Growing Better Salmon: **Balancing Economics with Environmental Impact**

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Aquaculture – growing fish or other aquatic species in captivity – is an important strategy for meeting the increasing demand for seafood from a growing human population, while also preserving wild fish stocks. However, aquaculture can also have negative environmental impacts. Researchers at the Universities of Windsor, Waterloo and Western Ontario in collaboration with industry and government partners are investigating ways to advance salmon aquaculture using methods that increase productivity, while reducing environmental impact. The implications for sustainable and profitable Chinook salmon farming in British Columbia and around the world are exciting.

According to the Canadian Department of Fisheries and Oceans, aquaculture represents about a third of Canada's total fisheries value and is growing rapidly; the value of aquaculture production has increased by 63% over the past ten years, to $962 million currently. As much as $634 million of this is attributable to salmon farming. Most salmon aquaculture focuses on Atlantic salmon, but, as Dr Daniel Heath, University of Windsor, explains: 'the culture of Pacific salmon for west coast aquaculture has great economic potential due to niche market price advantages and higher disease and parasite resistance.' He and his research team are investigating ways to improve Chinook salmon farming.

Chinook Salmon

Chinook salmon are native to the Pacific northwest and are big fish, maturing close to 1 metre-long and ranging from 18 to 55 kg in weight. As with other species of salmon, they are anadromous, meaning that they migrate from salt water to the freshwater streams and rivers where they were born in order to mate and lay their eggs. Chinook salmon are listed on the Endangered Species List in the United States, and several Chinook fisheries along the Pacific coast in the U.S. and Canada are limited by weak numbers. The fishery suffers from a range of threats, from habitat degradation to climate change. These low numbers of Chinook salmon are particularly

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concerning because the fish serve an important role in the marine and freshwater ecosystems by providing food for a variety of wildlife (such as bald eagles and grizzly bears), as well as contributing important nutrients and organic matter back to the freshwater and saltwater environments. They also hold cultural importance to their namesake, the indigenous Chinookan people of the Pacific Northwest.

The Research Team . . . and a Whole Lot of Fish!

The research team is an experienced group of seven scientists at the University of Windsor, University of Waterloo and Western University in Canada. Dr Heath has a Ph.D. in Genetics from the University of British Columbia and an M.Sc. in Biology from McGill University. He has served as Principal or Co-Principal research scientist on numerous grants to advance research around aquaculture, fish biology, animal science, and ecology. His expert research team includes Dr Dennis Higgs (University of Windsor) who focuses on sensory ecology of vertebrates, Dr Oliver

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Love (University of Windsor) who studies physiological traits in a variety of species across different ecosystems, Dr Brian Dixon (University of Waterloo) who is an expert in fish immunology and disease, Dr Christina Semeniuk (University of Windsor) who studies adaptive behavioural variation in social groups of animals with a focus on resource utilisation, Dr Bryan Neff (Western University) who focuses on the behaviour, genetics and ecology of fishes and Dr Trevor Pitcher (University of Windsor) who combines evolutionary ecology, reproductive biology and conservation biology, to study fishes from the Great Lakes and the Pacific coast of Canada.

Dr Heath and his team aim to reduce the environmental impact and increase the profit associated with farming Chinook salmon in the Pacific northwest by developing high performance Chinook salmon stocks that gain weight easily on less food and have improved immune function. The goal is to produce fish that will require less feed and fewer chemicals and antibiotics for disease control, thus significantly reducing both costs and pollution. Their current research, funded by the Natural Sciences and Engineering Research Council of Canada, involves multiple integrated research topics designed to culminate in high performing strains of Chinook salmon that can form the backbone of a profitable and environmentally sustainable Chinook aquaculture industry in the Pacific northwest.

As one can imagine, the research involves a lot of fish! The research team conduct their trials at Yellow Island Aquaculture, Ltd., an organic salmon farm on Vancouver Island and one of the industrial partners in the project. Juvenile fish were housed in 240 family tanks – 200 litres in size, and then transferred to several 5x5 metre saltwater net pens as they grew. Multiple groups of fish (and hence tanks and pens) are necessary to test the impact of different variables on the fish. A subset of 16,800 of the fish being studied also have a small electronic identification tag called a PIT tag that allows the researchers to track their growth and development in extreme detail.

Hybrid Vigour

Hybrid vigour is foundational to the research team's efforts to create high performing Chinook salmon breeding stock. Hybrid vigour describes the superior qualities that arise from cross breeding genetically different plants or animals (you might be familiar with this if you are a gardener growing prolific hybrid vegetable strains purchased from your local garden supply centre). Dr Heath and his team are working to achieve hybrid vigour in Chinook salmon stocks by crossing domestic and wild salmon. These hybrids have good potential for achieving higher growth and survival rates and better feed efficiency than either of the parent strains. By carefully studying these hybrids under different environmental conditions, researchers are able to continually select and breed for a highly productive fish.

This is no small task – creating these hybrid fish stocks involves taking 60,000 eggs from mature Chinook salmon females and collecting sperm (also called milt) from wild populations across Vancouver Island, a task only possible with the guidance of Dr Bob Devlin, a Department of Fisheries and Oceans Canada researcher. A portion of the sperm collected was cryopreserved for use in creating the experimental hybrids.

As the research team carefully builds the breeding stock, they monitor multiple variables closely – from growth and metabolic rates to aggressive behaviour patterns, energetic physiology, immune response, survival and flesh quality.

A Salmon Treadmill of Sorts: Assessing Growth and Neurobiology

Growth is measured not just in length and weight of the fish, but also according to the presence of growth and stress hormones and in terms of feed conversion and metabolic rates. Feed conversion efficiency (how much food it takes to grow to a specific size) is measured as a ratio of feed consumed to body size. How is metabolic rate measured? To obtain this measurement, a sample of 10 fish from each stock are put in a swim tunnel where a respirometer records their oxygen consumption at rest and at maximum

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sustained swimming speeds. Because water temperature impacts fish performance, swim tunnel measurements are taken across a range of water temperatures that correspond to climate change prediction models. To get a clear picture of growth rates throughout the full life cycle of this anadromous fish, the research team monitors growth in both freshwater and saltwater environments. Because captive environments have been shown to have the potential to alter the brain in a way that reduces efficient physical growth, the team also performs complex analyses on samples of brain tissue and relates those measurements to adaptive behaviour patterns in the fish.

Salmon Aggression: Assessing Behaviour and Endocrinology

Why do we care how fish behave when in groups? Dr Heath explains that fish behaviour 'is a key determinant of fish performance in aquaculture.' Aggression between fish can cause injuries and increases in cortisol (a stress hormone that, when elevated, can cause a multitude of physical problems). Aggressive behaviour can also reduce the growth rates among individual fish that have trouble accessing food, and the frequent speedy movements of fish either acting as aggressors or getting out of the way of an aggressor increases the fish's metabolic rate, in turn decreasing its food conversion efficiency. Interestingly, behaviour patterns related to aggressive behaviour have been shown to be a product of both genetic traits and the captive environment experienced by the individual. Therefore, it is possible to reduce aggressive behaviour through breeding.

In order to analyse and quantify fish behaviour, the research team uses both video analysis and blood samples (the latter detects levels of hormones, such as cortisol and testosterone, that are known indicators of stress response and social dominance in fish). They also analyse gene expression in brain tissue to identify the mechanisms of genetically-based aggressive tendencies.

Survival Rates, Pathogens and Stress

All fish can become susceptible to disease or parasites, but in crowded pens of farmed fish, the risk of economically devastating disease outbreaks is increased. Globally, aquaculture losses due to disease cost billions of dollars. Antibiotics and pesticides are costly and harmful to the environment, so developing a fish with a robust immune system is a top priority. Dr Heath's team is measuring immune response in their fish stocks by monitoring cytokines (small proteins that act as signals to cells and modulate immune response) as well as antibody production and granulocytes (a specific kind of white blood cell). Because stress hormones play a role in fish health, the relationship between stress hormone levels and survival is being documented. Analysis of DNA from both the salmon and their pathogens allows the researchers to identify pathogens and observe the relationships between genetic diversity and survival rates.

Immune Function

Further in-depth analysis of immune function is also ongoing and involves challenging fish by exposing them to disease via vaccine and bath exposure (in which fish are transferred to tanks containing disease). In addition to monitoring for survival (genetic variation among the fish means that some fish have better survival rates than others), the researchers analyse blood samples, along with spleen, gill and muscle tissues to monitor immune response. Finally, genotyping allows the scientists to examine individual DNA variation that may contribute to improved immune response and ultimately, survival.

Flesh Quality

High quality flesh is (of course!) an imperative for a successful salmon farm. However, flesh quality can be negatively impacted by stress associated with high density pens. It also tends to deteriorate as the fish ages. The research team monitors flesh quality (including pigment, fatty acid content and muscle composition) in relation to diet, the presence of stress hormones and maturation rates. These data help them better understand the optimum living environment for the stock as well as the optimum age for harvest.

Bringing it All to Market: Economic Assessment

The final piece to the puzzle involves calculating the economic potential of the newly developed fish stocks. To that end, the research team will combine all of its performance parameters, quantify the cost-benefit relationships associated with each hybrid strain developed through the research project, and produce a profitability analysis comparing Chinook salmon with the more commonly reared Atlantic salmon. The researchers expect that the analysis will help Canada's salmon farming industry diversify, increase profits and reduce negative environmental impacts.

Meet the researchers

Dr Daniel Heath

Dr Heath's (U Windsor) role is to correlate survival and growth with gene expression profiles. He has extensive experience with collaborative applied and academic aquaculture research, including molecular and quantitative genetic analyses of salmon. He is currently conducting research investigating the genetic contribution to migratory and maturation variation in salmon and trout and has worked in, and collaborated with, the Canadian salmon farming industry for over 30 years.

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Dr Oliver Love

Dr Love's (U Windsor) role is to evaluate hormonal mechanisms affecting performance (growth and survival). He has extensive experience measuring and interpreting physiological biomarkers of growth, performance and environmental stress. He is currently conducting NSERC- and Canada Research Chair-funded research investigating the mechanistic links between human-induced environmental stressors and performance in vertebrate systems, and has published on the mechanistic role of developmental and reproductive stressors in driving individual variation in fitness.

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Dr Bryan Neff

Dr Neff's (U Western Ontario) role is to evaluate feed conversion efficiency and the contributions of metabolic rate and activity to this trait. He has extensive experience studying the behavioural, ecological and evolutionary factors affecting life history traits in fishes. He is currently conducting NSERC-funded research to understand the genetic architecture of fitness in fishes, and to help restore Atlantic salmon to the Great Lakes.

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Dr Dennis Higgs

Dr Higgs' (U Windsor) role is to evaluate the neurobiology of growth. He has extensive experience in the growth and development of fish and neural correlates to performance. He is currently conducting NSERC-funded research on the growth performance of Chinook in aquaculture settings as well as NSERC-funded research on the effects of human-induced stressors on sensory performance and applied work utilising behavioural and neural responses of invasive species to improve ongoing remediation efforts.

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Dr Christina Semeniuk

Dr Semeniuk's (U Windsor) role is to correlate survival and growth with behavioural profiles at the individual and population levels. She has a background in behavioural ecology and has NSERC-funded research to examine the mechanistic drivers and functional outcomes of behavioural variation of animals experiencing human-induced rapid ecological change. Her program provides managers with necessary information to aid in the screening of optimal phenotypes for aquaculture, captive breeding, and conservation-related initiatives.

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Dr Trevor Pitcher

Dr Pitcher's (U Windsor) role is to evaluate flesh quality in relation to growth rates and survival to harvest size by quantifying carotenoid, lipid, fatty acid and muscle composition amongst the strains. Pitcher has extensive experience with Chinook salmon, including NSERC funding to study how incorporating ecological and evolutionary principles into breeding designs can improve aquaculture and reproduction in the context of evolutionary ecology.

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Dr Brian Dixon

Dr Dixon's (U Waterloo) role is to evaluate disease resistance and immune function to optimise Chinook salmon survival. He holds a Tier I Canada Research Chair in Fish and Environmental Immunology and was awarded the 2016 Wardle medal by the Canadian Society of Zoologists for lifetime achievement in fish immunology. His research program is focused on the immune response of fish to pathological and environmental stressors and his lab also has over 20 years in teleost fish MHC research, fish molecular immunology techniques and the development of antisera for examining expression of immunological molecules.

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