficient access for social species (such as Arctic charr), and

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[29]Hyvärinen, Pekka, and Petra Rodewald. "Enriched rearing improves survival of hatchery-reared Atlantic salmon smolts during migration in the River Tornionjoki." Canadian Journal of Fisheries and Aquatic Sciences 70.9 (2013): 1386-1395.

[30]T. Torgersen. Ornamental fish and aquaria. T.S. Kristiansen, A. Fernö, M.A. Pavlidis, H. van de Vis (Eds.), The Welfare of Fish, Springer (2020), pp. 363-374.

[31]Näslund, J., & Johnsson, J. I. (2016). Environmental enrichment for fish in captive environments: effects of physical structures and substrates. Fish and Fisheries, 17(1), 1-30.

sufficient distance for mutually aggressive or cannibalistic species (such as Atlantic salmon).

Occupational enrichment

- Physical and psychological stimulation allows for the expression of behaviors that promote psychological well-being. This can involve play, interactive feeding opportunities, and sufficient room to swim freely.

Physical / structural enrichment

- Holding environment modifications to include structural complexity, shelter, and visual stimulation. Can include adding silt, sand, or other incubation substrates to the floor, which allow animals to burrow.

Sensory enrichment

- Introducing a diversity of visual, auditory, olfactory, tactile and taste stimuli.

Dietary enrichment

- The use of feed enhanced with appropriate nutrients, the amount and variety of food available, feeding frequency, and/or delivery system.

While these domains offer very inclusive EE definitions that can appear complex to implement, we believe a variety of sub-categories exist within each that producers may be more receptive to at this time. As a result, we have identified “introductory” EE strategies that both fall within the aforementioned groups, and can be readily implemented in an array of rearing environments. An example of these “immediate surrounding” enrichments can be found in the table below.

Atlantic salmon (*Salmo salar*)		
Enrichment Category	Juvenile	Adult
Enclosure Coloration	Not enough information available at this time. Therefore, we default to the species' "natural" conditions at this stage.	Not enough information available at this time. Therefore, we default to the species' "natural" conditions at this stage.
Substrate Provision	An artificial alternative (polyethylene astroturf) may increase growth in alevins, because it provides vertical stability and the individuals do not need to swim and thus spend energy. Avoid fine material like sand and mud. (FishEthoBase)	For the most natural solution, provide a range of rock sizes from gravel to boulder (FishEthoBase)
Lighting	Optimal photoperiod must match natural limits (Friend of the Sea) Natural photoperiod is 8-18 hours, depending on the season. Provide access to natural (or at least simulated) photoperiod and daylight (FishEthoBase)	Optimal photoperiod must match natural limits (Friend of the Sea) Natural photoperiod is 8-18 hours, depending on the season. Provide access to natural (or at least simulated) photoperiod and daylight (FishEthoBase) Sensitive to blue light at low intensity (0.82 μmol/m2/s) at night: dived away to cage bottom (FishEthoBase).
Water Complexity	In their natural environment, juveniles avoid habitats with an average column velocity below 3 cm per second whereas they prefer velocities above 6 cm per second. (FishEthoBase)	Observations on farmed Atlantic salmon stocked in sea cages suggest that a moderate water current (0.8 body lengths/s) is ideal from a welfare perspective. (Solstorm et al., 2016) Changes in current speed within tanks via a system that can be adjusted to various speeds. Changes in direction may be added as an additional component. Bubble curtains or rings can also be used inside the pen or tank. (Global Animal Partnership's Animal Welfare Certified Pilot Standards for Farmed Atlantic Salmon v1.0, 2021)
Structures	Under yearlings reared with floating annular covers in fiberglass and polystyrene displayed increased growth rate and decreased stress (Pickering et al., 1987) From: Lorenzo Fruscella	Add hanging structures in pens or tanks to disrupt the flow of current. Hanging structures can be flexible or inflexible, and can be anchored either at the top or bottom of the pen or tank. The size and length of the hanging structures must be appropriate for the size of the pen or tank. (Global Animal Partnership's Animal Welfare Certified Pilot Standards for Farmed Atlantic Salmon v1.0, 2021)
Shelter	Substrates (rocks, pebbles, stones) provide shelter for juveniles during this time period. Fine materials such as mud or sand should be avoided. (FishEthoBase)	For the most natural solution, provide at least one coarse substrate shelter per individual; alternatively, provide artificial shelters inside the system (e.g., cut-up opaque plastic bottles, undercut banks or outside (e.g., fibreglass and polystyrene). Being able to shelter prevents weight loss otherwise resulting from shelter competition. (FishEthoBase) Visual barriers are structures which allow multiple salmon to shelter beneath or around them, e.g. branches, logs, or untreated wooden planks, and can be used at all life stages. (Global Animal Partnership's Animal Welfare Certified Pilot Standards for Farmed Atlantic Salmon v1.0, 2021)
Feeding System	Install a self-feeder and make sure all Atlantic salmon adapt to it (FishEthoBase)	Install self-feeder and make sure all Atlantic salmon adapt to it (FishEthoBase)

Table 1: Shows the "immediate surrounding" environmental enrichment interventions that are most prominent and translate to positive results identified through reviews conducted by ALI.

Recommendations for Initial Intervention

(Species-Specific Enrichment Tables)

1. Enclosure Coloration → *Colors, patterns, and/or other visualizations that comprise the animals' entire holding environment.*
   - When given a choice between two different coloured environments, fish can strongly prefer one colour over the other[32]. Juvenile Rainbow trout showed a preference for blue and green at 1° C and for green at 12° C, where they also exhibited increased growth[33]. Maia & Volpato (2016) showed that it takes at least 10 days of testing to find the colour preference for Nile tilapia, and that green and blue are the most preferred colours by the species[34]. And some species require diverse environmental coloration in order to develop pigmentation in their skin, which serves important social functions[35].
2. Substrate Provision → *Materials such as rocks, sand, gravel, or vegetation that occupy the foundation of the habitat.*
   - Appropriate substrate offers burrowing fish a place to hide, provides enrichment for bottom-dwellers that prefer to forage through the substrate for food, and could help reduce reflections within the tank that may cause stress for some fish. The addition of blue and red-brown glass substrate resulted in less aggression, better growth, and higher condition factors for adult and juvenile Gilthead seabream. Additionally, Gilthead seabream did not show improvements in the same welfare

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[32]Ritter, John A., and Hugh R. MacCrimmon. "Influence of environmental experience in response of yearling rainbow trout (Salmo gairdneri) to a black and white substrate." Journal of the Fisheries Board of Canada 30.11 (1973): 1740-1742.
[33]Luchiari and Pirhonen (2008) Effects of ambient colour on colour preference and growth of juvenile rainbow trout Oncorhynchus mykiss (Walbaum). Journal of Fish Biology. 72(6):1504-1514.
[34]Maia C.M. and Volpato G.L. (2016) A History-Based Method to Estimate Animal Preference. Sci. Rep. 6(2).
[35]Kang, Duk-Young, and Hyo-Chan Kim. "Importance of bottom type and background color for growth and blind-side hypermelanosis of the olive flounder, Paralichthys olivaceus." Aquacultural engineering 57 (2013): 1-8.

parameters when raised in barren tanks with blue painted bottoms, suggesting that the tactile interaction with the substrate was critically important to their welfare[36]. This theory is supported by the tendency for young / small wild juvenile seabream to anchor themselves in sand at night, suggesting that contact with the substrate itself is paramount to visual stimulation[37].

3. *Lighting → Natural or artificial illumination, using suitable intensities and colors, strategically placed to provide appropriate day/night simulations.*
    - Many species depend on natural lighting cycles for normal development, growth, and reproduction. Adequate light is crucial, as each species must be reared in a specific range according to their life stage and surrounding environment. Too much or too little light at suboptimal intensities could be detrimental to fish welfare and, in some cases, lethal [38]. Additionally, the swimming behavior of aquatic animals can be greatly affected by both natural and artificial lighting. Some studies have shown that strategically placing lamps at lower depths within the enclosure encouraged fish to swim deeper. As fish used more of the available space provided, this reduced crowding and chances of aggression, and improved the overall water quality and individual, physical experience of each fish[39].
4. *Water Complexity → Favorable flow rates, current directions, water features and variations, etc.*
    - Proper water movement is important for promoting gas exchange, supplementing filtration, and providing physical and mental activity for fish in all types of production. Several studies have shown that exercise or

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[36]Batzina, A., & Karakatsouli, N. (2014). Is it the blue gravel substrate or only its blue color that improves growth and reduces aggressive behavior of gilthead seabream Sparus aurata?. Aquacultural engineering, 62, 49-53.
[37]Studer, Billo Heinzpeter. 2018. Sparus aurata (Summary). In: FishEthoBase, ed. Fish Ethology and Welfare Group. World Wide Web electronic publication. Version 1.2. www.fishethobase.net.
[38]Boeuf, G. and Le Bail, P.-Y. (1999). Does light have an influence on fish growth? Aquaculture, 177(1-4), pp.129–152.
[39]Juell, Jon-Erik, and Jan Erik Fosseidengen. "Use of artificial light to control swimming depth and fish density of Atlantic salmon (Salmo salar) in production cages." Aquaculture 233.1-4 (2004): 269-282.

"swim training" induced by stimulating sustained swimming through integrating a variety of currents can have numerous health, welfare, and production benefits. Reported effects include the reduction of blood cortisol levels, improvement of recovery from acute stress, potential improvement of resistance to pathogenic infections, increased growth, improved aerobic performance, promoted schooling, and reduced aggressive interactions[40]. Furthermore, water aeration systems create bubble streams that some fish swim in[41]. These bubbles can create a sensory enrichment in the form of a bubble massage or variable water current.

5. Structures → *Interactive, submerged materials (ropes, artificial plants, debris) placed strategically throughout the animals' surroundings.*
   - Structural complexity is a vital factor in many aquatic ecosystems. Some fish species are pelagic throughout their lives, but most have at least a partial connection with structures at different life stages[42]. Environmental complexity, made up of physical structures (stones, roots, logs, plants, algae, sand, sessile animals, ice, artificial objects) play a substantial role in the natural environment of numerous species by providing shelter, reducing aggression, and improving cognitive performance through encouraging learning/exploratory behaviour[43]. For example, the provision of vertical plant-fibre ropes attached to the bottom of the cage and held up by buoys resulted in reduced aggression and fin erosion and improved horizontal distribution of juvenile Gilthead seabream[44]. The same enrichment strategy also enhanced cognition,

[40] Rodnick, K.J. and Planas, J.V. (2016). The Stress and Stress Mitigation Effects of Exercise: Cardiovascular, Metabolic, and Skeletal Muscle Adjustments. Fish Physiology, pp.251–294.

[41] Kadri, S. (2020). Managing fish welfare in intensive aquaculture. Aquatic Animal Welfare Conference.

[42] Nikolsky, G.V. (1963) The Ecology of Fishes. Academic Press Inc., London.

[43] Näslund, J. and Johnsson, J.I. (2014). Environmental enrichment for fish in captive environments: effects of physical structures and substrates. Fish and Fisheries, 17(1), pp.1–30.

[44] Arechavala-Lopez, P., Diaz-Gil, C., Saraiva, J. L., Moranta, D., Castanheira, M. F., Nuñez-Velázquez, S., & Grau, A. (2019). Effects of structural environmental enrichment on welfare of juvenile seabream (Sparus aurata). Aquaculture Reports, 15, 100224.

exploratory behaviour and brain physiological functions of juvenile seabream, an indication of improved resilience to stress[45]. *Note: type/amount of structures should be tailored to each species/rearing system in order to avoid increased aggression, territoriality, etc.*

6. Shelter → *Arrangements, such as submerged structures or overhanging covers, that allow animals to hide from conspecifics or seek refuge from unfavorable conditions.*
   - Shelters have been shown to reduce stress, increase growth, and reduce metabolic activity (allowing more energy to be converted into growth). It also allows fish to develop antipredator behavior, or ambush behavior, which enhances mental development. Welfare is especially compromised when animals live with chronic stress in a constant or repeated state of distress and anxiety from not being able to predict, escape from, or cope with danger[46]. This stress can lead to allostatic overload and the development of so-called anorexic "loser fish" with poor physiological functions and decreased ability to respond to additional stress[47]. Shelters reduce aggression in some fish, and the visual complexity of an environment could enhance brain development[48]. Overhead covers enable fish to shield from external stressors/undesirable conditions surrounding the rearing system.

[45]Arechavala-Lopez, P., Caballero-Froilán, J. C., Jiménez-García, M., Capó, X., Tejada, S., Saraiva, J. L., ... & Moranta, D. (2020). Enriched environments enhance cognition, exploratory behaviour and brain physiological functions of Sparus aurata. Scientific reports, 10(1), 1-10.

[46]Afonso, L.O.B. (2020). Identifying and managing maladaptive physiological responses to aquaculture stressors. Fish Physiology, pp.163–191.

[47]Vindas, M.A., Johansen, I.B., Folkedal, O., Höglund, E., Gorissen, M., Flik, G., Kristiansen, T.S. and Øverli, Ø. (2016). Brain serotonergic activation in growth-stunted farmed salmon: adaptation versus pathology. Royal Society Open Science, 3(5), p.160030.

[48]Näslund, J., & Johnsson, J. I. (2016). Environmental enrichment for fish in captive environments: effects of physical structures and substrates. Fish and Fisheries, 17(1), 1-30.

7. *Feeding System → Nutritional delivery that prevents adverse behavior (aggression, food monopolization, etc.) while providing some level of cognitive choice.*

    - Submerged dispensing machines could promote self-feeding, ultimately allowing fish more reliable access to food. Fish could learn about the machines and explore risk, as well as choose between several different machines containing varying feed formulations to self-regulate nutritional intake[49]. This choice allows fish access to variation, encourages exploratory behaviour, and has the additional benefits of reducing feed waste and minimizing the likelihood of leftover food adversely affecting water quality, both of which can help save on production costs[50]. Where the installation of a self-feeding system is deemed impossible, adjusting the feeding schedule/area where feed is dispersed to allow some level of variation could also have beneficial effects on welfare, so long as fish do not display competitive/aggressive behaviour, and the resting part of the population is not disturbed.

[49]Attia, Joël, et al. "Demand feeding and welfare in farmed fish." Fish Physiology and Biochemistry 38.1 (2012): 107-118.
[50]Blyth, P. J., G. J. Purser, and J. F. Russell. "Detection of feeding rhythms in sea caged Atlantic salmon using new feeder technology." Fish Farming Technology 1993 (1993): 209-215.

Case Study

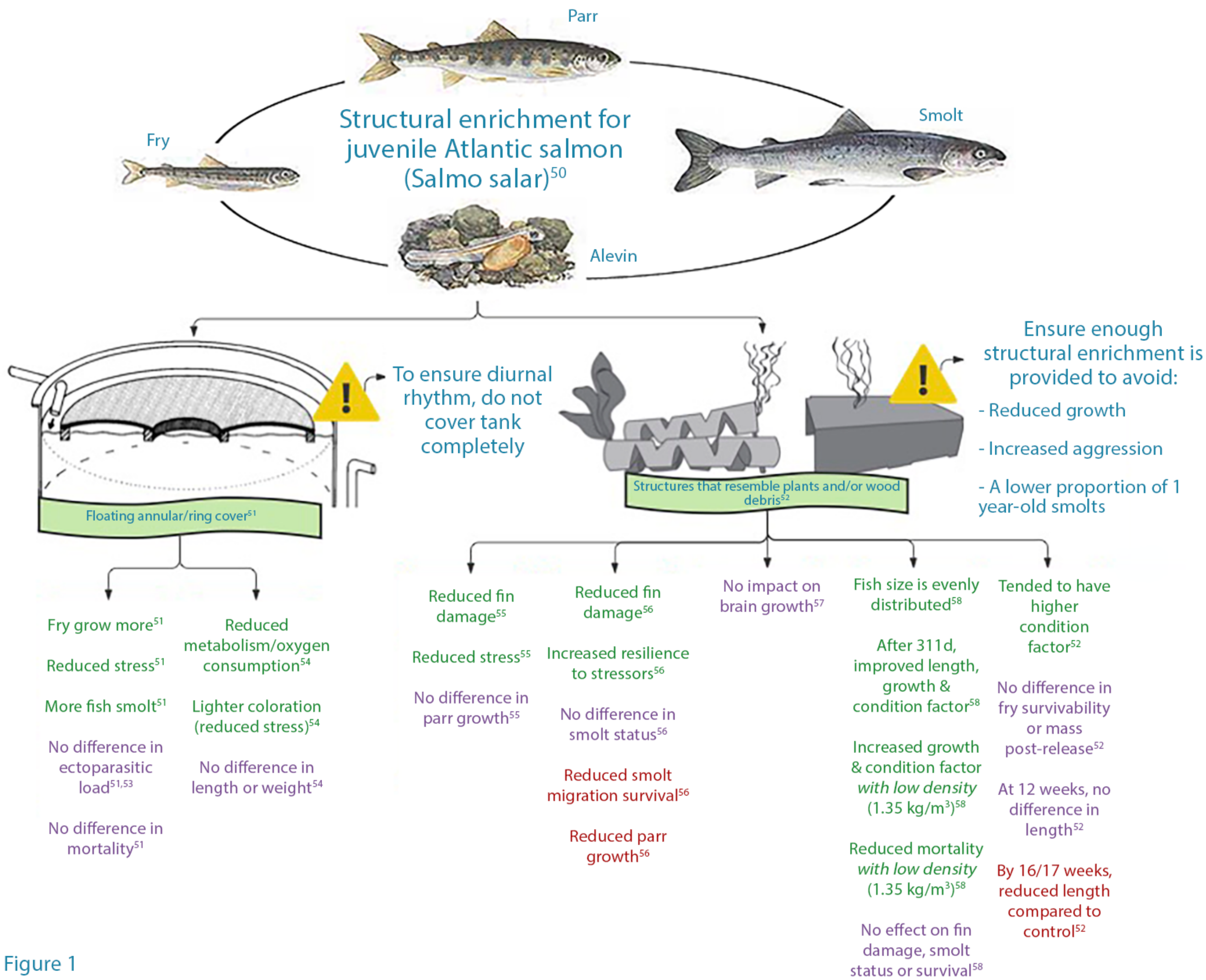

Figure 1

Figure 1: Experimental findings of the effects of structural (including shelter) enrichments for juvenile Atlantic salmon. Studies only examined the use of two kinds of structural enrichment: annular rings and structures that resemble plants or wood debris. Warning signs beside each enrichment indicate things to avoid to facilitate both positive welfare and production outcomes. Arrows below the enrichments point to columns that each represent one peer-reviewed study. The columns are color-coded to indicate the positive (green), neutral (purple) and negative (red) welfare and production outcomes found by each study (see reference footnotes on next page).

Case Study Discussion

This qualitative review found peer-reviewed studies that investigated the effect of structural enrichment on Atlantic salmon using two main types of structural enrichment: annular tank covers (AC) and plastic that resembles plants and/or wood debris (PW). Because salmon used these two enrichment types primarily as a way to hide from each other or humans, in this scenario, we consider shelters and other structures to be structural enrichment.

Although more studies investigated PW than AC, PW appears to produce positive welfare and production outcomes less consistently than AC, suggesting that AC are the superior type of structural enrichment at this time. However, the variety of outcomes associated with PW may be reflective of the different stocking densities (kg of fish/m^3 of tank space) or enrichment densities (m^3 of enrichment * m^3 of tank space / kg of fish) used in each study. For example, Brockmark et al.[58] examined the combined effects of stocking density and enrichment, and found that structural enrichment interacted with lower stocking density to reduce mortality and increase growth and condition factor. Therefore, studies that used higher stocking densities may report more negative outcomes compared to those that used lower stocking densities. Similarly, studies have found that not providing adequate enrichment

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[51]Image modified from: https://www.fws.gov/fisheries/fishmigration/atlantic_salmon.html

[52]Pickering, A. D., Griffiths, R., & Pottinger, T. G. (1987). A comparison of the effects of overhead cover on the growth, survival and haematology of juvenile Atlantic salmon, Salmo salar L., brown trout, Salmo trutta L., and rainbow trout, Salmo gairdneri Richardson. Aquaculture , 66(2), 109–124.

[53]Solås, M. R., Skoglund, H., & Salvanes, A. G. V. (2019). Can structural enrichment reduce predation mortality and increase recaptures of hatchery-reared Atlantic salmon Salmo salar L. fry released into the wild? Journal of Fish Biology, 95(2), 575–588.

[54]This is true for *Ichthyobodo* and *Trichodina,* but *Apiosoma* only occurred in tanks with covers, not in those without.

[55]Millidine, K. J., Armstrong, J. D., & Metcalfe, N. B. (2006). Presence of shelter reduces maintenance metabolism of juvenile salmon. Functional Ecology, 20(5), 839–845

[56]Näslund, J., Rosengren, M., Del Villar, D., Gansel, L., Norrgård, J. R., Persson, L., Winkowski, J. J., & Kvingedal, E. (2013). Hatchery tank enrichment affects cortisol levels and shelter-seeking in Atlantic salmon (Salmo salar). Canadian Journal of Fisheries and Aquatic Sciences. Journal Canadien Des Sciences Halieutiques et Aquatiques, 70(4), 585–590.

[57]Rosengren, M., Kvingedal, E., Näslund, J., Johnsson, J. I., & Sundell, K. (2017). Born to be wild: effects of rearing density and environmental enrichment on stress, welfare, and smolt migration in hatchery-reared Atlantic salmon. Canadian Journal of Fisheries and Aquatic Sciences. Journal Canadien Des Sciences Halieutiques et Aquatiques, 74(3), 396–405.

[58]Näslund, J., Rosengren, M., & Johnsson, J. I. (2019). Fish density, but not environmental enrichment, affects the size of cerebellum in the brain of juvenile hatchery-reared Atlantic salmon. Environmental Biology of Fishes, 102(5), 705–712

[59]Brockmark, S., Neregård, L., Bohlin, T., Björnsson, B. T., & Johnsson, J. I. (2007). Effects of rearing density and structural complexity on the pre- and postrelease performance of Atlantic salmon. *Transactions of the American Fisheries Society*, *136*(5), 1453–1462.

density has been associated with reduced growth[51,60] and increased aggression[19]. Unfortunately, at present, we cannot statistically compare AC to PW because the few studies that investigate structural enrichment in juvenile Atlantic salmon do not compare the two structural enrichment types against one another.

Despite the uncertainty around which form of structural enrichment provides the best outcomes, this review found a total of 14 positive outcomes, 9 neutral outcomes and 3 negative outcomes associated with the provision of structural enrichment. Therefore, the qualitative evidence suggests that the provision of structural enrichment provides a net positive outcome for welfare and production. However, because evidence cannot be weighed quantitatively, we suggest that producers seeking to implement structural enrichment form their decisions based on maintenance requirements and cost for their particular facility. For example, while PW may be cheaply made by cutting plastic garbage bags or plastic tubes, these may be more difficult to clean. In contrast, AC may be more expensive to implement initially, but were found to discourage algal growth due to diminished light penetration in the tanks[51], making them require less frequent maintenance than PW.

This case study highlights the need for more targeted studies of structural enrichment for Atlantic salmon, specifically studies that compare AC vs PW at low and high stocking and enrichment densities. Future studies should also evaluate whether or not the provision of AC and PW together in sufficient density enhances animal welfare more than using one kind of structural enrichment alone. Importantly, this case study did not examine structural enrichment for adult Atlantic salmon because, at the time of review, no literature on the structural enrichment of adult Atlantic salmon exists (evidence of structural enrichments for adult Atlantic salmon was anecdotal). Studies of structural enrichments other than AC and PW, structural enrichment for adult Atlantic salmon, in addition to other species should all be considered for future research.

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[60]Simpson, T. H., & Thorpe, J. E. (1976). Growth Bimodality in the Atlantic Salmon (p. 7). Int Counc Explor Sea, Anadromous and Catadromous Committee.

Practical Implications

The case study above represents a piece of a larger detailed review on the effects of environmental enrichment for Atlantic salmon. In addition to providing an accessible overview of the literature on this topic, the completed review can be used as a benchmark to characterize levels of enrichment for producers. For example, producers that implement 1-3 of the most easily implemented environmental enrichment interventions (see pages 13-17) would qualify as providing a 'Basic' level of enrichment for Atlantic salmon. Producers that implement 4-5[61] environmental enrichment interventions would qualify as providing an 'Advanced' level of enrichment for Atlantic salmon. A more detailed breakdown of the environmental enrichment levels will be explored upon release of the completed review.

Concluding Remarks

The aforementioned interventions can be easily integrated into existing farm structures, requiring minimum disruption and capital investment. Most of these interventions carry both intrinsic and instrumental benefits as they increase the welfare of the fish, but also improve their performance as a farmed animal.

[61]As indicated by the Species-specific enrichment table on p. 13, enclosure coloration is not applicable to Atlantic salmon. Additionally, because shelter and structures are combined here for Atlantic salmon, there are a maximum of 5 environmental enrichment interventions available for Atlantic salmon.