Scaling up the Sustainability of the Salmon Aquaculture Industry: Implementation of Integrated Multi-Trophic Salmon Aquaculture

Alexandra Marter

Abstract: *The current and rapid expansion of the fish farm industry gives it the potential to be sustainably shaped as a solution to diminishing wild fisheries and a means of food security for a growing human population. By focusing on salmon as a template species, this essay explores the current unsustainable problems negatively characterizing the aquaculture industry like inefficient baitfish feeds, disease, and pollution, while also presenting options for sustainable improvements. Research on diverse global salmon aquaculture production methods and policy was gathered through analysis of relevant texts including: scientific institute reports and publications, an aquaculture textbook, scientific journal articles, and a seafood expert's nonfiction writings. Integrated multi-trophic aquaculture (IMTA) was found to be a promising solution in terms of the ecological and economic sustainability of salmon aquaculture. This paper argues that world governments should promote sustainable salmon aquaculture by removing regulatory barriers and financially incentivizing IMTA.*

Aptly named the "king" of fish, salmon live a life with an incredible journey—a fascinating story of survival. Their grand adventure begins and ends in small river pools, from which they migrate downstream to the open ocean. They spend their formative years at sea: feeding on smaller bait fish, growing larger and stronger, and preparing for the next leg of their journey. When ready, the salmon use their powerful sense of smell to guide them back to the same river pools they were born in, sometimes thousands of miles away (Johnsen & Hasler, 1980). During their return upriver, they fight against all kinds of barriers, including a strong current, and even leaping up waterfalls. Eventually, the weary travelers make it back home with just enough energy left to reproduce and sustain the next generation of salmon (NOAA, 2016).

It's a different sort of journey, however, for most of the salmon who end up on the menu for the average seafood consumer.

According to fish expert Paul Greenberg (2011), farmed salmon are "the most consumed finfish in the Western world," taking up roughly 75% of the total salmon seafood supply (pp. 43-44). The domesticated life story of farmed salmon is one that might not seem quite so kingly or poetic, but nonetheless a journey with just as much importance in terms of sustaining future generations of wild fish and of humans. In a world with a rising human population, an increasing demand for seafood, and diminishing natural resources, world governments should promote sustainable aquaculture as a means of food security and ecological stability.

I. Salmon Aquaculture: Origins, Processes, and Sustainable Potential

Currently, human societies are at a pivotal point in the history of aquaculture: a new frontier. In comparison with the expansiveness of the land animal farming industry and its prominence in the world market, aquaculture is a relatively new commercial enterprise. The domestication of fish does have ancient Chinese origins, but the rapid growth of the fish farming industry to currently supplying almost half of the world's seafood supply took place in the past few decades (Halwell, 2008, p. 11). Brian Halwell describes this transformation as that of a "small-scale, artisanal pursuit into a large-scale science" (2008, p. 8). The science of aquaculture has indeed become a "large-scale topic" in a surprisingly short amount of time. Already there is an enormous variation in production techniques and systems, and an impressive array of different species that have been domesticated. The Wiley-Blackwell aquaculture textbook further reinforces the idea of this new, malleable frontier of aquaculture in comparison to animal agriculture "which is now based on a stable group of species." In comparison, "aquaculture is not stable in terms of the variety of species cultured and where they are cultured" (Lucas & Southgate, 2012, p. 14).

Along with variations on where and what species are cultured, the process of how they are cultured is constantly evolving, especially for large marine finfish like salmon. Brian Halwell points to salmon as "the best example of fish farming's evolution" with domestication beginning in the early 1970s in Norway, and production expanding as rapidly as the challenges of taming wild salmon were overcome (2008, p. 14). Today a majority of farmed salmon are produced in Norway, Chile, UK, and Canada (Lucas & Southgate, 2012, pp. 314, Table 15.4). With varied production and substantial international examples, salmon are an excellent aquaculture species to scale down the topic and explore sustainability.

Like the aquaculture industry, the world's human population is rapidly expanding, and this can have disastrous implications for a planet with limited natural resources. A United Nations Report shows the total human population level to have already reached 7 billion in 2015, and a projected growth to at least 9 billion by 2050 (Department of Economic and Social Affairs, Population Division, 2015, p. 1, Table 1). On a global level what kinds of proteins are currently nurturing this growth? A World Resources Institute (WRI) report from 2014 shows that fish make up about 17 percent of the world's animal-based protein supply (Waite et al., 2014, p.1). With an increasingly hungry world to feed, WRI experts point out an inevitable "animal protein gap" projected to form as the land meat and limited wild capture fisheries' industries struggle to keep up with population growth (Waite et al., 2014, p.2).

In the quest to define the ultimate source of efficient, healthy animal protein to fill the projected protein gap, many factors point to fish in comparison to traditional land meats. In terms of simple energy conversion, fish tend to convert their feed to flesh more efficiently than terrestrial animals, courtesy of the structural support and the type of less energy-taxing gravity that living in a watery medium provides (Greenberg, 2011, p. 44) The World Resources Institute report also held statistics measuring the amount of edible protein produced per unit of feed input among various animal protein. Compared to land animal products, farmed finfish like salmon proved to be the most efficient, second only to poultry eggs and four times as efficient as beef (Waite et al., 2014, p.13, Figure 6). Additionally, salmon and other fish are highly acclaimed for their heart health and general health benefits thanks to omega 3 fatty acids

(Greenberg, 2011, pp. 54-55). By providing a protein as healthy as it is efficient, fish like salmon may hold the solution to sustainable food security for a growing human population.

II. Aquaculture: Sustainability Challenges and Solutions

While salmon fish farming can serve as a domesticated substitute and can relieve fishing pressure on the farmed species' wild counterparts, scientists and environmentalists often point to the ecological issues that arise from the kinds of feeds that fish farmers use to grow carnivorous, domesticated fish like salmon. Brian Halwell refers to this as the "reducing fish to produce fish" concept; in other words, the amount of feed converted to fish flesh of predatory fish higher up the food chain is drastically unbalanced (2008, p. 17). With farmed salmon, resource conversions for one pound of salmon meat can be as high as six pounds of wild fish ground up and transformed into feed pellets (Greenberg, 2011, p. 43). This kind of ecological imbalance and net-drain on ocean fisheries can cause damage from an ocean systems perspective. Dr. Ellen Pikitch calls it, "pulling the rug out from underneath marine ecosystems" (as cited in Greenberg, 2011, p. 248). In sum, conventional baitfish feeds are pulling negatively from the base of the food chain, potentially causing collapse and unsustainability from below.

Many conservationists would label the baitfish feed issue as an ecological paradox; a problem that in many ways negates the idea that farmed fish reduce pressure on wild populations of fish. However, there is, an appealing array of solutions in the early stages of development around the world. Thanks to genetics, species like salmon have been bred to grow faster with less feeds; in recent decades, both the production cycle length and fishmeal portions of farmed salmon diets have dropped about 25 percent (Halwell, 2008, p.18). The simple concept of shaping feed pellets differently in a way that slows their sinking has greatly reduced food waste, nutrient pollution, and farming production costs (Halwell, 2008, p.18). Scientists and aquaculture innovators are also developing substitutes for fishmeal based diets. One industry's trash could be a treasure for farmed fish, as some analysts have proposed creating feeds out of slaughterhouse wastes like meat scraps. Others have suggested removing an intermediate trophic level altogether by substituting meat and fish meal feeds for plant-based alternatives. In salmon specifically, these types of alternative feeds have shown encouraging preliminary success (Halwell, 2008, p. 19).

Some of the main reasons that environmentalists villainize the aquaculture industry are the common problems seen in any kind of animal domestication on a large scale: cramped containment, diseases, and pollution. In the case of large, marine finfish like salmon, farming mostly takes place in floating pens or cages in the wild ocean environment, but this only amplifies the negative impacts on surrounding ecosystems of the aforementioned problems. Paul Greenberg (2011) points out the unfortunate, classic pattern that unaware fish farmers tend to fall into; they increase the density of salmon farmed to increase revenue, which subsequently increases nitrogenous waste buildup, parasites like the sea louse, or diseases like infectious salmon anemia. Moreover, Greenberg cites that poor location establishment of aquaculture facilities can magnify these issues due to weak water circulation (p. 49).

Fish in cramped cages, sea lice, and distasteful nutrient pollution are all rather repulsive labels associated with salmon farming and other types of aquaculture. However, the power to reduce or reverse issues such as these is all contained within the initial design of aquaculture systems. One of the most practical and comprehensive ways to lessen disease and pollution is by establishing aquaculture facilities in locations with a strong current and water circulation to filter out and disperse these problems (Waite et al., 2014, pp. 3-4). Another way of moving forward with solutions to these issues, may be through looking backwards. Thousands of years ago the Chinese mastered an ecological systems approach that greatly reduced wastes through a "four-way polyculture" (multiple species) type of fish farming where silk worms, ducks, rice, and carp were mutual beneficiaries (Greenberg, 2011, p. 69). One of the biggest salmon producers in Canada, Cooke Aquaculture, is a modern-day example of transcending typical monoculture (single species) systems to what scientists call integrated multi-trophic aquaculture, or IMTA (Halwell, 2008, p.7). The Cooke facility raises salmon, kelp, and shellfish, whose individual interactions support each other. Salmon effluent helps fertilize the kelp, and mussels filter the water of excess organic particulates. Combined with its location in the Bay of Fundy, one known for the largest tidal swings on earth, an IMTA facility like Cooke keeps the water clean, lowers disease rates, and provides a more sustainable example to fish farms everywhere (Halwell, 2008, p.7). In sum, the Cooke facility serves as an important model for the kinds of ecological- based solutions that should be implemented to improve the efficiency of the salmon aquaculture industry.

III. Government Implementation of Sustainable Aquaculture

As seen with the Cooke Aquaculture facility and IMTA, sustainable salmon aquaculture solutions exist. Whose responsibility is it, then, to promote sustainable expansion of salmon aquaculture? Environmentalists and activists often praise the power of individual consumer choice, or the potential for the consumer to create market driven demand for sustainable seafood. This concept is not without merit, especially with the development of the sustainable seafood movement and ecolabels like the Monterey Bay Aquarium's Seafood Watch program (Halwell, 2008, p.10). However, discrepancies and ambiguity in standardization for what constitutes sustainable fisheries and aquaculture weaken the individual consumer's decision-making power. Regarding the industry, most aquaculturists are well aware of the unsustainable flaws in their farm operations but lack the financial or scientific resources and training to reform their practices (Halwell, 2008, p. 33). Consumer and industry leaders are key players in the sustainable revolution of salmon aquaculture, but the impetus needed to spark action has to come from government policy, promotion, and incentives.

Policy solutions to environmental concerns usually consist of stricter regulations, but governments can also utilize subsidies. This is a positive reinforcement mechanism much more well-received by the industry when compared to stringent regulations. In fact, Daniel Lee, the Best Aquaculture Practices Coordinator with the Global Aquaculture Alliance, points out that fish farmers already want to improve their facilities: "[a]quaculturists are increasingly aware that it is in their best interests to adopt sustainable practices to reduce problems with pollution and disease" (Halwell, 2008, p. 33). Lee believes that "farm owners have an incentive to invest in the long-term viability of their operations, knowing that the benefits of good management will not be dissipated by outsiders" (Halwell, 2008, p. 33). One such incentive could be granting "nutrient credits" for farms that reduce their nutrient pollution levels, similar to "carbon credits" that businesses might receive for reducing greenhouse gas emissions (Halwell, 2008 p. 31). To encourage and reward sustainable, low-environmental impact salmon aquaculture production systems, governments should utilize subsidies and financial incentives.

In the search for environmentally and economically sound solutions to salmon aquaculture issues, scientists and industry officials alike often look to integrated multi-trophic aquaculture (IMTA). Ecologically, the IMTA method offers hope that one of the industry's biggest problems, nutrient pollution, can be solved by imitating natural ecosystem structures and services. In the proceedings of an IMTA workshop held in New Brunswick, scientists Chopin and Robinson (2004) concluded "that the solution to nitrification is not dilution but conversion within an ecosystem-based management perspective" (p. 7). Financially, IMTA is feasible for existing farms to implement based on infrastructure advantages. Aquaculture researcher Stephen Cross of the University of Victoria states that "the benefits of introducing this new approach includes opportunities for shared: 1) infrastructure, including on-site accommodation facilities and transportation logistics; 2) farm personnel; and 3) processing and marketing" (Cross, 2004, p.55). Patrick Fitzgerald, an aquaculture facility manager from New Brunswick, further reinforces this by saying, "Compared to finfish farming, IMTA requires relatively low capital investment. Setting up a mussel or seaweed raft does not involve a lot of sophisticated equipment" (Fitzgerald, 2004, p. 65). Overall, IMTA allows the industry to capitalize on the efficiency of ecosystem services.

Despite IMTA's widespread support, most governments are cautious about promoting it. Looking once more at the IMTA example of salmon, mussels, and kelp in New Brunswick's Bay of Fundy, the Canadian government's regulation approach consists of a complex licensing system with strict guidelines for the vicinity of shellfish and sources of organic waste like salmon effluent (McGeachy & Hill, 2004, p. 71). This system is built under the 1988 New Brunswick Aquaculture Act within the Department of Agriculture, Fisheries, and Aquaculture, and officials from this regulatory body stated that, "the department is supportive of slow, cautious, shellfish and seaweed aquaculture development in the Bay of Fundy" (McGeachy & Hill, 2004, p. 72). However, this type of "slow, cautious support" from the government is not conducive to the kind of rapid increase needed in IMTA development. When industry expert Patrick Fitzgerald (2004) was asked about the trials of implementing IMTA in the Bay of Fundy, he replied, "I'm seeing a big stumbling block with the regulators as far as getting permits to grow the mussels within 125 m from the fish cage. That is the number one problem today. We need to learn to walk before we run, but we're willing to try" (p. 67). As Fitzgerald summed, before seeing the growth of IMTA in Canada, "we need the blessing of the regulators to allow culture of seaweeds and shellfish in proximity to salmon" (2004, p. 66).

Like the regulatory stumbling blocks in Canada, nations in Europe have struggled to implement IMTA as well. A team of researchers from various universities in Europe conducted a study of European aquaculture policy, focusing on six key countries to "identify regulatory incentives and barriers to the development of IMTA" (Alexander et al., 2015, p.17). For European aquaculture policies overall, the study found that "national frameworks were generally amenable to experimental IMTA pilot schemes, but that for commercial expansion, substantial regulatory reform would be required" (Alexander et al., 2015, p.1). However, the regulatory focus shifts from country to county. For example, in Norway the policy aims to improve aquaculture by setting strict limits on pollutants and escapees. Irish and Italian policies, alternatively, are aimed more at regulating the diversification of species farmed and placing more funding into technological innovation (Alexander et al., 2015, p. 20). The study categorized the different types of policies as promotional, permissive, precautionary or preventive (Alexander et al., 2015, p. 22, Table 1), with a majority of the policies found to be precautionary. Precautionary regulations and policies analogous to those seen in the Bay of Fundy example, were defined as those that "slow the development of IMTA." characterized by "a myriad of agencies dealing with different aspects of aquaculture and where permissions have to be obtained from each and every one" (Alexander et al., 2015, p. 21). As exhibited with the Bay of Fundy example and European examples, the "politics of precaution" approach is not constructive; instead world governments should be implementing politics of promotion.

The potential strategies for promoting IMTA are as numerous as the regulations surrounding most salmon aquaculture industries today; however, the positive financial reinforcement strategies discussed earlier, like subsidies and nutrient credits, may have significant power in encouraging the industry to adopt IMTA. Another salmon aquaculture policy study that looked at Chile's industry found that there is not much flexibility for implementation of IMTA (Buschmann et al., 2009). The licensing and monitoring regulations that govern Chile's salmon farms today were developed in the 1990s (Buschmann et al., 2009, p. 244). Since that time, the number of salmon farms has doubled, and the current policy has not yet been updated to reflect this increase in farm density nor reflect the large amount of new research that has been conducted in the past years (Buschmann et al., 2009, p. 244). After analyzing a wide range of environmental strategies for sustainable development of salmon aquaculture, this particular study found that "if economically viable, IMTA will be an important driver for the development of seaweed farming and mussel aquaculture. If profitable, there is real promise that in the coming years IMTA will help bring together these new cultivation approaches and reduce the amount of waste produced by salmonid aquaculture" (Buschmann et al., 2009, p. 246). This "economic viability" can be established by revising outdated regulatory policy, removing barriers to IMTA's growth, promoting it by funding further IMTA research, and subsidizing industries that partake in IMTA. As the Chile study concluded, "the agency's immediate goal should be to fund research required to develop a transparent, ecosystem-based regulatory framework that promotes IMTA" (Buschmann et al., 2009, p. 243). This goal not only applies to Chile specifically but to all the major salmon farming nations explored earlier.

Overall, most current salmon aquaculture practices cannot really be considered sustainable in terms of energy and resource efficiency as well as environmental and ecological impact. However, because fish are a more efficient protein than land meats, and because wild fisheries along with land meats won't be able to supply enough protein to feed the growing human population, aquaculture is the most logical avenue forward. With salmon aquaculture specifically, viable and promising solutions like IMTA already exist and have unrealized potential for implementation. As stated in the Chile study, "It is clear that IMTA can increase profitability and reduce economic risks, as well as present a better environmental perception to the general public as compared to salmon monoculture" (Buschmann et al., 2009, p. 246). To promote healthy salmon aquaculture growth, world governments should loosen regulations on and subsidize the implementation of Integrated Multi-Trophic Aquaculture in the salmon aquaculture industry.

With immense complexity and stakeholders in multiple spheres, the controversy surrounding salmon aquaculture cannot be adequately covered in a single research paper; however, looking forward, the World Resources Institute states that "[o]ne thing is clear: improving the productivity and environmental performance of aquaculture— and ensuring it provides safe, affordable, and nutritious food to millions of people around the world—is an important item on the menu for a sustainable food future" (Waite et al., 2014, p.2). Like the incredible journey upriver that wild, adult salmon take to return to their original river pools, overcoming the challenges of spreading ecologically sound, efficient, salmon aquaculture will not be easy. It is an undertaking comparable to swimming against a strong current of widespread industrial problems and up waterfalls of public misconceptions. However, just like the end goal of mature salmon to breed and ensure survival for their progeny, promoting sustainable salmon aquaculture is a way to secure hope and survival for future generations of wild fish and human kind.

Note: This essay was composed in Dr. David Reamer's AWR 201 class.

References

Alexander, K. A., Potts, T. P., Freeman, S., Israel, D., Johansen, J., Kletou, D., …Angel, D. L. (2015). The implications of aquaculture policy and regulation for the development of integrated multi-trophic aquaculture in Europe. *Aquaculture, 443*, 16-23. https://doi.org/10.1016/j.aquaculture.2015.03.005

Buschmann, A. H., Cabello, F., Young, K., Carvajal, J., Varela, D. A., & Henriquez, L. (2009). Salmon aquaculture and coastal ecosystem health in Chile: Analysis of regulations, environmental impacts and bioremediation systems. *Ocean & Coastal Management, 52*, 243-249. https://doi.org/10.1016/j.ocecoaman.2009.03.002

Chopin, T. & Robinson, S. (2004). Defining the appropriate regulatory and policy framework for the development of integrated multi-trophic aquaculture practices: Introduction to the workshop and positioning of the issues. *Bulletin Aquaculture Association of Canada, 104* (3), 4-10. Retrieved from http://aquacultureassociation.ca/ ¬¬

Cross, S. (2004). Finfish-shellfish integrated aquaculture: Water quality interactions and the implication for integrated multi-trophic aquaculture policy development. Bulletin Aquaculture Association of Canada, 104 (3), 44-55. Retrieved from http://aquacultureassociation.ca/

Fitzgerald, P. (2004). Integrated multi-trophic aquaculture: An industry perspective. *Bulletin Aquaculture Association of Canada, 104* (3), 63-67. Retrieved from http://aquacultureassociation.ca/

Greenberg, P. (2011). *Four fish: The future of the last wild food*. New York: Penguin Group

Halwell, B. (2008). *Farming fish for the future*. Washington, DC: Worldwatch Institute.

Johnsen, P. B. & Hasler, A. D. (1980). The use of chemical cues in the upstream migration of coho salmon, *Oncorhynchus kisutch Walbaum*. *Journal of Fisheries Biology, 17*, 67-73. http://doi.org/ 10.1111/j.1095-8649.1980.tb02742.x

Lucas, J. S., & Southgate, P. C. (2012). *Aquaculture: Farming aquatic animals and plants* (2nd ed.). Chichester, West Sussex: Wiley Blackwell

McGeachy, S. & Hill, B. (2004). New Brunswick's role in developing and administering the culture of alternate species. *Bulletin Aquaculture Association of Canada, 104* (3), 71-72. Retrieved from http://aquacultureassociation.ca/

NOAA (National Oceanic and Atmospheric Administration). (2016, February 10). *Atlantic Salmon (Salmo Salar)*. Retrieved April 14, 2017, from http://www.fisheries.noaa.gov/pr/species/fish/atlantic-salmon.html

United Nations Department of Economic and Social Affairs, Population Division. (2015). World population prospects: The 2015 revision, key findings and advance tables. Retrieved from https://esa.un.org/unpd/wpp/

Waite, R., Beveridge, M., Brummet, R., Castine, S., Chaiyawannakarn, N., Kaushik, S., Mungkung, R., Nawapakpilai, S., & Phillips, M. (2014). Improving productivity and environmental performance of aquaculture. Retrieved from http://www.wr