CANADIAN AQUACULTURE

R&D REVIEW 2017

INSIDE

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Cover Photo (Front): Atlantic Salmon farm in Doctor's Cove, New Brunswick (Photo: Kobb Media)

Photo Inside Cover (Front): La Butte Ronde on the island of Havre-aux-Maisons, Magdalen Islands (Québec), overlooking baie de Plaisance (Photo: Dan McPhee – DFO)

Cover Photo (Back): Atlantic Salmon farm in Doctor's Cove, New Brunswick (Photo: Kobb Media)

Photo Inside Cover (Back): Shoreline on the island of Havre-aux-Maisons in the Magdalen Islands Québec (Photo: Dan McPhee – DFO)

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Editors: Dan McPhee, Johannie Duhaime, Alex Tuen, and G. Jay Parsons

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INTRODUCTION

Welcome to the seventh edition of the biennial Canadian Aquaculture R&D Review. The review is an ongoing compendium of the aquaculture research and development projects that have been underway over the past two years from all across Canada, whether they are undertaken by researchers from academia, government labs, or other research organisations. The review contains over 210 project descriptions detailing an impressive array of topics, disciplines, species, and geography. Projects include marine and freshwater species with topics ranging from finfish and shellfish health, seaweeds, production, husbandry technology, nutrition, integrated multi-trophic aquaculture, and environmental interactions to name a few.

This is the fourth issue of the review that has been produced by Fisheries and Oceans Canada (DFO) in partnership with the Aquaculture Association of Canada (AAC). This partnership is highly relevant and mutually beneficial to our respective roles in the area of knowledge translation and mobilisation at both the AAC and DFO. This collaboration has allowed us to produce this 2017 edition as an AAC Special Publication, which is an accessible, electronic citation. Digital versions of this document are also available on both the DFO and AAC websites.

Aquaculture continues to be an important and growing sector of the seafood industry in Canada as well as globally. As aquaculture continues to grow, the role of science in supporting the sustainable management, regulation, and responsible development of this sector is more crucial than ever. This is coupled with the growing need for healthy and secure seafood products while ensuring that it occurs in an environmentally responsible manner.

The AAC wants to profile advances in aquaculture research in Canada and provide this information to its members for an expanded dialogue on present and future challenges and opportunities for the industry. As such, this publication falls within the AAC's mandate of disseminating knowledge and further education and we hope it will be of interest to a wide audience. Likewise, DFO has a mandate to enable the sustainable development of Canada's aquatic resources, including aquaculture, and to provide access to information on its scientific activities underway within the department and elsewhere in Canada. Publication of ongoing aquaculture research in the Canadian Aquaculture R&D Review contributes towards achieving our shared mandates and to reach out to the science community, interested stakeholders, and the public. Additionally, the publication serves to increase the understanding and breadth of scientific activities underway and to encouraging development of collaborations, synergies, and coordination of future activities. Communication and analysis of scientific knowledge is also increasingly pertinent in ensuring a robust evidence-based approach to decision making and regulation of the aquaculture industry, which contributes to improved social acceptability and confidence.

We would like to take the opportunity to recognize and thank several people who contributed significantly to the production of this Review. Dan McPhee (DFO) undertook the overall coordination of this project and was instrumental in seeing this project through to completion from beginning to end. Johannie Duhaime and Alex Tuen were also actively involved in various aspects of this project. We would also like to thank the AAC office staff (Catriona McLanaghan) and Publications Committee for their support.

G. Jay Parsons, PhD
Ecosystems and Oceans Science Sector
Fisheries and Oceans Canada

Tillmann Benfey, PhD
President
Aquaculture Association of Canada

FINFISH: FRESHWATER

Ontario's Contributions to a Bi-National Initiative to Restore Bloater (*Coregonus hoyi*), an Extirpated Species, to Lake Ontario

Historically, Lake Ontario was home to four species of Deepwater Ciscoes (*Coregonus* spp.), a group of species related to Lake Whitefish. Collectively, these species formed the cornerstone of the deep water prey-fish community. Unfortunately, all four species were extirpated from the lake in the last century.

In 2010, the Ontario Ministry of Natural Resources and Forestry (MNRF) and the New York State Department of Environmental Conservation developed a draft plan to restore Deepwater Ciscoes to Lake Ontario which, if successful, would increase the availability of prey to native predators like Lake Trout and Atlantic Salmon. Initial efforts were to focus on Bloater (*C. hoyi*).

In winter 2011 and 2012, MNRF received its first fertilized gametes collected from wild populations in Lake Michigan. Given the challenge of collecting gametes at this time of year, a decision was made to set aside some surviving fish from each year class to begin developing brood stocks. Initial culture efforts were aimed simply at learning how to keep the fish alive. Our Lake Whitefish culture protocol was used as a starting point. While initial survival rates were very low, a variety of diet and temperature trials conducted over the next four years resulted in significant improvements in performance.

Six year classes of brood stock have now been established. While both sexes have shown signs of maturation, the timing and degree of maturation has been variable. Hormone induction and cryopreservation studies are now underway in collaboration with the University of Windsor. This research aims to restore a self-sustaining Bloater population within 25 years.

DATE: JAN. 2011–JAN. 2020

FUNDED BY: Ontario Ministry of Natural Resources and Forestry (MNRF)

CO-FUNDED BY: Canada-Ontario Agreement; Great Lake Fish and Wildlife Restoration Act

PROJECT LEAD: Kevin Loftus (MNRF)

PROJECT TEAM: Tim Drew, Ryan Zheng, Jennifer Smith, Jake Ruegg, Matt Brailey, Brian Rosborough, Chris Wilson (MNRF)

COLLABORATORS: NYSDEC; USFWS; USGS; Great Lakes Fishery Commission; U Guelph; U Windsor

CONTACT: ryan.w.zheng@ontario.ca

Bloater (*Coregonus hoyi*) yearling. Photo: MNRF

Female Bloater (*Coregonus hoyi*) brood fish. Photo: U Windsor

Development of Walleye (*Sander vitreus*) Intensive Culture Techniques to Enable Increased Production to Meet Demands

This research aims to increase the ability to produce Walleye for stocking into public waters to support provincial fisheries management objectives and to improve the ability to produce Walleye fingerlings to support the commercial aquaculture industry.

Walleye (*Sander vitreus*) is one of the most sought after recreational species in Ontario but some populations are in decline. The Ontario Ministry of Natural Resources and Forestry (MNRF) stocks Walleye at different life stages to enhance fishing opportunities and to restore degraded populations. Unfortunately, the MNRF is not able to meet the current demand for Walleye by stocking using traditional extensive (i.e., pond) culture methods. To address this gap, the MNRF is developing expertise in the intensive (i.e., indoor) culture of Walleye. They are building upon techniques pioneered in flow through systems by Summerfelt and colleagues in the 1990s and advanced by others in Iowa, Wisconsin and elsewhere. The ability to reliably grow Walleye intensively from hatch to the autumn fingerling stage would increase the options available to MNRF to meet stocking targets and would also provide benefits to the commercial aquaculture sector.

Two MNRF Fish Culture Stations (FCSs) are involved in this effort: Blue Jay Creek FCS with a Recirculating Aquaculture System (RAS); and White Lake FCS with a flow through system. Rearing trials have focused on finding a readily available, high quality, early rearing diet, and on investigating the effects of tank size on growth and survival. To date, there has been significant progress. We are now able to achieve survival rates in our flow through system comparable to those achieved by our U.S. colleagues, and similar performance is within sight in our RAS system. Success depends upon careful control of key parameters including turbidity, temperature, light, diet, and feeding regime.

Walleye rearing room at the Blue Jay Creek Fish Culture Station. Photo: MNRF

DATE: APR. 2013–OCT. 2018

FUNDED BY: Canada-Ontario Agreement

CO-FUNDED BY: Ontario Ministry of Natural Resources and Forestry (MNRF)

PROJECT LEAD: Kevin Loftus (MNRF)

PROJECT TEAM: Ryan Zheng, Jennifer Smith, Tim Drew, Paul Methner, Kyle Reynolds, Steffi Krause, Chris Wilson (MNRF)

COLLABORATORS: Alan Johnson (DNR); Greg Fischer (U Wisconsin at Stevens Point)

CONTACT: ryan.w.zheng@ontario.ca

Proprietary Infection Model for *Saprolegnia* Research Via *in Vitro* and *in Vivo* Systems

Infections by the Oomycete "water mould" (*Saprolegnia* sp.) are problematic at most freshwater fish hatcheries of the world. At some hatcheries, egg losses associated with *Saprolegnia* can vary between 10-50%. Infections on eggs can be manually removed via "egg picking"; however, it is quite laborious, can only be performed on eyed-eggs, and is not 100% efficient. The most commonly used approved therapeutant at hatcheries is formalin (Parasite-S™), but there are concerns about its safety for the fish and the user. Consequently, there is an urgent need to develop an alternative, safe treatment.

The Huntsman Marine Science Centre (HMSC) has developed a proprietary *Saprolegnia* infection model that can be used for *in vitro* or *in vivo* research. The model begins with *Saprolegnia* culture isolation and purification and has the option of infection via zoospores or hyphae. Moreover, the infection model allows control over rate of infection with specific control points on timing and temperature and has the added benefit of being maintained through *in vitro* or *in vivo* systems. Infections can be created and maintained on any life-stage of freshwater fish. The model has many applications: 1) new therapeutant development and testing; 2) regulatory approval data collection; 3) genomic profiling; 4) taxonomic assessment; and 5) investigative biology. In 2016, HMSC used the infection model with clients with great success to test efficacy, develop suggested use labels, re-infection rates following treatment, etc. One of the greatest advantages of the model is control over the infection process.

This model will be quite useful for research aimed at development of novel, alternative, and safe treatments against *Saprolegnia* infections at hatcheries.

DATE: FEB. 2016–ONGOING

FUNDED BY: New Brunswick Innovation Foundation (NBIF)

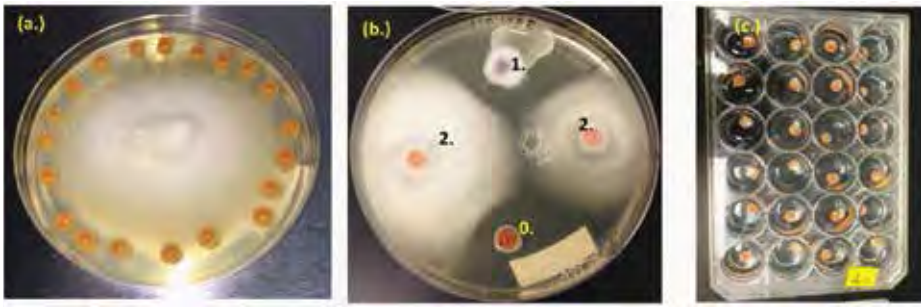
CO-FUNDED BY: National Research Council–Industrial Research Assistance Program (NRC–IRAP); Atlantic Canada Opportunities Agency (ACOA)

PROJECT LEAD: Duane Barker (HMSC)

PROJECT TEAM: Anne McCarthy, Esther Keddie (HMSC)

CONTACT: Duane.Barker@huntsmanmarine.ca

WEBSITE: http://www.huntsmanmarine.ca/



(a) Pure culture infection of *Saprolegnia* on SDA media. (b) SDA media plate of *Saprolegnia*-exposed eggs corresponding to scores of 0 (uninfected), 1 (infected), and 2 (heavy infection). (c) *Saprolegnia*-infected eggs in 24 micro-well, tissue culture plates for therapeutant testing. Photo: Duane Barker, Anne McCarthy (HMSC)

Reducing the Problem of Early Sexual Maturation in Arctic Charr

Top: Marketable silvery immature fish; bottom: unmarketable highly coloured mature fish. Photo: Paul MacIsaac (Dalhousie U)

Early sexual maturation among diploid Arctic Charr and other farmed salmonids remains a serious problem, reducing meat quality and revenue. Photoperiod, temperature, and food availability exert a strong influence on somatic growth and the decision to commence sexual maturation, but how they interact is unclear. Fraser River Arctic Charr is a good "model salmonid" for study as both sexes suffer a high rate (>70%) of early sexual maturation in culture (10°C groundwater), a trait that has limited its commercialization in Canada. Preventing sexual maturation would greatly increase commercial viability of farming diploid Arctic Charr.

Reducing the incidence of maturity to less than 20% has been consistently achieved in three year classes by rearing fish under 24 h light (LL) from October to February. The timing of both the start-date and end-date of LL has been shown to be critically important. Reduction of the maturation rate was independent of somatic growth. This leads us to question the conventional model that the physiological trigger to mature is dependent on defined threshold levels of growth and/or body size. Nevertheless, further reductions in the maturity rate, to 0% in some cases, were achieved by combining LL with reducing somatic growth in winter, by either food deprivation or rearing at 5°C rather than 10°C. Compensatory growth following the return to full ration in April indicates winter growth suppression is practical. We propose that a two-step gating mechanism controls the growth-independent and growth-dependent factors dictating the physiological decision to mature.

DATE: SEP. 2013–MAR. 2018

FUNDED BY: Atlantic Canada Opportunities Agency–Atlantic Innovation Fund (ACOA–AIF)

PROJECT LEAD: Jim Duston (Dalhousie U)

PROJECT TEAM: Qi Liu (Dalhousie U)

COLLABORATORS: Tony Manning (NB–Research and Productivity Council); Rodrigue Yossa (Coastal Zones Research Institute)

CONTACT: jduston@dal.ca

Development of Predictive Modeling Tools to Assist with Freshwater Aquaculture Site Decisions

Governmental agencies charged with the responsibility of licensing and regulating the aquaculture industry are in need of objective tools to assist in their decision-making processes. The development of such tools would also benefit industry, as currently, the primary factor limiting the expansion of the freshwater industry is access to new sites. The lack of tools to estimate ecological consequences of new sites has resulted in a very precautionary atmosphere, a complex and expensive application process, and ultimately, limited development of the industry.

The primary environmental concerns with cage aquaculture are related to benthic impacts and exceedance of the assimilative capacity of an ecosystem for nutrient inputs. Cage aquaculture has the potential to have far-ranging impacts on the lake ecosystem. Increased nutrient inputs can affect overall ecosystem productivity and excessive nutrient inputs can lead to eutrophication, which may include such undesirable consequences as the development of nuisance algal blooms, oxygen deficiency, and loss of biodiversity. The deposition of solid wastes under farms contributes to increased sediment oxygen demand, as well as the potential to significantly alter the quality of benthic habitat and the composition of benthic communities beneath and surrounding farms.

DATE: MAY 2012–MAR. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Wild West Steelhead

PROJECT LEAD: Cheryl Podemski (DFO)

COLLABORATORS: Rory Ylioja (Wild West Steelhead)

CONTACT: Cheryl.Podemski@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/CA-08-02-003-eng.html

Collecting sediment trap samples for suspended particle analyses. Photo: Kristy Hugill (DFO)

Collecting sediment cores for benthic invertebrate and chemistry analyses. Photo: Megan Otu (DFO)

Impacts of Stocking Density on the Welfare and Production Performance of Arctic Charr (*Salvelinus alpinus*)

This project aims to observe the effects of stocking density on Arctic Charr with respect to welfare. Currently, aquaculturally-reared salmonids are primarily stocked at high densities in order to stimulate schooling, reduce potential conspecific aggressive behaviour, and ultimately increase the production quantity of market quality product. However, with such high stocking densities, stress, and other factors, which can be attributed to high stocking densities, may result in increased instances of infection and other detriments to production performance. To date, little research has been done examining the effects of stocking density on the welfare of farmed fishes. As such, this project will analyze genetic, biochemical/proteomic, and physiological parameters pertaining to welfare among 5 treatment densities: 20, 40, 80, 120 and 160 kg•m^{-3} (low to excessive, respectively).

The goal of this project is to improve the welfare of farm-reared fishes (specifically that of Arctic Charr). Improving the welfare of farmed fishes may subsequently result in increased growth rates/improved production performance, thus increasing the quality of marketable product as well as quantity of farm sales.

DATE: NOV. 2016–DEC. 2017

FUNDED BY: Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)

PROJECT LEADER: Richard Moccia (U Guelph)

PROJECT TEAM: Andrew Sevier (U Guelph)

COLLABORATORS: Alma Aquaculture Research Station (U Guelph)

CONTACT: rmoccia@uoguelph.ca

WEBSITE: www.aps.uoguelph.ca/aquacentre/

Arctic Charr reared at 20 kg per cubic meter. Photo: Michael Burke (U Guelph)

Arctic Charr reared at 160 kg per cubic meter. Photo: Michael Burke (U Guelph)

Improving the Growth, Health, and Survival of Tilapia in a Greenhouse-Enclosed Intensive Recirculating Aquaculture System

Warm-water tilapia (*Oreochromis niloticus*) is becoming an important commercial freshwater fish in North America. Viva Aquaculture and Seafood Distribution Ltd. (Viva) in collaboration with The University of British Columbia (UBC) has engaged in sustainable tilapia aquaculture production to supply the strong market demand in British Columbia. To overcome technological uncertainties which cannot be removed using standard practice, the general project objective is to produce healthy tilapia in sustainable, environment-friendly, and in a less expensive way within a land-based facility without affecting the surrounding environment by generating "zero waste". Based on biological principles, the research team has developed a sustainable land-based tilapia aquaculture system in a Canadian climate. Beneficial nitrifying bacteria were used to convert toxic nitrogenous wastes into non-harmful compounds, which are absorbed by selected aquatic vascular plants and microalgae. Innovative bio-engineering design to recirculate clean water and conserve heat to maintain suitable condition for tilapia culture was employed. A "zero waste" system is being developed to make fish production more sustainable, profitable, and environment-friendly. Our research has yielded initial results that show encouraging outcomes during the first year of project implementation. It is expected that employing these new innovations will lead to lower production cost, increased economic benefits, and improved fish quality; all of which will lead to an environmentally sustainable production of live tilapia.

Culturing tilapia in a land-based, enclosed intensive recirculating system using innovative bioengineering design, beneficial microbes, algae, and vascular aquatic plants will lessen environmental impact, lower production cost, provide economic opportunities, and produce a healthy and diversified source of seafood for Canadian consumers.

DATE: FEB. 2015–DEC. 2018

FUNDED BY: Viva Aquaculture and Seafood Distribution Ltd. ("Viva")

CO-FUNDED BY: Hero Invincible Bio Aqua Farm

PROJECT LEAD: Jesse Ronquillo (UBC; Viva)

PROJECT TEAM: Chang Lin Ye, Kai Chen (Viva)

COLLABORATORS: David Kitts (UBC)

CONTACT: jesse.ronquillo@ubc.ca

WEBSITE: www.vivaseafood.com

Aquaponics system for intensive tilapia culture. Photo: Jesse Ronquillo (UBC)

Aquaponics system for intensive tilapia culture. Photo: Jesse Ronquillo (UBC)

Aquaponics system for intensive tilapia culture. Video: Jesse Ronquillo (UBC)

The Development of Fast Growing, Late Maturing, and Salinity Tolerant Strains of Arctic Charr

The genetic improvement of Canadian strains of Arctic Charr to reduce the undesirable characteristics of poor growth, early maturation, and inability to tolerate seawater (and stress in general) would greatly facilitate development of the industry. Our goal is to integrate genomic methodologies into selective breeding programs to develop better performing strains in a lower number of generations than by conventional breeding methods alone. We will first develop genomic resources for Arctic Charr: 1) discover genetic markers [single nucleotide polymorphisms (SNPs)] from the Fraser, Nauyuk, and Tree River strains; 2) find out where the SNPs are located relative to each other in the genome through genetic linkage mapping; and 3) develop a high resolution genotyping tool (array). We will then use those resources to find SNPs that are located in or near genes that control the economically important traits under study. Adult fish with these SNPs could then be bred to produce better quality offspring to serve as parents for the next generation. Rearing trials with families from the Fraser and Nauyuk strains have been conducted at the Coastal Zones Research Institute (New Brunswick) and the Alma Aquaculture Research Station (Ontario). We have tracked the phenotypic performance of individuals (growth, age of maturation, and salinity tolerance) and will genotype each of those fish for up to 90 thousand SNPs. Tracking the inheritance of these markers will also allow us to expand our current SNP based linkage map of the Arctic Charr genome.

The combination of detailed genotype and phenotype data will enable the identification of regions of the Arctic Charr genome associated with traits of economic interest. This information can facilitate marker assisted selection of Canadian aquaculture Arctic Charr, increasing the industry's productivity and worldwide competitiveness.

DATE: MAR. 2012–DEC. 2018

FUNDED BY: Atlantic Canada Innovation Fund (ACOA)

CO-FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)–Discovery Program

PROJECT LEAD: Moira Ferguson (U Guelph)

PROJECT TEAM: Cameron Nugent, Anne Easton, Roy Danzmann (U Guelph)

COLLABORATORS: Michael Burke (Alma Aquaculture Research Station); Claude Pelletier (CZRI); Ben Koop (UVic); William Davidson (SFU)

CONTACT: mmfergus@uoguelph.ca

Cameron Nugent and Oliver Franklin collecting Fraser strain Arctic Charr for measurement.
Photo: Anne Easton (U Guelph)

A sexually mature three year old female Arctic Charr. Photo: Anne Easton (U Guelph)

Change in Rainbow Trout Phosphorus Absorption: Physiological Adaptations to a Phosphorus Deficiency

Phosphorus-deficient Rainbow Trout in holding to measure specific absorption through the gills.
Photo: Émilie Proulx (U Laval)

The proposed project challenges the hypothesis that the only source of phosphorus (P) available to freshwater fish is their food. The assumption is that they are incapable of absorbing significant quantities of P from their environment is supported by the relatively low (< 0.1 ppm of P in the water) concentration of this element in the natural environment of freshwater fish. However, preliminary observations in a recirculated system, in which P concentrations were about 1 ppm, found that physiological mechanisms appear to enable trout to absorb ambient P. Phosphorus deficient Rainbow Trout therefore appears to develop the ability to absorb external P to maintain homeostasis by introducing sodium phosphate (NaPi) cotransporters into gill tissue.

To test these hypothesis, we propose to: 1) produce P-deficient fish through a prolonged dietary deficiency in phosphorus; 2) monitor the change in P status in scales and carcasses and the overexpression of sodium phosphate (NaPi) cotransporters in the tissue of trout (gills, pyloric caecum, proximal and distal intestine); 3) confirm the capacity of deficient trout to absorb ambient P through phosphorus absorption tests in tanks; 4) demonstrate the ability of deficient trout to absorb P specifically through the gills via the McKim and Goeden holding device (1982); and 5) confirm P absorption by monitoring P concentrations in the blood (aortic cannula) and urine (urinary catheter).

This project will contribute to significantly advancing knowledge on phenotypic plasticity in fish and on the impact of nutritional deficiency, and will help to identify new homeostasis strategies.

DATE: JAN. 2013–MAR. 2018

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC)

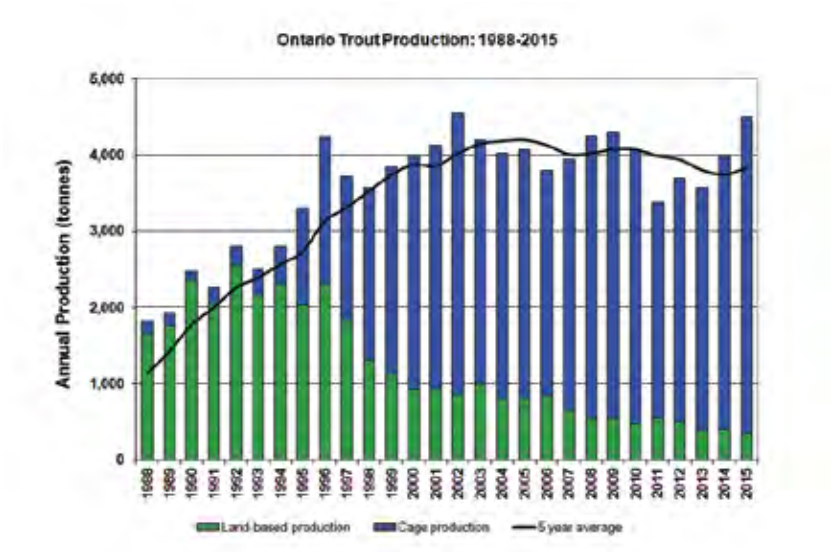
PROJECT LEAD: Grant Vandenberg (U Laval)

PROJECT TEAM: Waly Ndiay, Marie-Hélène Deschamps, Émilie Proulx (U Laval)

CONTACT: Grant.Vandenberg@fsaa.ulaval.ca

WEBSITE: http://www.vrrc.ulaval.ca/fileadmin/ulaval_ca/Images/recherche/bd/chercheur/fiche/424160.html

Aquastats: Ontario Aquaculture Statistics Program



Ontario trout production 1988-2015.

In 2015, we estimate that Ontario fish farms produced 4,510 tonnes of Rainbow Trout, primarily for human consumption. Lake-based cage production of Rainbow Trout in the North Channel & Eastern Georgian Bay area accounted for 92% of the total production. Our records suggest that approximately 66 facilities culture one or more of tilapia, Arctic Charr, Brook Trout, bass, Walleye, and other species, with an estimated total production of 380 tonnes in 2015.

The total farm-gate value of the 4,510 tonnes of Rainbow Trout produced is estimated to be $23.2 million, with an average price of $5.13/kg. The sale of tilapia, Arctic Charr, Brook Trout, bass, and other fish species is estimated to be an additional $2.2 million. More than 80 facilities are involved with pond stocking, typically Rainbow Trout, Brook Trout, and bass, conservatively estimated to be $1.5 million annually.

The Ontario aquaculture industry is estimated to have generated a total of 195 person-years of direct, on-farm employment (137 person-years of full-time and 58 person years of part-time employment). Indirect employment is conservatively estimated at 150 person-years.

The total annual contribution that aquaculture makes to the Ontario economy is estimated to be $80 million, with additional economic value realised via the recreational and aquaria trade.

This project maintains a 27-year data collection series on Ontario aquaculture.

DATE: JAN. 2016–MAY 2016

FUNDED BY: Ontario Ministry of Natural Resources and Forestry (MNRF)

CO-FUNDED BY: Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)

PROJECT LEAD: Richard Moccia (U Guelph)

PROJECT TEAM: David Bevan (U Guelph)

COLLABORATORS: Sarah Desjardins, Mary Duda (Ontario Ministry of Natural Resources and Forestry)

CONTACT: rmoccia@uoguelph.ca

WEBSITE: www.aps.uoguelph.ca/aquacentre/

Overview on the Improvement of the Fraser Strain of Arctic Charr (*Salvelinus alpinus*) at the Coastal Zones Research Institute

Arctic Charr (*Salvelinus alpinus*) mature broodstock. Photo: CZRI

The growers and scientists of the Atlantic region have identified the major challenges faced by the Arctic Charr (*Salvelinus alpinus*) aquaculture industry: early maturation, poor egg quality and supply, and inconsistency of fillet pigmentation. To solve these issues, the Coastal Zones Research Institute (CZRI) implemented a breeding program whose objectives are: 1) to develop a fast-growing Arctic Charr that is commercially profitable in Canada and abroad; and 2) to develop and provide certified high quality eggs to the industry. In collaboration with its industrial and scientific partners, CZRI has rigorously performed selected breeding in order to improve the growth potential of each generation of the Fraser strain of Arctic Charr, while minimizing inbreeding and reducing the occurrence of early maturation. A seventh generation with 41 families was obtained in the autumn of 2015 and 2016, with a weight gain potential which has increased by 121% compared with the first generation. Overall, the team at CZRI overcame important challenges over the last decade and is progressing toward the production of one of the most promising strains of Arctic Charr for aquaculture.

The overall objective is to provide a commercial and competitive Arctic Charr to the Canadian industry and abroad.

DATE: APR. 2013–MAR. 2019

FUNDED BY: Department of Agriculture, Aquaculture and Fisheries of New Brunswick (DAAF)

CO-FUNDED BY: Atlantic Canada Opportunities Agency (ACOA); Coastal Zones Research Institute (CZRI)

PROJECT LEAD: Claude Pelletier (U Moncton)

PROJECT TEAM: Caroline Roussel, Claude Landry, Luc Desjardins, Maurice Boudreau, Rodrigue Yossa (CZRI); Michel Desjardins (DAAF)

COLLABORATORS: Christophe Herbinger, Philippe Fullsack (Dalhousie U)

CONTACT: Claude.S.Pelletier@umoncton.ca

WEBSITE: http://www.irzc.umcs.ca/flash_content/anglais/nousjoindre.html

Evaluating Four Commercially Available Rainbow Trout Diets on the Growth and Feed Conversion of Ontario Domestic Rainbow Trout (*Oncorhynchus mykiss*)

In aquaculture, feed can account for approximately 40-60% of a Rainbow Trout farm's operating costs depending upon the type and size of the farm and the feeding husbandry practices followed. Since the introduction of high-pressure moist extrusion technologies in the 1980s, modern dry and durable high-energy salmon and trout diets have been available to Ontario Rainbow Trout farmers. Choice of manufacturer is dictated by the cost, availability, and performance of the fish. While unit cost and availability of the feed are easily determined by the farmer, the performance of the fish fed any particular brand of feed is more difficult to ascertain. Feed evaluations are usually offered by the manufacturer or by fish farmers. There are obvious problems with either of these sources. Manufacturers promote their feed with a bias and seldom provide the relevant data to support their claims. Evaluations of fish feeds from fish farmers tend to be largely anecdotal. Furthermore, the effects of environmental conditions (water temperature, dissolved oxygen, fish densities, etc.), fish genetics, and culture methodologies can have greater influences on the growth and mortality of fish than does nutrition. As these effects are seldom accounted for and vary greatly from farm to farm and year to year, data collected by farmers are generally considered ineffective in determining which brand of feed to use.

The purpose of this study is to grow Rainbow Trout (*Oncorhynchus mykiss*) from 450 g to market size of 1,200 g using four different commercially available grower feeds.

This trial will indicate which feeds result in superior growth rates and feed conversion so that the aquaculturalist can make an informed decision in selecting a feed manufacturer and/or brand of feed. A significant reduction in feed costs can be achieved if fish growth, feed conversion, and cost/unit feed can be reliably evaluated.

DATE: MAR. 2016–AUG. 2016

FUNDED BY: Aqua-Cage Fisheries Inc.

CO-FUNDED BY: Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)

PROJECT LEAD: Richard Moccia (U Guelph)

PROJECT TEAM: Alma Aquaculture Research Station (U Guelph)

COLLABORATORS: Martin Mills Inc.; Skretting Canada; Aqua-Cage Fisheries Ltd.

CONTACT: rmoccia@uoguelph.ca

WEBSITE: www.aps.uoguelph.ca/aquacentre/

Sampling Rainbow Trout for growth trial. Photo: David Bevan (U Guelph)

Evaluation of Four Commercial Starter Feeds for Rainbow Trout (*Oncorhyncus mykiss*) Held Under Typical Commercial Hatchery Conditions

The rapid proliferation of aquaculture over the past two decades has seen the growth of fish feed manufacturers on the global, national, and local levels. Choice of feed manufacturer is dictated by the cost, availability, and performance of the fish. While unit cost and availability is easily determined by the aquaculturalist, the performance of the fish fed any particular brand of feed is more difficult to ascertain. Feed evaluations are usually presented by the manufacturer or by fish farmers. There are obvious problems with either of these sources. Manufacturers promote their feed with a bias and seldom provide data that supports their claims. Evaluations of fish feeds from fish farmers tend to be largely anecdotal. Furthermore, the effects of environmental conditions (water temperature, dissolved oxygen, fish densities, etc.), fish genetics, and culture methodologies can have greater influences on the growth and mortality of fish than does nutrition. As these effects are seldom accounted for and vary greatly from farm to farm and year to year, data collected by farmers are generally considered ineffective in determining which brand of feed to use.

Starter feeds for rainbow trout. Photo: David Bevan (U Guelph)

The purpose of this study was to grow Rainbow Trout (*Oncorhynchus mykiss*) fry from first feeding to 35 g using starter feeds purchased from four different feed manufacturers. The objective was to determine which feeds best promoted growth and survivability.

There were no significant differences in either growth or mortalities when using starter feeds purchased from four different feed manufacturers. This suggests that the nutritional and energy requirements for Rainbow Trout starter feeds were meet, or exceeded, by all four manufacturers.

DATE: DEC. 2014–JUL. 2015

FUNDED BY: Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)

PROJECT LEAD: Richard Moccia (U Guelph)

PROJECT TEAM: Michael Burke (U Guelph)

COLLABORATORS: Alma Aquaculture Research Station (U Guelph)

CONTACT: rmoccia@uoguelph.ca

WEBSITE: www.aps.uoguelph.ca/aquacentre/

The Effects of Light Emitting Diodes on the Growth and Feeding Behaviour of Rainbow Trout (*Oncorhyncus mykiss*)

There is considerable economic pressure for hatcheries to switch from incandescent lighting to light emitting diodes, as these bulbs last longer and greatly reduce operating expenses. Current LEDs being marketed to the aquaculture industry produce a significantly different light spectrum than incandescent, with more short wavelength (blue-shifted) light and less long wavelength (red and infrared shifted) light.

In an aquaculture setting, Rainbow Trout are visual feeders, relying entirely on seeing the pellets to feed efficiently. Little is known on how the shift from incandescent to LEDs will affect feeding behaviour and growth of these commercially important salmonids. Feeding behaviour and growth rates will ultimately affect the bottom line of any hatchery or aquaculture facility; therefore, optimizing these under new lighting conditions is key.

Three decades of aquaculture research has been carried out at the Alma Aquaculture Research Station (AARS), a large portion of which has been done indoors using incandescent lighting. As the AARS is preparing to switch to LEDs to reduce energy costs, it is important to determine how these new lights will affect Rainbow Trout growth, and how this will change how previous studies are interpreted.

DATE: AUG. 2016–DEC. 2016

FUNDED BY: Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)

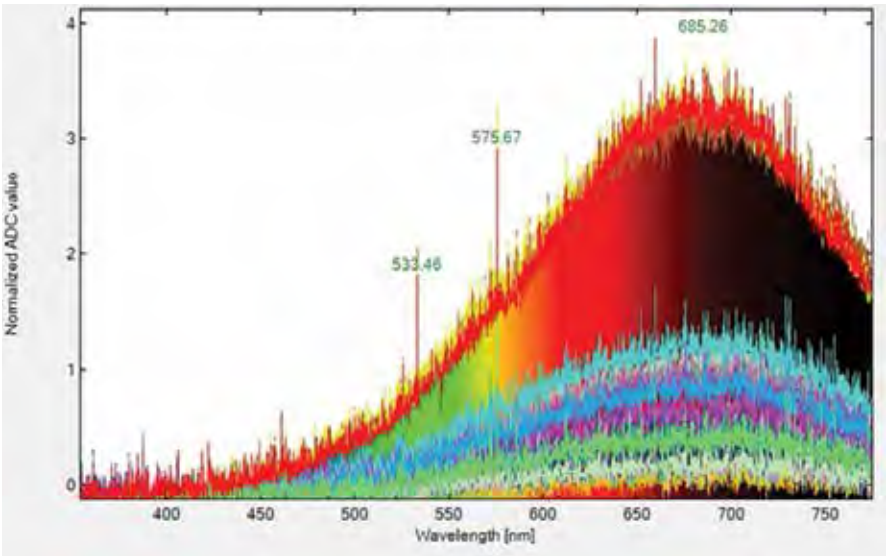
PROJECT LEAD: Richard Moccia (U Guelph)

PROJECT TEAM: Wes Chase (U Guelph)

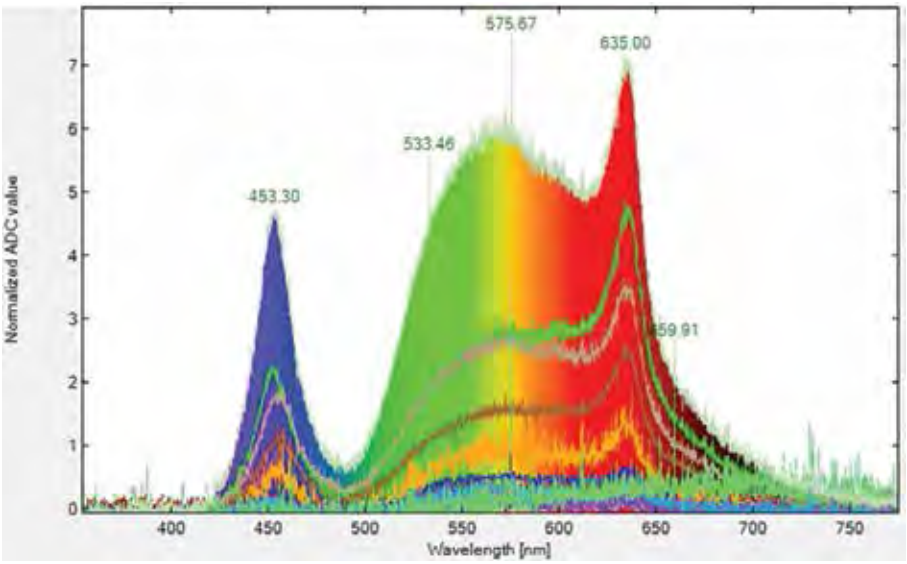
COLLABORATORS: Alma Aquaculture Research Station (U Guelph)

CONTACT: rmoccia@uoguelph.ca

WEBSITE: www.aps.uoguelph.ca/aquacentre/



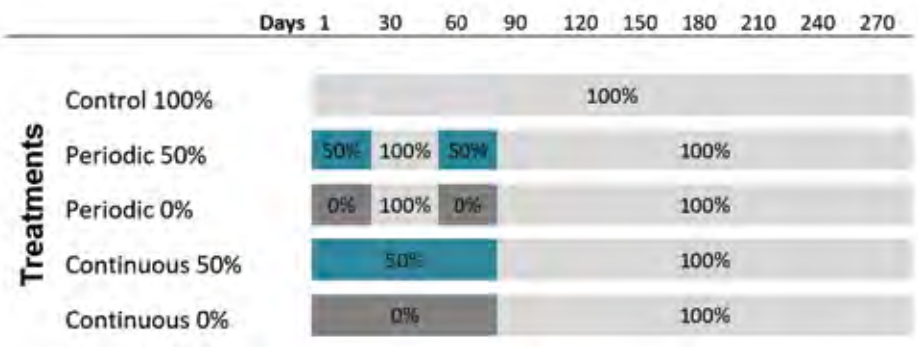
Spectrum emitted by traditional incandescent bulbs. Displays various intensity levels at different locations within AARS photoperiod lab.



Spectrum emitted by the AquaShift MLA-BL bulbs. Displays various intensity levels at different locations within AARS photoperiod lab.

Modulation of the Metabolism and Digestive Capacity of the Arctic Charr (*Salvelinus alpinus*) Through Dietary Restriction

Mirelle Caouette Houle, UQAR aquaculture tank room/ISMER, Pointe-au-Père (Rimouski).
Photo: Vincent Roy (UQAR)



Feeding sequences.

This project seeks to improve zootechnics for the development of a competitive Arctic Charr culture industry. Reducing or alternating the frequency of feeding can induce a mechanism that fish use to counter the effects of dietary restriction: compensatory growth. Salmonids can actually increase their conversion efficacy and remarkably, regain their body mass following a dietary restriction.

To assess the effects of various feeding methods on the productivity of commercial Arctic Charr culture, the physiological parameters that dictate growth performances, such as digestive capacity, will be examined. Dietary restriction modulates the fish's physiology in various ways based on the severity of restriction and feeding frequency. The goal of the project is to identify the most effective and sustainable feeding sequence that will ensure optimal physiological health and growth capacity. To achieve this, we will monitor digestive capacity after restriction and refeeding, and measure the digestibility parameters (e.g., trypsin activity and certain energy metabolism enzymes in the pyloric ceca).

Reducing the amount of food to reach a given growth level and optimizing food conversion helps reducing costs and reduce organic waste (e.g., phosphorus) in the environment. The current challenge is to increase the competitiveness of the aquaculture industry while maintaining good growth performances. Dietary restriction and refeeding trials have been conducted in partnership with Aquaculture Gaspésie Inc.

The goal of this project is to optimize zootechnics of the Arctic Charr, which is a strategic species in Canada for the development of consumer products.

DATE: SEP. 2014–APR. 2017

FUNDED BY: Atlantic Canada Opportunities Agency (ACOA)

CO-FUNDED BY: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)

PROJECT LEADS: Nathalie Le François (Biodome de Montréal); Pierre Blier (UQAR)

PROJECT TEAM: Mirelle Caouette Houle, Arianne Savoie (UQAR)

COLLABORATORS: Francis Dupuis (Aquaculture Gaspésie Inc.); Moïse Cantin, Catherine Roy (Pisciculture des Monts De Bellechasse)

CONTACT: nle_francois@ville.montreal.qc.ca

FINFISH: SALMON

Harvest Quality Trait Evaluation to Inform Atlantic Salmon Broodstock Selection

Enhancing Production in Coho: Culture, Community, Catch

Domestication Compromises Athleticism and Respiratory Plasticity in Response to Aerobic Exercise Training in Atlantic Salmon (*Salmo salar*)

What is a Farmed Salmon? Understanding the Life of a Seafood Commodity from Ocean to Table

Growth Performance of Aquadvantage® Salmon Using Two Different Diets

Detecting Hybridization among Wild and Farmed Escaped Atlantic Salmon in Southern Newfoundland: Field Collections

Genetic and Genomic Impacts of Escaped Farmed Salmon in Atlantic Canada: Evaluating the Use of Archived Atlantic Salmon Scales as a Source of Pre-Impact DNA

Fundy Salmon Recovery: Recovering Endangered Atlantic Salmon through Innovation and Collaboration with Atlantic Canada's Aquaculture Industry

Identification of Genetic Markers Associated with Growth Performance in a Soybean Meal Based Diet for Salmon

High Density SNP Linkage Map for North American Atlantic Salmon (*Salmo salar*)

Using a Genomics Approach to Identify Atlantic Salmon Aquaculture Escapees and Hybrids

Use of Hydro-Acoustic Methods to Assess the Migration Timing and Distribution of Juvenile Salmon in Discovery Islands and Johnstone Strait

The Historical and Social Dimensions of Salmon Aquaculture Science

Migration Timing and Distribution of Juvenile Salmon in Discovery Islands and Johnstone Strait

Spatial and Temporal Distribution and Survival of Farmed Atlantic Salmon after Experimental Release from Sea Cage Locations

Studying Effects of Atlantic Salmon Broodstock Age and Egg Size on Later Performance of Progeny

Thermal and pH Tolerance of Farmed, Wild, and First Generation Farmed-Wild Hybrid Salmon

Reduction of Ammonia and Solids from Chinook Salmon Culture Facilities

Determination of the Potential Spatial Overlap and Interaction Between Commercial Fisheries (American Lobster, Snow Crab) and Finfish Aquaculture Activities in Connaigre Bay, Newfoundland

Family Variation and Heritability of Male and Female Atlantic Salmon Fitness Traits

Hybridization of Farmed Escaped and Wild Atlantic Salmon: So What? An Empirical and Model Based Exploration of the Consequences for Wild Populations throughout the North Atlantic

Quantifying Direct Genetic Impacts of Escaped Farmed Salmon on Wild Salmon in Atlantic Canada

Probability of Detecting Escaped Aquaculture Salmon is Related to Distance Between Production Areas and Rivers

Heritability of Blood Parameters as Health Indices for an Atlantic Salmon (*Salmo salar*) Selective Breeding Program

Harvest Quality Trait Evaluation to Inform Atlantic Salmon Broodstock Selection

Harvest quality traits are those that are most important to the consumer. Associated traits that are under genetic control may be incorporated into selection indices within a breeding program. Nearly all of the harvest quality traits are not appropriate for or cannot be evaluated on the breeding population itself. Instead, these traits are assessed on a commercial comparison group of breeding nucleus siblings that are raised and harvested using accepted commercial practices. Harvest evaluations present the greatest opportunity to assess multiple important traits within a single sampling effort for potential inclusion in a selective breeding program. Over 30 harvest quality traits are presently evaluated within the Atlantic Salmon broodstock program at the Huntsman Marine Science Centre. Representative traits with associated heritability, h_2, for one year class include: fillet weight (0.48 ± 0.08); fillet brightness (0.39 ± 0.08); fillet redness (0.52 ± 0.09); fillet yellowness (0.55 ± 0.09); flesh moisture (0.62 ± 0.17); flesh fat content (0.60 ± 0.17); and flesh protein (0.36 ± 0.16). Additional traits assessed at this time include the omega fatty acids, other measurements of colour, maturation status, body/fillet shape, presence/absence of various deformities or abnormalities (e.g., pigmentation variation), and differential mortality/survival within commercial production environments. Each year class of the Atlantic Salmon broodstock program has an associated harvest evaluation completed that will continually build our dataset to improve selection efforts.

DATE: MAY 2015–APR. 2020

FUNDED BY: Atlantic Canada Opportunities Agency–Atlantic Innovation Fund (ACOA–AIF)

CO-FUNDED BY: New Brunswick Innovation Foundation; Northern Harvest Sea Farms Ltd.; Huntsman Marine Science Centre (HMSC)

PROJECT LEAD: Amber Garber (Huntsman Marine Science Centre)

PROJECT TEAM: Chris Bridger, Susan Hodkinson, Philip Wiper, Brooke Barrett, Jamie Carpenter, Anne McCarthy, Esther Keddie, Erica Harvey, Chantal Audet (HMSC)

COLLABORATORS: Aaron Craig (Northern Harvest Sea Farms Ltd.); Bruce Swift, Salvador Gezan (TRIGEN Fish Improvement)

CONTACT: Amber.Garber@huntsmanmarine.ca

WEBSITE: http://www.huntsmanmarine.ca/

Enhancing Production in Coho: Culture, Community, Catch

Coho Salmon, one of the most highly valued species in British Columbia (BC), began suffering declines in 1989 due to lower returns and high harvest rates to the point where the commercial fishery for Coho Salmon was essentially closed in 1997. Reopening the Coho Salmon fishery using recovered and enhanced populations would bring economic and social benefits to BC.

The Enhancing Production In Coho: Culture, Community, Catch (EPIC4) project aims to develop and use new genomics tools to address challenges facing safe, secure, and sustainable production of Coho Salmon. The interdisciplinary team has sequenced the Coho Salmon genome and the first results have resolved clear patterns of regional populations structuring, both within BC and at the scale of the entire distribution range. Genotyping of the hatchery broodstocks sampled in 2014 and 2015 showed strong regional population structuring and allowed high levels of accuracy in assigning salmon to specific hatcheries or geographic regions. In addition, first results on the heritability and genetic correlation shed light on the genetic basis of flesh colour and the response of this trait to artificial selection for harvest weight over the time course of eight generations. The team is also working with stakeholders, including First Nations, regarding the implementation of EPIC4 scientific knowledge about Coho Salmon to help revive and sustain the wild Coho fisheries. The work on this project could lead to more economically viable Coho Salmon fisheries serving both domestic and export markets. Our results should also be transferable to other species of Pacific Salmon as well as salmonids from other regions of Canada.

DATE: OCT. 2015–SEP. 2019

FUNDED BY: Genome Canada; Genome British Columbia

CO-FUNDED BY: Genome Quebec; DFO; University of Victoria (UVic); Aquainnovo S.A.; Ressources Aquatiques Québec (RAQ); Institut de Biologie Intégrative et des Systemes (IBIS); Thermo Fisher Scientific Inc.

PROJECT LEADS: William Davidson (SFU); Louis Bernatchez (U Laval)

PROJECT TEAM: Ben Koop, Rosemary Ommer (UVic); Roberto Neira, Jose Yanez (Universidad de Chile); Terry Beacham, Robert Devlin, Ruth Withler (DFO); Grant Murray (VIU, Duke U); Kerry Naish (U Washington); Rashid Sumaila, Ralph Matthews (UBC); Steven Jones (SFU)

COLLABORATORS: David Willis (DFO); Brian Riddel (PSF); Jean Paul Lhorente (Aquainnovo S.A.)

CONTACT: ksivak@sfu.ca

WEBSITE: http://www.epic-4.org

EPIC4's integrated approach toward sustainable fisheries & aquaculture

Domestication Compromises Athleticism and Respiratory Plasticity in Response to Aerobic Exercise Training in Atlantic Salmon (*Salmo salar*)

Exercise training Atlantic Salmon (*Salmo salar*) in the Brett-type two-channel swimming tunnel. Photo: Yangfan Zhang (UBC)

A closer look of exercise training Atlantic Salmon (*Salmo salar*) in motion in the Brett-type two-channel swimming tunnel. Photo: Yangfan Zhang (UBC)

In this project we address the possibility that the Norwegian Atlantic Salmon (*Salmo salar*) breeding program which focuses on commercially beneficial traits, such as rapid growth, may compromise the cardiorespiratory system. This may contribute to the mortality of smolts after seawater transfer.

A suite of respiratory indices (including standard metabolic rate, maximum rate of oxygen uptake, absolute aerobic scope, excess post-exercise oxygen consumption, critical oxygen level, and incipient lethal oxygen saturation) was used to evaluate aerobic capacity and hypoxia tolerance to test the hypothesis that exercise training improves the athletic robustness in both domesticated and wild strains of Atlantic Salmon. These hypotheses were tested with Atlantic Salmon parr of domesticated and wild strains that were reared under identical hatchery conditions. The two strains of fish were given either an 18-day exercise-training regime (an incremental water current of 2.0–2.8 FL s^{-1}), or were maintained at the control water current (0.5 FL s^{-1}) for 18 days.

While exercise training produced several tangible benefits for the wild fish, it produced very few for the domesticated fish. This shows that the domesticated strain was athletically less robust than the wild strain. These results imply that approximately ten generations of selective breeding for rapid growth in commercial aquaculture have reduced the overall athletic robustness of domesticated salmon as compared to their wild conspecifics. Given the success in improving athletic robustness of the wild strain, it still remains to be seen whether an exercise training protocol can be developed that will provide benefits to the salmon aquaculture industry.

DATE: JAN. 2013–DEC. 2016

FUNDED BY: The Research Council of Norway; The Fishery and Aquaculture Industry Research Fund

CO-FUNDED BY: Canada Research Chairs Program (CRCP); Kone Foundation–Elizabeth R. Howland Fellowship

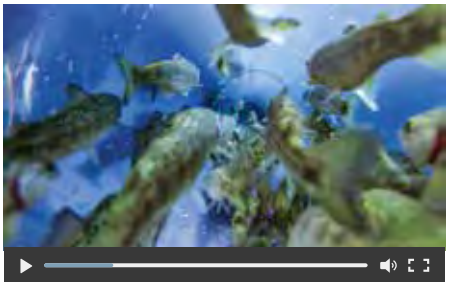
PROJECT LEADS: Sven Martin Jørgensen (Nofima AS); Anthony P. Farrell (UBC)

PROJECT TEAM: Yangfan Zhang (UBC); Gerrit Timmerhaus (Nofima AS); Harald Takle (Marine Harvest ASA)

COLLABORATORS: Guy Claireaux, Florian Mauduit (UBO); Katja Anttila (University of Turku); Torstein Kristensen (Nord University)

CONTACT: yangfan@zoology.ubc.ca

WEBSITE: http://www.zoology.ubc.ca/person/yangfan



Atlantic Salmon (*Salmo salar*) are swimming in the Brett-type two-channel swimming tunnel. Video: Sven Martin Jørgensen (Nofima AS)

What is a Farmed Salmon? Understanding the Life of a Seafood Commodity from Ocean to Table

Farmed Atlantic Salmon is one of the world's most valuable and widely traded seafood commodities. Its consumption is driven by increased global consumer demand that can no longer be met by wild fisheries alone. It is now the fastest growing food production system in the world. It also provides jobs and revenue for many coastal communities, including in BC where the sector is a significant economic driver in some rural, largely resource-dependent communities, including some First Nations villages. However, despite its significant economic contributions, and the ever increasing global demand for the product, both current operations and growth of the sector in BC have been consistently challenged by social license constraints (community intolerance for new and increased aquaculture development) that reflect, among other things, the deeply embedded plurality of perspectives regarding farmed salmon. Research about farmed salmon can be widely found in the ecological, economic, and business literature; however, there is a noteworthy gap in the social sciences literature.

This research uses multi-sited ethnographic methodology (observation, conversational interviews, and document analysis) to 'follow the fish' along the commodity chain–recording, comparing, and contrasting ideas, beliefs and knowledge about the product, both positive and negative, amongst people who engage with it on its path from production to consumption. Research sites include fish farms, processing plants, sales and distribution centres, and restaurants in Tofino, Port Hardy, Campbell River, and San Francisco.

This research will produce rich, qualitative information from employees, customers, stakeholders, and others about the production, processing, transport, culinary preparation, sales, and consumption practises for Atlantic Salmon farmed in BC. This information will increase our understanding of social-cultural issues along the entire value chain, contributing to the social license dialogue by providing greater understanding of the broader social-cultural perspectives about farmed salmon, at a time when the sector is pursuing new and increased opportunities in Canada and abroad.

DATE: OCT. 2015–SEP. 2018

FUNDED BY: MITACS Accelerate (PhD Fellowship)

CO-FUNDED BY: Grieg Seafood BC Ltd.; Marine Harvest Canada Limited; BC Jobs Plan

PROJECT LEAD: Michele Patterson (UVic)

PROJECT TEAM: Rosaline Canessa (UVic); Grant Murray (Duke U)

COLLABORATORS: Marilyn Hutchinson (Grieg Seafood); Sharon DeDominicis (Marine Harvest Canada Limited)

CONTACT: patterson.michele1@gmail.com

Growth Performance of AquAdvantage® Salmon Using Two Different Diets

Attempts to enhance salmon productivity by improving diets, while maintaining low production costs, has been a challenge for the aquaculture industry. The possibility of using triploid salmon (having an extra set of chromosomes) instead of the naturally occurring diploids has increased the challenge for providing an adequate diet. AquAdvantage® salmon is a rapidly growing, all female, and triploid line of Atlantic Salmon. The objective of the current study was to examine the productivity impact of a premium diet on AquAdvantage® salmon compared to a commercial diet. For this study, 300 AquAdvantage® salmon received two different diets during two different stages of development established by weight, while 300 AquAdvantage® salmon received only a commercial Atlantic Salmon feed for the whole experimental period (~7 months). AquAdvantage® salmon fed experimental diets had significantly ($P \leq 0.05$) increased thermal growth coefficient (TGC) and specific growth rate (SGR) than those fish fed the commercial feed. Results showed that the growth rate of AquAdvantage® salmon was significantly ($P \leq 0.05$) improved in fish fed both starter and grower experimental diets (TGC > 2.65) as compared to the commercial feed (TGC < 2.50). At the end of the seventh month, the average weight gain difference was 184.3 g in favour of the experimental diet ($P \leq 0.05$). This study suggests an opportunity to further improve growth performance in new improved diets even in a rapidly growing line. Performance of the experimental groups and effects on body composition will be discussed.

DATE: MAY 2015–DEC. 2015

FUNDED BY: National Research Council–Industrial Research Assistance Program (NRC–IRAP)

PROJECT LEAD: Dawn Runighan (Aqua Bounty Canada Inc.)

PROJECT TEAM: Armando Heriazon, Christina Bullerwell (Aqua Bounty Canada Inc.); Rachid Ganga (Tyson Foods Inc.); André Dumas (Center for Aquaculture Technologies)

CONTACT: aheriazon@aquabounty.com

WEBSITE: https://aquabounty.com/

Difference in size of AquAdvantage® Salmon and conventional Atlantic Salmon. Photo: Berni Wood (Reel Media Studio)

Aqua Bounty Canada Inc. molecular laboratory showing the types of feed that were prepared. Photo: Berni Wood (Reel Media Studio)

Genetic and Genomic Impacts of Escaped Farmed Salmon in Atlantic Canada: Evaluating the Use of Archived Atlantic Salmon Scales as a Source of Pre-Impact DNA

Aquaculture escapes are a threat to the persistence and stability of wild salmon populations; however, the presence and magnitude of these genetic impacts are difficult to quantify in practice, largely due to a lack of pre-impact genetic baseline. Historically, monitoring activities for Atlantic Salmon have collected scales for aging purposes, and these archived scales could represent a powerful source of pre-impact DNA. The main objective of this project was to explore the use of various extraction methodologies to maximize DNA yield and estimate genotyping success rate from archived Atlantic Salmon scales. Extracted DNA was quantified and used for microsatellite genotyping to demonstrate the utility of this approach. The ultimate goal was future comparison of pre- and post-aquaculture DNA samples from Atlantic Salmon in Atlantic Canada to quantify the presence and magnitude of genetic impacts due to escaped farmed salmon, thereby directly informing mitigation strategies through a quantification of impacts in space and time.

DATE: APR. 2014–MAR. 2016

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Ian Bradbury (DFO)

PROJECT TEAM: Lorraine Hamilton, Patrick O'Reilly, Geoff Perry (DFO)

CONTACT: Ian.Bradbury@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-NL-01-eng.html

Detecting Hybridization among Wild and Farmed Escaped Atlantic Salmon in Southern Newfoundland: Field Collections

The monetary value of aquaculture production has now surpassed the total value of wild fisheries. Balancing the rapid industry expansion with environmental sustainability remains a challenge, with impacts for both wild populations and industry production. Aquaculture escapees represent a continued threat to the genetic integrity of wild populations, and have been shown to interbreed with wild fish, eroding local adaptation. In southern Newfoundland, wild Atlantic Salmon populations remain at record lows and are considered 'threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Potential impacts associated with the developing aquaculture industry cannot be ruled out as a contributing factor. The aim of this study was to collect young-of-the-year Atlantic Salmon following a large (>20,000 individuals) escape event in 2013 in southern Newfoundland. This escape event was equal to or greater than the estimate of wild salmon abundance in the region. Given the magnitude of this release event, and reports of mature escapees in freshwater, these samples are expected to contain a mixture of wild and hybrid individuals. In total, 2000 juvenile Atlantic Salmon were collected. Future genomic screening of these samples will be used to quantify the rates of successful hybridization and evaluate the potential genetic impact of aquaculture escapees on wild populations in Newfoundland and Labrador.

DATE: APR. 2014–MAR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Ian Bradbury (DFO)

PROJECT TEAM: Lorraine Hamilton, Patrick O'Reilly, Geoff Perry (DFO)

CONTACT: Ian.Bradbury@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-NL-02-eng.html

Fundy Salmon Recovery: Recovering Endangered Atlantic Salmon through Innovation and Collaboration with Atlantic Canada's Aquaculture Industry

Conservation sea cages–marine aquaculture sites designed to rear wild salmon–have the potential to return adults to their native rivers in numbers rivalling historic highs, provided sufficient smolts can be collected. This model could improve not only depressed numbers of wild Atlantic Salmon, but freshwater ecosystems impacted by reduced nutrient input caused by collapsed returns of diadromous fish.

The Fundy Salmon Recovery project is a collaborative approach to species recovery that includes government, nongovernment, industry, academic, and First Nation partners. Building on the success of a pilot project (2009-2012), an innovative yet practical rearing strategy has been implemented to boost endangered inner Bay of Fundy (iBoF) Atlantic Salmon populations in two native rivers. Wild smolts collected from rivers by Fundy National Park and Fort Folly First Nation are transported to Dark Harbour on Grand Manan Island, site of the world's first wild salmon marine conservation farm. Maintained and operated by Cooke Aquaculture Inc. with support from the Atlantic Canada Fish Farmers Association, smolts are held at Dark Harbour until reaching sexual maturity. In early October, mature adults are transported to their natal rivers and released to allow for wild spawning, producing progeny free of captive exposure and associated domestication effects. Since releases of marine reared iBoF Atlantic Salmon began in 2015, over 1000 adults have been returned to the wild to spawn throughout the Upper Salmon River in Fundy National Park and the Petitcodiac River. Ongoing research through the University of New Brunswick tracks movement patterns and nutrient contributions of adults throughout the period of spawning activity.

The potential impacts of sea cage rearing are: 1) post-smolts mature in a semi-natural marine environment in the Bay of Fundy; 2) significant numbers of adults produced for release to native rivers to spawn; 3) increase in river ecosystem productivity through marine nutrient inputs; and 4) increased offspring fitness through reduced captive exposure.

Specially designed smolt pen utilised by the Wild Salmon Conservation Farm at Dark Harbour. Pens use a smaller mesh to accommodate smaller sized wild fish, and allow for feeding of smaller numbers of fish than typical salmon rearing operations. Photo: Nigel Fearson

Becky Graham (DFO) passes a dip net of wild exposed smolt to Garrett Momberquette (PC). These fish have been held at the DFO Mactaquac Biodiversity Facility until ready for transport to the Cooke Aquaculture Inc. operated Wild Salmon Conservation Farm at Dark Harbour on the island of Grand Manan. Photo: Nigel Fearson

DATE: MAR. 2014–MAR. 2019

FUNDED BY: Environment and Climate Change Canada (ECCC)–National Conservation Plan

CO-FUNDED BY: Atlantic Canada Fish Farmers Association (ACFFA); Cooke Aquaculture Inc.; New Brunswick Department of Agriculture, Aquaculture and Fisheries (NBDAAF); Fort Folly First Nations; University of New Brunswick (UNB)

PROJECT LEAD: Corey Clarke (PC)

PROJECT TEAM: Betty House (ACFFA); Tom Taylor (Cooke Aquaculture Inc.); Michael Beattie (NBDAAF); Tim Robinson (Fort Folly First Nations); John Whitelaw (DFO); Kurt Samways (UNB)

CONTACT: Corey.Clarke@pc.gc.ca

WEBSITE: http://www.fundysalmonrecovery.com/

Staff from Department of Fisheries and Oceans, Parks Canada Agency, University of New Brunswick, Fort Folly First Nations, and Cooke Aquaculture Inc. load wild exposed Inner Bay of Fundy Atlantic Salmon smolt into transport trucks. Staff started before dawn to make the first ferry to the island of Grand Manan where smolt will be grown at the Dark Harbour Wild Salmon Conservation Farm. Photo: Nigel Fearson

Identification of Genetic Markers Associated with Growth Performance in a Soybean Meal Based Diet for Salmon

To date, soybean meal (SBM) inclusion in salmon feed has been rather limited due to poor performance and negative physiological impacts in fish fed SBM-containing diets. However, studies have shown that there is significant individual and family variation in the ability to use SBM derived protein, and that this trait has moderately high heritability. It is thus possible to develop lines of salmon with increased efficiency in utilizing SBM. Marker assisted selection (MAS), using genetic markers such as single nucleotide polymorphisms (SNPs) associated with traits of interest, can be used to compliment traditional breeding and reduce the time required to achieve genetic gains.

This study is aimed at using genome-wide association studies (GWAS) to identify Atlantic Salmon SNPs associated with increased efficiency or tolerance to SBM as a protein source. A 60-day feeding trial was conducted to evaluate the effects of two different SBM inclusion levels (Control and Test diets with 5% and 30% SBM, respectively) on weight gain, feed efficiency, body composition, and nutrient deposition. Thirty full-sib families (initial body weight: 12.3 ± 1.0 g) of Atlantic Salmon (Saint John River strain) were utilized for the trial. Six fish per family were allocated to six different 325-liter tanks so that all families were represented equally in each tank. Each fish was tagged with passive integrated transponders (PIT) and each diet was allocated to three tanks.

The expected outcome of this project is a set of SNPs associated with increased tolerance and/or efficiency in utilizing SBM as a protein source. These novel markers will play a key role in the development of improved genetic lines that will allow for a significant increase in SBM inclusion in aquafeeds for Atlantic Salmon.

DATE: MAY 2016–DEC. 2016

FUNDED BY: Soy Aquaculture Alliance

PROJECT LEAD: Jason Stannard (CAT)

PROJECT TEAM: John Buchanan (CAT); Debbie Plouffe, Tiago Hori, André Dumas (CATC)

COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: adumas@aquatechcenter.com

WEBSITE: http://aquatechcenter.com/

High Density SNP Linkage Map for North American Atlantic Salmon (*Salmo salar*)

Atlantic Salmon continue to be a commercially and ecologically important species. In regards to aquacultural practices, understanding where genes that influence commercially important traits (such as growth and disease resistance) are located on the genome as well as determining how often genes from the same chromosome are inherited together is of growing importance for improving the development of selective breeding programs. Creating genetic linkage maps and using genetic markers such as single nucleotide polymorphisms (SNPs) to trace inheritance from parents to offspring between individuals is a necessary first step before quantitative traits can be mapped onto the genome.

We used 220K and 50K SNP chip genotypes from the parents and offspring of seven large families for constructing sex-specific genetic linkage maps through the "onemap" package in R (a software and coding language commonly used for statistical computing and data analysis). The initial male and female maps for each of the 27 chromosomes were created using 11K SNP genotypes from three families of North American Atlantic Salmon (Saint John River strain). We currently aim to create consensus linkage maps that would merge individual chromosomes between families for all 45,000 SNPs that overlap both custom SNP chips. In addition to benefitting selective breeding programs, the consensus linkage maps will also be compared to the newly published physical map for European Atlantic Salmon. This will facilitate the identification of genes for commercially important traits that may differ in genomic location between geographically distinct populations.

Creating highly informative consensus maps for North American *S. salar* will enable selective breeding programs to identify causal loci that influence important traits such as growth or disease resistance. It will also facilitate research in salmon conservation by identifying functional genetic differences among stocks.

DATE: JAN. 2016–AUG. 2018

FUNDED BY: Genome Canada; Genome Atlantic; Ontario Genomics

CO-FUNDED BY: NRC–Industrial Research Assistance Program (NRC–IRAP); Kelly Cove Salmon Ltd.

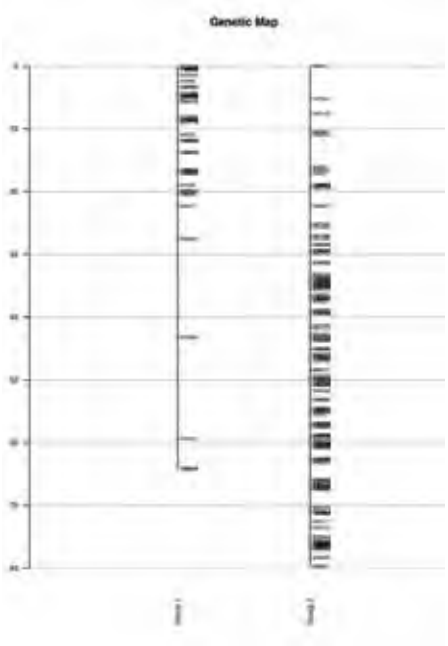
PROJECT LEADS: Elizabeth Boulding (U Guelph); Keng Pee Ang (Kelly Cove Salmon Ltd.)

PROJECT TEAM: Melissa MacLeod-Bigley, Forest Dussault, Jane Tosh, Melissa Holborn, Larry Schaeffer (U Guelph); Jake Elliott, Frank Powell (Cooke Aquaculture Inc.)

COLLABORATORS: Matthew Kent, Harald Grove, Sigbjørn Lien, Thomas Moen (Norwegian U Life Sciences)

CONTACT: boulding@uoguelph.ca

WEBSITE: https://www.uoguelph.ca/ib/boulding



"Chromosome 1"–Linkage maps for chromosome 1 of male (left) and female (right) North American Atlantic Salmon.

Using a Genomics Approach to Identify Atlantic Salmon Aquaculture Escapees and Hybrids

The cultivation of Atlantic Salmon has increased exponentially since the late 1960s with expansion into new geographic areas (e.g., Newfoundland) and the use of new selectively bred strains from North America and Europe. Coincident with this expansion has been an increased risk of farmed salmon escapes, which has the potential to impact the diversity of wild Atlantic Salmon populations. This project attempts to identify and apply targeted groups of genetic markers to quantify the genetic impacts of farmed Atlantic Salmon on wild populations and the frequency of interbreeding in the wild. This proposal directly targets client needs and is a first step towards identifying impacts and strategies for alleviating those impacts that result from interactions between wild and farmed salmon escapees in Atlantic Canada.

This project extends earlier work that developed expertise for genome wide marker development in non-model species. In this proposal, the impact of farmed escapees on wild populations will be quantified by: 1) combining existing genomic data and modern DNA sequencing methods to develop a group of genetic markers (single nucleotide polymorphisms or SNPs) for rapid and accurate identification of farmed salmon escapees, including all strains in use, or under consideration for use, in Atlantic Canada; and 2) applying this genomic screening tool to rapidly and accurately quantify, both, the presence of escapes and recent hybrids in the wild focusing on Newfoundland and Maritimes regions.

Research has confirmed that escaped farmed salmon are breeding with wild salmon and producing offspring in many rivers in Newfoundland.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Genomics Research and Development Initiative (DFO–GRDI)

CO-FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Ian Bradbury (DFO)

PROJECT TEAM: Lorraine Hamilton, Patrick O'Reilly (DFO)

COLLABORATORS: Geoff Perry, Dounia Hamoutene, Martha Robertson (DFO); Elizabeth Barlow (DFA); Jon Carr (Atlantic Salmon Federation); Ross Hinks (Aboriginal Government–Miawpukek First Nation)

CONTACT: Ian.Bradbury@dfo-mpo.gc.ca

WEBSITE: http://dfo-mpo.gc.ca/science/rp-pr/grdi-irdg/projects-projets/016-eng.html

Sampling for possible offspring of escaped farmed Atlantic Salmon. Photo: Chris Hendry (DFO)

Use of Hydro-Acoustic Methods to Assess the Migration Timing and Distribution of Juvenile Salmon in Discovery Islands and Johnstone Strait

During their migration to the Northern Pacific, juvenile wild salmon from the Strait of Georgia pass through the Discovery Islands and Lower Johnstone Strait, where salmon farming occurs.

This project seeks to inform the risk of disease transfer associated with interactions between wild and farmed salmon in this area by studying wild salmon migratory pathways and the duration of their residency in the vicinity of these fish farms.

In conjunction with traditional survey/sampling methods (including purse seining, beach seining, and trawling) using hydro-acoustics offers a cost-effective way of monitoring fish abundance, behaviours, and distribution for extended and continuous periods of time. This will enable observation and data collection on juvenile wild salmon migration in the area of fish farms, thus gaining insights into potential impacts of wild salmon on farmed salmon and vice versa.

The results of this project will:

- Assist in informing a risk assessment process to investigate the risks of pathogen transfer from farmed to wild salmon, particularly in the Discovery Islands.
- Improve our understanding and inform and support the development of evidence-based aquaculture management approaches.
- Provide information in addressing critical uncertainties and recommendations as identified in the Cohen Report with respect to: 1) marine survival in their early marine life; 2) disease transfer and interactions between wild and farm salmon; and 3) assessing the cumulative impacts of multiple stressors on Fraser River Sockeye Salmon productivity.
- Inform operational decisions and best practices engaged in by the BC salmon aquaculture industry.

DATE: MAY 2015–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: BC Salmon Farmers Association (BCSFA)

PROJECT LEAD: Stéphane Gauthier (DFO)

PROJECT TEAM: Stewart Johnson, Marc Trudel, Chrys-Ellen Neville (DFO)

COLLABORATORS: Joanne Liutkus (BCSFA)

CONTACT: Stephane.Gauthier@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-P-02-eng.html

The Historical and Social Dimensions of Salmon Aquaculture Science

For three decades, salmon aquaculture has been a focus of environmental research. In this project I am applying the tools of environmental history and science and technology studies to understand how this research has developed, as well as the roles it has played in public discussions regarding the industry. Several more specific objectives are also being pursued.

First, I am writing an environmental history of salmon aquaculture science. This history will explore the relations between scientific research and the evolving environmental, social, and political dimensions of the industry.

Second, I am examining how the diverse institutions engaged in environmental research–governments, universities, industry, and public interest organizations–have shaped research priorities, research results, and the application of these results.

Third, I am investigating the movement of scientific knowledge of salmon aquaculture among research sites in Canada, Norway, Ireland, and Scotland.

Fourth, I am examining the aspects for effective science that is al contribute to help resolve controversies regarding this industry.

While this project is examining the full range of environmental science relating to salmon aquaculture, a special focus is on research relating to sea lice.

This project is providing a better understanding of how salmon aquaculture science has developed in relation to the growth of the industry in its varied environmental and social contexts.

DATE: JUN. 2007–DEC. 2018

FUNDED BY: Social Sciences and Humanities Research Council of Canada (SSHRC)

PROJECT LEAD: Stephen Bocking (Trent U)

CONTACT: sbocking@trentu.ca

WEBSITE: http://people.trentu.ca/sbocking/Bocking-Salmon.html

Salmon farm near Campbell River, British Columbia. Photo: Stephen Bocking (Trent U)

Migration Timing and Distribution of Juvenile Salmon in Discovery Islands and Johnstone Strait

This research is determining how juvenile salmon utilize the Strait of Georgia, including the Discovery Islands area, with a focus on Fraser River Sockeye Salmon and to a lesser extent, Chinook Salmon. It will also provide the information required to fully assess the risks of disease transfer from salmon arms to the wild, understand the potential consequences of such transfers, and inform farm management policies.

Purse seines and DFO trawl surveys have greatly increased the understanding of the migration and health of juvenile salmon within the Strait of Georgia, BC, especially for Sockeye Salmon. Surveys conducted in 2010–2012 revealed that Fraser River Sockeye Salmon do not enter the Discovery Islands area (a fish farming area) until the end of May, and that they are widely distributed throughout this area for at least part of June. To further assess risks associated with interactions between farmed and wild fish, information in the following key areas is needed: 1) knowledge of migratory pathways of salmon and the duration of their residency in the vicinity of fish farms; 2) knowledge of the prevalence of pathogens and diseases within wild and farmed populations; and 3) knowledge of environmental and host conditions during the periods wild salmon reside in the vicinity of fish farms. Additionally, more information is required to further understand when and for how long juvenile salmon are present in the vicinity of fish farms, as well as to describe migration timing of juvenile Fraser River Sockeye Salmon out of the Strait of Georgia. To gain this required information, sampling will be performed using a three-year trawl survey in the Strait of Georgia and a three-year purse seine combined with hydroacoustic surveys in Johnstone Strait.

Discovery Islands. Photo: Dan McPhee (DFO)

DATE: APR. 2014–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Marine Harvest Canada Limited; Grieg Seafood BC Ltd.; Cermaq Canada Ltd.

PROJECT LEAD: Stewart Johnson (DFO)

PROJECT TEAM: Marc Trudel, Chrys-Ellen Neville (DFO); Diane Morrison (Marine Harvest Canada Limited); Patrick Whittaker (Grieg Seafood BC Ltd.); Barry Milligan (Cermaq Canada)

CONTACT: Stewart.Johnson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-14-01-001-eng.html

Spatial and Temporal Distribution and Survival of Farmed Atlantic Salmon after Experimental Release from Sea Cage Locations

The expansion of the aquaculture industry in Newfoundland and the decline in wild salmon stocks have raised questions regarding the possible impacts escaped farmed salmon may have on local wild populations. Despite increased industry awareness and the implementation of a code of containment, escape events can still occur. Spawning between aquaculture-origin Atlantic Salmon and wild Atlantic Salmon has been scientifically documented in Newfoundland. Further research is needed to better understand the potential risk of escapees on wild salmon populations. The objective of this project is to determine the residency time, locations, migratory routes, and survival rates of escaped farmed Atlantic Salmon by monitoring the movements of acoustically-tagged smolts, post-smolts, and adults, following a simulated escape of a group of fish at different times of the year. Identifying the migratory routes followed by escapees, as well as residency patterns and how they vary with the timing of the escape event (seasonal effects), will help in designing more efficient recapture strategies.

The research results from this study will inform federal and provincial ecosystem-based management of the industry and provide key information for the development of strategies to minimize potential impacts of escaped farmed Atlantic Salmon on the environment and wild salmon populations.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Dounia Hamoutene (DFO)

PROJECT TEAM: Curtis Pennell, Kimberley Marshall, Dwight Drover, Sebastien Donnet, Keith Clarke, Geoff Perry (DFO)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca

WEBSITE: http://dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-NL-04-eng.html

Studying Effects of Atlantic Salmon Broodstock Age and Egg Size on Later Performance of Progeny

Atlantic Salmon broodstock that have not matured after four years might be culled or retained for use the following year for various reasons. For example, families of Atlantic Salmon that have a higher than average prevalence for late sexual maturation may be bred to try to delay sexual maturation within production fish. Female broodstock that mature at five years of age have significantly larger eggs (on average) compared with eggs from four-year-old females. Anecdotally, it is often believed that this larger egg size provides an advantage to the same individuals throughout the production cycle–larger eggs yield larger progeny that is carried on through to harvest. We are comparing egg sizes from all donor female broodstock and resulting growth performance of progeny at various ages at the time of measurement where female and male broodstock of different ages were crossed (four-year-old female x four-year-old male, 4 x 5, 5 x 4, and 5 x 5). These crosses are controlled within the same production cycle and at the same physical location thereby reducing and/or removing environmental variation. To date, egg size has not defined juvenile size (assessed up to a post-smolt, pre-harvest stage). With the first year of data evaluated, the largest progeny, on average, resulted from 4 x 4 year old crosses despite having the smaller egg size. It appears that the growth potential of juveniles is based on inherent genetic variation or essentially genetic growth potential rather than egg size.

Various factors are considered when retaining broodstock based on age or eggs based on average egg size from a batch. This line of research has direct commercial relevance within production or selection of broodstock even in the absence of a pedigreed broodstock program.

DATE: FEB. 2016–APR. 2020

FUNDED BY: Atlantic Canada Opportunities Agency–Atlantic Innovation Fund (ACOA–AIF)

CO-FUNDED BY: New Brunswick Innovation Foundation; Northern Harvest Sea Farms Ltd.; Huntsman Marine Science Centre (HMSC)

PROJECT LEAD: Amber Garber (HMSC)

PROJECT TEAM: Chris Bridger, Susan Hodkinson, Philip Wiper, Jamie Carpenter, Danny Craig, Esther Keddie, Brooke Barrett, Erica Harvey, Chantal Audet (HMSC)

COLLABORATORS: Aaron Craig (Northern Harvest Sea Farms Ltd.)

CONTACT: Amber.Garber@huntsmanmarine.ca

WEBSITE: http://www.huntsmanmarine.ca/

Thermal and pH Tolerance of Farmed, Wild, and First Generation Farmed-Wild Hybrid Salmon

In Newfoundland and Labrador (NL), all farmed Atlantic Salmon (*Salmo salar*) originate from the Saint John River strain (New Brunswick). It is believed that wild stocks have developed adaptations to their local environment; therefore the vulnerability of these local, genetically distinct stocks to farmed escapees through interbreeding is a concern. Studies on interactions between wild and farmed salmon have shown that this issue is area-specific and therefore these interactions need to be further explored within Newfoundland and Labrador.

This research sought to clarify the ability of F1 hybrids (offspring of local wild and domesticated strains) to survive under local environmental conditions (i.e., reduced pH level of river waters and low spring seawater temperatures) occurring in Newfoundland and Labrador. The results of this research provide information on the potential impact of farmed escapees on wild stocks.

We found that after a 90-day exposure to low pH water, no differences were observed between pure wild parr and F1 hybrids in survival, growth, and gill enzymes indicative of seawater readiness, but pure farmed parr had lower survival than the F1 hybrids. Additionally, we found no significant differences in total mortality among wild, farmed, and hybrids after transfer to seawater and exposure to very cold temperatures.

While pure farmed salmon might be affected in river conditions, this research suggests that hybrids (most likely the outcome of farm-wild reproductive interactions) would not experience a significant mortality due to low pH in Newfoundland rivers. The findings also suggest that hybrids resulting from crossing wild salmon and farmed Saint John River salmon are as likely to survive seawater migration in cold temperatures as their wild counterparts.

DATE: APR. 2014–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Cold Ocean Salmon Inc.; Northern Harvest Sea Farms Ltd.

PROJECT LEAD: Dounia Hamoutene (DFO)

PROJECT TEAM: Lynn Lush, Kimberley Burt (DFO)

COLLABORATORS: Julia Jensen (Cold Ocean Salmon Ltd.); Jennifer Caines (Northern Harvest Sea Farms Ltd.)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/N-14-01-002-eng.html

Reduction of Ammonia and Solids from Chinook Salmon Culture Facilities

In farmed fish, metabolic processes produce nitrogenous (principally ammonia) wastes which are released into the environment. That fish are not efficiently utilizing the feed for growth and maintenance represents a potential economic loss. Additionally, the release of nitrogenous wastes into the environment can have implications for the ecosystem and the fish farm, and regulatory consequences for culture facilities.

This study explored how feed regimes designed to stimulate compensatory growth may be used during Chinook Salmon production to reduce nitrogen excretion into the environment and increase food utilization by the fish. When faced with modest periods of food deprivation, the salmon were found to maintain growth and excrete less nitrogen, despite the similarity of their final weights to the control group. This indicates that repeated short-term food deprivation of two days duration over a seven week cycle may provide a useful strategy for reducing nitrogen loss to the environment, while minimizing the loss of growth potential of the fish.

The results of this research indicate the possibility for using cyclical feeding to reduce nitrogen excretion during salmon farming. This would be especially beneficial at land-based salmon farms with systems where the water discharge is focused to a single outflow, recirculating aquaculture, and multiple net-pens or tanks.

DATE: AUG. 2012–SEP. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Agrimarine Industries Inc.

PROJECT LEAD: Ian Forster (DFO)

PROJECT TEAM: Lawrence Albright (AgriMarine Industries Inc.)

COLLABORATORS: Lawrence Albright, Robert Walker (AgriMarine Industries Inc.)

CONTACT: Ian.Forster@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-12-01-001-eng.html

Determination of the Potential Spatial Overlap and Interaction Between Commercial Fisheries (American Lobster, Snow Crab) and Finfish Aquaculture Activities in Connaigre Bay, Newfoundland

The objective of this project was to provide valuable information to inform future site development initiatives and contribute to the sustainability of the fishing and aquaculture industries on the south coast of Newfoundland and Labrador.

There is rarely an opportunity to collect and compare ecological data before, during, and after a salmon farming site has been approved and is under production. This collected environmental and biological data at two newly approved salmon aquaculture sites in Connaigre Bay, Newfoundland and Labrador–a bay that has not yet held salmon production sites. Unfortunately, the aquaculture sites were not stocked according to the expected time-frame, thus, the project was terminated prematurely. Data collected over the course of the project are currently being employed to establish habitat preferences and species distribution mapping. This can be used as a tool to advise on potential spatial overlap between aquaculture sites and local fisheries.

DATE: APR. 2012–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Fish, Food, and Allied Workers Union (FFAW); Cold Ocean Salmon Inc.

PROJECT LEAD: Dounia Hamoutene, Pierre Goulet (DFO)

PROJECT TEAM: Andry Ratsimandresey, Dwight Drover, Darrell Mullowney, Don Stansbury (DFO); Jeff Barrell, Jon Grant (Dalhousie U)

COLLABORATORS: Harvey Jarvis (FFAW); Jennifer Woodland (Cold Ocean Salmon Inc.)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca, Pierre.Goulet@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/N-12-02-001-eng.html

Family Variation and Heritability of Male and Female Atlantic Salmon Fitness Traits

There is minimal information published associated with the heritability of male or female Atlantic Salmon broodstock fitness traits. Documenting relevant data requires tracking individuals from known families through maturation and gamete collection. During the 2014 and 2015 spawning seasons of mature Atlantic Salmon, 1056 milt samples were assessed from 529 males and egg samples were assessed from 1139 females. These broodstock originated from 130 different families over two year classes with various levels of relatedness among families. Heritability and genetic correlations were assessed considering various traits including: for both males and females total body weight (kg) and gamete volume (mL); for males only sperm density, milt volume from repeated stripping (repeatability); and for females only egg size. From collected data, fecundity and total number of gametes by individual were calculated. Data continues to be collected with each new spawning season. In addition, effect of age (primarily four and five year old broodstock) and photo-thermal manipulation of spawning time on male and female gamete production related traits is under evaluation.

Knowledge of fitness traits and heritability may inform decisions within a broodstock program related to selection, numbers of each sex to maintain, and expected number of eggs resulting from the Atlantic Salmon retained for spawning.

DATE: NOV. 2014–APR. 2020

FUNDED BY: Atlantic Canada Opportunities Agency–Atlantic Innovation Fund (ACOA–AIF)

CO-FUNDED BY: New Brunswick Innovation Foundation; Northern Harvest Sea Farms Ltd.; Huntsman Marine Science Centre (HMSC)

PROJECT LEAD: Amber Garber (HMSC)

PROJECT TEAM: Chris Bridger, Susan Hodkinson, Philip Wiper, Jamie Carpenter, Danny Craig, Esther Keddie, Brooke Barrett, Erica Harvey, Chantal Audet (HMSC)

COLLABORATORS: Aaron Craig (Northern Harvest Sea Farms Ltd.)

CONTACT: Amber.Garber@huntsmanmarine.ca

WEBSITE: http://www.huntsmanmarine.ca/

Hybridization of Farmed Escaped and Wild Atlantic Salmon: So What? An Empirical and Model Based Exploration of the Consequences for Wild Populations throughout the North Atlantic

The farming of Atlantic Salmon now exceeds two million tonnes worldwide which exceeds the natural production of wild populations. Interbreeding between wild and escaped farmed salmon has been reported both in Europe and North America and can alter wild population characteristics, eroding local adaptation and causing wild population declines. However, the extent and magnitude of these genetic impacts are difficult to predict. The resiliency of wild populations, the recovery time following hybridization, and the efficacy of possible mitigation strategies remain unclear.

The overall goal of this international collaborative research project is to provide the basis for robust scientific advice regarding the genetic impacts of escaped farmed Atlantic Salmon on wild populations both locally (i.e., Newfoundland) and across the North Atlantic. As well, potential successes of various mitigation strategies will be explored by using data collected in parallel research projects from across the North Atlantic. This work will directly complement existing studies and will: 1) quantify the magnitude of hybridization between wild and escaped farmed salmon and explore growth, survival, and biological differences between wild and hybrid individuals; and 2) develop an international collaborative project focused on evaluating different models used throughout the North Atlantic.

Identifying risks and potential mitigation strategies associated with Atlantic Salmon aquaculture escapees is necessary for the successful conservation of wild salmon populations, the stability of recreational and Aboriginal fisheries, and continued growth of a sustainable aquaculture industry. Through an examination of the presence of interbreeding and introgression, this work will help identify strategies for maintaining the rapid growth of the aquaculture industry without altering population structure or local adaptation of wild salmon populations. By doing so, this work will directly assist DFO in meeting Canada's commitment to ensure the aquaculture industry develops sustainably.

DATE: MAR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Ian Bradbury (DFO)

COLLABORATORS: Ian Flemming, Matt Rise (MUN); Kjetil Hindar (Norwegian Institute for Nature Research); Kevin Glover (Institute of Marine Research, Norway); Mark Coulson, Eric Verspoor (The Rivers and Lochs Institute, Scotland); Phil McGinnity (School of Biological, Earth, and Environmental Sciences, Ireland); Einar Nielsen (Technical University of Denmark); Kristen Gruenthal (NOAA Fisheries)

CONTACT: Ian.Bradbury@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-NL-11-eng.html

Quantifying Direct Genetic Impacts of Escaped Farmed Salmon on Wild Salmon in Atlantic Canada

Aquaculture escapes are a threat to the persistence and stability of wild salmon populations, with impacts occurring through both genetic and ecological interactions. The goal of this study is to quantify the presence and magnitude of direct genetic impacts that escaped farmed salmon have on wild salmon populations in order to inform management decisions and advise on mitigation strategies. Specifically, this study addresses three objectives: 1) to quantify the magnitude of low level chronic escapes through an annual targeted survey; 2) to quantify annual variation in hybridization among wild and farm escaped Atlantic Salmon; and 3) to evaluate at sea survival of hybrids in Newfoundland.

Identifying risks and potential mitigation strategies associated with Atlantic Salmon aquaculture escapees is critical to both the successful continued growth of the aquaculture industry and the conservation of wild salmon populations.

This study will begin to quantify the extent of genetic impacts from farm escaped Atlantic Salmon on wild populations over time and in different areas in Atlantic Canada.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Ian Bradbury (DFO)

PROJECT TEAM: Lorraine Hamilton, Carole Grant, Chris Hendry, Brian Dempson, Ross Jones (DFO)

COLLABORATORS: Ian Fleming (MUN); Jon Carr (Atlantic Salmon Federation); Ross Hinks (Miawpukek First Nation); Tony Blanchard, Derek Tobin, Gerald Cline, Lloyd Slaney, Helen Griffiths (DFO)

CONTACT: Ian.Bradbury@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-NL-02-eng.html

Probability of Detecting Escaped Aquaculture Salmon is Related to Distance Between Production Areas and Rivers

Salmon that escaped from sea cage aquaculture facilities have been detected in a large number of rivers in Eastern North America with the detection of escapees seemingly related to the distance of the river from the production areas. Morris et al. (2008) compiled the existing information available to 2007 on aquaculture escapees in rivers of Eastern North America but did not provide any quantitative analysis that could be used to link the detection of escapees relative to the distance of the rivers from the production areas. This project proposes to update the compilation of observations from Morris et al. (2008) to 2015, to review the literature on the behaviour of escaped salmon, and based on these components, to examine a series of models with differing assumptions on behaviour and diffusion, for their ability to generate the empirical observations of escapees in monitored rivers. The objective is to examine models that would provide probability statements of observing an escaped salmon in a river based on the distance of the river from the escape location, the intensity of the escape event, and the river monitoring effort. This knowledge will inform aquaculture management siting decisions.

Reference: Morris, MRJ., Fraser, D.J., Heggelin, A.J., Whoriskey, F.G., Carr, J.W., O'Neil, S.F., and Hutchings, J.A. 2008. Prevalence and recurrence of escaped farmed Atlantic Salmon (*Salmo salar*) in Eastern North American rivers. Can. J. Fish. Aquat. Sci. Vol. 65: 2807-2826.

DATE: MAY 2016–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Ian Bradbury (DFO)

PROJECT TEAM: Brian Dempson, Ross Jones, Alex Levy (DFO)

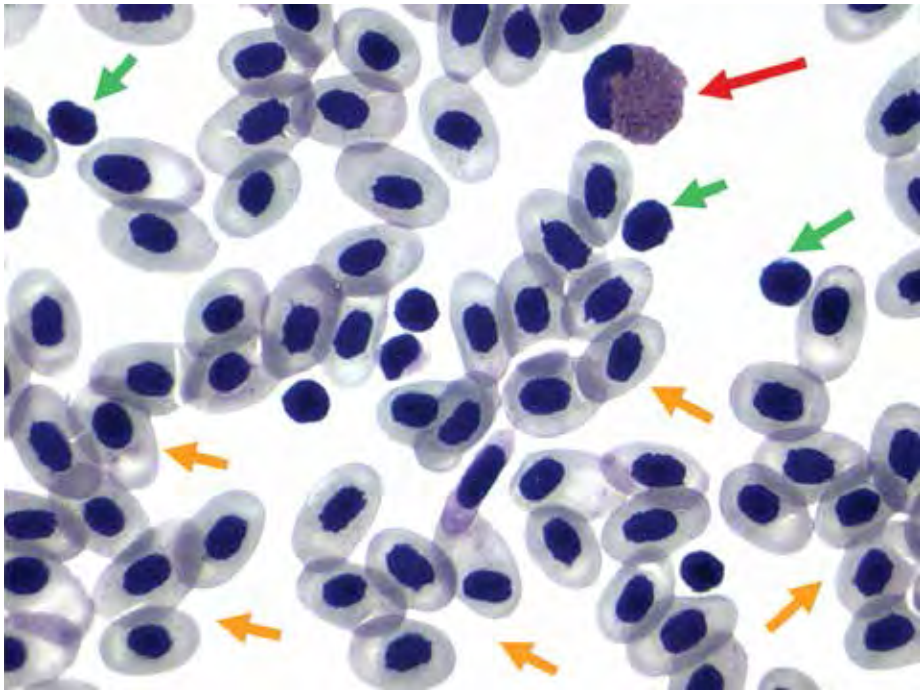
CONTACT: Ian.Bradbury@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-NL-14-eng.html

Heritability of Blood Parameters as Health Indices for an Atlantic Salmon (*Salmo salar*) Selective Breeding Program

The Atlantic Salmon broodstock program at the Huntsman Marine Science Centre (HMSC), with commercial partner Northern Harvest Sea Farms Ltd., is selecting for traits that are important to commercial production. Many of these traits cannot be measured directly on breeding candidates but have to be recorded on close relatives (e.g., progeny from the same families), thereby selecting based on performance of the family versus the individual. One limitation of this approach is that it is possible to select an individual that does not possess enhanced performance for the desired trait (e.g., disease resistance/susceptibility). Use of genomic markers in a broodstock program mitigates this issue after the molecular markers are demonstrated to be reliable for predictive purposes. Alternatively, biological proxy indicators may be discovered that are readily measurable and closely correlate with specific commercial traits of interest to increase selection efficiency as well. As an example, during the 2016 spawning season, 1217 blood samples were collected from individual male and female broodstock representing 195 families from three ages, multiple rearing conditions, and at various points during and after typical spawning. Blood parameters recorded from samples included lymphocyte and neutrophil density, erythrocyte size, and hematocrit. Heritability of these parameters, their reliability as health indicators, and correlations among these traits and other commercial traits are under evaluation. Preliminary analysis indicates significant differences in hematocrit among broodstock reared under ambient conditions compared to those receiving photo-thermal-advanced conditions.

The encouraging preliminary research complements the extensive data array for the Atlantic Salmon broodstock program and may provide another monitoring tool in the production of salmon.



Fish blood (stained with Diff-Quik™) illustrating predominantly erythrocytes (orange arrows), with few lymphocytes (green arrows) and one neutrophil (red arrow). Image captured at 1000X. Photo: Duane Barker (HMSC)

DATE: OCT. 2016–DEC. 2020

FUNDED BY: Atlantic Canada Opportunities Agency–Atlantic Innovation Fund (ACOA–AIF)

CO-FUNDED BY: New Brunswick Innovation Foundation; Northern Harvest Sea Farms Ltd.; Huntsman Marine Science Centre (HMSC)

PROJECT LEADS: Duane Barker, Amber Garber (HMSC)

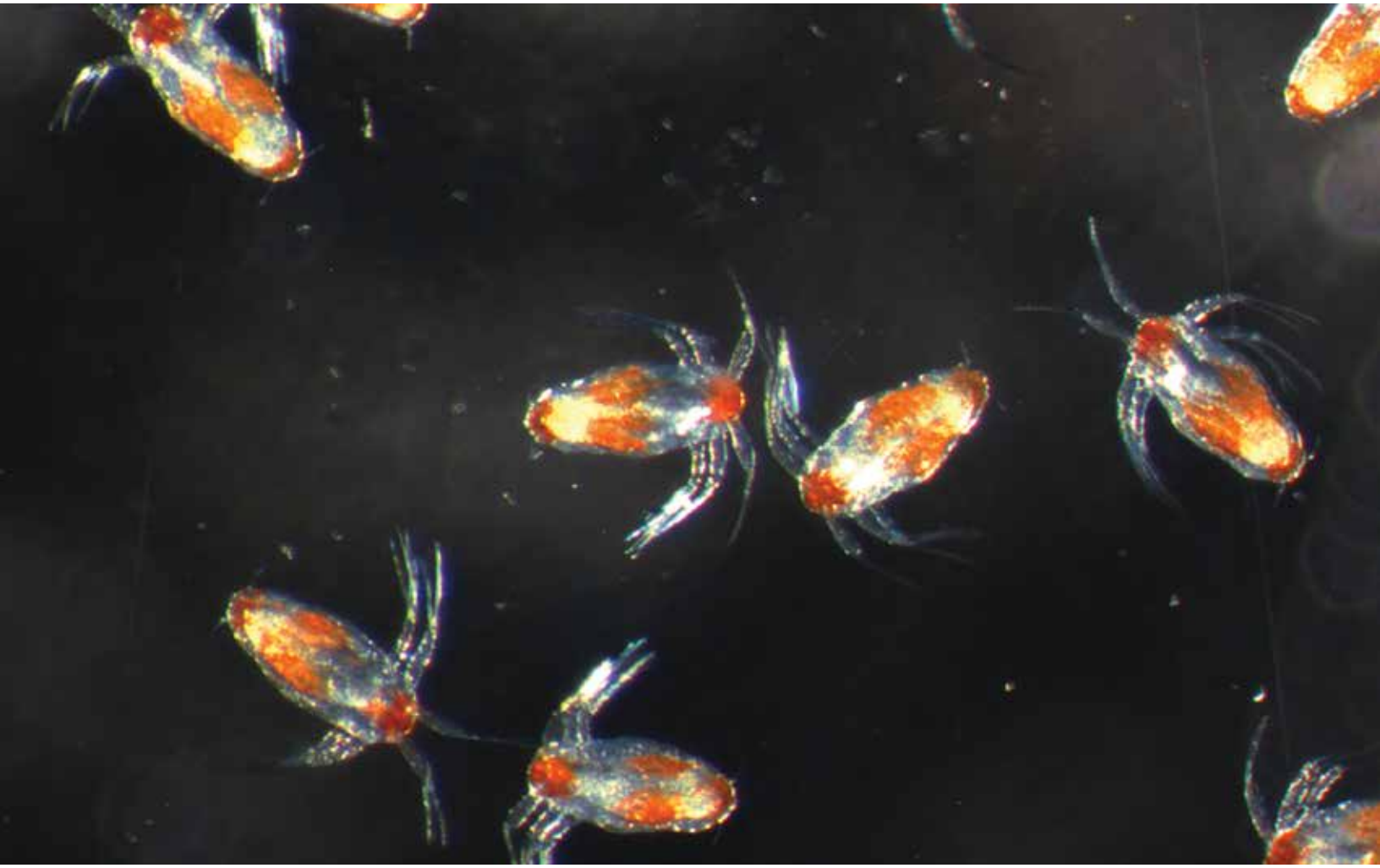
PROJECT TEAM: Anne McCarthy, Chris Bridger, Susan Hodkinson, Esther Keddie, Rebecca Eldridge, Erica Harvey, Ellen Fanning, Chantal Audet, Brooke Barrett (HMSC)

COLLABORATORS: Aaron Craig (Northern Harvest Sea Farms Ltd.)

CONTACT: Duane.Barker@huntsmanmarine.ca

WEBSITE: http://www.huntsmanmarine.ca/

SEA LICE



Characterizing the Mechanism of Salmon Louse (*Lepeophtheirus salmonis*) Rejection by Coho Salmon (*Oncorhynchus kisutch*) Using a Novel Dual RNA-Sequencing Approach

The Use of Kelp Perch and Pile Perch to Control Sea Lice (*Lepeophtheirus salmonis*) on Infested Atlantic Salmon Smolts

Wild Salmon Sea Lice Data Integration–Sea Lice Monitoring Network Development for Wild Salmon in Vancouver Island Coastal Waters

Susceptibility of Farmed and Wild Atlantic Salmon (*Salmo salar*) to Experimental Infestations with Sea Lice (*Lepeophtheirus salmonis*)

The Effects of Sea Lice in Modulating Salmonid Susceptibility to Viruses

Defining the Risk of Sea Lice Infections Through the Development of an Understanding of the Early Life History Population Dynamics of Sea Lice Associated with Atlantic Salmon Aquaculture Sites in the Bay of Fundy

Development of Bacterial Biomarkers of Salmon Microbiota Mediated Resistance Against the Sea Louse *Lepeophtheirus salmonis*

Safety Assessment of an Oxygen Gas Infusion System Used During Various Hydrogen Peroxide (H_2O_2) Treatments on Atlantic Salmon (*Salmo salar*)

Developing a Non-Chemical Means to Effectively Remove All Forms of Sea Lice from Aquaculture Salmon Using Warm Water

An Investigation of the Relationship Between Environmental Parameters, Oceanographic Zones of Influence, and the Prevalence of Parasitic Copepods on Three-Spine Stickleback in Bay D'Espoir Newfoundland with Specific Reference to Salmonid Aquaculture Sites

Studies of Sea Lice Infection Levels on the Health of Juvenile Salmon in the Strait of Georgia and Adjacent Waters

Refining the Use of Warm Water Showers to Remove Sea Lice from Atlantic Salmon and Understanding the Fish Health Implications of the Technique

Characterizing the Mechanism of Salmon Louse (*Lepeophtheirus salmonis*) Rejection by Coho Salmon (*Oncorhynchus kisutch*) Using a Novel Dual RNA-Sequencing Approach

After infection with larval sea lice (*Lepeophtheirus salmonis*), juvenile Coho Salmon are able to rapidly reject the parasite. This rejection is associated with aggressive hyperplasia and infiltration of cellular effectors; however, the molecular mechanisms of this response have not been characterized. This project aims to explore the response of both salmon and sea louse simultaneously by leveraging high-throughput modern sequencing technologies (dual RNA-seq). Samples of Coho Salmon fins with and without visible sea lice infestation were used to generate a pool of transcripts originating from both the sea lice and the salmon. Reads arising from either organism were separated using publicly available transcriptome/genome information for both species. Differential expression was analyzed for both the host and the parasite comparing different time-points throughout the progression of the infection. Several pathways of the immune response were shown to be activated in Coho Salmon such as the complement cascade, tissue remodelling, and an acute phase response, while a concomitant response in the sea louse featured activated oxidative stress and cell death pathways. The analysis also revealed that mRNA expression reached basal levels after 18 days post-infection, indicating that rejection mechanisms were most likely completed by that time. To our knowledge, this is the first time the transcript expression of both host and parasite has been simultaneously investigated in salmonids using RNA-seq.

The results of this project demonstrates the feasibility of dual RNA-seq while also putting forward many hypotheses related to the molecular mechanism behind sea lice resistance.

DATE: DEC. 2015–DEC. 2017

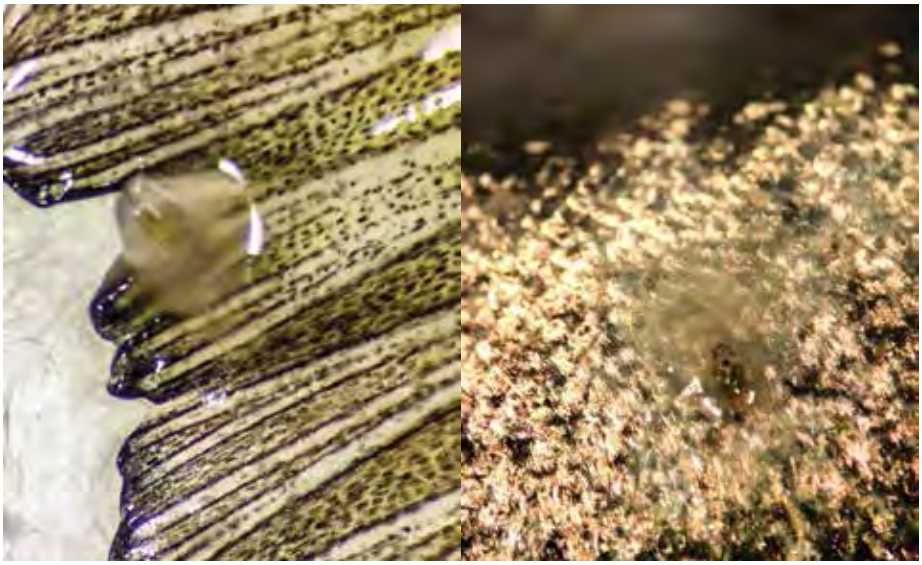
FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)–Postdoctoral Fellowship Program

CO-FUNDED BY: Elanco Animal Health

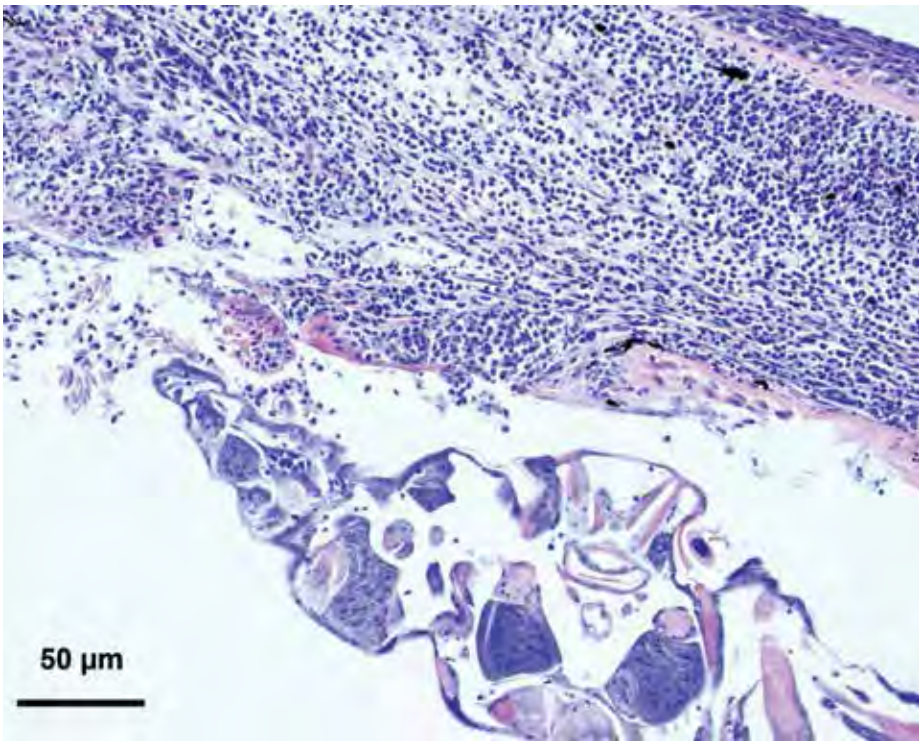
PROJECT LEAD: Mark Fast (UPEI–AVC)

PROJECT TEAM: Laura Braden (UPEI–AVC); Tiago Hori (CAT); Phil Byrne (DFO)

CONTACT: lbraden@upei.ca



Sea lice are encapsulated by an aggressive host response in the skin (right) and fin (left) of Coho Salmon (shown here at 6 days post-infection). Photo: Laura Braden (UPEI-AVC)



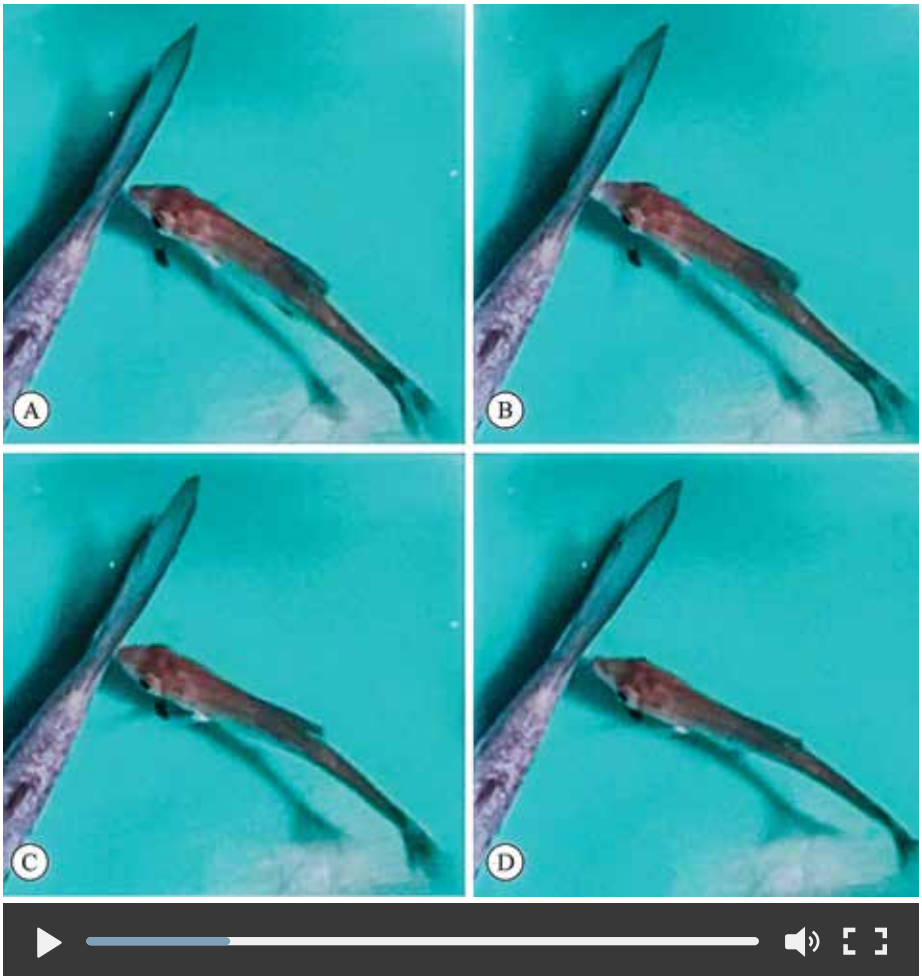
A micrograph (H&E, 200X magnification) showing a sea louse attached to Coho Salmon fin, with massive recruitment of cellular responders (small round blue cells) below attachment site at four days post-infection.

The Use of Kelp Perch and Pile Perch to Control Sea Lice (*Lepeophtheirus salmonis*) on Infested Atlantic Salmon Smolts

Sea lice infestations in farmed Atlantic Salmon require regular monitoring and, sometimes, treatments with chemicals such as SLICE®. Alternative methods to control sea lice infestations are needed to improve the sustainability of Atlantic Salmon farming. Biological controls as a method to control sea lice infestations have been considered as viable mitigation tools to reduce sea lice infestations for many years and are now being successfully used in Norway and Scotland, with cleaner fish such as wrasse and lumpfish.

The goal of this research was to demonstrate if Kelp Perch (*Brachyistius frenatus*) and Pile Perch (*Rhacochilus vacca*) would clean sea lice off infested Atlantic Salmon. Several cohabitation trials have been performed whereby Kelp or Pile Perch were placed in tanks with sea lice infested salmon. While variation in feeding activity exists, perch of both species actively cleaned infested salmon of parasitic sea lice within 48 hours of cohabitation. Video evidence supports this result showing perch actively feeding on parasitic sea lice. Additionally, digested sea lice were found within cohabitating perch gastrointestinal tracts and in fecal casts recovered from experimental tanks. Salmon body condition and health showed no observable differences between experimental and control tanks, indicating that active sea lice predation by perch does not result in negative health impacts to infested salmon.

This research addresses a large issue facing the salmon farming industry in BC by conducting research to find a sustainable way to reduce the environmental, economic, and public perception issues related to sea lice infestations in farm raised Atlantic Salmon. The use of cleaner fish to reduce sea lice infestations is an environmentally friendly solution to this issue of protecting wild salmon populations.



Kelp Perch (*Brachyistius frenatus*) cleaning sea lice off of an Atlantic Salmon (*Salmo salar*) smolt. (A) Kelp Perch approaching the left side of the tail of an Atlantic Salmon. (B) The instant the Kelp Perch picks a sea louse off of the salmon, notice the jaw protrusion. (C) and (D) The moments after the pick as the perch begins to retreat from the salmon. Photo: Sam Ferguson (Vancouver Aquarium)

DATE: DEC. 2014–ONGOING

FUNDED BY: Sea Pact; BCSFA–Marine Environment Research Program (BCSFA–MERP)

CO-FUNDED BY: Marine Harvest Canada Ltd.

PROJECT LEAD: Shannon Balfry (Vancouver Aquarium)

PROJECT TEAM: Maureen Finn (Living Elements Ltd.); Sam Ferguson, Selina Thorberg (Vancouver Aquarium)

COLLABORATORS: Diane Morrison (Marine Harvest Canada Ltd.); Simon Jones (DFO)

CONTACT: Shannon.Balfry@vanaqua.org

Wild Salmon Sea Lice Data Integration–Sea Lice Monitoring Network Development for Wild Salmon in Vancouver Island Coastal Waters

The coastal waters of British Columbia. Photo: BCSFA

Sea lice monitoring programs on wild Pacific smolts have served to broaden the understanding of sea lice ecology and help to further develop sea lice management protocols on salmon farms. Studies where a large amount of annual data has been collected present a novel opportunity to study patterns over time, particularly where such studies offer structured snap-shots in space and/or time. To fully capture the value of these types of studies, it is essential that they be integrated for the purposes of comparison and aggregation.

This program aims to create a single repository for sea lice monitoring data from wild fish in British Columbia (BC), collected by the salmon farming industry, and supplemented by additional data sets generated from conservation groups, academics, First Nations, and government. Large sets of consistent, annual data can be used in sea lice population studies, not only to determine abundance and intensity, but also to help map clustering patterns in predicting where sea lice will likely be most prevalent in a particular area by stage and time of year.

The program is currently synthesizing existing sea lice data sets into a useful format to communicate historical data trends, while also collecting and storing data from current industry-sponsored sea lice monitoring programs. This includes ongoing monitoring of sea lice on wild fish. By bringing these data together, new opportunities will arise to conduct further analyses, report on trends noted in various regions, and increase transparency as well as the potential for information sharing.

By integrating data sets from conservation groups, academia, First Nations, government, and salmon farming companies, greater analytical and modelling opportunities arise. This should ultimately benefit all contributing parties and the sustainability of the aquatic ecosystem along the BC coast.

DATE: APR. 2016–MAR. 2017

FUNDED BY: BC Salmon Farmers Association (BCSFA)

PROJECT LEAD: Crawford Revie (UPEI)

PROJECT TEAM: Thitiwan Patanasatienkul (UPEI)

CONTACT: crevie@upei.ca

WEBSITE: http://www.upei.ca/avc/crawford-revie

Susceptibility of Farmed and Wild Atlantic Salmon (*Salmo salar*) to Experimental Infestations with Sea Lice (*Lepeophtheirus salmonis*)

Sea lice (*Lepeophtheirus salmonis*) are common pests on farmed Atlantic Salmon and can have large economic consequences for the salmon industry. These consequences can include treatment costs, increased mortalities, and negative public perception. Sea lice originating from aquaculture farms may also negatively impact wild stocks of salmonids, although the extent of the impact is unclear. Salmonid species have been shown to have different susceptibilities to sea lice infection. Atlantic Salmon have been shown to exhibit substantial genetic variation (in addition to phenotypic variation) in resistance to sea lice.

This project will utilize controlled sea lice laboratory infestations to determine variations in sea lice susceptibility of three groups of fish: wild salmon from two origins (Garnish River, Conne River) and farmed salmon. Results from this project will: 1) aid the aquaculture industry in understanding and monitoring any potential wild-farmed interactions to ensure sustainable production of fish; 2) better inform on potential differences in sea lice susceptibility between farmed and wild salmon; and 3) provide information on stress levels for salmonids following sea lice infestations in all groups of fish.

DATE: APR. 2015–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Cold Ocean Salmon Inc.

PROJECT LEAD: Dounia Hamoutene (DFO)

PROJECT TEAM: Harry Murray, Lynn Lush, Kimberley Burt (DFO)

COLLABORATORS: Julia Bungay (Cold Ocean Salmon Inc.)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-G-02-eng.html

The Effects of Sea Lice in Modulating Salmonid Susceptibility to Viruses

The sea louse, *Lepeophtheirus salmonis*, is a naturally occurring parasite and a serious pest of farmed Atlantic Salmon in both Eastern and Western Canada. As sea lice are found on a number of wild host species in the marine environment and co-occur with endemic viruses, mixed infections of sea lice and viruses are likely. Despite the widespread occurrence of sea lice in both wild fisheries and aquaculture, there have been no controlled studies that have explicitly examined the effect of *L. salmonis* on disease caused by viral pathogens. Sea lice infected salmon may be more likely to develop severe infections with second pathogens, either because the sea louse serves as a vector, transmitting the secondary pathogens, or because the sea louse infection compromises the host immune response. The latter possibility is supported by the observation of reduced expression of genes associated with anti-viral responses and adaptive immunity in several salmon species during laboratory infections with *L. salmonis*.

This research project will focus on two viral pathogens, the Infectious Hematopoietic Necrosis Virus (IHNV) and the Infectious Salmon Anemia Virus (ISAV). IHNV infects wild and cultured salmonids throughout the Pacific Northwest of North America. ISAV infects and causes disease in farmed Atlantic Salmon in Eastern Canada. For both viral pathogens, there is a need to better understand if sea lice parasitism influences virus transmission and susceptibility of salmon to infection. This research project addresses this issue by integrating parallel investigations into IHNV and ISAV interactions with sea lice in Western and Eastern Canada, respectively. The goal of the study is to determine level of sea lice infestation at which intervention or pest management strategies may be needed to prevent further damage from viral infection. This research will provide scientific information for management decisions regarding sea lice infestation thresholds for use in salmon aquaculture.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Simon Jones (DFO)

PROJECT TEAM: Kyle Garver (DFO)

COLLABORATORS: Mark Fast (UPEI–AVC)

CONTACT: Simon.Jones@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-P-12-eng.html

Defining the Risk of Sea Lice Infections Through the Development of an Understanding of the Early Life History Population Dynamics of Sea Lice Associated with Atlantic Salmon Aquaculture Sites in the Bay of Fundy

Sea lice continue to be a challenge for Atlantic Salmon farmers worldwide despite the development of various chemo-therapeutant treatments and advanced application measures (e.g., well boats). While some chemicals can be effective at controlling sea lice populations on the farm, they can sometimes affect other invertebrate groups and therefore need to be part of an Integrated Pest Management Plan (IPMP) that includes a variety of treatments to address various life stages of sea lice and are suited to varying environmental conditions. Nonchemical measures such as genetic selection for resistance or mechanical devices that can remove sea lice are currently being actively examined. All management techniques are ultimately premised on the ability to control the lifecycle of the sea lice from larvae to adult. However, there has been surprisingly little empirical field work done on the planktonic early life history stages of sea lice where the largest numbers of individual animals exist and the infection first spreads. This is due to the logistic difficulties of working in the field on commercial sites where production priorities take priority over scientific requirements, making it difficult to sample. Previous studies from this team conducted in the Bay of Fundy have revealed that the highest densities of sea lice larvae are consistently found around salmon farms, suggesting a specialised internal mechanism for retention. A better understanding of the early life history of sea lice in the Bay of Fundy will allow for insights on when to intervene in the lifecycle of the animal. Also, by assessing the degree to which aquaculture farms retain sea lice larvae and how they leave the site, we can begin to assess the risk to other farms and whether or not they could affect wild species in their spread.

Through this work, it may be possible to determine where the critical points are in the farming operation that may promote sea lice infestations and what may be done to reduce the infestations through protocol changes and engineering applications.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Emily Nelson, Steve Neil, Craig Smith (DFO)

COLLABORATORS: Joel Halse (Kelly Cove Salmon Ltd.)

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-M-02-eng.html

Plankton net with flow meter used to sample sea lice larvae (inset) in and around salmon farms in the Bay of Fundy. Photo: Shawn Robinson (DFO)

Development of Bacterial Biomarkers of Salmon Microbiota Mediated Resistance Against the Sea Louse *Lepeophtheirus salmonis*

Sea lice, *Lepeophtheirus salmonis*, parasitism of salmon represents an animal health issue for both wild and farmed salmon. Existing treatments are generally experiencing a loss of efficacy or variable results. Current research is exploring strategies such as vaccines, selective breeding, novel drugs, and non-chemical and biological control for the treatment, reduction, and removal of sea lice from farmed fish. This study represents a first step in developing strategies to reduce infections resulting from sea lice prevalence and sea lice landing by employing a probiotic approach.

Atlantic Salmon smolts were designated as non-exposed or exposed to a sea lice infection pressure of 40 copepodids per fish and monitored at regular time points as the sea lice developed from chalimus to large pre-adult. The mucosal and gut microbiome of salmon smolt was surveyed and population changes in response to *L. salmonis* infestation were examined. Study results suggest that sea lice infestation drives imbalances in salmon mucus microbiota, which could underlie some of the morbidity associated with sea louse infection. Principle component analysis and frequency distributions suggested that, over the course of the experiment, the sea lice exposed mucus microbiome became increasingly different over time, while water and biofilm remained similar. Although the control and treatment microbiome composition differed at the outset of the trial making strong assertions difficult, infected salmon microbiome changed more over time. This work demonstrates how a disrupted microbial community structure could allow for potential secondary infection to occur. Future research could examine ways to stabilize the community structure, reducing this risk.

This project provided a survey of the microbial ecology of farmed Atlantic Salmon. It also showed how the microbial community structure changed with respect to sea lice exposure and how the change increases with time post exposure as compared to non-infested salmon.

DATE: APR. 2013–MAR. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd. (KCS); U Laval (NSERC–Engage)

PROJECT LEAD: Steven Leadbeater (DFO)

PROJECT TEAM: Martin Llewellyn (Glasgow U); Keng Pee Ang (KCS); Nicolas Derome (U Laval)

CONTACT: Steven.Leadbeater@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/index-eng.html

Safety Assessment of an Oxygen Gas Infusion System Used During Various Hydrogen Peroxide (H_2O_2) Treatments on Atlantic Salmon (*Salmo salar*)

Numerous strategies have been developed to control sea lice infestations within the farmed Atlantic Salmon industry. Unfortunately, sea lice resistance to many chemotherapeutants has now been reported globally. Thus, the exploration of new therapeutants for sea lice is warranted and timely. Hydrogen peroxide (H_2O_2) has been used in combination with other products (e.g., SLICE, Salmosan) as part of a sea lice integrated pest management plan, but there are concerns regarding fish welfare when temperatures are high (>14°C) and fish are excessively stressed during treatment. One solution to minimize fish stress during treatment is to increase the dissolved oxygen saturation (via the GIS Gas Infusion System Transport Module) in the surrounding water, thereby creating a slight narcosis among the treated fish.

The Huntsman Marine Science Centre (HMSC) is currently evaluating the safety and efficacy of using a gas infusion system (to create 150% ± 10% O_2 saturation while maintaining total gas pressure of 100%) when exposing Atlantic Salmon to H_2O_2 at varying treatment dosages (0-1500 ppm and exposure times 15-40 mins). Subsequent investigations will explore: 1) histological analysis of cellular and tissue-level sub-lethal effects; 2) additional dosages and exposure times; 3) the impact of using freshwater (e.g., bath treatment for amoebic gill disease, AGD); 4) the effect of various environmentally relevant temperatures; and 5) sea lice removal efficacy. Initial results are encouraging, with no ill-effects observed on commercially-sized salmon exposed to H_2O_2 dosages and exposure times that reflect industry practices.

This research is innovative and quite timely. New strategies to mitigate sea lice infestations, especially those that will have minimal to no impact on fish welfare, are needed globally.

DATE: JAN. 2017–ONGOING

FUNDED BY: GIS Gas Infusion Systems Inc.

CO-FUNDED BY: New Brunswick Innovation Foundation (NBIF)

PROJECT LEAD: Duane Barker (HMSC)

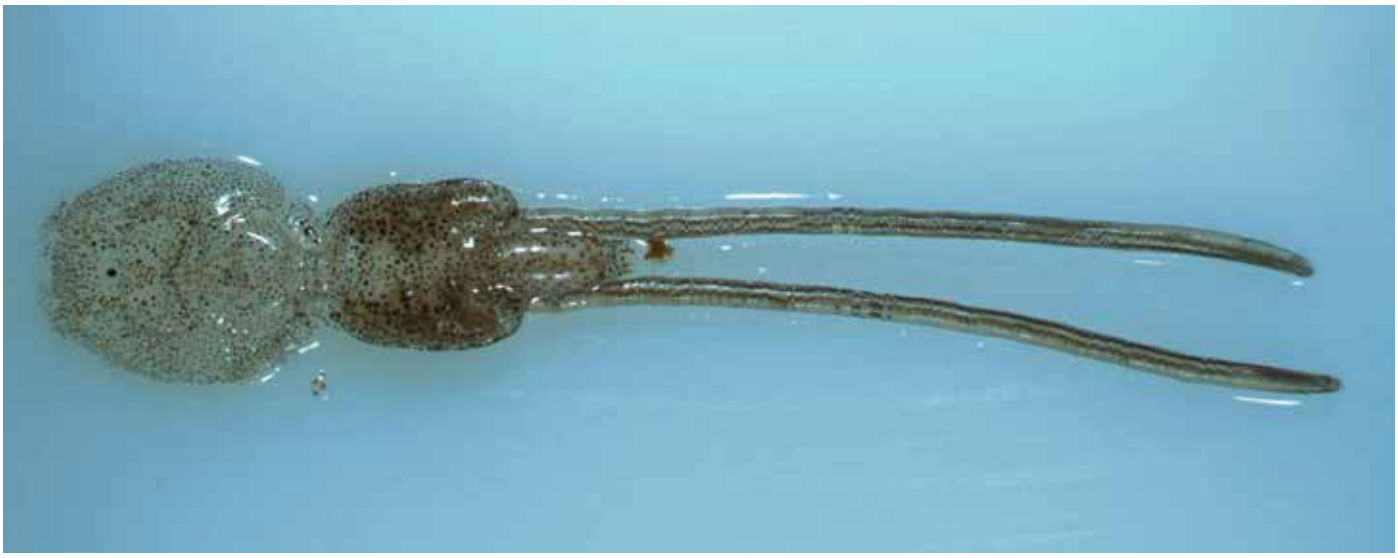
PROJECT TEAM: Anne McCarthy, Chris Bridger, Rebecca Eldridge, Esther Keddie, Ellen Fanning (HMSC)

COLLABORATORS: Mike Beattie (GIS Gas Infusion Systems Inc.)

CONTACT: Duane.Barker@huntsmanmarine.ca

WEBSITE: http://www.huntsmanmarine.ca/

Developing a Non-Chemical Means to Effectively Remove All Forms of Sea Lice from Aquaculture Salmon Using Warm Water



An adult egg-bearing female (gravid) of the salmon sea lice (*Lepeophtheirus salmonis*) removed using a warm water shower from an adult salmon. Photo: Shawn Robinson (DFO)

The sea louse (*Lepeophtheirus salmonis*) remains a global challenge for salmon farming, with considerable resources expanded to manage this pest. Sea lice are becoming resistant to many of the traditional treatment chemicals which are also lethal to non-target organisms. Consequently, many non-chemical alternative treatments are being tested, including predators (cleaner-fish), traps (physiological or biological), and physical exclusion devices (nets, electrical fields).

A promising technique uses warm water showers to remove all attached stages of sea lice and prevent the detached sea lice from being returned to the ocean. This project aims to develop protocols for safe and effective showers to remove sea lice from Atlantic Salmon, and to understand why it works. Research results are expected to provide the required information for ongoing modification of the commercial sea lice warm water shower device, as well as inform sea lice management strategies.

Specifically, the following results were found:

- The use of a warm water shower will remove over 95% of all attached mobile stages of the sea lice at temperatures over 30°C.
- Mortality rates of fish going through the treatment are close to 0% for healthy fish, but slightly higher for fish that are in poor condition due to heavy infections.
- A small amount of surface mucus from the fish is removed during the process, but this is not significant.
- Lower salinities of the treatment water do not improve the removal efficiency.
- A technique was developed to quickly and easily quantitatively measure the mucus layer on a fish without harming the animal.

Developing a new, environmentally benign treatment option for industry will significantly increase the sustainability of the sector. The research is being done in close hands-on collaboration with the industry's design engineers, healthcare professionals, and farm staff. The results are being applied to the next generation commercial prototype that is currently being designed.

This project supports the DFO objectives of environmental performance and optimal fish health.

DATE: JUN. 2014–JUN. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd. (KCS)

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Steve Neil, Craig Smith (DFO); Joel Halse (KCS)

COLLABORATORS: Keng Pee Ang (KCS)

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/M-14-02-001-eng.html

An Investigation of the Relationship Between Environmental Parameters, Oceanographic Zones of Influence, and the Prevalence of Parasitic Copepods on Three-Spine Stickleback in Bay D'Espoir Newfoundland with Specific Reference to Salmonid Aquaculture Sites

Sea lice infestation has increased with farmed salmon expansion in Newfoundland and Labrador's Bay D'Espoir and Fortune Bay. The gill louse (*Ergacilus labracis*) was the most abundant sea lice species observed, but their impact on farmed salmonids has not yet been characterized. This study investigates the potential correlation between the distribution of sea lice on Three-Spine Stickleback and farmed salmonids in the region.

The results of this research will help provide information on the potential of wild non-salmonid fish species to act as sea lice reservoirs (with the potential to re-infect farmed fish), as well as a potential predictor of infestation levels in Bay Management Areas. The bays investigated in this study are defined by specific environmental conditions which can dictate how the sea lice community is partitioned. This study is one of the first to draw correlations between environmental conditions and sea lice ecology in the region.

This project supports the DFO objective of optimal fish health. Specifically, the following results were found:

- These bays can be divided in distinct zones based on environmental conditions.
- These zones are characterized by distinct populations of sea lice.
- Upper Bay D'Espoir is defined primarily by the presence of the parasite *Ergasilus labracis* and its relationship with Three-Spine Stickleback.
- Upper Hermitage Bay region is defined by the presence of the parasite *Lepeophtheirus salmonis* and its relationship with farmed Atlantic Salmon.
- The ecological needs of these different species likely act as partial biological barriers to their successful movement across zones.

Further monitoring is necessary to track the status of each parasite and continued diligence on the part of industry will be required to successfully manage the parasites prominent in each region.

DATE: JUL. 2014–MAR. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Cold Ocean Salmon Inc.

PROJECT LEAD: Harry Murray (DFO)

PROJECT TEAM: Andry Ratsimandresey, Alexandra Eaves, Sebastien Donnet, Dwight Drover, Sharon Kenny (DFO); Keng Pee Ang (Cold Ocean Salmon Inc.)

COLLABORATORS: Cold Ocean Salmon Inc.

CONTACT: Harry.Murray@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/N-14-02-001-eng.html

Studies of Sea Lice Infection Levels on the Health of Juvenile Salmon in the Strait of Georgia and Adjacent Waters

To assess risk associated with sea lice and microbe transfer between farmed and wild salmon, we have undertaken a detailed study on the: 1) migratory pathways of wild salmon and the duration of their residency in the vicinity of fish farms; 2) the prevalence of pathogens and diseases within wild and farmed populations; and 3) the overall physiological well-being and health of wild populations as this impacts their susceptibility to infection. Using net-based surveys we have examined the duration of juvenile Fraser River Sockeye Salmon residency within the Strait of Georgia, as well as in the vicinity of salmon farms in the Discovery Islands. We have found that the majority of juvenile Fraser River Sockeye Salmon pass through the Discovery Islands over a two to three week period in early to mid-June. *Caligus clemensi* was the dominant species of sea lice present, but was in low abundance on juvenile salmon, Pacific Herring, and Three-spined Sticklebacks. There was no significant increase in the numbers of sea lice on juvenile salmon in the vicinity of salmon farms in the Discovery Islands. Infections with the Hematopoietic Necrosis Virus (IHNV) and the parasites *Parvicapsula minibicornis* and *Myxobulus articus* have been seen in samples collected in the lower Fraser River and throughout the Strait of Georgia. The prevalence of infection of these agents is highly variable among years and stock of origin. We have neither found Piscine Orthoreovirus (PRV) nor *Renibacterium salmoninarum* in any of the fish that we tested.

DATE: APR. 2010–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR); DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP); Pacific Salmon Commission (PSC)

PROJECT LEADS: Stewart Johnson, Marc Trudel (DFO)

PROJECT TEAM: Chrys Neville, Kyle Garver, Simon Jones (DFO)

CONTACT: Stewart.Johnson@dfo-mpo.gc.ca, Marc.Trudel@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2010-P-02-eng.html

Refining the Use of Warm Water Showers to Remove Sea Lice from Atlantic Salmon and Understanding the Fish Health Implications of the Technique

Considerable effort is expended (via chemo-therapeutants and animal husbandry practices) to manage parasitic infections by the sea louse, *Lepeophtheirus salmonis*, a globally acknowledged challenge for salmon farmers. The parasite is gaining resistance to treatments and new approaches are urgently needed. Recent research suggests that any technique must remove parasites from fish and also control the release of larvae and mobile parasitic stages within the farm which seem to contribute to the magnification of the infection cycles on the salmon leases for Southwest New Brunswick.

Over the last two years, a new technology was introduced to salmon farming in the Bay of Fundy in which salmon were exposed to a warm water shower. Through a series of laboratory and field trials, this technology was found to be very effective at removing mobile stages of sea lice (over 90%) and was able to retain virtually all of the removed sea lice, preventing them from being reintroduced into the water column near the salmon cages and re-infecting the fish. This project will refine and build on the results gathered from previous research through investigations on the effect of fish health on the efficiency of removal as well as the dynamics of the removal process itself.

Adding a new, environmentally benign treatment option for industry will significantly increase the sustainability of the sector and reduce the substantial investment in management controls by the regulatory sector. The research will be done in close hands-on collaboration with the industry's design engineers, healthcare professionals, and farm staff. The results will be immediately applied to the next generation commercial prototype currently being designed.

This project supports the DFO objectives of environmental performance and optimal fish health.

Testing the efficiency of the lab-based model of the warm water shower in the field with industry partners in the Bay of Fundy. Photo: Shawn Robinson (DFO)

DATE: JUL. 2016–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd. (KCS)

PROJECT LEAD: Shawn Robinson (DFO)

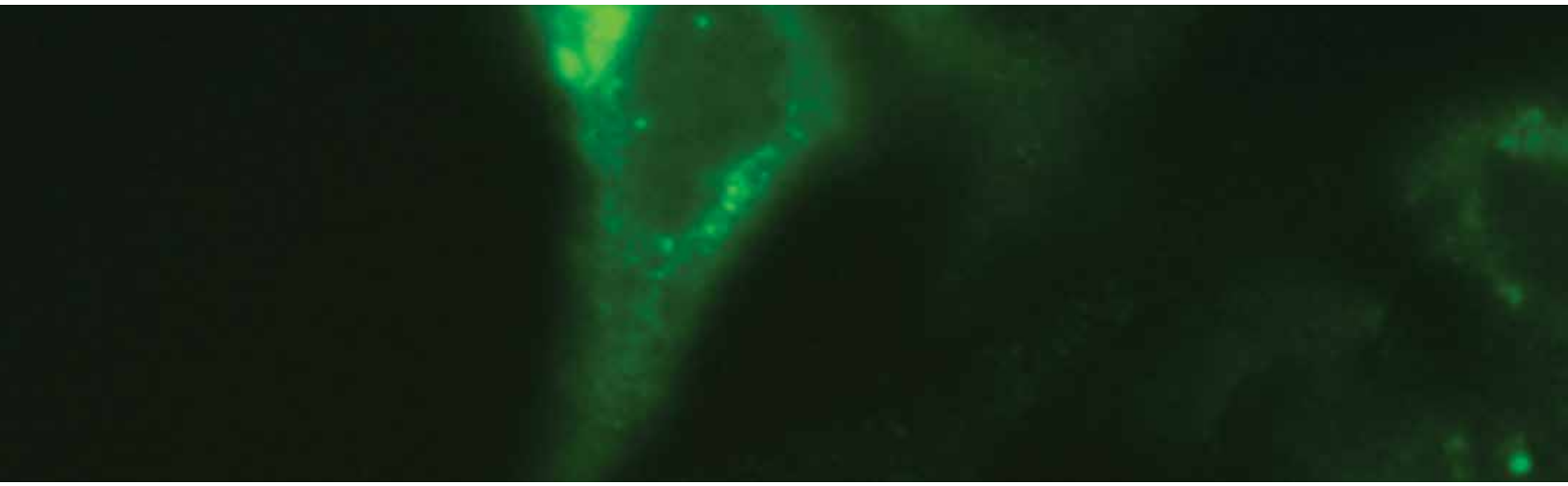
PROJECT TEAM: Steve Neil, Craig G. Smith (DFO); Joel Halse (KCS)

COLLABORATORS: Keng Pee Ang (KCS); Duane Barker (HMSC)

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-M-01-eng.html

FISH HEALTH



Study of Genomic Diversity in *Aeromonas salmonicida*, the Etiological Agent that Causes Furunculosis, to Establish its Resistome, Epidemiological Markers, and Potential Treatments

The Effect of Dietary Camelina Oil on the Health of Salmon

Prophylactic Effect of *Haslea ostrearia* Culture Supernatant Containing the Pigment Marennine Against the Pathogenic Bacteria *Vibrio splendidus* in Bivalve Hatcheries

Investigating Probiotic Bacteria and Their Bacteriocins as Part of a Disease Management Strategy in Salmon Aquaculture

The Effects of Smolt Size on the Intensity of *Kudoa thyrsites* Infections in Atlantic Salmon

Comparison of Field Isolates of *Moritella viscosa*: Characterization and *in Vivo* Challenge Model Development to Address Winter Ulcer Mitigation in Canada

Estimating the Potential for Waterborne Transmission of Infectious Haematopoietic Necrosis (IHN) Disease between Salmon Farms and Wild Sockeye Salmon in the Discovery Islands, British Columbia

Optimizing the Fish Health Reporting and Data Management System

Screening of Cultured Atlantic Salmon for Resistance and Susceptibility to Infection by Sea Lice (*Lepeoptheirus salmonis*) and *Renibacterium salmoninarum*, the Causative Agent of Bacterial Kidney Disease (BKD)

Microbial Impacts on Shellfish Aquaculture in Relationship to Ocean Acidification

Low Pathogenic Infectious Salmon Anemia Virus (ISAV) *in Vivo*: A Comparative Genomic Study

The Effects of Prior Exposure and Body Size on the Intensity of *Kudoa thyrsites* Infections in Farmed Atlantic Salmon

Net Pen Liver Disease Project–Developing a Fluorescent Antibody Test to Prove the Causative Agent

Improving the Survival, Health, Quality, and Food-Safety of Post-Transported Tilapia and Barramundi

Piscine Reovirus (PRV): Characterisation, Atlantic Salmon Susceptibility, and Initial Survey in Farmed and Wild Salmonids in Atlantic Canada

Salmon Gill Poxvirus-Like (SGPV-Like): Characterisation, Atlantic Salmon Susceptibility, and Initial Survey in Farmed and Wild Salmon

Description of Oceanographic Conditions within Hermitage Bay, Newfoundland, at Sites with and without the Occurrence of an ISA Outbreak

Investigations into Ulcerative Skin Disease Agents, *Moritella viscosa* and *Tenacibaculum* spp. in Atlantic Salmon: Interactions and *in Vivo* Challenge Development

Cyprinid Herpes Virus 3 (CyHV-3) in Wild Common Carp (*Cyprinus carpio* L.) in Manitoba, Canada

Marine Reservoirs of Infectious Agents Associated with Proliferative Gill Disorders in Farmed Salmon

Pathogen Susceptibility of Sockeye Salmon–Phase 1: Infectious Salmon Anemia Virus (ISAV) and Salmon Alphavirus (SPDV or SAV)

The Transfer Potential of Fish Pest and Pathogen from Farmed to Wild Salmon: Stocking Density Effect

Reverse Transcription Quantitative Polymerase Chain Reaction (RT-qPCR) Assays For Detection of Spring Viremia of Carp Virus–Phases IV and V Diagnostic Validation

Marine Reservoirs of Infectious Agents Associated with Proliferative Gill Disorders in Farmed Salmon

Epidemiological Analysis and Modelling of Aquatic Pathogens

Diagnostic Validation of Three Test Methods for Detection of Cyprinid Herpesvirus 3

Physiological Consequences of Piscine Orthoreovirus (PRV) Infection of Atlantic and Pacific Salmonids

Does Infection with Piscine Reovirus (PRV) Affect How Salmon Respond to Challenge with Infectious Hematopoietic Necrosis Virus (IHNV)?

Addressing the Question of Sturgeon Nucleo-Cytoplasmic Large DNA Virus (sNCLDV) Systematics

Stage 1 Validation of Real-Time PCR (qPCR) Assay for the Detection of *Bonamia* spp.

Development and Diagnostic Validation of a qPCR Assay to Detect *Mikrocytos mackini* and its Application in Understanding the Transmission Risks and General Biology of the Pathogen

Effects of Pooling Animals on the Probability of Detection: MSX and ISAV

Identification of Vectors of MSX to Support Introductions and Transfers Decisions Related to Inter-Provincial Movements of Mussels: Is Mussel Intra-Valvular Liquid a Vector for MSX Transmission?

Effect of Water Temperature on the Immune Response of American Lobster (*Homarus americanus*) Experimentally Infected with White Spot Syndrome Virus

Developing a Genomics Tool (FIT-CHIP) for In-Season Information on Salmon Health

Susceptibility of Sockeye Salmon to Viral Hemorrhagic Septicemia Virus

Epidemiology of Ulcer Disease in Salt Water Atlantic Salmon

Infectious Salmon Anemia Virus Susceptibility and Health Status of Wild Versus Farmed Atlantic Salmon: A Comparative Study

Rapid Detection of Replicating Infectious Salmon Anemia Virus (ISAV)

Disease and Parasite Resistance Genomics in a Commercial Strain of North American Atlantic Salmon

Development of Artificial Reference Material for Assessing IHNV and VHSV RT-qPCR Assays

Study of Genomic Diversity in *Aeromonas salmonicida*, the Etiological Agent that Causes Furunculosis, to Establish its Resistome, Epidemiological Markers, and Potential Treatments

The *Aeromonas salmonicida* bacterium is the infectious agent that causes furunculosis in salmonids (salmon, trout, Arctic Charr, etc.). Controlling this disease, which is very harmful to the aquaculture industry, can prove to be quite demanding and fruitless, mainly due to the logistic constraints of the vaccination and the very frequent resistance of *A. salmonicida* to several antibiotics. We are therefore studying the genomic diversity of *A. salmonicida* to better understand its virulence and its antibiotic resistome (all genes conferring resistance to antibiotics). Through familiarization with this diversity, tools and alternative treatments for preventing or curing furunculosis can be created. In concrete terms, we are developing a kit for quickly diagnosing antibiotic resistance. We are also studying the action of mobile DNA elements in the evolution, host adaptation, and geographic distribution of *A. salmonicida*, and their potential activation by various treatments, including the effect of certain essential oils, with a view to developing a treatment. It is also our intent to verify the potential of bacteriophages (viruses that infect bacteria) as a cure for furunculosis. It is a recurrent disease, hard to control and, as such, all of these approaches must be considered.

Increased knowledge of the pathogen, *A. salmonicida*, will aid Canadian aquaculture productivity while enabling fish farmers to: 1) make appropriate use of antibiotics during treatment; 2) better track the pathogen's location; and 3) suggest alternatives to antibiotics as treatment. Ultimately, our work will offer an integrated approach to follow, control, and treat *A. salmonicida* infections.

DATE: NOV. 2012–MAR. 2019

FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)

CO-FUNDED BY: Ressources Aquatiques Québec (RAQ); Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)

PROJECT LEAD: Steve Charette (U Laval)

PROJECT TEAM: Antony Vincent, Valérie Paquet, Katherine Tanaka, Sabrina Attéré, Alex Bernatchez, Mélanie Trudel, Jean-Guillaume Edmond-Rheault (U Laval)

COLLABORATORS: Nicolas Derome, Michel Frenette, Sylvain Moineau (U Laval); Andrée Lafaille (UdeM)

CONTACT: steve.charette@bcm.ulaval.ca

WEBSITE: www.amibe.org

The Effect of Dietary Camelina Oil on the Health of Salmon

Traditional salmon feeds use high levels of fishmeal and fish oil to meet the nutritional needs of the fish, but these ingredients face large fluctuations in price and availability. Lower-cost alternatives have been investigated, including canola oil, soy oil, and poultry fat. Oil from the plant species *Camelina sativa* is another promising option that is already able to replace fish oil in diets for Atlantic Cod, Atlantic Salmon, and Rainbow Trout with little or no reduction in growth or feed efficiency. However, substitution of dietary fish oil with vegetable oils (such as Camelina oil) in fish feed may elicit inflammatory changes due to the different fatty acid profiles. There are limited data available on changes to the gut, and no data for vegetable oil's health effects on Chinook Salmon.

This project seeks to examine the influence of fish oil substitution by Camelina oil on susceptibility to intestinal inflammation of Chinook Salmon under culture conditions. Inflammation is energetically demanding and stressful, thus influencing disease resistance. By using Camelina oil to trigger gut inflammation in Chinook Salmon, results from this project will increase knowledge and understanding of these effects in order to develop better management practices surrounding disease impacts on cultured finfish species.

START DATE: SEP. 2015–OCT. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Creative Salmon Co. Ltd.

PROJECT LEAD: Ian Forster (DFO)

PROJECT TEAM: Simon Jones (DFO); Marije Booman (UVic); Barb Cannon, Tim Rundle (Creative Salmon Co. Ltd.); Jack Grushcow (Linnaeus Plant Sciences Inc.); Brad Hicks (Taplow Ventures, Ltd.)

COLLABORATORS: Barb Cannon, Tim Rundle (Creative Salmon Co. Ltd.)

CONTACT: Ian.Forster@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-2-P-03-eng.html

Prophylactic Effect of *Haslea ostrearia* Culture Supernatant Containing the Pigment Marennine Against the Pathogenic Bacteria *Vibrio splendidus* in Bivalve Hatcheries

A primary requisite in any shellfish culture or farming operation is an abundant, reliable, and inexpensive supply of juveniles. Hatchery-produced seed is increasingly becoming the standard raw material for aquaculture. However, repeated bacterial infections result in heavy mortalities, causing major losses and great expenses for shellfish growers. This project explores the possibility of using the supernatant of cultured diatoms (*Haslea ostrearia*) containing marennine, a natural microalgal pigment, as an antimicrobial agent in bivalve hatcheries. The Blue Mussel (*Mytilus edulis*) and the Sea Scallop (*Placopecten magellanicus*) were used as model animals, and the pathogenic marine bacteria, *Vibrio splendidus*, was used to induce larval mortality. The hypothesis tested was that *V. splendidus* pathogenicity in larval rearings can be controlled by using marennine-containing culture supernatants. The effect of three marennine concentrations was tested on a larval rearing over 20 days for *M. edulis* and 9 days for *P. magellanicus*. At a low dose (0.1 mg/L), survival and physiological condition were both higher than in the control. In bacterial challenges, larvae were exposed to *V. splendidus* for 72 hours, with or without marennine. The bacterial challenge caused significant mortality when compared to control, while the marennine-treated larvae showed a significantly higher survival. The results show that marennine is an interesting molecule for pathogen control in hatcheries as it is active at low concentrations and can significantly enhanced larval survival and physiological condition.

DATE: MAY 2013–FEB. 2016

FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)

CO-FUNDED BY: Ressources Aquatiques Québec (RAQ); Fermes Marines Inc.

PROJECT LEAD: Réjean Tremblay (UQAR–ISMER)

PROJECT TEAM: François Turcotte, Bertrand Genard, Karine Lemarchand, Réjean Tremblay (UQAR–ISMER); Jean-Luc Mouget (U Maine); Jean-Sébastien Deschênes (UQAR)

CONTACT: Rejean_Tremblay@uqar.ca

Investigating Probiotic Bacteria and Their Bacteriocins as Part of a Disease Management Strategy in Salmon Aquaculture

On salmon farms, diseases caused by bacterial infections are managed by minimizing the risk of exposure to pathogens, vaccination, and ensuring the availability of sufficient high quality water and feed. There are concerns regarding the effectiveness and long term sustainability of using antibiotics to treat bacteria, so to help further reduce antibiotic use, this study focused on the therapeutic potential of probiotics in aquaculture.

Probiotic bacteria can enhance the immune system of the fish, and can change the composition of the intestinal microbiota, which function in overall fish health. Probiotic bacteria may also secrete antimicrobial compounds that kill other bacteria, including fish pathogens. This project used probiotic bacteria and antimicrobials with activity against common salmon pathogens, and evaluated their application as feed additives to improve fish health.

This project supports the DFO objective of optimal fish health.

Specifically, this project found the following results:

- *Paenibacillus terrae* and *Paenibacillus polymyxa* showed antimicrobial activity against five salmon pathogens. *P. terrae* was selected for further trials as it showed a stronger activity.
- There was no evidence that the probiotic diets caused a reduction in feed attraction or appetite.
- No significant effect of the probiotic diets was found on the survival rate of salmon after exposure to the pathogen *Vibrio anguillarum*.
- *P. terrae* survived in salmon intestines but did not colonize the gut.
- The results suggested that the live *P. terrae* diet may cause changes in the abundance and/or the diversity of the intestinal microbiota. This is currently being examined in more detail.
- Increased knowledge of the effect of *P. terrae* on fish health will help determine its suitability as a therapeutic probiotic feed additive for salmon, which will benefit the aquaculture industry.

DATE: APR. 2014–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Mainstream Canada (Cermaq Canada Ltd.); Marine Harvest Canada Limited

PROJECT LEAD: Simon Jones (DFO)

PROJECT TEAM: Marije Booman, Steve Cho (DFO)

COLLABORATORS: Peter McKenzie (Mainstream Canada (Cermaq Canada Ltd.)); Diane Morrison (Marine Harvest Canada Limited)

CONTACT: Simon.Jones@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-14-01-003-eng.html

The Effects of Smolt Size on the Intensity of *Kudoa thyrsites* Infections in Atlantic Salmon

Atlantic Salmon infected with *Kudoa thyrsites* do not exhibit clinical signs of disease. However, protease secretion from this parasite rapidly deteriorates affected muscle in the salmon when the fillet is processed, resulting in economic loss for the grower. Earlier research suggested the risk of *K. thyrsites* was reduced when salmon were transferred to sea as larger smolts. This research project involves a more robust test of the size hypothesis by conducting trials that examine how smolts of a range of size classes respond to exposure to the *K. thyrsites* parasite.

The results of this project may help to improve the competitiveness of the Canadian salmon aquaculture industry by assessing a problem that greatly affects the marketability of Atlantic Salmon produced in British Columbia.

An understanding will be gained in the relative importance of fish size (smolts) in influencing the development of *K. thyrsites*. Data obtained from the project will help inform *K. thyrsites* management strategies.

START DATE: OCT. 2015–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Marine Harvest Canada Limited; Cermaq Canada Ltd.

PROJECT LEAD: Simon Jones (DFO)

COLLABORATORS: Diane Morrison (Marine Harvest Canada Limited); Kathleen Frisch (Cermaq Canada Ltd.)

CONTACT: Simon.Jones@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-2-P-01-eng.html

Comparison of Field Isolates of *Moritella viscosa*: Characterization and *in Vivo* Challenge Model Development to Address Winter Ulcer Mitigation in Canada

The bacteria *Moritella viscosa* is associated with cold-water ulcer disease in farmed Atlantic Salmon at sea. Over the past decade, skin ulcers have also been noted in warmer water in Eastern Canada. The role of *M. viscosa* remains unclear due to its infrequent recovery from summer ulcers, however, suspicion of its involvement persists. At the onset of this research, there was no vaccine for ulcer disease based on Canadian isolates. Salmon producers had limited tools to manage this disease, and though commercial vaccines used in Europe existed, no information existed with regard to their efficacy against Canadian isolates.

For this project, Canadian field isolates were collected and characterized by establishing *in vitro* growth curves at different temperatures. Differences in protein profiles and immunogenic proteins through gel electrophoresis and Western blotting methods were examined. Ultimately, the characterization steps allowed for the development of an *in vivo* challenge model using an isolate of adequate virulence with appropriate culturing and challenge exposure methodologies. When employed at 8°C, the model was successful in inducing lesions consistent with clinical cold-water sores found on sea cage Atlantic Salmon. In addition, the live challenge model also verified that a recent Atlantic isolate, originating from a summer ulcer field case, was virulent at 12°C and caused lesions in unvaccinated animals at this warmer temperature. Diagnostically, *M. viscosa* can be recovered by bacteriology with a high success rate from all stages of lesions present on challenged fish. The developed challenge model can be used for evaluating and developing potential commercial vaccines and was shown to be an excellent model for the study of ulcerative disease progression.

DATE: AUG. 2014–MAR. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Cooke Aquaculture Inc.; Novartis Animal Health Canada Inc.

PROJECT LEAD: Steven Leadbeater (DFO)

PROJECT TEAM: Anthony Manning (RPC); Leighanne Hawkins (Cooke Aquaculture Inc.); Allison MacKinnon (Novartis Animal Health Canada Inc.)

CONTACT: Steven.Leadbeater@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/M-14-01-003-eng.html

Estimating the Potential for Waterborne Transmission of Infectious Haematopoietic Necrosis (IHN) Disease between Salmon Farms and Wild Sockeye Salmon in the Discovery Islands, British Columbia

Infectious Haematopoietic Necrosis Virus (IHNV) is responsible for major economic losses in British Columbia salmon aquaculture operations. Viral transmission patterns and oceanographic circulation models for the Discovery Islands region provide estimates for the potential of IHNV outbreak and spread to neighbouring farms.

This study quantified the transmission potential of IHN disease between farms and wild Sockeye Salmon. It also determined the capacity of vaccinated Atlantic Salmon and IHNV-carrying Sockeye Salmon to transmit the virus to naïve hosts (ones who have never before been infected).

Specifically this project found the following results:

- Neighbouring naïve farms can become infected via waterborne transmissions. Adherence to the stringent disease management practices (such as immediately quarantining an infected farm site) reduces transmission of infectious doses to other farms.
- The model simulations demonstrated that using commercially available IHN vaccines greatly reduces the risk of transmission by lowering the overall number of susceptible fish. It also reduced the virus shedding capacity of the vaccinated farm population if it were to become infected with IHNV. To date, vaccinated farmed Atlantic Salmon populations have not developed IHN disease, while unvaccinated populations have been declared INHV positive.
- With some modifications, the modelling tools can be applied to other diseases and to simulate transmission from farmed to wild populations and vice versa. It will be possible to estimate the risk of infection for fish swimming in proximity to diseased farms and assess the relative effectiveness of disease and farm management practices such as vaccination, quarantine, depopulation, and determining optimal locations for aquaculture sites.

Aerial photo of the Discovery Islands in British Columbia. Photo: Kyle Garver (DFO)

DATE: JUN. 2013–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Marine Harvest Canada Limited; Grieg Seafood BC Ltd.; Mainstream Canada (Cermaq Canada Ltd.)

PROJECT LEAD: Kyle Garver (DFO)

PROJECT TEAM: Mike Foreman, Darren Tuele, Ming Guo, Dario Stucchi, Peter Chandler (DFO)

COLLABORATORS: Diane Morrison (Marine Harvest Canada Limited); Barry Milligan (Grieg Seafood BC Ltd.); Peter McKenzie (Mainstream Canada (Cermaq Canada Ltd.))

CONTACT: Kyle.Garver@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-13-01-001-eng.html

Optimizing the Fish Health Reporting and Data Management System

The Centre for Coastal Health (CCH) is conducting a utility assessment of the current BC Salmon Farmers Association (BCSFA) fish health database, which houses fish health data contributed by industry members from 2001-2016. The results of the utility assessment will be used to determine how the database can be used to generate useful fish health information for BCSFA members and other stakeholders, including the public. The CCH is also developing a portfolio of fish health reports from data contained within the database.

The overall objectives of this project are to: 1) understand fish health information and accessibility needs, and to determine the uses and limitations of the BCSFA fish health database; 2) design new fish health reports from the BCSFA database that assist farm management and aid in communications; and 3) identify changes that could be made to the database to expand its utility.

The current fish health database functions as a repository of data, from which limited analysis can be conducted. The outcomes from this project should improve the functionality of the database, and enable improved reporting of fish health events.

DATE: APR. 2015–MAR. 2016

FUNDED BY: BC Salmon Farmers Association

PROJECT LEAD: Carl Ribble (CCH)

PROJECT TEAM: Tyler Stitt, Theresa Burns, Stefan Iwasawa (CCH)

COLLABORATORS: Kyle Garver (DFO)

CONTACT: carl.ribble@gmail.com

WEBSITE: www.centreforcoastalhealth.ca

Screening of Cultured Atlantic Salmon for Resistance and Susceptibility to Infection by Sea Lice (*Lepeoptheirus salmonis*) and *Renibacterium salmoninarum*, the Causative Agent of Bacterial Kidney Disease (BKD)

While vaccination is one approach to impart disease resistance, there is significant variation among Atlantic Salmon in terms of vaccine responsiveness. It is imperative to assess the genetic stocks of salmon for their robustness against disease.

This research project will test family crosses of farmed salmon for resistance to *Lepeoptheirus salmonis* (sea lice) and *Renibacterium salmoninarum* (the causative agent of Bacterial Kidney Disease, BKD). Testing of more than one disease agent (in this case, *L. salmonis* and *R. salmoninarum*) will help assess what resistance to one agent type may mean for resistance to another common agent. Information resulting from this project will aid in broodstock selection with the goal of enhancing resistance of farmed fish to both sea lice and BKD infections. This will serve to reduce losses to farmed fish and improve the sustainability of the Canadian aquaculture industry.

Post mortem examination of salmon from *Renibacterium salmoninarum* exposure challenge. From foreground Melissa Holborn (U Guelph), Steven Leadbeater, and Ann Kinney (DFO). Photo: Cindy Hawthorne (DFO)

DATE: SEP. 2015–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd. (KCS)

PROJECT LEAD: Steven Leadbeater (DFO)

PROJECT TEAM: Keng Pee Ang (KCS); Jake Elliott, Frank Powell (Cooke Aquaculture Inc.); Anthony Manning (RPC)

COLLABORATORS: Keng Pee Ang (KCS)

CONTACT: Steven.Leadbeater@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-M-01-eng.html

Project team members collecting gravid female sea lice on a harvest boat. Egg strings will be hatched to be used in exposure challenges. Clockwise from top left, Cindy Hawthorne, Steven Leadbeater (DFO), and Melissa Holborn (U Guelph). Photo: DFO

Cindy Hawthorne (DFO) collecting samples from fish following a sea lice exposure challenge. Photo: Melissa Holborn (U Guelph)

Microbial Impacts on Shellfish Aquaculture in Relationship to Ocean Acidification

Ocean acidification (characterized by high dissolved carbon dioxide (pCO_2) levels) can affect shellfish fertilization rates, hatching success, larval development, shell deformation, seed production, and survival. However, it is not clear whether high pCO_2 levels alone are responsible for poor performance in some West Coast shellfish operations. While hatcheries have successfully controlled levels of pCO_2 for larval and nursery production through the use of buffering systems, there have continued to be high variations in batch to batch survival. This suggests that other uncontrolled aspects of the seawater composition during high pCO_2 events may be at play, most notably bacterial compositions. Researchers are applying a metabarcoding approach to assess the shifts in bacterial community composition that occur in sea water coming into a Pacific Northwest shellfish hatchery, post pCO_2 buffering, and throughout larval culture and comparing bacterial compositions in larvae and water between batches of good and poor performance. Ultimately, the project will identify the degree to which initial pCO_2 levels impact bacterial communities of cultured shellfish and identify whether certain bacterial species are more common in seed batches demonstrating poor survival.

The knowledge obtained through this research will be useful in the development of a mitigation strategy to reduce the impact of ocean acidification on the shellfish industry on Canada's West Coast. Additionally, the identification of factors that contribute to farmed shellfish mortality may lead to the development of monitoring tools. This would ultimately assist the industry in enhancing environmental sustainability and economic viability of shellfish aquaculture.

This project supports the DFO objective of optimal fish health.

DATE: JUN. 2014–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Island Scallops Ltd.; Fanny Bay Oysters Ltd.

PROJECT LEAD: Kristi Miller-Saunders (DFO)

COLLABORATORS: Barb Bunting, Rob Saunders (Island Scallops Ltd.); Brian Yip (Fanny Bay Oysters Ltd.)

CONTACT: Kristi.Saunders@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-14-02-001-eng.html

Low Pathogenic Infectious Salmon Anemia Virus (ISAV) *in Vivo*: A Comparative Genomic Study

Infectious Salmon Anaemia (ISA) is a threat to the salmon aquaculture industry. This study investigated different Infectious Salmon Anemia Virus (ISAV) strains with varying degrees of virulence (harmful effects). The virus was observed *in vivo* in Atlantic Salmon and the infectious potential of surviving/carrier fish was evaluated. Tested fish showed significant differences in susceptibility. Specifically, this project found the following results:

- Fish exposed to a low pathogenic ISAV had detectable viral RNA in their tissues 18 months past exposure.
- Fish surviving a high pathogenic ISAV returned to a near negative state rapidly after the end of mortalities, but are also potential long term carriers of ISAV.
- Low pathogenic ISAV can be transmitted horizontally and create a state similar to "herd immunity", where a proportion of fish were exposed and are thus naturally immune to ISAV infections, thus reducing the risk of an outbreak caused by a virulent ISAV. Still, those fish could continue to transmit infections due to their long term carrier state.
- Low virulence ISAV strains showed little to no fish mortalities, thus confirming observations in the field about their low pathogenicity.
- The high virulence ISAV strains produced between ~40% and 80% mortalities. The differences in observed mortality using this strain shows the possibility of selecting fish with specific genotypes that might be associated with favourable traits such as disease resistance, which is beneficial for breeding programs and the aquaculture industry.

DATE: DEC. 2011–JUN. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd. (KCS)

PROJECT LEAD: Nellie Gagné (DFO)

PROJECT TEAM: Francis Leblanc, Steven Leadbeater, Mélanie Roy, Mark LaFlamme (DFO)

COLLABORATORS: Keng Pee Ang (KCS)

CONTACT: Nellie.Gagne@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/MG-11-01-004-eng.html

Necropsy of Atlantic Salmon to detect the presence of Infectious Salmon Anemia. Photo: (DFO)

Atlantic Salmon infected with Infectious Salmon Anemia–operculum removed to show pale gills. Photo: Nellie Gagné (DFO)

The Effects of Prior Exposure and Body Size on the Intensity of *Kudoa thyrsites* Infections in Farmed Atlantic Salmon

The parasite *Kudoa thyrsite*s is the cause of soft-flesh syndrome in post-harvest Atlantic Salmon farmed in British Columbia. Infected fish exhibit no clinical signs of disease, but affected muscle deteriorates after processing depending on the severity of infection. The industry in BC is subject to substantial economic loss because of *Kudoa*-associated changes to fillet quality. Currently, there are no vaccines or approved strategies for treatment for *K. thyrsites*.

This study investigated three management options for *K. thyrsites* infections:

- The efficacy of ultraviolet irradiation of seawater as a method to inactivate *K. thyrsites* in the laboratory.
- The influence of prior exposure to *K. thyrsites* on parasite development during subsequent exposure.
- The influence of fish size on the prevalence and severity of the infection.

The knowledge gained through this research project will lead to a greater understanding of disease transmission and wild-farmed interactions. Additionally, this information will allow for better finfish cage siting and decision making and the development of tools to help further manage this disease.

This project supports the DFO objective of optimal fish health.

Specifically, the following results were found:

- Ultraviolet irradiation of seawater significantly reduces risk of infection in Atlantic Salmon. UV-irradiation is not practical in current net pen production systems, but would prove valuable in a closed-containment system.
- Previous infection with *K. thyrsites* reduces the risk of a severe subsequent infection. This is consistent with observations made by industry that initial rearing of smolts at a low-risk site reduces the severity of infection following transfer to high-risk sites. It would be valuable to further investigate alternative methods of simulating an earlier exposure.
- No consistent relationship between fish size and susceptibility to *K. thyrsites* was observed. Further research will explore alternative methods of testing the size hypothesis.

DATE: JUN. 2013–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Marine Harvest Canada Limited; Mainstream Canada (Cermaq Canada Ltd.)

PROJECT LEAD: Simon Jones (DFO)

PROJECT TEAM: Diane Morrison (Marine Harvest Canada Limited); Peter McKenzie (Mainstream Canada (Cermaq Canada Ltd.))

CONTACT: Simon.Jones@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-13-01-002-eng.html

Net Pen Liver Disease Project–Developing a Fluorescent Antibody Test to Prove the Causative Agent

An incidence of Net Pen Liver Disease (NPLD) was diagnosed in a population of adult Atlantic Salmon at a Grieg Seafood farm site in Nootka Sound, British Columbia, June 25, 2014. Previous presentations of the disease at company sites were limited to poor performers, three to four months post sea water entry. This new presentation was different as it affected well established grow out fish of approximately 3.6 kg. Based upon historical information, the disease had been associated with a hepatotoxic mycrocystin–LR (MC). Phase 1 of the project was to develop a fluorescent antibody test to positively identify the microcystin toxin present in affected fish.

Histological surveys of smolts (500 g) growing within an adjacent inlet did not test positive for NPLD; feed rate and mortality remained normal. Water samples were taken from the affected site and a site located geographically distant from the affected site both tested positive for the presence of MC.

Atlantic Salmon were experimentally exposed to the microcystin toxin thought to be the causative agent of the disease. Liver tissue samples were harvested over various timescales and the tissues were sent to the Animal Health Centre in Abbotsford, BC for histological processing and evaluation. Samples with lesions attributed to toxin exposure were used to develop a fluorescent antibody which was able to detect the presence of the toxin. Future work will optimize the test including determining both the level of sensitivity of the antibody and the strength of antibody required for accurate testing. This study provides proof of concept for the causative agent for Net Pen Liver Disease.

DATE: AUG. 2016–MAR. 2017

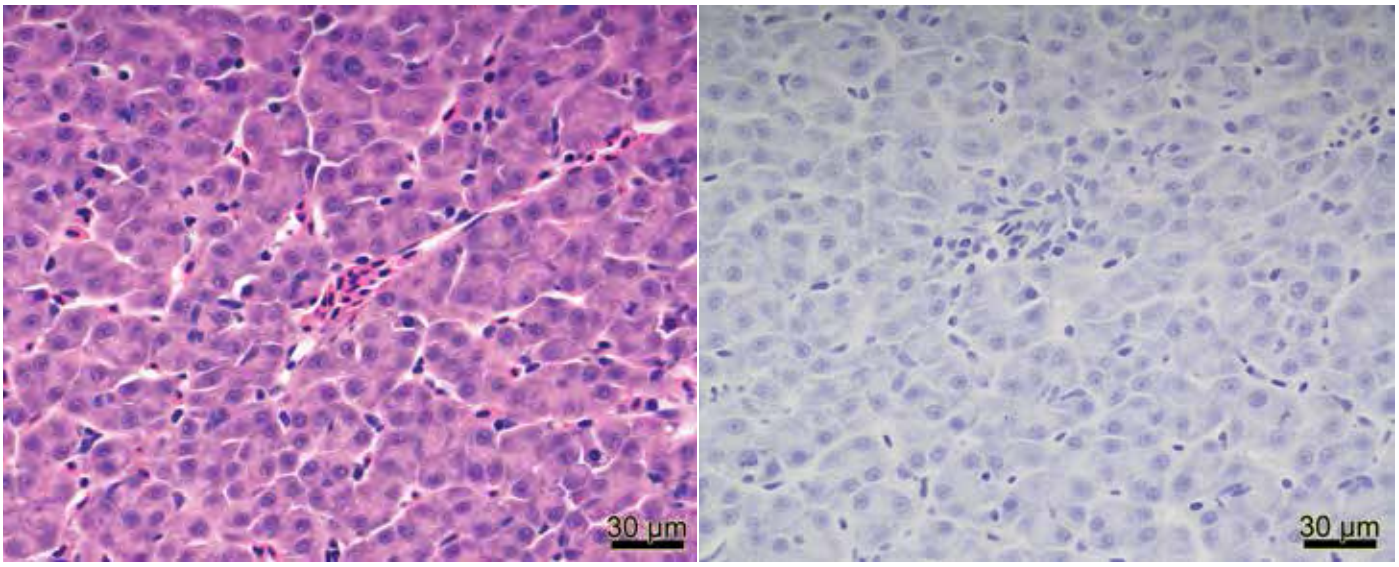
FUNDED BY: Grieg Seafood BC Ltd.

PROJECT LEAD: Tim Hewison (Grieg Seafood BC Ltd.)

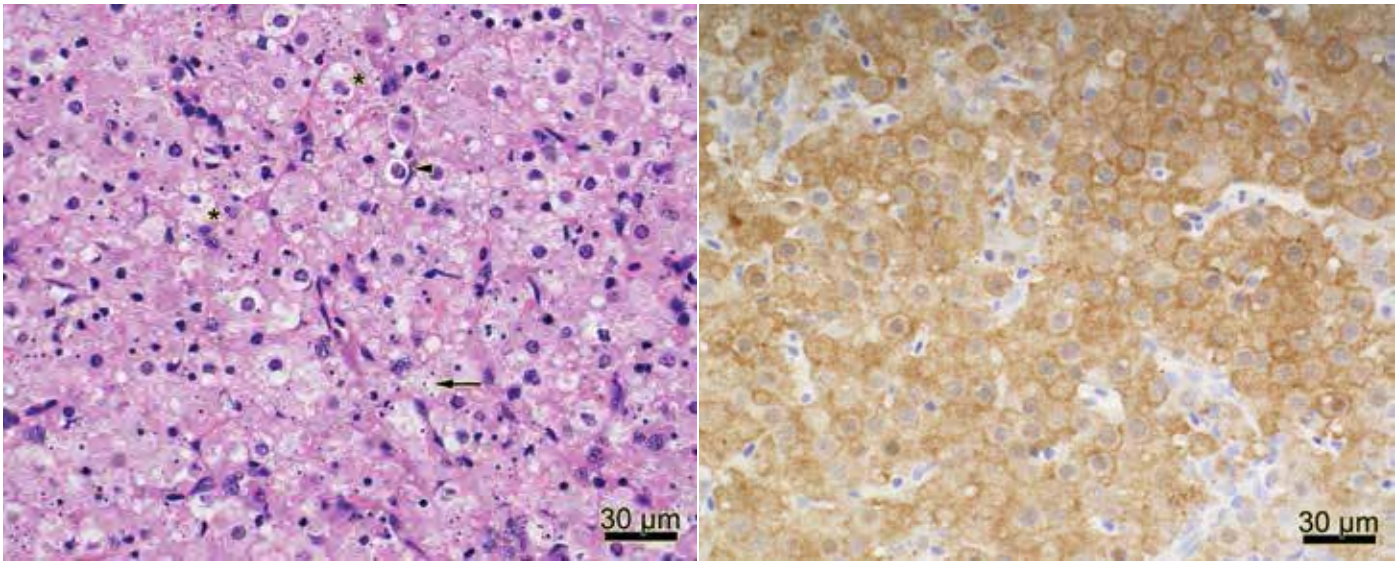
PROJECT TEAM: Matthew Patterson, Patrick Whittaker, Graeme Cooper (Grieg Seafood BC Ltd.)

COLLABORATORS: Heindrich Snyman (BC Ministry of Agriculture)

CONTACT: Tim.Hewison@griegseafood.com



Histological pictures of normal liver tissue from an Atlantic Salmon stained by H&E (left) and stained by IHC–anti–Microcystin–LR (right).
Photo: Heindrich Snyman (BC Ministry of Agriculture)



Histological pictures of liver tissue from an Atlantic Salmon exposed to the toxin Microcystin stained by H&E (left) and stained by IHC–anti-Microcystin-LR (right).
Photo: Heindrich Snyman (BC Ministry of Agriculture)

Improving the Survival, Health, Quality, and Food-Safety of Post-Transported Tilapia and Barramundi

The market demand for live Tilapia (*Oreochromis niloticus*) and Barramundi (*Lates calcarifer)* in Metro-Vancouver is steadily increasing. The stress and physical injury that occurs to fish during transport from USA to Langley, B.C. for acclimation and maintenance prior to retail sales have resulted in high fish mortalities and large economic losses to Viva Aquaculture and Seafood Distribution Ltd. (Viva). Developing viable and sustainable protocols to improve the survival, health, and quality of post-transported fish will benefit the company and retailers economically, and will also provide consumers with better food safety and quality fish products. It will also lead to new economic and employment opportunities locally, as well as be a source of diversified and nutritious seafood products for consumers in British Columbia. The University of British Columbia (UBC) and Viva have established a research collaboration to improve the survival and quality of fish transported from USA to Langley, BC. The specific objectives of this collaborative project were: 1) to increase the survival rate of adult Tilapia transported from Idaho, USA, by improving water quality through the manipulation of salinity, alkalinity, hardness, pH, temperature, and dissolved oxygen, and the elimination of toxic nitrogenous wastes; and 2) to improve the quality and food safety of fish during the post-transport recuperation and acclimation period using government-approved therapeutants and prophylactics, as well as indigenous microalgae, to eliminate potential microbial pathogens that might be present in the source water used to transport the fish from USA.

The results of this research project will lead to the development of post-transport protocols that are applicable in a commercial scale; are viable, efficient, safe, and sustainable for the maintenance rearing of adult fish destined for the retail market and human consumption in Canada.

DATE: FEB. 2015–DEC. 2018

FUNDED BY: Viva Aquaculture and Seafood Distribution Ltd. (Viva)

PROJECT LEAD: Jesse Ronquillo (UBC; Viva)

PROJECT TEAM: Chang Lin Ye, Kai Chen (Viva)

COLLABORATORS: David Kitts, Siyun Wang (UBC)

CONTACT: jesse.ronquillo@ubc.ca

WEBSITE: www.vivaseafood.com

Tilapia (*Oreochromis niloticus*). Photo: Jesse Ronquillo (UBC)

Barramundi (*Lates calcarifer*). Photo: Jesse Ronquillo (UBC)

Piscine Reovirus (PRV): Characterisation, Atlantic Salmon Susceptibility, and Initial Survey in Farmed and Wild Salmonids in Atlantic Canada

The piscine reovirus or PRV is a recently identified virus that has been linked to Heart and Skeletal Muscle Inflammation (HSMI) in Atlantic Salmon. HSMI was demonstrated as an infectious disease, however, the role of PRV in HSMI continues to be studied, as PRV is often found without symptoms of HSMI. Although the host range of this virus appears primarily restricted to salmonids, it has been occasionally detected in a few non-salmonid species.

In 2015, a small sample of Atlantic Salmon from different sources on the East Coast was tested and the presence of PRV was detected for the first time. During genetic sequencing, it was discovered that the strain of virus found on the East Coast bore a close resemblance to the West Coast strain of PRV. As there are no reports of HSMI-like syndromes in salmon on the East coast, the significance of PRV detection is unclear. HSMI was recently diagnosed for the first time on the Pacific Coast; given that no cases of HSMI have been diagnosed on the Atlantic Coast, this suggests that PRV on the East Coast of Canada may not be harmful, or that factors other than the presence of PRV are required to cause the disease.

A survey and characterisation of the local PRV are important in order to know the current distribution of the virus on the East Coast, and the potential for PRV to compromise wild and farmed Atlantic Salmon. This research builds on other studies about PRV.

DATE: APR. 2016–MAR. 2020

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd.

PROJECT LEAD: Nellie Gagné (DFO)

PROJECT TEAM: Delphine Ditlecadet, Crystal Collette-Belliveau, Jean-René Arseneau, Francis Leblanc, Steven Leadbeater, Philip Byrne (DFO)

COLLABORATORS: Keng Pee Ang (KCS)

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/index-eng.html

Salmon Gill Poxvirus-Like (SGPV-Like): Characterisation, Atlantic Salmon Susceptibility, and Initial Survey in Farmed and Wild Salmon

Poxviruses are large DNA viruses of vertebrates and insects causing disease in many animal species. In the spring of 2006, a new poxvirus, the salmon gill poxvirus (SGPV), was discovered on the gills of salmon suffering from proliferative gill disease (PGD) in freshwater in Northern Norway. Later the same year, this virus was also found on salmon gills at two marine sites in Western Norway where all farms suffered high losses associated with the presence of this virus. Clinical disease symptoms are lethargy, respiratory distress, and mortality.

In 2015, an unknown virus was isolated from tissues sampled from a suspected escaped farmed Atlantic Salmon caught in a river in New Brunswick. Using Next Generation Sequencing, researchers found that there was an 80-90% similarity to Norwegian SGPV, hence "SGPV-like". The significance of SGPV-like detection is unclear, although there are anecdotal reports that salmon gill diseases of unknown etiology were previously detected on the East Coast of Canada. A survey and characterisation of the local SGPV are needed to determine the extent of the virus distribution on the East Coast, and its potential to compromise the health of salmon.

DATE: APR. 2016–MAR. 2020

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd. (KCS)

PROJECT LEAD: Nellie Gagné (DFO)

PROJECT TEAM: Delphine Ditlecadet, Valérie Godbout, Jean-René Arseneau, Francis Leblanc, Steven Leadbeater, Philip Byrne (DFO)

COLLABORATORS: Keng Pee Ang (KCS)

CONTACT: Nellie.Gagne@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-G-02-eng.html

Description of Oceanographic Conditions within Hermitage Bay, Newfoundland, at Sites with and without the Occurrence of an ISA Outbreak

Infectious Salmon Anemia (ISA) is an important viral disease in the salmon farming industry. The ISA virus (ISAV) has also been found on wild fish and can be transmitted to farmed fish through a number of vectors. ISA outbreaks have been reported in Newfoundland salmon farms between December 2012 and November 2013.

This study aimed to understand how environmental conditions (e.g., temperature, salinity, and dissolved oxygen) at farm sites might favour ISA outbreaks. The link between conditions and ISA outbreaks would help identify other areas at risk of potential outbreaks, assist the aquaculture industry in mitigating the risk, and improve the sustainability of salmon farming.

This project found that ISA outbreaks in Bay d'Espoir occurred in spring/early summer and late autumn and that the general conditions at sites with ISA outbreaks were similar to those without.

At the sites with ISA occurrences, the environmental conditions prior to outbreaks were different between the spring and autumn cases. However, a common range of temperature, salinity, and dissolved oxygen concentration has been observed two weeks prior to the ISA events. A clear link could not be established between the environmental conditions, their variability, and the occurrence of ISA in the outer Bay d'Espoir area.

The occurrence of ISA events in the region could be the result of a combination of various factors including the environmental conditions reported in the present study as well as other processes (e.g., water and particle, ISA virus, movement between sites). Due to the limitation of the data and cases (only four ISA occurrences), further research is required should more cases of ISA events occur in the area.

This project supports the DFO priority of optimal fish health.

START DATE: JUN. 2014–MAR. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO– ACRDP)

CO-FUNDED BY: Cold Ocean Salmon Inc.; Newfoundland Aquaculture Industry Association

PROJECT LEAD: Andry Ratsimandresey (DFO)

PROJECT TEAM: Sebastien Donnet, Steve Snook, Kevin Le Morzadec (DFO)

COLLABORATORS: Julia Bungay (Cold Ocean Salmon Inc.); Miranda Pryor (Newfoundland Aquaculture Industry Association)

CONTACT: Andry.Ratsimandresey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/N-14-01-003-eng.html

Investigations into Ulcerative Skin Disease Agents, *Moritella viscosa* and *Tenacibaculum* spp. in Atlantic Salmon: Interactions and *in Vivo* Challenge Development

This project examines two pathogens of concern to the salmon farming industry, *Moritella viscosa* and *Tenacibaculum* spp., and their roles in skin ulcerative diseases. The primary focus is to study bacterial isolates of the genus *Tenacibaculum* which causes a condition called tenacibaculosis. Recent experience in developing immersion challenge models with *M. viscosa* will be applied to produce a disease challenge model for tenacibaculosis using a Canadian *Tenacibaculum* isolate. The secondary focus is to study *in vitro* interactions among *M. viscosa* and *Tenacibaculum* isolates and other bacteria associated with skin ulcers. The project focuses on isolates found on the East Coast of Canada in the context of the range of environmental temperatures at which pathogenicity is observed in clinical cases.

The project develops a basis for reproducing tenacibaculosis in Atlantic Salmon within a lab environment, and will provide a challenge model for testing diagnostic techniques for recovery of *Tenacibaculum* spp. during disease progression. This information could provide the aquaculture industry with improved techniques for early identification of potential causative agents of skin diseases. In addition, a reproducible live challenge model could be used for testing efficacy of treatments and vaccines.

Results of the study can be used by the aquaculture industry for research on genetic selection for disease resistance, help the fish health community apply better diagnostic methodology for confirming and treating ulcerative skin diseases, and improve understanding of naturally occurring diseases that impact wild and farmed salmon.

DATE: APR. 2016–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Cooke Aquaculture Inc.

PROJECT LEAD: Steven Leadbeater (DFO)

PROJECT TEAM: Allison MacKinnon (Elanco Canada Ltd.); Anthony Manning (RPC)

COLLABORATORS: Leighanne Hawkins (Cooke Aquaculture Inc.)

CONTACT: Steven.Leadbeater@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-M-02-eng.html

Cyprinid Herpes Virus 3 (CyHV-3) in Wild Common Carp (*Cyprinus carpio* L.) in Manitoba, Canada

Lake Manitoba was the site of a 2008 Koi herpes virus disease (KHVD) outbreak due to the presence of the aetiological agent CyHV-3 in resident Common Carp populations. This study was designed to test whether CyHV-3 is enzootic in Common Carp in Lake Winnipeg and Lake Manitoba. Test methods included quantitative PCR (qPCR), enzyme-linked immunosorbent assay (ELISA), duplex conventional PCR, and DNA sequence and phylogenetic analysis. Over the course of four years, carp from Netley Marsh (23.5%; n=17) and Delta Marsh (27.2%; n=235) tested positive for CyHV-3 by qPCR. Virus loads ranged from <5 to $2.9x10^4$ equivalent plasmid copies per µg of DNA (average $7.2x10^2$ copies/µg of DNA ± $3.6x10^3$). Sequence analysis of two variable regions of CyHV-3 DNA located between ORF29 and ORF31 (marker I) and near the 5' end of ORF133 (marker II) identified a single virus genotype in Manitoba. The marker II allele contained the same novel 13 base pair deletion associated with isolates from East Asia and Southeast Asia. Phylogenetic analysis using the thymidine kinase DNA sequence showed that the Manitoba CyHV-3 isolate shared a closer relationship to isolates from the Asian lineage than with those from the European lineage. Analysis of the ELISA test results suggested that 66.9% (n=239) of the carp sampled were CyHV-3 seropositive. Together, these results suggest that CyHV-3 is now enzootic in Common Carp populations residing in the two largest lakes in Manitoba.

This study examines subsequent changes in carp population dynamics, reports on the distribution, transmission and genetics of CyHV-3 and provides evidence of a carrier state in convalescent carp. The results provide insight into CyHV-3 ecology and are useful to regulators considering the use of CyHV-3 as a biocontrol mechanism for feral Common Carp populations causing widespread water habitat destruction.

DATE: JUL. 2009–FEB. 2017

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEAD: Sharon Clouthier (DFO)

PROJECT TEAM: Tamara Schroeder, Melissa Lindsay (DFO): Darius Khambatta (U Manitoba)

COLLABORATORS: Dale Wrubleski, Bob Emery (Ducks Unlimited Canada); Eric Anderson (Ste. Anne, MB)

CONTACT: Sharon.Clouthier@dfo-mpo.gc.ca

Aerial view of Clair Lake of Delta Marsh with the southern tip of Lake Manitoba evident in the foreground. Photo: Dale Wrubleski (Ducks Unlimited Canada)

Marine Reservoirs of Infectious Agents Associated with Proliferative Gill Disorders in Farmed Salmon

Gill diseases and disorders among Atlantic Salmon raised in seawater net pens are an emergent and important cause of losses. There is a need to better describe the causes, distribution, and possible control of gill diseases, which have been attributed to infections with parasites, bacteria, viruses, as well as exposure to algal blooms, jellyfish, and other non-infectious agents.

This project focuses on associations of viruses and parasites such as *Paramoeba perurans* and *Desmozoon lepeophtherii* with proliferative gill disorders (PGD) in order to improve understanding of reservoirs of infections. Infectious causal factors will be studied in populations of wild and farmed salmon sharing common bodies of water to better understand the epidemiology of proliferative gill disorders.

This project will develop knowledge related to the distribution and causes of PGD in British Columbia, which will inform further development of farmed fish health management strategies and improve the understanding of the role of gill disorders in the conservation of wild salmon.

DATE: APR. 2016–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: BC Salmon Farmers Association (BCSFA)

PROJECT LEAD: Simon Jones (DFO)

PROJECT TEAM: Gary Marty (BC Ministry of Agriculture); Sonja Saksida, Marc Trudel (DFO); Diane Morrison, Sharon DeDominicis (Marine Harvest Canada Limited)

COLLABORATORS: Jeremy Dunn, Joanne Liutkus, Rachel Saraga (BCSFA)

CONTACT: Simon.Jones@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-P-02-eng.html

Pathogen Susceptibility of Sockeye Salmon–Phase 1: Infectious Salmon Anemia Virus (ISAV) and Salmon Alphavirus (SPDV or SAV)

In recent years, Sockeye Salmon populations in Canada have been experiencing declines in productivity; of particular note is the Fraser River Sockeye Salmon stock. The reasons for this decline remain speculative but it is thought the susceptibility of Sockeye to pathogens may be a key contributing factor. However, the susceptibility of Sockeye Salmon to Infectious Salmon Anemia Virus (ISAV) or Salmon Alphavirus (SPDV or SAV) has never been tested. These pathogens are known to affect cultured Atlantic Salmon in various salmon producing regions and countries (e.g., ISAV on the east coast of Canada, ISAV and SPDV in Norway).

This project examines the disease resistance or susceptibility of Sockeye Salmon to pathogens known to affect Atlantic Salmon and the potential transmission of disease for a priority list of pathogens (ISAV, SPDV). Additionally, this project compares the viral response to ISAV at a cellular level (e.g., using gill tissue) between Sockeye and Atlantic Salmon, and their long-term immunity in response to exposure. This research is necessary in order to predict the consequences of an introduction or outbreak of these pathogens at an aquaculture site to the health and sustainability of Sockeye Salmon. The outcome of this work will allow Fisheries and Oceans Canada to improve disease surveillance, detection and management strategies, and help to minimize the impacts of pathogens on cultured and wild fish.

DATE: JUL. 2014–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Marine Harvest Canada Limited

PROJECT LEAD: Nellie Gagné (DFO)

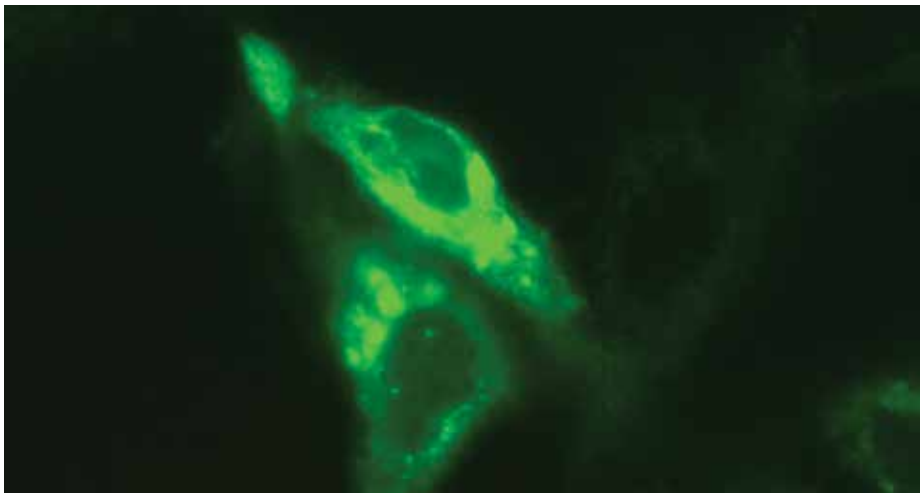
PROJECT TEAM: Francis Leblanc, Philip Byrne, Steven Leadbeater (DFO)

COLLABORATORS: Diane Morrison (Marine Harvest Canada Limited)

CONTACT: Nellie.Gagne@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-14-01-003-eng.html

DFO's Gulf Biocontainment Unit – Aquatic Animal Health Laboratory in Charlottetown, PEI. Photo: Nellie Gagné (DFO)



Immunostained ISAV infected cells. Photo: Mélanie Roy (DFO)

The Transfer Potential of Fish Pest and Pathogen from Farmed to Wild Salmon: Stocking Density Effect

Salmon farms can become infected with the Infectious Salmon Anemia Virus (ISAV) from wild fish stocks. Should this occur, farms could potentially become an amplified source of ISAV that could, in turn, impact wild fish. ISAV is transported and dispersed by water currents, and the resulting plumes or ISAV zones may contribute to the transfer of ISAV between farms and to migrating wild salmon that intersect the plumes.

Fisheries and Oceans Canada (DFO) regulators in the Maritimes Region are particularly interested in the role of stocking density in pest and pathogen transfer from existing farms to endangered wild Atlantic Salmon populations. This project aims to produce new experimental information: 1) quantifying the transfer rates of ISAV from farmed Atlantic Salmon; 2) new information on the minimum exposure dose needed to infect naïve salmon; 3) virus shedding rate of infected fish; 4) ultraviolet (UV) and survival of virus in water; as well as 5) models for predicting the potential for waterborne transfer of ISAV from commercial salmon farms under a range of stocking and farm density scenarios. The information will help inform regulators, as well as the aquaculture and recreational salmon industries who are working toward developing and implementing strategies and actions aimed at mitigating the potential for transfer of ISAV from farmed to wild salmon.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEADS: Fred Page, Nellie Gagné (DFO)

PROJECT TEAM: Blythe Chang, Francis Leblanc, Steve Leadbeater, Kyle Garver (DFO)

COLLABORATORS: Michael Beattie (NBDAAF); Ian Gardner, Larry Hammel, Crawford Revie, Sophie St. Hilaire, Raphael Vanderstichel (UPEI-AVC)

CONTACT: Fred.Page@dfo-mpo.gc.ca, Nellie.Gagne@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-m-01-eng.html

Reverse Transcription Quantitative Polymerase Chain Reaction (RT-qPCR) Assays For Detection of Spring Viremia of Carp Virus–Phases IV and V Diagnostic Validation

Spring viremia of carp virus (SVCV) is the aetiological agent of an aquatic animal disease that is listed as notifiable to the World Organization for Animal Health (OIE) and reportable to the Canadian Food Inspection Agency (CFIA). In this multi-year study, two RT-qPCR tests targeting either the glycoprotein or nucleoprotein gene were designed and optimized for their analytical performance. They were then evaluated along with the virus isolation by cell culture test in a diagnostic validation study to assess their fitness as diagnostic tools for detection of SVCV. Test performance metrics of diagnostic precision were repeatability and reproducibility. Sensitivity and specificity were measured to assess diagnostic accuracy. Estimates of test accuracy, in the absence of a gold standard reference test, were generated using latent class models. Test samples originated from domesticated koi that were either virus free or experimentally infected with the virus. Two tissues, kidney and brain, were evaluated for their relative suitability as target tissues for the RT-qPCR assays. Four laboratories in Canada participated in the precision study. Estimates of test precision and accuracy are being evaluated in the final two phases of the project. The results will determine if any of the three tests are suitable diagnostic tools for detection of SVCV.

Canada is a member of the OIE and the World Trade Organization and as such is obligated, for trade purposes, to implement OIE standards for disease diagnosis. The OIE has SVC on its list of notifiable diseases and in Canada it is currently designated as a CFIA reportable disease. The diagnostic tools developed in this project will be used by member laboratories of the National Aquatic Animal Health Laboratory System to help Canada meet its obligations to protect the health of wild and cultured aquatic animals within the country and globally.

DATE: APR. 2013–MAR. 2018

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEAD: Sharon Clouthier (DFO)

PROJECT TEAM: Tamara Schroeder, Shaorong Li, Crystal Collette-Belliveau, Jason Allen, Melissa Lindsay, Sandra Aldous, Philip Byrne (DFO)

COLLABORATORS: Carol McClure (AquaEpi Research); Eric Anderson (Ste. Anne, MB)

CONTACT: Sharon.Clouthier@dfo-mpo.gc.ca

Marine Reservoirs of Infectious Agents Associated with Proliferative Gill Disorders in Farmed Salmon

Gill diseases contribute to economically important production losses in Atlantic Salmon aquaculture. This project will improve our understanding of reservoirs of infections with infectious agents associated with these disorders. One of these, amoebic gill disease (AGD), was diagnosed for the first time in BC in 2014 and the causative agent, *Paramoeba perurans*, has been detected in BC. Another agent that is associated with proliferative gill inflammation (PGI) in Europe, the microsporidian, *Desmozoon lepeophtherii*, has been detected in BC and Washington State. Several cases of a PGI-like condition were reported in farmed salmon in BC in 2015. This project capitalizes on an opportunity to benefit from a unique set of samples; juvenile salmon collected by industry as part of their sea lice certification program. Specifically, these samples will be examined for evidence of their involvement as reservoirs of infection with agents associated with proliferative gill disorders in farmed salmon.

The objectives of this project are to:

1) determine distribution of *P. perurans* and *D. lepeophtherii* in wild Pacific Salmon and salmon lice collected in proximity to marine netpens;
2) describe the occurrence of proliferative gill lesions in wild fish;
3) characterize the genomic sequence of BC variants of *P. perurans* and *D. lepeophtherii*; and
4) conduct laboratory transmission studies to identify and quantify (host and environmental) parameters surrounding transmission of the causative agent between candidate reservoir species and Atlantic Salmon.

These objectives reflect the knowledge gaps concerning PGI and causal agents in farmed salmon in BC. The key anticipated project outcome will be knowledge related to the distribution and causes of PGI in BC. This knowledge will inform further development of farmed fish health management strategies.

DATE: APR. 2016–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Simon Jones (DFO)

PROJECT TEAM: Anne-Marie Flores, Sonja Saksida (DFO)

COLLABORATORS: Diane Morrison, Sharon DeDominicis (Marine Harvest Canada Limited); Marc Trudel (DFO)

CONTACT: Simon.Jones@dfo-mpo.gc.ca

WEBSITE: http://www.dfo-mpo.gc.ca/aquaculture/parr-prra/index-eng.html

Epidemiological Analysis and Modelling of Aquatic Pathogens

One of the big questions concerning disease processes of aquatic pathogens is what factors influence pathogen prevalence in wild and cultured fish populations. The prevalence and intensity of pathogens can vary annually within and between fish stocks, yet the drivers behind such annual fluctuations remain unresolved. Some fish populations can be free of virus one year, yet be greater than 80% positive in subsequent years. The occurrence of such dramatic “on and off periods” begs the questions “Why now?” and “Why was there an absence of virus in previous years?”

To better understand variations in aquatic pathogen prevalence in wild and farmed populations, this project will use epidemiological analytical approaches to study the patterns of aquatic pathogens in wild and cultured fish populations with the goal of identifying the factors that influence the occurrence of pathogens and disease.

To help understand the main drivers of pathogen epidemiology in aquatic systems, this project will: 1) gather and assemble a comprehensive dataset of fish health analyses and salmon population metrics across multiple river systems; 2) examine and compare annual pathogen prevalence among wild sockeye populations from multiple river systems; and 3) explore host, pathogen and environmental factors for potential correlates with pathogen variability in wild sockeye populations.

DATE: APR. 2016–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Kyle Garver (DFO)

PROJECT TEAM: Christine MacWilliams (DFO)

COLLABORATORS: Carl Ribble (Centre for Coastal Health Society)

CONTACT: Kyle.Garver@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-P-02-eng.html

Diagnostic Validation of Three Test Methods for Detection of Cyprinid Herpesvirus 3

Cyprinid herpesvirus 3 (CyHV-3) is the aetiological agent of koi herpes virus disease (KHVD) in Common Carp (*Cyprinus carpio* L.) and Koi. The disease is notifiable to the World Organization for Animal Health (OIE). Three tests [quantitative polymerase chain reaction (qPCR), conventional PCR (cPCR), and virus isolation by cell culture (VI)] were validated to assess their fitness as diagnostic tools for detection of CyHV-3. Test performance metrics of diagnostic accuracy were sensitivity (DSe) and specificity (DSp). Repeatability and reproducibility were measured to assess diagnostic precision. Estimates of test accuracy, in the absence of a gold standard reference test, were generated using latent class models. The test samples originated from wild Common Carp naturally exposed to CyHV-3 or domesticated Koi, either virus-free or experimentally infected with the virus. Three laboratories in Canada participated in the precision study. Moderate to high repeatability (81% to 99%) and reproducibility (72% to 97%) were observed for the qPCR and cPCR tests. The lack of agreement observed between some of the PCR test pair results was attributed to cross contamination of samples with CyHV-3 nucleic acid. Accuracy estimates for the PCR tests were 99% for DSe and 93% for DSp. Poor precision was observed for the virus isolation test (4% to 95%). Accuracy estimates for VI/qPCR were 90% for DSe and 88% for DSp. Collectively, the results show that the CyHV-3 qPCR test is a suitable tool for surveillance, presumptive diagnosis, and certification of individuals or populations as CyHV-3 free.

Canada is a member of the OIE and the World Trade Organization and as such is obligated, for trade purposes, to implement OIE standards for disease diagnosis. The OIE has KHVD on its list of notifiable diseases and in Canada it is designated as reportable to the Canadian Food Inspection Agency. The diagnostic tools developed in this project for detection of CyHV-3 will be used by member laboratories of the National Aquatic Animal Health Laboratory System (NAAHLS) to help Canada meet its obligations to protect the health of wild and cultured aquatic animals within the country and globally.

DATE: JUL. 2009–NOV. 2016

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEAD: Sharon Clouthier (DFO)

PROJECT TEAM: Tamara Schroeder, Megan Desai, Laura Hawley, Sunita Khatkar, Melissa Lindsay, Geoff Lowe, Jon Richard (DFO)

COLLABORATORS: Carol McClure (AquaEpi Research); Eric Anderson (Ste. Anne, MB)

CONTACT: Sharon.Clouthier@dfo-mpo.gc.ca

Physiological Consequences of Piscine Orthoreovirus (PRV) Infection of Atlantic and Pacific Salmonids

Piscine Orthoreovirus (PRV) commonly occurs in healthy salmon which are asymptomatic of heart and skeletal muscle inflammation (HSMI) disease. The capacity of PRV to establish long-term infections and the potential association with the HSMI disease in fish has raised concerns towards its ability to impact salmon physiology and overall fish health. As such, the role of PRV in HSMI continues to be studied.

This project aims to determine if PRV infections have physiological consequences and whether the virus can directly impact salmon health. This laboratory study addresses these questions by evaluating the cardiorespiratory performance (swimming ability) of PRV-infected Atlantic and Sockeye Salmon in comparison to uninfected controls. Oxygen binding potential and maximum oxygen consumption will be measured and compared between infected and non-infected individuals.

This research builds on other studies about PRV. The outcome of this study will provide a better understanding of whether PRV infections are associated with physiological consequences. Results of the study will inform Fisheries and Oceans Canada management strategies for PRV.

DATE: AUG. 2016–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: BC Salmon Farmers Association (BCSFA)

PROJECT LEAD: Kyle Garver (DFO)

PROJECT TEAM: Mark Polinski (NSERC); Anthony Farrell, Colin Brauner (UBC)

COLLABORATORS: Jeremy Dunn (BCSFA)

CONTACT: Kyle.Garver@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/index-eng.html

Does Infection with Piscine Reovirus (PRV) Affect How Salmon Respond to Challenge with Infectious Hematopoietic Necrosis Virus (IHNV)?

Piscine reovirus (PRV) is a virus common in wild and farmed salmon in BC and likely establishes long term infections in its host. It is inevitable that mixed infections of PRV and known pathogens will occur. One pathogen that is in the same geographical area with PRV is the infectious hematopoietic necrosis virus (IHNV) which occurs naturally in Pacific Northwest waters. With the appropriate virus strain, host condition, and environmental parameters, IHNV can cause an acute disease (IHN) in all five species of Pacific salmon, Atlantic Salmon, and Rainbow Trout.

This project seeks to examine the consequences of viral co-infections of PRV and IHNV in Sockeye Salmon. The study will address how Sockeye Salmon hosts, infected with viruses with no or low pathogenic effect, respond to challenge with other viruses. Challenge trials will be used to examine IHN disease progression in naïve (never before infected) and PRV-infected Sockeye Salmon. This challenge trial will determine if there are differences between groups in morbidity associated with IHNV challenge, and to generate biological samples for gene and microRNA expression studies. This research will help to determine what, if any, additional risk is posed to wild and/or farmed fish due to changes in their ability to respond to exposure to IHNV, thereby contributing to the knowledge base important for the sustainable management of the salmon aquaculture industry.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEADS: Stewart Johnson, Kyle Garver (DFO)

PROJECT TEAM: Jon Richards, Julia Bradshaw (DFO)

COLLABORATORS: Matthew Rise (MUN); Rune Adnreassen (Oslo and Akershus University College of Applied Sciences)

CONTACT: Stewart.Johnson@dfo-mpo.gc.ca, Kyle.Garver@dfo-mpo.gc.ca

WEBSITE: http://www.dfo-mpo.gc.ca/science/rp-pr/parr-prra/projects-projets/2014-P-13-eng.html

Addressing the Question of Sturgeon Nucleo-Cytoplasmic Large DNA Virus (sNCLDV) Systematics

Sturgeon nucleo-cytoplasmic large DNA viruses (NCLDV) are epitheliotropic viruses associated with mortality in nine sturgeon species in North America and Europe. White Sturgeon iridovirus (WSIV), a member of this group, causes a disease that is reportable to the Canadian Food Inspection Agency (CFIA). When the virus was originally described in the 1990's, it was classified as a member of the *Iridoviridae* family based on its morphological characteristics. In 2009, Namao virus (NV) was discovered in populations of moribund lake sturgeon in Manitoba, Canada and found to be genetically related to WSIV. This study was undertaken to investigate the evolutionary relationship of NV to other NCLDVs. The goal was to resolve the systematics of NV within the proposed order Megavirales given that our initial phylogenetic analyses with the major capsid protein sequence of five sNCLDVs suggested that the taxa formed a monophyletic group outside of the *Iridoviridae* family. NV genome sequence has been determined for three non-overlapping contigs with an overall length of 288.4 kb. A set of 10 orthologous genes present in the genomes of all NCLDVs are being used to build a series of phylogenetic trees for each gene and to construct a consensus tree. A total of 40 taxa representing genera from six virus families have been chosen. The sequences for each gene will be aligned and the evolutionary relationship of NV with other NCLDVs will be examined using multiple phylogenetic software packages including coalescent analyses with the BEAST suite of programs and maximum likelihood analyses using MEGA.

The study has been designed so that the phylogeny outcomes would be taxonomically informative to the International Committee on Taxonomy of Viruses. The results of this research may impact how WSIV and, by extension, other sNCLDVs are regulated by the CFIA and by regulators of national aquatic animal health programs in Europe and the United States.

DATE: JAN. 2012–JUN. 2017

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

CO-FUNDED BY: Manitoba Hydro

PROJECT LEAD: Sharon Clouthier (DFO)

COLLABORATORS: Rachel Breyta, Gael Kurath (US Geological Survey–Western Fisheries Research Center); Eric Anderson (Ste. Anne, MB)

CONTACT: Sharon.Clouthier@dfo-mpo.gc.ca

Stage 1 Validation of Real-Time PCR (qPCR) Assay for the Detection of *Bonamia* spp.

Assays for this pathogen vary in their ability to detect one or both of pathogens regulated by the Canadian Food Inspection Agency (CFIA); *Bonamia ostreae* and *Bonamia exitiosa*. The objectives of this project are: 1) to complete a World Organization for Animal Health (OIE) stage 1 validation (determine the operating range, analytical specificity and sensitivity, repeatability and characterization of inhibition) for a modified version of a previously published real-time PCR (qPCR) assay capable of detecting both of these pathogens; 2) the design and characterization of an artificial internal positive control (G-block) for use with the assay; and 3) the verification of a previously published conventional, PCR based, confirmatory assay which, along with Sanger based DNA sequencing, distinguishes between these species. The results of this validation and control development will be described in a validation dossier prepared for the National Aquatic Animal Health Program (NAAHP).

1) A sybr-green based qPCR (based on the work of Hill *et al*., 2010 and 2014), capable of distinguishing between *Bonamia* spp. using melt-curve analysis, has been validated to OIE stage 1 requirements. 2) An artificial internal positive control (IPC) has been created that is distinguishable from both 'wild-type' infections and demonstrates the same reaction kinetics as natural infections of both *B. ostreae* and *B. exitiosa*. 3) An existing conventional PCR confirmatory assay (based on the work of Cochennec *et al*., 2000) was optimized and tested on *B. ostreae*, *B. exitiosa* and the IPC and was able to distinguish between the two pathogens but did not amplify the IPC (this is by design to prevent false 'detected' results). However, it should be noted that the confirmatory assay was found to be less sensitive than the screening assay.

DATE: APR. 2016–MAR. 2017

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEADS: Cathryn Abbott, Geoff Lowe (DFO)

CONTACT: Cathryn.Abbott@dfo-mpo.gc.ca

Development and Diagnostic Validation of a qPCR Assay to Detect *Mikrocytos mackini* and its Application in Understanding the Transmission Risks and General Biology of the Pathogen

This project will finalize the validation process and produce a manuscript and validation dossier for the recently developed qPCR diagnostic assay intended for routine shellfish screening. The validated qPCR assay provided field data for the project described below and publication of the data and a validation dossier is in progress. Once completed, this will provide the international aquatic animal health community with a fully validated and characterized assay for the detection of this important shellfish pathogen.

The second part of this project will use the qPCR described above to: 1) determine the environmental stability of *Mikrocytos mackini*; 2) assess the ability and practicality for environmental diagnostic screening; 3) map *M. mackini* infections within host tissues so as to better understand routes of transmission that can be used to identify/manage disease outbreaks; and 4) lead to a publication and dissemination of these findings that will aid in Canadian and international management of *M. mackini* (and likely, by extension, other related parasites).

In this project we expanded the utility of this assay to detect *M. mackini* from environmental samples and demonstrated that *M. mackini* was shed into culture water from infected oysters following experimental injection. Further investigation revealed limited environmental stability of *M. mackini*, as most material became non-infectious after a period of 24 h in seawater. Mapping of infections within host tissues revealed that exposure to *M. mackini* of naïve oysters in an aquatic environment demonstrated gill associated parasites within one day following exposure. These results indicate that in natural environs, *M. mackini* may be shed into the water by infected oysters but the limited environmental stability of the parasite likely restricts its spread causing focal infection dynamics within a host population.

DATE: APR. 2016–MAR. 2017

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEADS: Cathryn Abbott, Mark Polinski (DFO)

PROJECT TEAM: Gary Meyer, Geoff Lowe, Eliah Kim (DFO)

CONTACT: Cathryn.Abbott@dfo-mpo.gc.ca

Effects of Pooling Animals on the Probability of Detection: MSX and ISAV

Although pooling of animals is not currently used in the National Aquatic Animal Health Laboratory System (NAAHLS), it is often discussed, as it has the advantage of processing multiple animals at once. This can greatly reduce the processing time and increase the throughput of a laboratory. By pooling two animals, one doubles the throughput, and pooling more than two animals is possible. However, there is a trade-off to pooling; when only one animal is infected, and the animal is infected at a level near the limit of detection, the dilution effect of the pooling process reduces the probability of detection. This reduction in diagnostic sensitivity needs to be carefully evaluated at the bench level.

This project will provide: 1) a set of data (probability of detection) of a single positive animal in a pool of two, three, four, or five negative animals, for DNA extraction methods (with MSX as a pathogen) and RNA extraction methods (ISAV pathogen); and 2) in practice, the data produced in this project should be transferable directly to other assays where pooling is desired.

Knowing the impact of pooling, clients will be able to decide if the decline in sensitivity is worth the trade-off, based on their reason for testing and the current disease prevalence.

DATE: APR. 2015–MAR. 2016

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEAD: Nellie Gagné (DFO)

PROJECT TEAM: Francis Leblanc, Crystal Collette-Belliveau, Valérie Godbout (DFO)

CONTACT: Nellie.Gagne@dfo-mpo.gc.ca

Identification of Vectors of MSX to Support Introductions and Transfers Decisions Related to Inter-Provincial Movements of Mussels: Is Mussel Intra-Valvular Liquid a Vector for MSX Transmission?

Multinucleated sphere "X" (MSX) is an infectious disease that causes heavy mortalities in American Oysters (*Crassostrea virginica*) although it does not affect human health. The transfer of live shellfish, such as mussels, are regulated under Section 56 of the *Fisheries (General) Regulations* and are reviewed on a case by case basis by the DFO Introductions and Transfer Committees (ITC) of the receiving Province. Prior DFO analysis of mussels collected from heavily infected MSX positive areas of the Bras d'Or Lakes, and from MSX positive areas outside of the Lakes, had not detected MSX in the soft tissues/intra-valvular liquid. In the absence of information, epifauna on mussel lines was considered potentially positive for MSX and mitigation was recommended by the ITCs. In this project, targeted sampling of wild mussels and epifauna in an area with MSX infected wild oysters resulted in the detection of MSX by Real Time Polymerase Chain Reaction (qPCR) but the disease was not visually detected histologically. These results support industry concerns that although mussels are not believed to be a host of MSX, a life stage of the parasite may be present in the intra-valvular fluid of the mussels or the intermediate host may be found within the associated epifauna. Therefore, based on the results of this project, continued mitigation to reduce the risk of the inadvertent spread of MSX should be considered during risk assessments of industry activities.

DATE: APR. 2013–MAR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Mary Stephenson (DFO)

PROJECT TEAM: Nellie Gagné, Marie-Line Cournoyer (DFO)

COLLABORATORS: Andrew Bagnall (NSDFA)

CONTACT: Mary.Stephenson@dfo-mpo.gc.ca

WEBSITE: http://www.dfo-mpo.gc.ca/aquaculture/parr-prra/index-eng.html

Effect of Water Temperature on the Immune Response of American Lobster (*Homarus americanus*) Experimentally Infected with White Spot Syndrome Virus

Water temperature influences many basic biological functions of the American Lobster (*Homarus americanus*); yet, little is known about the effects of temperature on the immune response of *H. americanus*. White Spot Syndrome Virus (WSSV) is one of the largest impediments to shrimp aquaculture worldwide; there are no reports of naturally occurring WSSV infection in lobster. The World Organization for Animal Health (OIE) lists WSSV as a notifiable disease with the potential to infect all crustacean decapods.

This project utilized a previously established infection challenge model to investigate the constraints imposed by a range of temperatures (10°C, 15°C, 17.5°C, and 20°C) on the clinical, tissue, and molecular immune responses of American Lobster experimentally infected with WSSV. The infection model utilized intramuscular injection inoculation of WSSV. This study found that WSSV amplification was associated with increased water temperatures (17°C and 20°C). Significant differences in total haemocyte concentration between infected and control *H. americanus* at 17.5°C and 20°C, but not at 10°C and 15°C. This suggests a decrease in clinical condition of WSSV infected *H. americanus* at warmer temperatures. Light and transmission electron microscopy were used to elucidate tissue changes in the host and confirmed the antennal gland as a key target tissue for WSSV. A lobster specific microarray identified 717 significantly differentially expressed genes between infected and control animals at the various temperatures. Microarray results highlighted differential expression of various temperature and immune-related genes. At 20°C, *H. americanus* appears to produce a targeted immune response to injected WSSV.

This project used a range of diagnostic tools and experimental temperatures in order to broaden our understanding of how temperature influences host pathogen interactions in the economically important crustacean species, the American Lobster (*H. americanus*). Although this project and other work done involving DFO and the Lobster Science Centre collaboration suggests that WSSV is not a threat to lobster, the use of the WSSV experimental infection model has been useful for enabling a comparative examination of the lobster immune response to different kinds of pathogens (bacterial, protozoal, and viral).

DATE: SEP. 2014–SEP. 2016

FUNDED BY: University of Prince Edward Island–Atlantic Veterinary College (UPEI–AVC)

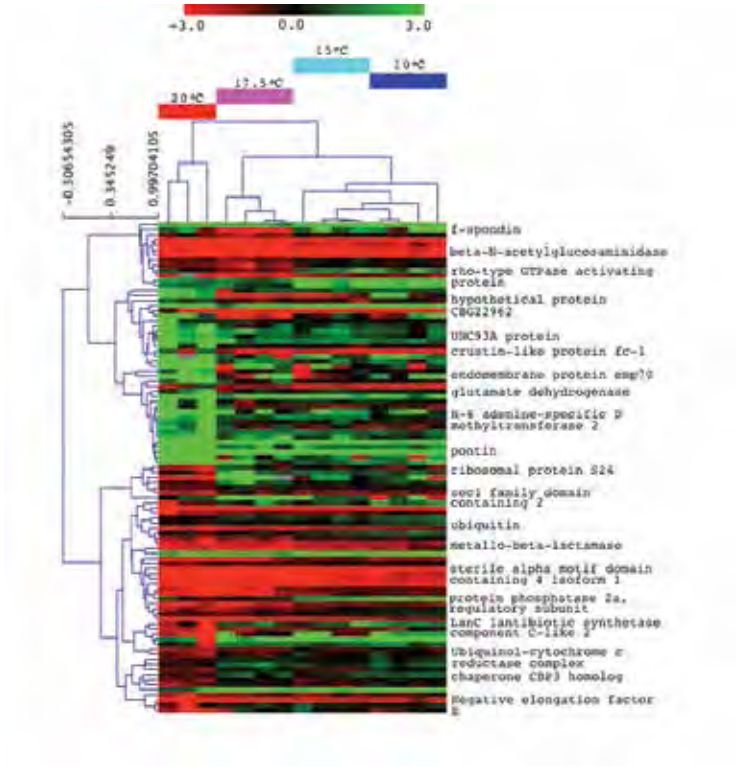
CO-FUNDED BY: Federal Student Work Experience Program (FSWEP); DFO–Centre for Aquatic Animal Health Research and Diagnostics DFO–CAAHRD)

PROJECT LEADS: Philip Byrne (DFO); Spencer Greenwood (UPEI-AVC)

PROJECT TEAM: Louise-Marie Roux (UPEI–AVC; DFO)

COLLABORATORS: Fraser Clark, Mark Fast, Glenda Wright, Dorota Wadowsk (UPEI-AVC)

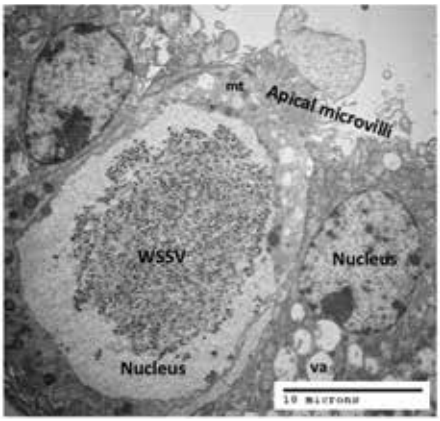
CONTACT: LRoux@upei.ca



Heat map with hierarchical clustering of significantly differentially expressed genes identified between infected *Homarus americanus*, two-week post inoculation at 10°C, 15°C, 17.5°C, and 20°C.

Red represents a threefold or greater decrease in gene expression whereas green represents a threefold or greater increase in gene expression.

Louise-Marie Roux in the Gulf Biocontainment Unit (DFO) facility collecting a haemolymph sample from American Lobster (*Homarus americanus*). Photo: Phil Byrne (DFO)



Transmission Electron Micrograph of WSSV infected *Homarus americanus* antennal gland, two-weeks post inoculation at 17.5°C.

Hypertrophic nuclei showing marginated host chromatin and containing WSSV viral particles within the nucleus identified by an electron dense nucleocapsid center and a trilaminar envelope. Virions ranged from 200-350 nm in length. Nucleus, apical microvilli, mitochondria (mt), and vacuole (va) labelled.

Developing a Genomics Tool (FIT-CHIP) for In-Season Information on Salmon Health

Climate change, genetic challenges, ecological inconsistency, and disease can all be listed as potential stressors to wild populations of salmon on Canada's West Coast. This project plans to address the physical states of wild populations through the development of a series of "salmon FIT-CHIPs" which will be used as a predictor of salmon condition. The system offers extreme flexibility, allowing biological markers to be easily customized for stress or other conditional states to different life-history stages, environments, and in different tissues. This tool will provide the first in-season method to incorporate information on salmon condition into fisheries management decision making.

A text search will be conducted on abstracts or full papers for key protein (biomarkers) word associations that have been linked to a given stressor. The project will then continue by data-mining the huge in-house microarray databases produced from dozens of studies that encompass more than 4,900 microarrays and three salmon species (Chinook, Sockeye, and Coho) as well as over 60 stress-challenge microarray studies conducted across a broad range of salmon species available in public databases. Tests will be developed that should work across all three species, and preferentially across Atlantic Salmon and Rainbow Trout as well. In all, it is anticipated that five FIT-CHIPS will be developed through this project.

The ultimate aim is to discover biomarkers predictive of the presence of specific stressors or conditions and to translate these into a tool (FIT-CHIP) that can inexpensively and rapidly identify the presence of multiple stressors or conditions in a group of fish at once.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Genomics Research and Development Initiative (DFO–GRDI)

CO-FUNDED BY: Genome BC

PROJECT LEAD: Kristi Miller-Saunders (DFO)

PROJECT TEAM: Norma Ginther, Tobi Ming, Colin Wallace (DFO)

COLLABORATORS: Paul Pavlidis (UBC)

CONTACT: Kristi.Saunders@dfo-mpo.gc.ca

Susceptibility of Sockeye Salmon to Viral Hemorrhagic Septicemia Virus

As part of the sustainable management of finfish aquaculture, there are regulatory requirements that are designed to minimize the transfer of pathogens from farmed finfish to wild fish. However, finfish cultured in ocean net pens have the potential to be exposed to naturally occurring pathogens and to transfer pathogens to wild fish. Viral Hemorrhagic Septicemia Virus (VHSV) has been identified in farmed Atlantic Salmon, *Salmo salar*, in British Columbia. VHSV is a naturally occurring pathogen in British Columbia and is a cause of serious disease in wild Pacific Herring, *Clupea pallasii*. Pacific Herring are known to enter and remain in Atlantic Salmon net pens, thereby increasing the potential for the virus to be transferred to farmed Atlantic Salmon. Although the occurrence of VHSV in farmed salmon is rarely accompanied with significant disease and mortality, experimental studies have shown that the VHS virus can persist in the tissue of farmed Atlantic Salmon. This causes concern for potential host adaptation and viral spillback to fish sharing the marine environment.

This study is investigating what effect, if any, the occurrence of VHSV in farmed Atlantic Salmon may have on wild Sockeye Salmon. Previous studies have shown that Coho, Chinook, and Chum Salmon are natural hosts of VHSV, but less is known about the susceptibility of Sockeye Salmon to VHSV. To address this knowledge gap, this project will determine the susceptibility of Sockeye Salmon smolts to VHSV using laboratory exposure studies. The results of this study will contribute to the development of adaptive management strategies in British Columbia aimed at minimizing the transfer of pathogens between farmed Atlantic Salmon and wild Pacific salmon.

DATE: APR. 2015–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Kyle Garver (DFO)

PROJECT TEAM: Paul Hershberger (United States Geological Survey); Jon Richard (DFO)

CONTACT: Kyle.Garver@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-P-01-eng.html

Epidemiology of Ulcer Disease in Salt Water Atlantic Salmon

Working with the aquaculture industry, we investigated the pattern of ulcer disease occurrence in salt water Atlantic Salmon. We also conducted a laboratory trial to: 1) evaluate waterborne transmission of *Moritella viscosa*; 2) describe the progression of the disease within a population; and 3) determine if skin ulcers could be induced from exposure to the extracellular toxins produced by *M. viscosa*.

To effectively treat ulcer disease, our research suggests that treatments would likely have to be applied very early in the disease process because fish stop eating once they develop the ulcer. Further, it is relatively difficult to transmit *M. viscosa* via water, and the lesion associated with *M. viscosa* can be induced by exposure to the extracellular toxins of *M. viscosa*. The latter may explain why fish have a strong tissue response when exposed to *M. viscosa*, but bacteria are difficult to identify on histological evaluation.

DATE: MAR. 2015–OCT. 2016

FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)

PROJECT LEAD: Sophie St-Hilaire (UPEI)

PROJECT TEAM: Brett MacKinnon (UPEI)

CONTACT: ssthilaire@upei.ca

Infectious Salmon Anemia Virus Susceptibility and Health Status of Wild Versus Farmed Atlantic Salmon: A Comparative Study

There are concerns about the potential for interaction between farmed and wild Atlantic Salmon in areas where they coexist. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has designated wild Atlantic Salmon populations in Atlantic Canada as threatened or endangered. While the health status and disease resistance of farmed Atlantic Salmon is well documented, the information for wild Atlantic Salmon is less abundant. For example, Infectious Salmon Anemia Virus (ISAV) remains a recurrent problem for cultured salmon in Atlantic Canada, with outbreaks detected in Nova Scotia and Newfoundland since 2012. There are knowledge gaps regarding the prevalence of this virus in wild populations as well as the potential transmission between wild and cultured stocks. As such, the aim of this project is to use *in vivo* disease challenges and next generation sequencing technologies to compare the susceptibility of wild Atlantic Salmon stocks (Saint John River, Inner Bay of Fundy, Miramichi, Margaree River stocks) and cultured stocks (Saint John River origin) to diseases such as ISAV and others. This study will examine genetic differences and measure immune responses, which could potentially explain any observed differences in susceptibility of wild and cultured salmon to ISAV. It will also provide a general assessment of the health status of wild stocks. The evolution rate of ISAV will be examined by looking at full ISAV sequences in tissue of farmed and wild Atlantic Salmon sampled throughout the course of the *in vivo* challenges. This project will address the knowledge gap regarding the susceptibility of wild Atlantic Salmon compared to farmed Atlantic Salmon to ISAV.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Nellie Gagné (DFO)

PROJECT TEAM: Francis LeBlanc, Mark Laflamme, Gérald Chaput, Steven Leadbeater, John Whitelaw (DFO)

COLLABORATORS: Mark Hambrook (Miramichi Salmon Association)

CONTACT: Nellie.Gagne@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-G-11-eng.html

Atlantic Salmon from the Miramichi River. Photo: Steven Leadbeater (DFO)

Rapid Detection of Replicating Infectious Salmon Anemia Virus (ISAV)

In the diagnostic lab, the traditional methods of virus detection are based on the culture or isolation of the virus. These methods are quite sensitive, and very reliable. They are based on the observation that many viruses will replicate in cells, and eventually rupture the cells. These burst cells can be seen under a microscope, and thus burst cells equal the presence of a replicating (live) virus. However, this observation can take many days. Emerging, modern methods are based on the detection of virus nucleic acids through amplification by polymerase chain reaction (PCR). These methods are ultra-sensitive, and very fast, but they are only indirectly detecting virus. In other words, it is debatable whether what is being detected can be associated to a replicating virus or just "dead" viruses.

Our rapid detection protocol uses both traditional and modern techniques in a "best of both worlds" approach. Test material is put in culture with cells, and a molecular PCR assay is done at that time as well. The PCR assays determines the presence of all viral particles, whether they are "alive" or "dead". A few days later, a second PCR is done on the cell culture. If the number of viral particles has increased, this can only be explained by the fact that viruses were replicating.

The combined use of two PCR reactions along with the infection of cell lines can identify replicating virus an average of 25 days faster than using the current virus isolation protocol alone. Currently, the detection of the ISA virus can take over 40 days. Given the immense impact this virus can have on cultured fish, this is simply too long. Our protocol can provide decision makers with a much earlier warning.

DATE: MAR. 2014–MAR. 2016

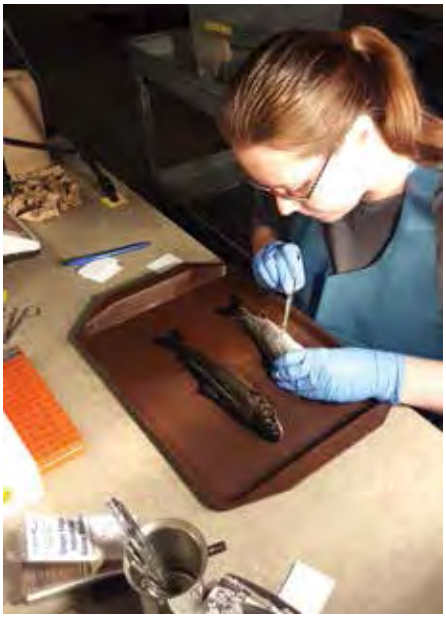
FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEAD: Mark LaFlamme (DFO)

PROJECT TEAM: Jean-René Arseneau (DFO)

CONTACT: Mark.LaFlamme@dfo-mpo.gc.ca

Disease and Parasite Resistance Genomics in a Commercial Strain of North American Atlantic Salmon



Melissa Holborn (U Guelph) counting salmon lice on Atlantic Salmon smolts. Photo: Cindy Hawthorne (DFO)

Bacterial kidney disease (BKD), infectious salmon anemia (ISA), and salmon lice (*Lepeophtheirus salmonis*) are economically important pathogens to Atlantic Salmon aquaculture on the east coast of Canada. This research project aims to detect molecular markers (SNPs) that are associated with pre-existing genetic resistance in the Saint John River strain of Atlantic Salmon for BKD, ISA, and *L. salmonis*.

Smolts from the breeding nucleus are exposed to each pathogen in separate challenges to quantify the level of resistance of siblings of potential broodstock. Challenged fish were genotyped using a custom 50,000 (50K) SNP chip designed specifically for North American Atlantic Salmon. Analysis of the SNP genotypes, resistance phenotypes, and the pedigree information can identify SNP markers associated with resistance to these pathogens. These markers can then be incorporated into breeding programs to develop Atlantic Salmon lines that have an increased resistance to BKD, ISA, and *L. salmonis*.

DATE: APR. 2014–MAR. 2018

FUNDED BY: Genome Canada

CO-FUNDED BY: Cooke Aquaculture Inc.; Genome Atlantic; Ontario Genomics; DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP); Industrial Research Assistance Program (NRC); Atlantic Canada Opportunities Agency (ACOA)

PROJECT LEAD: Elizabeth Boulding (U Guelph)

PROJECT TEAM: Melissa Holborn, Larry Schaeffer, Jane Tosh (U Guelph); Keng Pee Ang, Jake Elliott, Frank Powell (Cooke Aquaculture Inc.); Steven Leadbeater (DFO); Brian Glebe (Genome Atlantic)

COLLABORATORS: Norwegian University of Life Sciences

CONTACT: boulding@uoguelph.ca

WEBSITE: https://www.uoguelph.ca/ib/boulding

Development of Artificial Reference Material for Assessing IHNV and VHSV RT-qPCR Assays

Reference materials, commonly referred to as controls or standards, are substances with extremely well defined properties used in the assessment of diagnostic methods. The Virology laboratory at DFO's Pacific Biological Station (PBS) has been experimenting with various control materials that can be used to accurately assess the validity of IHNV and VHSV molecular diagnostic tests. The Virology laboratory has initiated the use of an artificial positive control (APC) for monitoring test performance. APCs have an advantage over traditional controls due to the fact that they are unrelated to the target pathogen and can be easily differentiated from each other, facilitating the identification of false positive results.

Results from small scale pilot studies proved promising for proficiency testing of IHNV and VHSV RT-qPCR in that the artificial transcripts mimicked the biological target, could be accurately quantified, and present extremely low false positive risk due to its unique identity. However, uncertainties remain concerning the large scale production of such panels. In particular, what are the best manufacturing methods suitable for generating large batches of homogenous aliquots? What preservation methods are best for large batches of proficiency panels and what is the expected stability? The aims of this study was threefold: 1) establish procedures for generating large batches of IHNV and VHSV artificial reference material for use as standards, controls, and proficiency testing; 2) identify optimal storage practices and best before dates of bulk reference materials; and 3) develop characterization procedures for IHNV and VHSV bulk reference materials.

Artificial positive controls are now an integral component of laboratory quality management systems and a requirement of ISO 17025. By using APCs, the NAAHLS eliminates the risk of false positives. Reference materials are distributed among the NAAHLS as needed to ensure compliance with national protocols and certify testing competency.

DATE: SEP. 2014–MAR. 2015

FUNDED BY: DFO–Centre for Aquatic Animal Health Research and Diagnostics (DFO–CAAHRD)

PROJECT LEAD: Kyle Garver (DFO)

PROJECT TEAM: Laura Hawley, Jon Richard (DFO)

CONTACT: Kyle.Garver@dfo-mpo.gc.ca

ENVIRONMENTAL INTERACTIONS

Developing Hard-Bottom Indicators from BC Archived Benthic Video Surveys Associated with Aquaculture Activities

Development and Validation of a Biomonitoring Tool to Assess the Impacts of Salmon Aquaculture on Marine Benthic Communities Using Metabarcoding

Assessment of Biodiversity and Functional Changes in Benthic Communities Associated with Aquaculture Activities in Newfoundland

Biochemical Oxygen Demanding (BOD) Dispersion Model Validation Standards

Exploration of Methodologies for Environmental Effects Monitoring of Finfish Aquaculture Sites in Sandy Bottom Environments with Natural Disturbances: Shelburne, Nova Scotia

Analysing the Impact of Freshwater Aquaculture on Wild Fish Populations using DIDSON Technology

Oceanographic Study of the South Coast of Newfoundland (Baie D'Espoir and Fortune Bay)

Temporal Assessment of Organic Loading from Finfish Aquaculture on Hard Bottom Communities in Newfoundland

Alternative Detection Methods for Performance Indicators of the Oxic State of Bottom Sediments: Indicator Inter-Calibration and Thresholds

Feeding Pressure of *Styela clava* on Plankton (Phytoplankton and Zooplankton) in Malpeque Bay, Prince Edward Island

Can Hard Clams (*Mercenaria mercenaria*) Increase the Rate of Eelgrass (*Zostera marina*) Recovery in Areas Impacted by Oyster Aquaculture?

Recovery of Neural Function in Lobsters Following Sub-Lethal Salmosan® Exposure

Impact of Global Warming on Aquaculture Production in the Magdalen Islands: Blue Mussel, Atlantic Deep-Sea Scallop, and American Oyster

Study of the Effects on Adult American Lobsters (*Homarus americanus*) Consuming Clams Exposed to Atlantic Salmon Sea Lice Therapeutants

Study on the Sublethal Effects of the Sea Lice Pesticide Salmosan® (Azamethiphos) on Adult Male Lobsters (*Homarus americanus*)

Study of The Effects of Emamectin Benzoate or Ivermectin in Sediments on Juvenile American Lobsters (*Homarus americanus*)

Validation of the Robustness of the Ecosystem Carrying Capacity Models Being Developed for St. Peters Bay

Effects of Organophosphate Aquaculture Pesticide Azamethiphos on Stage I and Stage IV American Lobster (*Homarus americanus*) Larvae

Paving the Way for Salmon-Kelp Integrated Aquaculture in British Columbia: A Foundational Field Trial Assessing Sugar Kelp (*Saccharina latissima*) Growth and Quality at BC Salmon Farms

The Effects of Sublethal Aquaculture Chemotherapeutant Exposure on Pink Salmon

The Lethal, Physiological, and Behavioural Effects of Anti-Sea Lice Therapeutants in Non-Target Crustacean Species

The Effects of Anti-Sea Lice Chemotherapeutants on Sensitive Life Stages of Non-Target Crustacean Species in Combination with Environmental Stressors

The Environmental Fate and Non-Target Effects of Sea Lice Drugs and Pesticides Used in Salmon Aquaculture

Structure and Function of the Salmon Farm "Reef"

Identifying Critical Ecological Thresholds for Tunicate Infestations on Mussel Farms

Co-Culture of Blue Mussel (*Mytilus edulis*) and Sugar Kelp (*Saccharina latissima*): Exploring the Potential Effect of Seaweeds in Deterring the Effect of Duck Predation on Mussels, Cascapedia Bay (Quebec)

Tracking *in Situ* Real-Time Responses of Ocean Acidification Effects on Biological Organisms and Influence on Plankton Diversity

Building an Understanding of the Mobile Wild-Farmed Interactions Occurring around Aquaculture Farms in the Bay of Fundy

Meta-Analysis of Freshwater Aquaculture Provincial Water Quality Monitoring Data

Evaluation of Benthic Far-Field and Site Recovery Effects from Aquaculture within the Letang Inlet, New Brunswick

Freshwater Finfish Cage Aquaculture: Development of Sediment Biogeochemical Indicators for Regulation of Freshwater Cage Aquaculture

Effect of Wind Forcing on the Oceanographic Conditions of Fortune Bay–Belle Bay: Identification of Changes in Water Physical Conditions and Ocean Currents, and Development of a Forecasting Tool

Robustness of Alternative Benthic Impact Indicators: Quantification of Spatial and Temporal Variability of Alternative Methods, and Application at Aquaculture Sites Across Different Farm and Environmental Conditions

The Development of a Robust Methodology for Sulfide Probe Calibration and Sediment Sampling

Sustainable Development of Offshore Bivalve Culture in the Magdalen Islands: Production Capacity and Interactions with Commercial Fisheries

Developing the Benthic Component of Integrated Multi-Trophic Aquaculture to Reduce the Impact of Organic Nutrients from Fish Farms and Evolving Standard Operating Procedures

Impact of Finfish Farms in Eastern Canada on Lobster Distribution and Condition

Influence of Eastern Oyster (*Crassostrea virginica*) Aquaculture Overwintering on Eelgrass (*Zostera marina*)

Evaluating the Effectiveness of Fallowing as a Mitigation Tool at Predominantly Hard-Bottom Aquaculture Sites in Newfoundland

Characterization of Pesticide Post-Deposit Exposure Zones

Effects of Cage Aquaculture on Freshwater Benthic Communities

Comparing the Impact of Bottom and Suspended Oyster Culture on Bay-Scale Food Resources (Foxley/Trout River, PEI)

Developing Hard-Bottom Indicators from BC Archived Benthic Video Surveys Associated with Aquaculture Activities

Under the *Aquaculture Activities Regulations* (AAR), and previously as a condition of licence, the Pacific aquaculture industry has been required to conduct seafloor monitoring of finfish aquaculture sites. This project is applying a standard analytical approach to a large collection of archived video surveys collected during a seven-year period (2004-2010) and over a wide range of coastal settings (fjordic inlets, Broughton Archipelago, the west coast of Vancouver Island, Johnstone Strait, etc.). The measurement of redox and sulphide from sediment samples is an accepted standard practice for soft-bottom seabeds. However, past monitoring practices involving grab sampling for redox and sulfide analyses have presented challenges at aquaculture sites located over hard bottom substrates. Section 10(2) of the AAR allows for visual monitoring instead of sediment grab samples if it is not possible to obtain benthic substrate samples. Results supported the use of primary and secondary indicator species (*Beggiatoa* spp. and Opportunistic Polychaete Complexes–OPC). Potential additional indicators that may warrant further investigation include Giant Plumose Anenomes as this species is tolerant to organic enrichment and was observed as co-occurring with *Beggiatoa*-like bacteria and OPCs at some farm sites, as well as taxa that tend to occur at the transition between oxic states could be investigated (e.g., sea urchins, brittle stars, tube dwelling anemones, shrimp, etc.).

DATE: SEP. 2011–MAR. 2016

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Terri Sutherland (DFO)

PROJECT TEAM: Andrea Bartsch, Michelle Ou (DFO)

COLLABORATORS: Bernie Taekema, Kerra Shaw, March Klaver, Jon Chamberlain (DFO)

CONTACT: Terri.Sutherland@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2011-P-13-eng.html

Sponge and Squat Lobster community on a rock cliff in British Columbia. Photo: Terri Sutherland (DFO)

Development and Validation of a Biomonitoring Tool to Assess the Impacts of Salmon Aquaculture on Marine Benthic Communities Using Metabarcoding

Salmon aquaculture causes organic enrichment of surrounding sediments which has been shown to affect biodiversity and biomass of benthic fauna concomitant with sediment chemical changes. Environmental impact assessments have generally focused on changes in macro-invertebrate communities based on manual taxonomic identification, requiring a substantial investment of labour and taxonomic expertise, or have relied on abiotic proxies like sulfide measurements with uncertain accuracy and reliability. Next-generation DNA sequencing methods offer an efficient and reliable lower-cost alternative by cataloging the diversity and abundance of benthic communities through metabarcoding of environmental DNA (eDNA). This approach has been successful at identifying environmental impacts associated with farming activities in Scotland, New Zealand, and Norway. This project will develop a new eDNA-based metabarcoding tool for assessing the impacts of farming on benthic metazoan and foraminiferan communities in BC and will validate its use for ongoing biomonitoring through comparisons with existing methods. This research will also address existing knowledge gaps about the impacts of salmon farming on benthic metazoans and foram communities and enrich DNA barcode databases for these taxa from BC inshore waters.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Cathryn Abbott (DFO)

PROJECT TEAM: Xiaoping He, Terri Sutherland, Kristi Miller-Saunders, Kara Aschenbrenner, Scott Gilmore, Kerra Shaw (DFO)

COLLABORATORS: Jan Pawlowski (U Geneva)

CONTACT: Cathryn.Abbott@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-P-06-eng.html

Assessment of Biodiversity and Functional Changes in Benthic Communities Associated with Aquaculture Activities in Newfoundland

This research project builds on the work being completed through two ongoing projects funded through the Program for Aquaculture Regulatory Research (DFO–PARR) (Evaluating the efficacy of the fallowing period as a mitigation tool at predominantly hard-bottom aquaculture sites in Newfoundland; and Development of a framework to assess the scale of year to year impacts from finfish aquaculture on hard ocean substrates in NL). This ongoing work allowed us to identify knowledge gaps and highlight the importance of linking biochemical oxygen demanding (BOD) fluxes with observed benthic indicators.

First, a better knowledge of the natural communities needs to be established through completion of a reference database of the natural Newfoundland benthic communities in areas of aquaculture development. This will allow a better documentation of the biodiversity hot spots and/or the areas with low natural richness. Through a paired/matched comparison of baseline data (reference) with biodiversity data post-aquaculture (gathered through the two other PARR initiatives), an evaluation of the 50% biodiversity loss areas and associated indicator presence will be attempted. Second, a characterization of the functional change of the natural benthic communities will be completed. Third, species richness and biodiversity data will be analyzed through linear mixed-effects (LME) models to examine whether species richness on the seafloor beneath and adjacent to aquaculture sites could be explained using available explanatory variables (visual indicators, distance, depth, and fallow period when applicable) treated as categorical variables.

The results of this research will be used to provide science advice to Fisheries and Oceans Canada's Aquaculture Management Directorate on the impact of finfish aquaculture over hard bottom substrates.

DATE: MAY 2016–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Dounia Hamoutene (DFO)

PROJECT TEAM: Flora Salvo, Sebastien Donnet, Shannon Cross, Dwight Drover, Fred Page (DFO)

COLLABORATORS: Suzanne Dufour (MUN); Roberty Sweeney (SIMCorp Marine Environmental)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-NL-09-eng.html

Biochemical Oxygen Demanding (BOD) Dispersion Model Validation Standards

The *Aquaculture Activity Regulations* (AAR) under the *Fisheries Act* came into effect in July 2015. The AAR Monitoring Standard for finfish marine aquaculture requires that dispersal models be used to predict contours of the rate of bottom deposited biochemical oxygen demanding matter released from fish farms and that some form of an aquaculture waste deposition model be used to make these predictions. The model to be used is not specified. In an effort to help farm owners, operators, and regulators become sufficiently aware of models that are potentially available, along with an identification and evaluation of how they function, what they assume, and what the accuracy of their predictions are, this project will: 1) review existing literature on aquaculture deposition models, and their applicability to AAR requirements and potential model audit criteria; 2) conduct an initial evaluation of a new release of the popular DEPOMOD model; and 3) review resuspension model literature and refine some recent aquaculture motivated resuspension models.

The results of this project will help provide information about the acceptability of models for the AAR requirements.

DATE: APR. 2016–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Fred Page (DFO)

PROJECT TEAM: Adam Drozdowski, Brent Law, Blythe Chang, Susan Haigh, Stacey Paul, Andry Ratsimandresey (DFO)

CONTACT: Fred.Page@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-M-13-eng.html

Exploration of Methodologies for Environmental Effects Monitoring of Finfish Aquaculture Sites in Sandy Bottom Environments with Natural Disturbances: Shelburne, Nova Scotia

The project will contribute to a better understanding of the limitations of existing methods and models and provide the basis for better informed and more extensive proposals focused on the development of survey, monitoring, and modelling approaches for this type of environment. Existing and proposed finfish sites in parts of Nova Scotia are located on sandy bottoms that experience annual disturbance by near-bottom currents generated by offshore waves. Current regulatory benthic sampling techniques (cores and light weight grabs) and models (DEPOMOD) used to monitor and predict deposition and benthic degradation have been developed for muddy bottoms. The suitability of these approaches for sandy disturbed environments is scientifically uncertain and has been questioned by Nova Scotia provincial authorities and aquaculture consultants.

The purpose of this project was to test several benthic sampling approaches, including: grab samplers; Remotely Operated Vehicle (ROV) camera systems; acoustic echo sounder; side-scan sonar systems; monitoring the water current and wave environment during the anticipated disturbance season (autumn-winter); analyze sediments (and acoustic signals, where appropriate) for bottom type, grain size, organic matter, and sulphide content; gather water column density profile information (i.e., Conductivity, Temperature, and Depth (CTD) profiles); and run DEPOMOD scenarios for currents representing the disturbance season. As an extension to the project, sediment re-suspension and transport models will be incorporated into the FVCOM and fine-tuned for the Shelburne area. The final analyses for this project are currently underway.

DATE: APR. 2012–APR. 2016

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Fred Page (DFO)

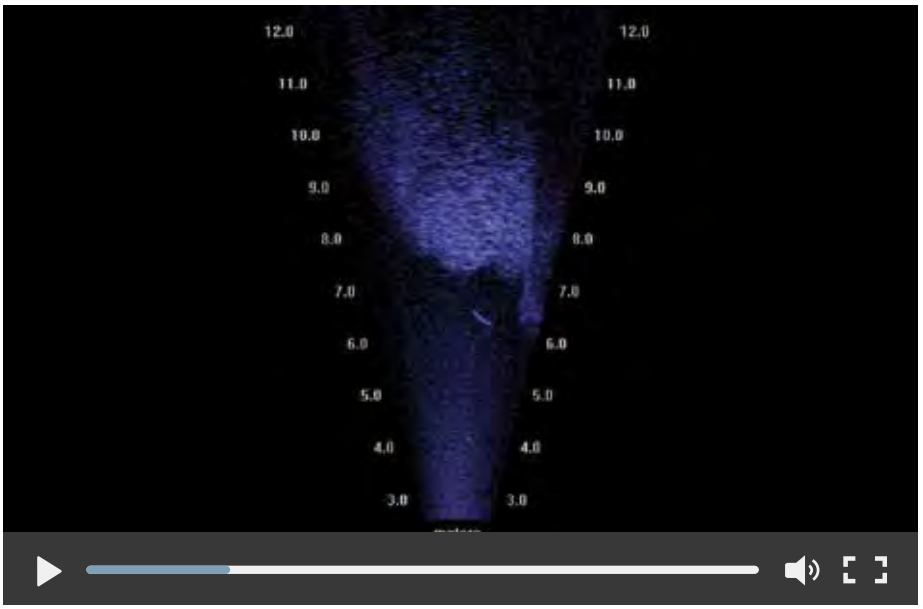
PROJECT TEAM: Blythe Chang, Mark McLean, Ed Parker, Randy Losier, Brent Law, Herb Vandermuelen, Sara Scouten (DFO)

COLLABORATORS: Mike Szemerda (Cooke Aquaculture Inc.)

CONTACT: Fred.Page@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2012-M-06-eng.html

Image of the Kadla Coulee aquaculture site in Lake Diefenbaker, Saskatchewan, Canada. Photo: Victoria Danco (DFO)



A wild fish observed swimming towards the Rainbow Trout (*Oncorhynchus mykiss*) that are milling within the aquaculture cage. The video was captured using DIDSON (Sound Metrics Corporation, Lake Forest Park, Washington, USA) on October 21, 2015. Video: Victoria Danco and Adam Waterer (DFO).

Analysing the Impact of Freshwater Aquaculture on Wild Fish Populations using DIDSON Technology

We explored the distribution of wild fish surrounding aquaculture cages using an innovative Dual-frequency IDentification SONar (DIDSON) in Lake Diefenbaker, Saskatchewan, Canada. The aim of this project was to test the DIDSON technology as a monitoring tool for the impact of freshwater aquaculture on wild fish populations. We collected DIDSON footage before (2011-2013) and after (2014-2015) the installation of net cages at a new aquaculture site in Kadla Coulee and at a reference site in Lake Diefenbaker. We assessed the efficacy of the DIDSON to detect changes in wild fish habitat use around fish farms.

DIDSON technology is non-destructive towards fish habitat and allows for the non-intrusive detection of fish during both day and night, regardless of the turbidity. This multi-beam sonar technology uses 1.8 MHz frequency and 96 sub-beams to effectively fill the gap between underwater cameras and commonly used multi-frequency single-beam, dual-beam, or split-beam sonar equipment. We established an operational protocol and data analysis procedure for the niche-application of DIDSON within an aquaculture setting and provided advice for future DIDSON surveys.

This research seeks to narrow the knowledge gap on the environmental interactions between cultured and wild fishes in order to make informed management decisions.

DATE: APR. 2015–MAR. 2016

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Eva Enders (DFO)

PROJECT TEAM: Victoria Danco, Cheryl Podemski, Cynthia Wlasichuk (DFO)

CONTACT: Eva.Enders@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-CA-05-eng.html

Oceanographic Study of the South Coast of Newfoundland (Baie d'Espoir and Fortune Bay)

The expansion of aquaculture activities in new areas in Newfoundland's south coast presents a challenge to the biosecurity and the sustainability of this growth. This project sought to understand the oceanographic conditions (including circulation) in Newfoundland's south coast and provide scientifically sound information to help establish Bay Management Areas. Building on these objectives, environmental data (temperature, salinity, currents, sea level, and wind speed and direction) collection, analysis, and modelling development were performed. The study first covered Bay d'Espoir and Hermitage Bay, later extending to Fortune Bay and Connaigre Bay where aquaculture activity has expanded or will expand. When possible, data collection was conducted in different seasons.

This study's results will provide insight into the fundamental processes governing the ocean conditions and circulation in the area. Such knowledge helps to develop a model to simulate and map potential zones of influence associated with finfish aquaculture. These zones will be used to establish production management areas to support fish health management for finfish aquaculture and will support the estimation of potential environmental zones of benthic influence associated with the aquaculture activity. The analysis of the observation data provides a comprehensive overview of the physical environment of the area, showing temporal and spatial variation leading to differences among bays driven by complex dynamics. Comparison of the observation with model data shows that the model is a good tool to simulate the sea level variability in the area. However, the model is at an early calibration stage with limited forcing physics to accurately represent the complexity of the dynamics of the study area. This limits the possibility of conducting full comparison and validation between observed and modelled water circulation.

DATE: APR. 2010–APR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Andry Ratsimandresey (DFO)

PROJECT TEAM: Sebastien Donnet, Dwight Drover, Shannon Cross, Fred Page, Randy Losier, Danny Ings, Mike Foreman (DFO)

COLLABORATORS: Newfoundland Department Fisheries, Forestry, and Agrifoods

CONTACT: Andry.Ratsimandresey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2010-NL-09-eng.html

Temporal Assessment of Organic Loading from Finfish Aquaculture on Hard Bottom Communities in Newfoundland

Fisheries and Oceans Canada (DFO) recently developed and is now implementing the *Aquaculture Activities Regulations* (AAR) to clarify conditions under which aquaculture operators may treat their fish for disease and parasites, as well as deposit organic matter (i.e., uneaten feed and faeces). These regulations permit aquaculture operators to deposit organic matter and treatments within certain restrictions while avoiding, minimizing, and mitigating potential impacts of aquaculture on fish habitat and on commercial, recreational, and Aboriginal fisheries. In support of the AAR, there is a need to evaluate monitoring standards and protocols for biochemical oxygen demanding (BOD) deposits (i.e., organic matter) in locations where it is not possible to collect sediment samples (i.e., hard-bottom substrates). So far, research findings suggest that video (i.e., visual) monitoring should be the primary tool for environmental assessment; however, a better understanding of its limitations is necessary.

To assess the impacts from unconsumed fish feed and fish faeces on the benthic community, it is necessary to validate video monitoring data with information on the benthic community. Samples of the waste that builds up under finfish farm net-pens will be collected and analyzed for changes in fauna and flora, and specifically for the presence or absence of indicator species (i.e., Polychaete worms and bacterial mats) known to occur near finfish farms. The study will also evaluate the use of remote video survey methods (ROVs) for monitoring benthic impacts, based on the protocol used in British Columbia. The results from this study will support the development of science advice on the best practices for monitoring the effects of finfish aquaculture on the hard bottom benthic community.

DATE: APR. 2015–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Dounia Hamoutene (DFO)

PROJECT TEAM: Flora Salvo, Dwight Drover, Kimberly Burt (DFO); Suzanne Dufour (MUN); Robert Sweeney (SIMCorp)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-NL-07-eng.html

Alternative Detection Methods for Performance Indicators of the Oxic State of Bottom Sediments: Indicator Inter-Calibration and Thresholds

Potential impacts associated with biochemical oxygen demanding (BOD) matter effluents at aquaculture sites are currently assessed by monitoring the oxic state of the bottom sediment. Performance indicators, including sulfide concentrations and redox potential (Eh), are currently used to determine the effects of BOD matter deposits on benthic organisms. Previous research has shown that the standard method for quantifying total free sulfides in sediments can provide highly inaccurate results as a result of contamination with mineral sulfides, calibration variability, and inappropriate sample storage. Eh measurements are also known to exhibit high variability.

This project continues ongoing research designed to evaluate an alternative indicator (dissolved oxygen) and to develop accurate and practical methods for total free sulfides analysis. Results from several oxic state indicators will be compared with the intention of identifying common thresholds that equate to the DFO management objective of no greater than 50% biodiversity loss. This project will also develop and evaluate sediment porewater sampling technologies as a potential alternative to the traditional use of grabs and cores in aquaculture monitoring programs.

DATE: APR. 2016–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Peter Cranford (DFO)

PROJECT TEAM: Lindsay Brager, Fred Page, David Wong, Cathryn Abbott (DFO)

CONTACT: Peter.Cranford@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-M-07-eng.html

Lindsay Brager (DFO) conducting field tests of a new method for rapidly and accurately measuring sediment sulfide concentrations. Photo: Peter Cranford (DFO)

Feeding Pressure of *Styela clava* on Plankton (Phytoplankton and Zooplankton) in Malpeque Bay, Prince Edward Island

Traditionally, bivalve aquaculture carrying capacity has been viewed in the context of maximizing stocking biomass and profitability at the farm scale; however, ecological carrying capacity is now at the forefront. Ecological carrying capacity is defined as the most intensive aquaculture activity that can be supported in a given ecosystem without unacceptable changes in ecological processes. Most carrying capacity models do not integrate fouling organisms, such as tunicates, due to a lack of information on their biology and feeding physiology. Both industry and regulators recognize the need to evaluate the ecological impact of tunicates (such as *Styela clava*) within mussel farms to further improve carrying capacity numerical models.

This project proposes five objectives: 1) assess the biomass and size structure of *S. clava* on mussel socks; 2) determine *S. clava* clearance rates on natural phytoplankton communities; 3) measure *S. clava* retention efficiency on zooplankton communities; 4) evaluate *S. clava* capacity to retain lobster larvae (stages I and IV); and 5) integrate results in a numerical model to provide new carrying capacity outputs inclusive of fouling *S. clava*.

Results from this study will provide quantitative information on the *S. clava* biomass in mussel farms as well as its filtration pressure on plankton, including phytoplankton and zooplankton (such as lobster larvae). This study may also contribute to more detailed modelling exercises in tunicate infested mussel culture bays. The outcome will reinforce the quantitative framework for assessing carrying capacity scenarios (present or future) in Malpeque Bay, PEI.

START DATE: APR. 2015–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

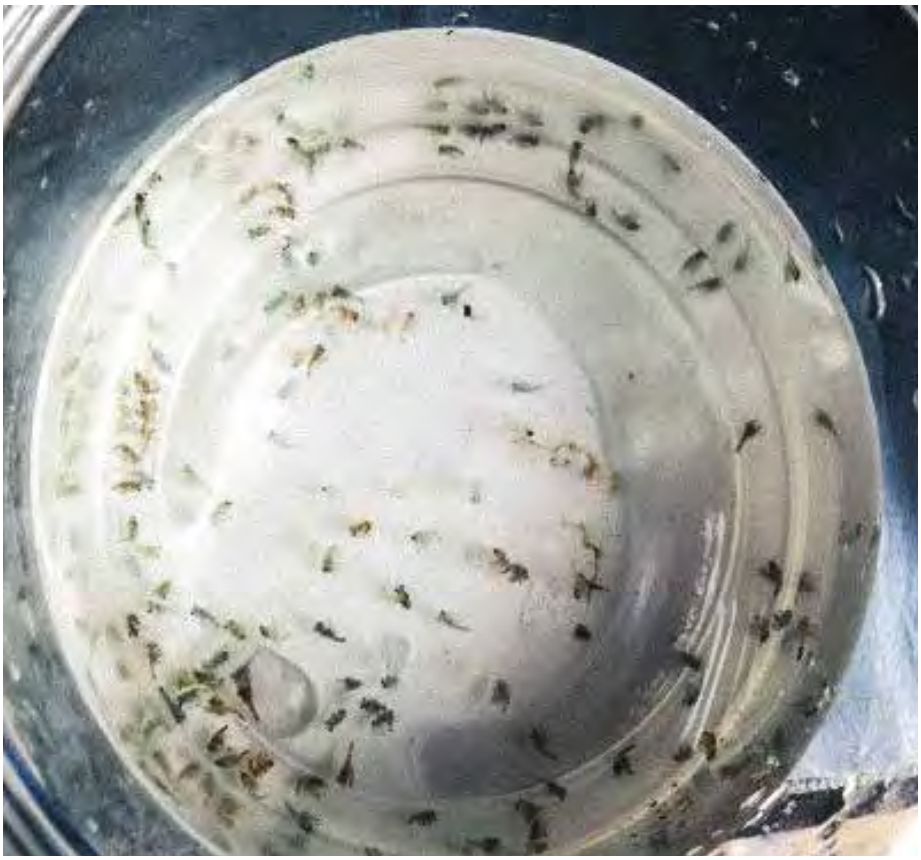
PROJECT LEAD: Rémi Sonier (DFO)

PROJECT TEAM: Luc Comeau, André Nadeau (DFO)

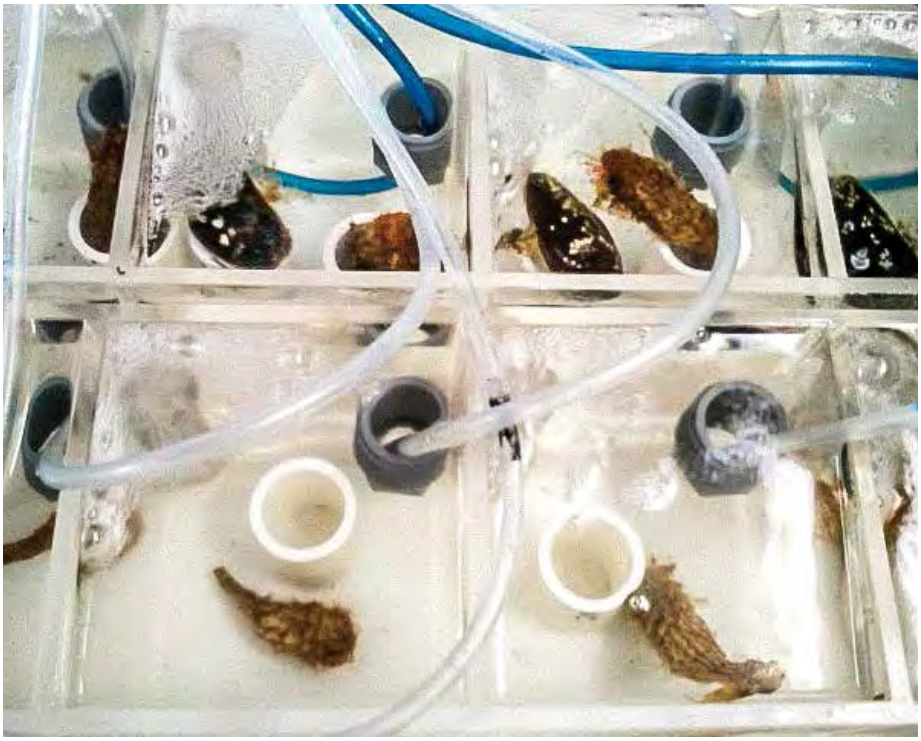
COLLABORATORS: Ramon Filgueira (Dalhousie U), Jeffrey Davidson (UPEI)

CONTACT: Remi.Sonier@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-G-10-eng.html



Reared lobster larvae. Photo: Luc Comeau (DFO)



Mussels and *Styela clava* in metabolic chambers. Photo: Remi Sonier (DFO)

Can Hard Clams (*Mercenaria mercenaria*) Increase the Rate of Eelgrass (*Zostera marina*) Recovery in Areas Impacted by Oyster Aquaculture?

The strategies tested in this study may promote the development of environmentally-friendly practices for the aquaculture industry by mitigating the negative impacts of active leases and eliminating the impacts of sites no longer in use.

Eelgrass communities are declining in many areas of the world, mainly due to increased inputs of nutrients and sediments from land-based sources, but also due to shading from aquaculture structures. Enhancement activities such as manual seed dispersal and transplanting whole plants have been explored to help counter eelgrass habitat declines. This has had limited success at a substantial cost. Bivalves have been found to stimulate eelgrass growth by clarifying the water column, thereby increasing light availability and increasing nitrogen levels through the production of waste products (faeces, pseudofaeces).

This project aims to determine whether the seeding of hard clams (*Mercenaria mercenaria*) can enhance eelgrass recovery in areas impacted by oyster aquaculture. Various densities of hard clams were introduced to areas with bare or sparse patches of eelgrass due to shading from previous commercial off-bottom oyster operations. Sediment characteristics, such as porosity, organic content, and carbon/nitrogen levels will be monitored along with the growth and recovery of the eelgrass over three years. Additionally, clams were sown directly under lines of suspended oyster bags at an active aquaculture site, to determine if their presence will encourage the growth of eelgrass in this heavily-impacted area.

This project supports the DFO priority of environmental performance.

DATE: MAY 2014–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: L'Étang Ruisseau Bar Ltd.

PROJECT LEAD: Monica Boudreau (DFO)

PROJECT TEAM: Claire Carver (Carver Marine Consulting)

COLLABORATORS: André Mallet (L'Étang Ruisseau Bar Ltd.)

CONTACT: Monica.Boudreau@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-14-01-004-eng.html

Eelgrass (*Zostera marina*). Photo: Selma Pereira (DFO)

Recovery of Neural Function in Lobsters Following Sub-Lethal Salmosan® Exposure

From a fish health and welfare perspective, the treatment of sea lice infestations is a critical component of managing New Brunswick's salmon farming industry. As with terrestrial farming, chemical pesticides are often a key component of integrated pest management for keeping such parasites at bay. However, many pesticides that are effective against sea lice cannot be used for this purpose because of their toxicity to non-target organisms. Salmosan® is one of the few pesticides approved for treating sea lice on farmed salmon in the Bay of Fundy, but it is known to be toxic to lobsters. Most research done to date on determining acceptable treatments with this compound has focused on acute lethality to lobsters, but it is also important to understand the non-lethal effects of exposure to this pesticide in order to model, and thereby better predict, the environmental impacts of sea lice treatments. The objective of this research is therefore to conduct controlled experiments to determine the rate at which lobsters recover from sub-lethal exposure to Salmosan®, using both behavioural and biochemical endpoints.

This research will provide essential data to support parallel oceanographic studies that are modelling pesticide dispersal following sea lice treatments, with the goal of improving application protocols that maximize treatment efficacy without undue harm to wild lobsters and their commercial harvesting and shipping.

DATE: SEP. 2015–MAY 2017

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

CO-FUNDED BY: New Brunswick Department of Agriculture, Aquaculture and Fisheries (NBDAAF); University of New Brunswick (UNB)–Environmental Research Fund

PROJECT LEAD: Tillmann Benfey (UNBF)

PROJECT TEAM: Danielle Deonarine (UNBF)

COLLABORATORS: : Duane Barker (HMSC); Les Burridge (Burridge Consulting)

CONTACT: benfey@unb.ca

WEBSITE: www2.unb.ca/biology/Faculty/Benfey.html

MSc. candidate Danielle Deonarine holding an experimental lobster. Photo: Anne McCarthy (HMSC)

Impact of Global Warming on Aquaculture Production in the Magdalen Islands: Blue Mussel, Atlantic Deep-Sea Scallop, and American Oyster

Cages used to monitor mussel aquaculture yields. Photo: Pascale Chevarie (Merinov)

Mariculture is an important economic activity in the Magdalen Islands, which produce Blue Mussels (*Mytilus edulis*), Atlantic deep-sea scallops (*Placopecten magellanicus*), and American Oyster (*Crassostrea virginica*). However, in recent years, mariculture stakeholders have noted that organisms in lagoon breeding sites are showing signs of weakening. These changes appear to coincide with increased exposure time to temperatures above 20°C and higher than normal summer temperatures. To answer industry's questions about the effects of warmer water temperatures on production and to help industry deal with this new problem, it is important to consider scenarios that will ensure sustainable aquaculture management in the context of global warming.

The main objective of the project is to assess the ability of Magdalen Islands mariculture production to adapt to global warming by studying the three species of bivalves produced at two experimental sites. During the three-year project, the environmental conditions of the breeding sites were measured, and aquaculture production yields were assessed for survival, growth, and condition index. Physical, biochemical, and genomic measurements were used to assess the status of the bivalves. Relationships established among the environmental characteristics of aquaculture sites, aquaculture yields, trophic conditions of the environment, and the physiological status of individuals will provide a better understanding of the impact of global warming on the Magdalen Islands and will be used to study potential scenarios for producers.

The research results will suggest potential concrete solutions to help Magdalen Islands shellfish producers adapt to global warming.

DATE: JUN. 2014–JUL. 2017

FUNDED BY: Fonds de recherche du Québec en Nature et technologies (FRQNT); Merinov and UQAR–Fonds d'Amorçage de Partenariat (FAP)

PROJECT LEAD: Lisandre Gilmore-Solomon (Merinov)

PROJECT TEAM: Madeleine Nadeau, François Gallien, Francine Aucoin, Jules Arseneau, Michèle Langford, Chantal Vigneau, Claude Poirier, Denis Boudreau, Yvon Chevarie, Francis Poirier, Pascale Chevarie, Mickael Cyr (Merinov)

COLLABORATORS: Réjean Tremblay (UQAR-ISMER)

CONTACT: lisandre.solomon@merinov.ca

WEBSITE: www.merinov.ca

Respirometry system for measuring the physiological status of bivalves. Photo: Lisandre Gilmore-Solomon (Merinov; CÉGEP de la Gaspésie et des Îles)

Study of the Effects on Adult American Lobsters (*Homarus americanus*) Consuming Clams Exposed to Atlantic Salmon Sea Lice Therapeutants

A common approach to control infestations of sea lice on farmed Atlantic Salmon involves the use of in-feed pharmaceutical products, such as emamectin benzoate and ivermectin, both of which persist in marine sediments. The effects of these treatments on non-target species such as the American Lobster have been studied in the past but focussed primarily on lethality tests conducted over short time frames. New research is needed to determine chronic lethal and sublethal effects under realistic exposures. The present study will be completed in 2017 to provide further essential non-target ecotoxicology data associated with the response of adult American Lobsters following voluntary consumption of exposed clams. Marine clams will be exposed to sediment with varying concentrations of the commercial formulations of emamectin benzoate and ivermectin, individually and in combination. In addition to providing toxicological data on native species exposed to two relevant chemotherapeutants, this approach will initiate the study of food chain effects on American Lobsters providing insight into effects within a more environmentally relevant scenario where sea lice treatment compounds are found in the benthic environment.

This study provides new information on uptake and effects of presently used anti-sea lice treatments in marine clams and the American Lobster.

DATE: DEC. 2016–MAR. 2017

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

PROJECT LEAD: Dounia Daoud (UPEI; Homarus Inc.; EcoNov Inc.)

PROJECT TEAM: Jason Bernier (CBCL Limited); Chris Bridger, Anne McCarthy, Duane Barker (HMSC); Martin Mallet (EcoNov Inc.)

CONTACT: Dounia.Daoud@econov.net

Study on the Sublethal Effects of the Sea Lice Pesticide Salmosan® (Azamethiphos) on Adult Male Lobsters (*Homarus americanus*)

Sampling for hemolymph on adult male lobsters (*Homarus americanus*) exposed to sublethal levels of Salmosan® (azamethiphos). Photo: Dounia Daoud (EcoNov Inc.)

Salmosan® (active ingredient: azamethiphos) is one of two pesticides currently permitted for use as a bath treatment to control sea lice in farmed salmon in Atlantic Canada. The release of pesticides from fish farms has raised concern regarding the potential for indigenous, non-target species to be exposed. In particular, there are growing concerns regarding the potential for effects on American Lobsters, a commercially important species in Atlantic Canada that is found in the near-shore environment where fish farms are located. Lobsters have been found to be the most sensitive species tested in laboratory assays examining the acute lethality of azamethiphos in the Salmosan® formulation. In this study, adult male lobsters were exposed to 0.06, 0.5, and 5 µg L^{-1} azamethiphos for one hour, repeated five times, over 48 h. Lobsters were assessed immediately after exposure and over six days of recovery.

Highlights: Inhibition of muscle cholinesterase activity detected in lobsters exposed to 0.5 and 5 µg L^{-1} azamethiphos. The 5 µg L^{-1} dose was considered lethal (93% cumulative mortality). Significant changes in hemolymph plasma biochemistry were most apparent in the 5 µg L^{-1} exposure group in the immediate post-exposure samples. Citrate synthase activity was significantly lower in muscles of the 0.5 µg L^{-1} exposure group compared to control lobsters. These results suggest that sublethal effects on lobster energetics may occur under laboratory exposure conditions (i.e., concentrations and duration) considered environmentally relevant, which could result in impairment under natural conditions.

This study provides new information on the sublethal effects of current use anti-sea lice pesticide on adult American Lobsters.

DATE: JAN. 2014–JUN. 2015

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

PROJECT LEAD: Dounia Daoud (UPEI; Homarus Inc.; EcoNov Inc.)

PROJECT TEAM: Jason Bernier (CBCL Limited); Jordana Lynne Van Geest (Golder Associates Ltd.); Michael Van Den Heuvel (UPEI); Andrea Battison (CrustiPath Inc.); Nathalie Lefort, Marc Surette (U Moncton)

COLLABORATORS: Homarus Inc.

CONTACT: Dounia.Daoud@econov.net

Adult male lobster (*Homarus americanus*) exposed to sublethal levels of Salmosan® (azamethiphos) placed in metabolic chamber for oxygen consumption measurements. Photo: Dounia Daoud (EcoNov Inc.)

Study of the Effects of Emamectin Benzoate or Ivermectin in Sediments on Juvenile American Lobsters (*Homarus americanus*)

Stage V lobsters exposed to sediment spiked with ivermectin and emamectin benzoate using commercial formulations in thermoregulated room. Photo: HMSC

Sea lice are large ectoparasitic copepods having a pan-global distribution and are pathogenic to salmonid species (e.g., Atlantic Salmon), especially populations in cage culture where the stocking density is unnaturally high. A common approach to reduce infection of sea lice to farmed Atlantic Salmon involves use of approved in-feed pharmaceutical products. Field studies have often measured these active ingredients in sediments proximal to salmon farms post treatment. The effects of these products on non-target species such as the American Lobster (*Homarus americanus*) has been studied in the past but not associated with lethal and sub-lethal effects from dosed sediment on which the juvenile lobsters live. The goal of this study was to assess the availability of two currently used sea lice treatments (active ingredients emamectin benzoate and ivermectin) and to measure acute mortality and sub-lethal effects on juvenile American Lobsters following extended exposure to dosed sediment in a static bath with water renewal. The study will provide ecotoxicology data associated with the response of juvenile American Lobsters when exposed to varying concentrations of emamectin benzoate- and ivermectin-dosed sediment using the commercial formulations.

This study provides new information on the effects of presently used anti-sea lice drugs on early post-settled life stages of *H. americanus*.

DATE: APR. 2016–MAR. 2017

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

PROJECT LEAD: Dounia Daoud (UPEI; Homarus Inc.; EcoNov Inc.)

PROJECT TEAM: Jason Bernier (CBCL Limited); Chris Bridger, Anne McCarthy, Duane Barker, Les Burridge (HMSC)

CONTACT: Dounia.Daoud@econov.net

Aerated jar with stage V lobster exposed to sediment spiked with emamectin benzoate using commercial formulation. Photo: HMSC

Pill cups loaded with individual stage V lobsters before exposure to spiked sediment with ivermectin and emamectin benzoate (via commercial formulations). Photo: HMSC

Validation of the Robustness of the Ecosystem Carrying Capacity Models Being Developed for St. Peters Bay

Although mussel aquaculture is a significant industry in Prince Edward Island (PEI), Canada, a moratorium on further leasing there was established in 1999–2000. Recently, a Marine Spatial Planning process was initiated in order to review the moratorium and explore the potential expansion of mussel culture in Malpeque Bay. In this study, we have focused on the effects of a projected expansion scenario (590 ha) on current mussel lease (770 ha) productivity and availability of suspended food resources. The goal was to provide the most robust scientific assessment possible using available datasets. Towards that aim, three different modelling approaches have been carried out: 1) a connectivity analysis among the different culture areas of the bay; 2) a scenario analysis of organic seston dynamics based on a simplified biogeochemical model; and 3) a scenario analysis of phytoplankton dynamics based on a nutrient-phytoplankton-seston-bivalve ecosystem model. In addition, sensitivity tests were carried out in order to identify the parameters and processes for which further research is needed to reduce model uncertainty. The main outcomes of these modelling exercises suggest: 1) an 8% (± 2%) reduction in mussel growth in the Marchwater area due in part to direct connectivity among leases but also to bay-scale effects driven by the overall increase in bivalve biomass within the bay; and 2) a 17.7% net reduction of chlorophyll a at the bay-scale compared to a hypothetical scenario without aquaculture.

DATE: APR. 2011–APR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Luc Comeau (DFO)

PROJECT TEAM: Michel Starr, Liliane St-Amand, Thomas Guyondet, Rémi Sonier (DFO); Jon Grant, Ramon Filgueira (Dalhousie U)

CONTACT: Luc.Comeau@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2011-G-04-eng.html

Effects of Organophosphate Aquaculture Pesticide Azamethiphos on Stage I and Stage IV American Lobster (*Homarus americanus*) Larvae

Holding tank for stage IV lobster larvae (*Homarus americanus*) exposed to sublethal levels of Salmosan® (azamethiphos). The high water bubbling tends to decrease natural cannibalism. Photo: Laura Taylor (UPEI)

Both the American Lobster fishery and salmon aquaculture are important to the economy of Atlantic Canada. Where these industries operate in close proximity, research is needed to better understand any interactions and their possible effects. Salmosan® (active ingredient azamethiphos) is an organophosphate therapeutant used to treat Atlantic Salmon for infestations of parasitic sea lice. The sensitivity of crustaceans to Salmosan® has been studied but few studies have examined the pesticide's effects on the health of larval lobsters. Three-hour exposures using stage I and IV *H. americanus* larvae were carried out using a range of azamethiphos (as Salmosan®) concentrations between 0.04–71.11 µg L^{-1}. Median lethal concentrations at three hours were determined to be 5.87 ± 2.01 µg L^{-1} for stage I and 20.45 ± 12.77 µg L^{-1} for stage IV lobsters. Post-exposure, surviving stage IV larvae were raised to stage V and sublethal parameters including intermoult period, specific growth rate, moult increment, and global gene expression were determined. General linear model analysis (α = 0.05) determined that intermoult period was significantly increased in the 71.11 µg L^{-1} azamethiphos treatment when compared to the control (<0.05 µg L^{-1} azamethiphos). Moult increment and specific growth rate were not significantly affected. RNA sequencing was performed using Illumina Hiseq 2500 PE125 and subsequent RT-qPCR was performed to confirm expression of genes of interest. Gene expression was used to establish effects on biological pathways of *H. americanus* in order to determine unique gene induction patterns. Established gene induction patterns may be used as a potential diagnostic tool for pesticide exposure in lobster.

This study provides new information on the effects of a current use anti-sea lice pesticide on Stage I and IV *H. americanus* larvae.

DATE: APR. 2015–MAR. 2016

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

PROJECT LEAD: Dounia Daoud (UPEI; Homarus Inc.; EcoNov Inc.)

PROJECT TEAM: Jason Bernier (CBCL Limited); Spencer Greenwood, Michael Van Den Heuvel, Laura Taylor (UPEI); Fraser Clark (Mount Allison University)

COLLABORATORS: Martin Mallet (Homarus Inc.)

CONTACT: Dounia.Daoud@econov.net

Stage IV lobster larvae (*Homarus americanus*) were exposed for three hours to Salmosan® (azamethiphos) in 1 L jars. Photo: Laura Taylor (UPEI)

Stage IV lobster larvae (*Homarus americanus*) weighted and measured after a three hour exposure to various levels of Salmosan® (azamethiphos). Photo: Laura Taylor (UPEI)

Paving the Way for Salmon-Kelp Integrated Aquaculture in British Columbia: A Foundational Field Trial Assessing Sugar Kelp (*Saccharina latissima*) Growth and Quality at BC Salmon Farms

Kelp is a fast-growing marine crop that requires virtually zero energy inputs, utilizing sunlight and dissolved nutrients (e.g., nitrogen, phosphorus) from the surrounding environment for growth. This study examined the feasibility of growing kelp on commercial salmon farm tenures where levels of dissolved nitrogen and phosphorus may be locally-enriched.

In January 2016, Sugar Kelp (*Saccharina latissima*) seed was deployed on 5 m vertical polyethylene lines at 15 salmon farms and two oyster farms around Vancouver Island. Kelp was harvested in the summer after approximately 150 days; frond length, width, wet/dry weight, proximate analysis, and metal accumulation were measured. Maximum frond length ranged from <20 cm to >330 cm, depending on the site. Proximate analysis (KJ, protein, ash, fat, calories, carbohydrates, moisture) of dried kelp revealed site-specific differences in nutritional parameters, with carbohydrates ranging from 20.4% to 47.5% of tissue dry weight. Metal accumulation (Al, As, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, P, Pb, Zn) in kelp tissue from the 15 salmon farms is being measured using inductively coupled plasma optical emission spectrometry (ICP-OES). A follow-up, more intensive kelp production trial at select sites will commence in 2017 using horizontal kelp lines deployed from customized floating rafts.

The siting of many salmon farm operations in British Columbia would support excellent Sugar Kelp production, a sustainable crop with diverse commercial applications. Through field studies such as this we hope to demonstrate the feasibility of salmon-kelp integrated aquaculture in BC with the goal of improving the environmental and socio-economic performance of salmon farm tenures.

DATE: OCT. 2015–DEC. 2017

FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)–Industrial Research Chairs for Colleges Grant (NSERC–IRCC)

CO-FUNDED BY: Cermaq Canada Ltd.; Creative Salmon Co. Ltd.; Grieg Seafood BC Ltd.; North Island College (NIC)

PROJECT LEAD: Stephen Cross (NIC)

PROJECT TEAM: Allison Byrne (NIC)

COLLABORATORS: NIC-CARTI; Cermaq Canada Ltd.; Creative Salmon Company Ltd.; Grieg Seafood BC Ltd.; Mac's Oysters Ltd.; Odyssey Shellfish Ltd.

CONTACT: Stephen.Cross@nic.bc.ca

WEBSITE: https://www.nic.bc.ca/research

Stephen Cross examining a Sugar Kelp, *Saccharina latissima*, frond. Photo: Allison Byrne (NIC)

The Effects of Sublethal Aquaculture Chemotherapeutant Exposure on Pink Salmon

Swim tunnel used for assessing fish swimming performance (critical swimming speed [Ucrit]) following exposure to chemotherapeutants. Photo: Feng Lin (SFU)

DATE: SEP. 2014–MAR. 2017

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

CO-FUNDED BY: Simon Fraser University (SFU)

PROJECT LEAD: Chris Kennedy (SFU)

PROJECT TEAM: Katerina Vasilenko (SFU)

CONTACT: ckennedy@sfu.ca

An improved understanding of chemical impacts on near-shore ecosystems is essential to responsible stewardship of Canada's coastal areas. In order to accurately assess the risk to non-target marine fish species posed by the use of the chemotherapeutants emamectin benzoate, azamethiphos, deltamethrin, cypermethrin, or hydrogen peroxide in the receiving environment, information regarding their sublethal toxicity is essential. Pink Salmon (*Oncorhynchus gorbuscha*) embryos were hatched in the laboratory, transferred to seawater, and raised until they were the appropriate size for swimming and behavioural assays following exposure (pulse: 1 h, 3 h, 6 h; and longer term: 96 h) to several concentrations of each aquaculture chemical. Fish were tested for swimming performance using a measure of critical swimming speed (Ucrit), avoidance/attraction behaviour, and the ability to detect food. All aquaculture pesticides (except hydrogen peroxide) reduced Ucrit values at concentrations below 96 h-LC_{50} values determined for this species in preliminary toxicity tests. For azamethiphos, cypermethrin, deltamethrin, and emamectin benzoate, concentration-dependent reductions in swim performance were seen. Fish actively avoided all chemicals except deltamethrin at similar concentrations and avoidance to hydrogen peroxide only occurred at the highest concentration. Following exposure to each chemical at various concentrations for longer exposures (6 and 96 h), a loss of attraction to food was noted in olfactory response tests. The data obtained from this research will allow regulators to assess the risks posed to the environment adjacent to salmon aquaculture facilities and the risks posed to non-target fish species from chemotherapeutant use.

New data will support assessments of risks posed to the environment adjacent to salmon aquaculture facilities and the risks posed to non-target fish species from chemotherapeutant use.

The Lethal, Physiological, and Behavioural Effects of Anti-Sea Lice Therapeutants in Non-Target Crustacean Species

Environmental contamination and effects on non-target organisms associated with the chemotherapeutic control of sea lice infestations in salmonid aquaculture has emerged as a significant concern. This research specifically addresses information gaps that need to be filled to properly manage any risks associated with the use of three chemicals currently used in Canada. Several shrimp species were tested for the acute lethal effects of current-use chemicals: the reference species Mysid shrimp (*Mysidopsis bahia* East coast species), and several species of Pacific shrimp including the Coonstripe (*Pandalus hypsinotus*), Dock (*Pandalus danae*), and Pink Shrimp (*Pandalus jordani*), Spot Prawn (*Pandalus platyceros*), Ghost Shrimp (*Neotrypaea* spp.), and an unidentified sand shrimp. Shrimp were exposed to at least five concentrations of either SLICE®, Salmosan®, or Paramove 50® for 1 to 96 h. Juvenile Pacific coast shrimp were equally as sensitive to all three chemicals as their east coast counterparts. Spot Prawn (*Pandalus platyceros*) exposed to water containing the active ingredients of SLICE®, Salmosan®, and Paramove 50® (emamectin benzoate, azimethiphos, and hydrogen peroxide) resulted in concentration-dependent increases in oxygen consumption. In a choice/avoidance assay, unexposed Spot Prawns, acclimated in a shuttle box apparatus, showed conflicting results to hydrogen peroxide, emamectin benzoate, and azamethiphos at several concentrations. Prawns were actively attracted and actively avoided all chemicals at low concentrations. This research will ensure the appropriate regulation of chemotherapeutant use in Canadian aquaculture and maintain the goal of protecting non-target organisms in the marine environment.

New data will support assessments of risk from current-use chemotherapeutants posed to a range of non-target benthic crustaceans found in proximity to Pacific salmon aquaculture facilities.

DATE: OCT. 2015–MAR. 2017

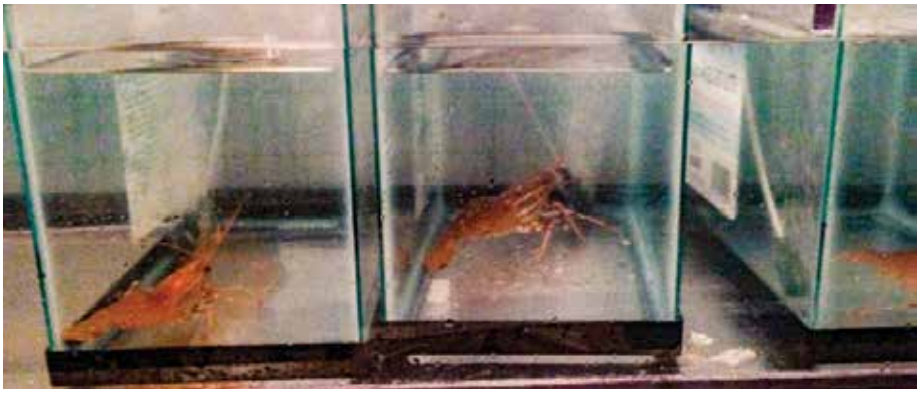
FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

CO-FUNDED BY: Simon Fraser University (SFU)

PROJECT LEAD: Chris Kennedy (SFU)

PROJECT TEAM: Jill Bennett (SFU)

CONTACT: ckennedy@sfu.ca



Tanks holding Spot Prawn (*Pandalus platyceros*) for lethal and sublethal toxicity experiments. Photo: Kate Mill (SFU)

The Effects of Anti-Sea Lice Chemotherapeutants on Sensitive Life Stages of Non-Target Crustacean Species in Combination with Environmental Stressors

Exposure tanks for Spot Prawn (*Pandalus platyceros*) for toxicity experiments under multiple stressor conditions. Photo: Feng Lin (SFU)

There is specific concern regarding the use of the anti-sea lice therapeutants Salmosan®, SLICE®, and Paramove 50® in the aquaculture industry specifically in regard to their toxicity to Pacific coast region organisms. In real world scenarios, organisms are often challenged with multiple environmental stressors simultaneously, including those of a physical nature (e.g., oxygen, temperature, and salinity fluctuations). In these studies, the range of oxygen, temperature, and salinity tolerances in Spot Prawn, *Pandalus platyceros*, were determined in order to design experiments to measure the acute toxicity of these chemicals under varying physical conditions. In acute lethality studies, Spot Prawn juveniles and adults were exposed to five concentrations of each individual chemical formulation in glass 40-L glass aquaria for up to 96 h under varying oxygen, temperature, and salinity conditions. Juvenile Spot Prawns were much more sensitive to all chemicals than adults, and acute toxicity was exacerbated by exposure to physical conditions approaching tolerable limits. In particular, oxygen concentrations, followed by temperature, and then salinity had the most pronounced effects on increasing chemical toxicity. This research specifically addresses information gaps that need to be filled in order for proper assessments of the environmental consequences of sea lice pesticide use in Canada to be made. This research provided information on the toxicity of these chemicals under environmentally realistic conditions to a representative and sensitive Pacific coast marine organism.

New data will support assessments of risk from chemotherapeutant use in combination with environmental stressors posed to a non-target benthic crustacean found in proximity to Pacific coast salmon aquaculture facilities.

DATE: SEP. 2014–MAR. 2017

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

CO-FUNDED BY: Simon Fraser University (SFU)

PROJECT LEAD: Chris Kennedy (SFU)

PROJECT TEAM: Kate Mill, Jill Bennett (SFU)

CONTACT: ckennedy@sfu.ca

The Environmental Fate and Non-Target Effects of Sea Lice Drugs and Pesticides Used in Salmon Aquaculture

Five chemotherapeutants used globally to control sea lice in salmon farming operations of particular interest with regard to their fate and toxicity are: deltamethrin, cypermethrin, azamethiphos, hydrogen peroxide, and emamectin benzoate; the latter three of which are currently used in Canada. Predictions of the persistence and toxicity of these chemicals to non-target organisms has been difficult, and data gaps make estimations of risk highly inaccurate. The main objectives of this research were to assess: 1) the environmental persistence and partitioning of these compounds, and 2) their acute and sublethal toxicity to non-target marine organisms. In micrososm experiments, the partitioning behaviour, and water and sediment half-lives were determined. Emamectin benzoate, cypermethrin, and deltamethrin partitioned mainly into sediments, while azimethiphos and hydrogen peroxide remained in the aqueous phase. Generally, the persistence of these chemicals was cypermethrin > deltamethrin > emamectin benzoate > azimethiphos > hydrogen peroxide. In standardized acute toxicity tests, the susceptibility to each chemical was species-specific and no general trends were evident. Kelp *Macrocystis pyrifera* germination and growth were only affected by hydrogen peroxide. Echinoderm *Strongylocentrotus purpuratus* fertilization was affected by cypermethrin > deltamethrin > emamectin benzoate > hydrogen peroxide. Bivalve *Mytilus edulis* development was affected by hydrogen peroxide > emamectin benzoate > azamethiphos. For the mysid *Americamysis bahia*, all chemicals tested were highly toxic at concentrations far below those used in aquaculture (deltamethrin > cypermethrin > emamectin bezoate > azimethiphos > hydrogen peroxide). This research yields important information required to ensure the proper and safe use of aquaculture pesticides, and to appropriately regulate these important aquaculture chemicals to protect the environment.

New information on the environmental fate and non-target toxicity of five chemotherapeutants will inform decisions on the responsible use and management of these products for the control of sea lice.

DATE: SEP. 2014–MAR. 2017

FUNDED BY: DFO–National Contaminants Advisory Group (DFO–NCAG)

CO-FUNDED BY: Simon Fraser University (SFU)

PROJECT LEAD: Chris Kennedy (SFU)

PROJECT TEAM: Fauve Strachan (SFU)

COLLABORATORS: Frank Gobas, Victoria Otton (SFU; Nautilus Environmental)

CONTACT: ckennedy@sfu.ca

Structure and Function of the Salmon Farm "Reef"

The presence of fish farm infrastructure provides habitat for native marine flora and fauna from the surrounding environment, in many ways acting as an artificial "reef". This project is documenting the reef community structure at four salmon farms in different environments around Vancouver Island. Scraped samples and high-resolution photos of the community at each site are being collected seasonally from billets on all sides of the farm. The abundance (biomass per unit area) and composition (biodiversity) of the communities will be compared within and between sites over time. In addition to seasonal billet sampling, five hard plastic panels were deployed at 1 m depth at each site and will remain in the water undisturbed (with the exception of being photographed) for 18 months. These will be used to document and compare the settlement rate and composition in different farming environments.

Understanding the community of native species inhabiting fish farm infrastructure over time and in different locations will help identify key relationships between salmon farms and the surrounding environment, providing insight into the function of these dynamic communities.

DATE: APR. 2016–MAR. 2018

FUNDED BY: BCSFA–Marine Environmental Research Program (BCSFA–MERP)

CO-FUNDED BY: Cermaq Canada Ltd.; Creative Salmon Co. Ltd.; Grieg Seafood BC Ltd.; Marine Harvest Canada Limited; North Island College (NIC)

PROJECT LEAD: Stephen Cross (NIC)

PROJECT TEAM: Chris McKindsey (DFO); Allison Byrne (NIC)

COLLABORATORS: NIC–CARTI; Cermaq Canada Ltd.; Creative Salmon Company Ltd.; Grieg Seafood BC Ltd.; SEA Vision Group Inc.;

CONTACT: Stephen.Cross@nic.bc.caW

WEBSITE: https://www.nic.bc.ca/research

Examples of different reef communities observed on fish farm billets. Photo: NIC

Identifying Critical Ecological Thresholds for Tunicate Infestations on Mussel Farms

Mussel farmers in PEI have developed treatment regimens to control invasive tunicates (*Ciona intestinalis* and *Styela clava*). To study the ecological thresholds of these treatments on the benthic environment and the water column, we set up field and laboratory experiments and used modelling to predict farm-scale effects. Firstly, we studied high pressure water treatment for *C. intestinalis* in St. Mary's Bay. Treatments effectively removed 54% and 78% of *C. intestinalis* from infested socks in July and September, respectively. During treatment, drifting tunicates were observed in narrow patches, but most of the sinking biomass fell directly below the pressure-washed line. We found no significant difference in organic enrichment in sediments below the treated line and those below the untreated line. These results could be due to heavy predation by crabs during treatment activities. For most stations, mean redox fell within the anoxic category. A synoptic survey of the Bay of St. Mary's found hypoxic sediment conditions in July and oxic conditions in November, regardless of whether sediments were within or outside of the mussel farm. A preliminary modelling assessment indicated that *C. intestinalis* fouling is best controlled by applying early treatments (combination July and August) to limit impacts in terms of food reduction and total organic sedimentation under the lines. Secondly, we studied water pH variation during hydrated lime treatment for *S. clava* in Malpeque Bay. Overall the treatment produced a negligible pH signal in the water column and on the benthic substrate with a short-term increase followed by a quick return to baseline values.

DATE: APR. 2011–APR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Thomas Landry (DFO)

PROJECT TEAM: Andrea Locke, Chris McKindsey, Monique Niles, Daniel Bourque, Thomas Guyondet, Luc Comeau (DFO); Aaron Ramsay (DFARD); Jeff Davidson, Thitiwan Patanastienkul (UPEI–AVC)

CONTACT: Thomas.Landry@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2011-G-05-eng.html

Co-Culture of Blue Mussel (*Mytilus edulis*) and Sugar Kelp (*Saccharina latissima*): Exploring the Potential Effect of Seaweeds in Deterring the Effect of Duck Predation on Mussels, Cascapedia Bay (Quebec)

In Europe and Canada, the economic losses in Blue Mussel (*Mytilus edulis*) farms due to duck predation represent a major problem. In this proof of concept experiment, an alternative approach will be presented that aims to reduce duck predation in Canadian mussel farms where traditional techniques are not effective. These methods generally either focus on protecting mussels by isolating them in nets or cages, or use active repelling techniques (sound, light, etc.). Such techniques are often expensive, stressful to duck populations, only effective for a short time, and do not take into consideration drifting ice. To solve the problem, Sugar Kelp (*Saccharina latissima*) will be cultivated above the mussel culture line, to visually shield the mussels. The hypothesis is that by hiding the mussels from ducks' field of vision, they could get some protection without imposing further stress on the ducks. Additionally, it is suggested that Sugar Kelp and Blue Mussels could benefit from each other's proximity in terms of production yields, consumption, and excretion. The Sugar Kelp plantlets were outplanted at sea in November 2016. Their biomass and overall aspect will be recorded simultaneously with the mussels' yield (wet kg / m), survival rate (# indiv. / m), and overall quality (Body Condition Index) during the summer of 2017. This proof of concept is being carried out in the Cascapedia Bay (Québec) in partnership with the mussel industry.

This work will contribute to provide alternative solutions to prevent the predation of culture mussel by sea ducks. It will also document the potential benefits of polyculture in a mussel farm.

DATE: AUG. 2016–JUL. 2017

FUNDED BY: Ministère de l'éducation et de l'enseignement supérieur du Québec (MÉES) [Québec Ministry of Higher Education and Training]

CO-FUNDED BY: Merinov

PROJECT LEAD: Pierre-Olivier Fontaine (UW; CEGEP–EPAQ)

PROJECT TEAM: Estelle Pedneault, Éric Tamigneaux, Quentin Cometti (CEGEP–EPAQ)

COLLABORATORS: Éric Bujold (La Ferme Maricole du Grand Large)

CONTACT: POFontaine@cegepgim.ca

The twine carrying the Sugar Kelp (*Saccharina latissima*) plantlets is wound around the culture line on the mussel farm. Photo: Pierre-Olivier Fontaine (UW; CEGEP-EPAQ)

Setting artificial kelp made of fabric (control treatment) on the mussel farm. Photo: Pierre-Olivier Fontaine (UW; CEGEP-EPAQ)

Tracking *in Situ* Real-Time Responses of Ocean Acidification Effects on Biological Organisms and Influence on Plankton Diversity

Coastal margins are under increasing human-induced pressures including eutrophication and ocean acidification, which interact with natural environmental fluctuations in ways that can exacerbate calcium carbonate ($CaCO_3$) mineral corrosivity. Ocean acidification negatively impacts a range of species, especially those dependent on $CaCO_3$ saturation states for shell formation, including socio-economically important species like marine shellfish. The capacity for marine populations to adapt to these changes is unknown, and the loss of dominant coastal and estuarine organisms such as shellfish may significantly alter marine ecosystem structure and function, as well as threaten food security.

This research combines lower trophic level monitoring (plankton analysis), physiological responses (functional genomics of multiple species of shellfish) and high speed (0.5Hz) near real-time oceanographic monitoring at a field site in the northern Salish Sea in British Columbia (BC). This initial project is a novel pairing of these technologies *in situ*, and provides information on coastal variability and impacts on ecosystem productivity in a poorly sampled portion of the BC coastal margin. This work is currently ongoing, but preliminary results of gene expression studies of multiple commercial shellfish species and accompanying plankton work are underway. Recent equipment updates have allowed direct sampling of biological responses to ocean acidification conditions in a real world environment, to enable the examination of the impact of ocean acidification on the long-term health and productivity of coastal ecosystems in BC and elsewhere.

DATE: FEB. 2015–ONGOING

FUNDED BY: Hakai Institute

CO-FUNDED BY: Pacific Salmon Foundation (PSF); Vancouver Island University (VIU)

PROJECT LEADS: Helen Gurney-Smith (DFO); Wiley Evans (Hakai Institute)

PROJECT TEAM: Kayla Mohns, Caitlin Smith (VIU); Tamara Russell (VIU; Microthalassia Inc.)

COLLABORATORS: Léo Pontier, Katie Pocock, Alex Hare (Hakai Institute)

CONTACT: Helen.Gurney-Smith@dfo-mpo.gc.ca

WEBSITE: http://seaomics.wixsite.com/research/research-blog

Quadra Island field-site. Photo: Kayla Mohns (VIU)

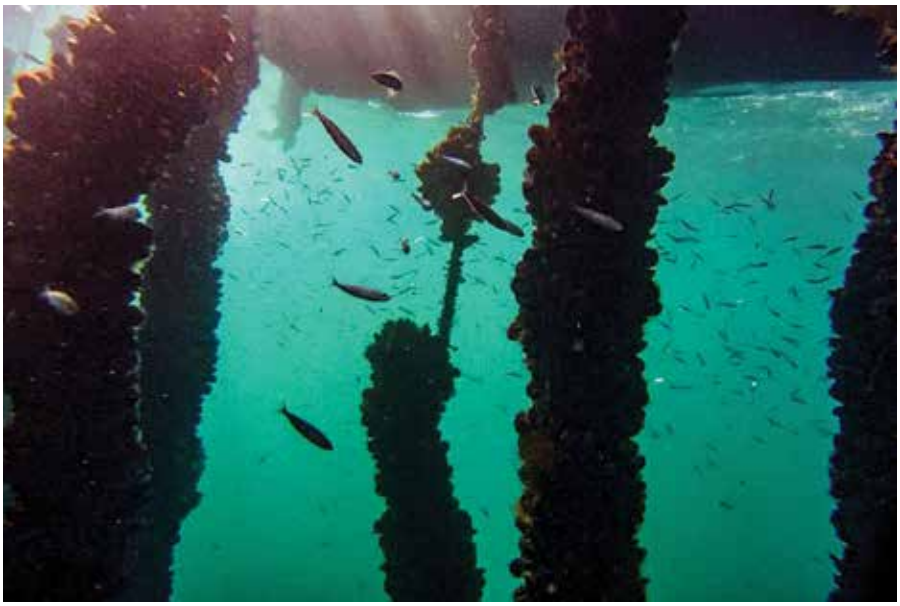
One of the test species and life stages – adult Pacific Oyster (*Crassostrea gigas*). Photo: Kayla Mohns (VIU)

Molecular laboratory analysis (Kayla Mohns). Photo: Caitlin Smith (VIU)

From left to right, Caitlin Smith, Helen Gurney-Smith (DFO), and Léo Pontier (Hakai Institute) at a shellfish raft monitoring station. Photo: Kayla Mohns (VIU)

Building an Understanding of the Mobile Wild-Farmed Interactions Occurring around Aquaculture Farms in the Bay of Fundy

Man-made structures in the ocean are often attractive to a multitude of different species. Not only do these three-dimensional structures provide habitat and shelter from predation for various organisms, structures such as fish farms, where food is added on a daily basis, often provides nourishment for the food webs that become established on these structures. The biological interactions that occur on aquaculture farms are easily apparent in the form of naturally occurring biofouling organisms. They coat the lines and nets, causing increased physical drag on the system from currents as well as a reduction in water flow through the nets. This can sometimes affect oxygen levels in the water within the cage. These organisms are often sessile and many studies have been done on their development and possible methods for control. However, there is also a mobile suite of species, both benthic and pelagic, that are attracted to the energy and habitats associated with aquaculture farms. These organisms are much more transitory and difficult to sample and as a result, very little is known of their ecological interactions and their relative presence on the site. This study is starting to document the mobile fauna that are using the site on a seasonal basis through a combination of acoustic and photographic technologies to assess the potential interactions that they may have with the cultured species. These observations will form the basis of an understanding on the scale of benefits that these species may accrue and also the potential risks they represent.



Utilization of a mussel farm by wild fish and biofouling species at an aquaculture farm site in Spain. Similar situations occur in the Bay of Fundy around aquaculture farms, however, poor water visibility prevents a clear photo representation. Photo: Shawn Robinson (DFO)

Understanding the scale at which wild species are utilizing intensively cultured aquaculture sites will provide a basis for the determination of the likelihood of negative interactions happening. These interactions can go both ways from either farm to wild or vice versa and can be either detrimental or beneficial. It has implications on fish health (parasites and disease) and the zone of influence from farming activities.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Chris McKindsey, Gregor Reid, Steve Neil, Craig Smith, Jonathan Day (DFO)

COLLABORATORS: Eva Enders (DFO)

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: http://www.mar.dfo-mpo.gc.ca/SABS/Home

Meta-Analysis of Freshwater Aquaculture Provincial Water Quality Monitoring Data

Recent increases in production capacity in Ontario, Saskatchewan, and British Columbia have prompted regulators to consider strategies for managing freshwater finfish aquaculture, in particular, ecosystem carrying capacity which is tightly coupled with the phosphorus released in aquaculture waste. Currently in Ontario, a water quality monitoring program is imposed as a condition to aquaculture licenses to ensure that the release of phosphorus from finfish farms does not exceed regulatory thresholds. The program, however, does not address phosphorus levels near or downstream from freshwater finfish farms, or if phosphorus concentrations have increased over the decade that sampling has been conducted. One of the primary environmental concerns restricting the expansion of the freshwater finfish cage industry is the ability of the environment to assimilate waste, in particular phosphorus. Phosphorus is the nutrient that limits the biomass of primary producers; excessive amounts of phosphorus released from aquaculture cages pose a risk of eutrophication in freshwater ecosystems.

A decade of water monitoring data collected through the historic Ontario monitoring program was analyzed to determine if there is evidence that freshwater finfish cages are contributing to elevated phosphorus concentrations and to the eutrophication in the environment. The results from this work have a high probability of being used to improve social license for the industry as they demonstrate to the public that the industry is being carefully monitored by the provincial regulator and that there has been no trend of decreasing water quality at active aquaculture sites.

DATE: APR. 2014–MAR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Cheryl Podemski (DFO)

CONTACT: Cheryl.Podemski@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-CA-09-eng.html

Evaluation of Benthic Far-Field and Site Recovery Effects from Aquaculture within the Letang Inlet, New Brunswick

One of the primary environmental effects of coastal marine aquaculture is related to the deposition of organic material (uneaten fish food and feces) to the seabed and the associated change in benthic organisms inhabiting the affected area. While the obvious effects of organic deposition are limited to close proximity of an aquaculture site, there exists concern that there may be impacts in the far-field from the cumulative effect of multiple commercial operations within a limited area.

In the restricted area of the Bay of Fundy's Letang Inlet in New Brunswick, there is some concern about these types of effects where changes in the macrofauna species composition have been previously observed. The industry has attempted to remediate this situation using various management strategies such as reduction of operational sites, and employment of fallowing periods according to Bay Management Areas designation. However, the effectiveness of these changes has not yet been assessed. This project assesses the far-field environmental effects of marine aquaculture on the benthic community structure within the Letang Inlet over a four-year period. It will also compare these far-field effects to a previous baseline study to determine whether the management approaches within Letang Inlet have stabilized or improved conditions. This will provide valuable information to aquaculture regulators and the industry on the effectiveness of current management measures.

This project supports the DFO priority of environmental performance.

DATE: JUN. 2013–JUN. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Northern Harvest Sea Farms Ltd.

PROJECT LEADS: Andrew Cooper (DFO); Gerhard Pohle (Huntsman Marine Science Centre)

PROJECT TEAM: Rebecca Milne, Lou Van Guelpen (Huntsman Marine Science Centre); Marc Blanchard (DFO); Robert Findlay (U Alabama); Robert Clarke (Plymouth Marine Laboratory); Karl Whelan (Eastern Charlotte Waterways Inc.)

COLLABORATORS: Larry Ingalls (Northern Harvest Sea Farms Ltd.)

CONTACT: Andrew.Cooper@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/M-13-01-003-eng.html

Gerhard Pohle taking a water sample during field work on board the CCGS *Viola M. Davidson*. Photo: Andrew Cooper (DFO)

Freshwater Finfish Cage Aquaculture: Development of Sediment Biogeochemical Indicators for Regulation of Freshwater Cage Aquaculture

Benthic macroinvertebrates play a major role in waste assimilation (recycling waste) and in the transfer of carbon and energy from aquaculture wastes to higher trophic levels within lake ecosystems (i.e., they eat the waste and grow larger, thus becoming a bigger source of food for species higher up in the food chain).

Waste from freshwater finfish cage farms directly impacts nearby benthic invertebrate abundance and diversity. Preserving the function of benthic invertebrate communities is necessary given their role in organic carbon cycling near freshwater aquaculture farms.

Benthic invertebrates are typically used as indicators of benthic condition; however, sample collection and taxonomic identification of the various species within a monitoring program framework are time consuming and costly. The development of a reliable, readily measurable proxy for benthic invertebrate indicators would expedite the process of sediment monitoring. Such a proxy is contingent on a well-established relationship to the invertebrate community structure and requires testing across a range of locations to ensure cross-region applicability.

This project will:

1) Study the biogeochemistry of sediments receiving a gradient of aquaculture wastes;
2) Describe the gradient of effects of organic carbon deposition on the biology and geochemistry of the freshwater benthic environment;
3) Identify thresholds of geochemical changes in freshwater sediments associated with major changes in the structure of the invertebrate community;
4) Support the development of regulatory thresholds for managing the deposition of aquaculture wastes at levels that would maintain an acceptable degree of benthic alteration;
5) Support the assessment of risk associated with the deposits of wastes; and
6) Contribute to the development of regulatory standards and monitoring protocols for aquaculture-affected sediments, including fallowing practices for freshwater aquaculture, by identifying potential sediment recovery targets.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Cheryl Podemski (DFO)

PROJECT TEAM: Megan Otu, Cyndi Wlasichuk, Jian Zhang, Doug Geiling (DFO)

CONTACT: Cheryl.Podemski@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-CA-08-eng.html

Effect of Wind Forcing on the Oceanographic Conditions of Fortune Bay–Belle Bay: Identification of Changes in Water Physical Conditions and Ocean Currents, and Development of a Forecasting Tool

Results of recent research have indicated that while the tide accounts for less than 10% of the ocean current variability in most of Fortune Bay–Belle Bay (Newfoundland and Labrador), wind forcing and water physical structure have a significant, if not dominant, influence. Present findings also suggest that large-scale (e.g., at scale of Fortune Bay and/or the Newfoundland shelf) mechanisms affecting the water physical conditions and ocean currents are taking place as a response to wind forcing.

This project aims to identify and describe some of the dominant mechanisms responsible for short-term upwelling and downwelling events as well as surface and sub-surface oceanic circulation induced by wind forcing. This project will also develop a high resolution numerical (computer) model able to reproduce and forecast the consequences of wind events on oceanographic features which will be applied to aquaculture related issues.

For instance, results from this project will help inform the aquaculture industry as they conduct aquaculture operations such as when best to apply pesticides, choose appropriate sites and design the infrastructure to prevent failure. Results from this project will also help inform the regulators in matters such as fish pest and pathogen management, release of organic matter into the environment as well as cumulative effects and ecosystem management.

DATE: APR. 2015–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Newfoundland Aquaculture Industry Association; Cold Ocean Salmon Inc.; Northern Harvest Sea Farms Ltd.; IFREMER

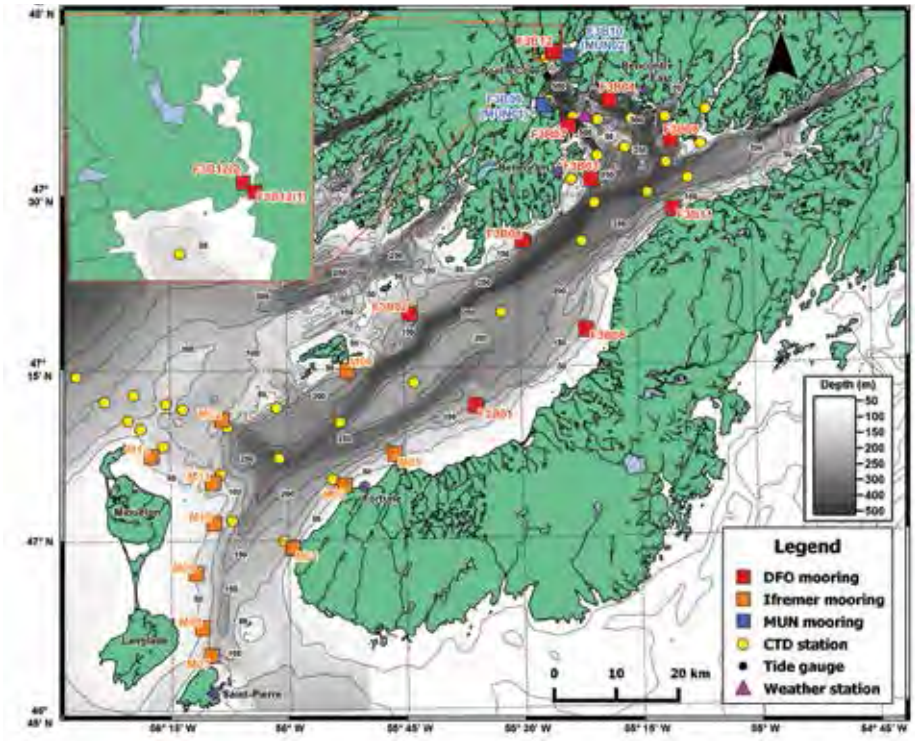
PROJECT LEADS: Sebastien Donnet, Andry Ratsimandresy (DFO)

PROJECT TEAM: Dwight Drover, Pierre Goulet, Shannon Cross, Guoqi Han (DFO); Pascal Lazure (IFREMER)

COLLABORATORS: Mark Lane (NAIA); Julia Bungay (Cold Ocean Salmon Inc.); Jennifer Caines (Northern Harvest Sea Farms Ltd.)

CONTACT: Sebastien.Donnet@dfo-mpo.gc.ca, Andry.Ratsimandresy@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-N-02-eng.html



Location of field activities conducted in November 2016. Photo: Pierre Goulet (DFO)

Project lead Sebastien Donnet (DFO) preparing an oceanographic mooring to be deployed in Fortune Bay. Photo: Pierre Goulet (DFO)

Robustness of Alternative Benthic Impact Indicators: Quantification of Spatial and Temporal Variability of Alternative Methods, and Application at Aquaculture Sites Across Different Farm and Environmental Conditions

Casey O'Laughlin and Emma Poirier (DFO) bringing a sediment core on board the CCGS *Viola M. Davidson* at a salmon aquaculture study site near Southwest Nova Scotia. Photo: Peter Cranford (DFO).

Benthic effects associated with biochemical oxygen demanding (BOD) matter effluents at aquaculture sites are currently assessed by monitoring the oxic state of surficial sediment. The *Aquaculture Activity Regulations* (AAR) require measurements of sulfide concentrations around finfish aquaculture sites as a proxy for benthic biodiversity impacts. However, it has been widely recognized that there are some problems with current protocols used for monitoring the oxic state of sediments. Alternative methods for measuring sulfide and oxygen concentrations have been developed that may address some of the weakness of the methods traditionally used. This project will test these new methodologies and technologies across a range of aquaculture (shellfish and finfish) and seabed conditions (mud, sand, and mixed) in Canada to determine the general applicability of these methods for reaching conclusions on sediment oxic state and related benthic impacts, and to measure the temporal and spatial variability in oxic state indicators among these different methods.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Lindsay Brager (DFO)

PROJECT TEAM: Peter Cranford, Fred Page, David Wong, Brent Law (DFO)

CONTACT: Lindsay.Brager@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-M-08-eng.html

The Development of a Robust Methodology for Sulfide Probe Calibration and Sediment Sampling

DATE: JUL. 2014–JUN. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Atlantic Canada Fish Farmers Association (ACFFA); SIMCorp

PROJECT LEAD: Monica Lyons (DFO)

PROJECT TEAM: Blythe Chang, David Wong, Kenneth MacKeigan, Fred Page, Ed Parker, Nathan Blasco (DFO); Bob Sweeney, Leah Lewis-McCrea, Tara Daggett, Amanda Smith, Janelle Arsenault (SIMCorp); Jessica Whitehead (NSDFA); Troy Lyons (NB–DELG); Betty House (ACFFA)

COLLABORATORS: Betty House (ACFFA); Bob Sweeney (SIMCorp)

CONTACT: Monica.Lyons@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/M-13-01-001-eng.html

The results of this project can contribute to the development of a reliable, accurate, consistent, and robust methodology for sediment sampling, which could be adopted by provincial regulators.

In various provinces, sulfide concentrations in sediment are measured as the fundamental indicator of environmental impacts from aquaculture. Because each provincial government has established its own SOPs for interpreting sulfide concentrations, the evaluation of environmental impacts could differ among provinces.

Previous research has revealed that the standard solutions ("standards") used in sediment sulfide monitoring and probe accuracy (post-calibration) degrade significantly over time. These findings suggest the need for standardized sediment sulfide methodologies. This study examines potential sources of error related to the methods used in the collection, storage, transportation, and handling of sediment samples.

This project supports the DFO objective of environmental performance. Specifically, the following results were found:

- **Sample collection:** No one sampler worked well in all sediment types investigated. In all sediment types, multiple samples may need to be taken before an acceptable one is collected. Video footage of deployment and retrieval of gear was useful in assessing gear performance and confidence in the integrity of collected samples.
- **Sample storage:** During storage, sediment sulfide concentration changed over time, depending on sediment type, level of sulfide present, and storage temperature. To reduce variability due to storage, all samples should be treated uniformly until analyzed.
- **Sample analysis:** Sulfide measurements should be made as soon as possible after collection, with a standardized time of analysis established. The differing ages of probes used in analyses were not a concern in readings.

Sulfide probe, temperature probe, meter (left to right). Photo: Fred Page (DFO)

Sustainable Development of Offshore Bivalve Culture in the Magdalen Islands: Production Capacity and Interactions with Commercial Fisheries

DATE: JUN. 2013–JUN. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Merinov; Société de Développement de l'Industrie Maricole Inc. (SODIM); University of Quebec– Rimouski (UQAR); University of Quebec–Chicoutimi (UQAC); Ressources Aquatiques Québec (RAQ)

PROJECT LEAD: Chris McKindsey (DFO)

PROJECT TEAM: Philippe Archambault, Céline Audet (UQAR–ISMER); François Bourque, Madeleine Nadeau (Merinov); Pascal Sirois (UQAC); Luc Comeau, Andrea Weise (DFO)

COLLABORATORS: Madeleine Nadeau (Merinov); Gilbert Scantland (SODIM); Philippe Archambault (UQAR); Pascal Sirois (UQAC)

CONTACT: Chris.McKindsey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/Q-13-01-001-eng.html

To expand the shellfish industry in Québec, MAPAQ wishes to establish an offshore bivalve (mussel) culture site (15 to 25 m depth) in the Magdalen Islands.

There are concerns that the production carrying capacity (maximum harvest) will exceed the ecological carrying capacity (when ecological impacts become unacceptable), depleting plankton (food source for mussels) and producing excessive organic waste (feces). The interactions between offshore culture sites and commercially important wild species (lobster, rock crab, and winter flounder) are largely unknown, remaining a concern for local fisheries and industry stakeholders. This study investigates both concerns, along with the use of standard geochemical measures for monitoring the organic loading in the proposed offshore site.

This project supports the DFO objective of environmental performance. It found that modelling combined with *in situ* measurements showed that a stocking density of 2.5 times that of densities used in the existing farm site could be deployed in the entire proposed bivalve culture zone without going over the carrying capacity of Baie de Plaisance. The abundance of most animals (e.g., lobster, seastars, crabs, and flounder) was much greater in the farm than the areas around it. Lobster movement was followed throughout the spring/summer using telemetry. Lobster movements did not differ greatly between farm and surrounding areas other than the animals concentrating their movements in smaller areas within the farms. Although the communities living in sediments within the farm boundary differed slightly from those in sediments outside of the farm, geochemical measures showed no patterns.

Developing the Benthic Component of Integrated Multi-Trophic Aquaculture to Reduce the Impact of Organic Nutrients from Fish Farms and Evolving Standard Operating Procedures

Photograph of Northern Sea Cucumbers in the lab feeding actively on particles in the water. The feathery orange structures are the feeding tentacles that capture the food and put it into the mouth of the sea cucumber. Photo: Terralynn Lander (DFO)

There is a desire and requirement for aquaculture sites to control the amount of organic loading that comes from commercial fish farms. Integrated Multi-Trophic Aquaculture (IMTA) is an advanced ecological engineering technique that has been developing in Canada for over a decade on both the East and West Coasts. IMTA mimics a natural ecosystem by combining the farming of multiple, complementary species from different levels of the food chain in a way that allows a portion of the uneaten feed, wastes, nutrients, and by-products of one species to be recaptured and converted into fertilizer, feed, and energy for the growth of the other species.

Different trophic levels have different extraction efficiencies. The third extractive level of the IMTA food chain (benthic portion) needs further research to develop the suite of species and the structures for industry to adopt to viably reduce the environmental footprint for open water, marine aquaculture sites practicing IMTA. Specifically, this project will develop protocols for juvenile production, assess the organic particle capture efficiencies, scan for pathogens, and explore potential wild-farmed interactions. Three target species are being studied: Northern Sea Cucumber (*Cucumaria frondosa*), Green Sea Urchin (*Strongylocentrotus droebachiensis*), and Sea Scallop (*Placopecten magellanicus*). Results are showing the species can take up fish farm nutrients and experience significantly increased growth rates compared to their wild conspecifics.

The results of this project will provide some of the information required by the aquaculture industry to create effective Standard Operating Procedures to farm these species in a way that reduces the environmental impact of the site. It will also identify research areas that may be profitable for further biological or technological development.

This project supports the DFO objectives of environmental performance and optimal fish health.

DATE: APR. 2014–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Kelly Cove Salmon Ltd.

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Terralynn Lander, Craig Smith (DFO)

COLLABORATORS: Keng Pee Ang (KCS)

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/M-14-01-002-eng.html

Impact of Finfish Farms in Eastern Canada on Lobster Distribution and Condition

Organic waste from coastal net-pen fish farming may settle to the sea bottom close to farms, becoming a novel and attractive food source for wild animals. In addition, the physical structures associated with net-pens may act as artificial reefs and attract a variety of mobile predatory and scavenging species. Little work has addressed how such changes may have bottom-up effects that impact fisheries species. Impacts may not be restricted to aggregating animals around farm sites, but may also include impacts to wild fisheries due to altered productivity, distribution, or catchability of target species. Indeed, some fishers believe that lobsters congregate in aquaculture sites and thus deploy their traps immediately outside of farm sites whereas others avoid farms areas and do not consider these areas as high quality fishing grounds. Lobster is one of the most widely and intensively fished species in Eastern Canada and landings are at historically high levels. Concurrently, the production and the number of fish farms have also increased. Concerns about the influence of finfish aquaculture sites on lobster distribution and condition may create challenges for managers, especially if the lobster fishery faces challenges, such as shell disease or decreases in landings, in the coming years as scientific information on the subject is largely absent.

This project examines the spatial distribution and movement of lobster within and around finfish aquaculture sites to evaluate their association with fish farms areas. We will also evaluate how bottom-up effects induced by farm-related organic loading influences lobster condition.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Chris McKindsey (DFO)

PROJECT TEAM: Rénald Belley, Andrew Cooper, Annick Drouin, Julien Gaudette, Frédéric Hartog, Peter Lawton, Shawn Robinson, Paul Robichaud, François Roy, Anne-Sara Sean, Émilie Simard (DFO)

COLLABORATORS: Ocean Tracking Network (OTN); Rémy Rochette (UNB); Pierre Blier (UQAR); Keng Pee Ang (Cooke Aquaculture Inc.)

CONTACT: Chris.McKindsey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-P-01-eng.html

A lobster fitted with an acoustic transmitter to follow their movements within and around salmon farms in southwest New Brunswick. Photo: Chris McKindsey (DFO)

Deployment of hydrophones around a salmon farm in Doctor's Cove, southwest New Brunswick, to triangulate signals from acoustic transmitters to follow lobster movements. Photo: Émilie Simard (DFO)

Influence of Eastern Oyster (*Crassostrea virginica*) Aquaculture Overwintering on Eelgrass (*Zostera marina*)

Shade produced by floating and off-bottom oyster bag culture has been shown to significantly impact the localized structure and productivity of eelgrass beds. Considering these results, the objective of the present study was to determine if the overwintering of oyster gear directly on eelgrass beds could produce results similar to those observed during the growing season. To test this hypothesis, we assessed impacts of overwintering practices in an experimental overwintering area and a 13-year-old active overwintering site. Overall, the results of our study suggest no apparent impacts of oyster overwintering practices on eelgrass beds. We recommend additional studies in other bays to assess potential impacts of this practice under different environmental conditions (i.e., different types of sediments) and also operations of other culturists. We hypothesize that light limitation may not impact mature eelgrass during the autumn and winter months because the oyster bags are placed on the bottom as the plants undergo a period of low/no photosynthetic activity.

DATE: APR. 2012–APR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Simon Courtenay (DFO; U Waterloo)

PROJECT TEAM: Monica Boudreau (DFO); Marc Skinner (Stantec Consulting Ltd.; Canadian Rivers Institute)

COLLABORATORS: André Mallet (L'Étang Ruisseau Bar Ltd.)

CONTACT: simon.courtenay@uwaterloo.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2012-G-01-eng.html

Evaluating the Effectiveness of Fallowing as a Mitigation Tool at Predominantly Hard-Bottom Aquaculture Sites in Newfoundland

Atlantic Salmon aquaculture sites in Newfoundland are located predominantly over hard ocean substrates where sediment samples are consistently difficult to obtain and require the use of visual imaging to monitor aquaculture impacts. Fallowing (leaving the site without fish) at the end of a production cycle is the primary mitigation measure to manage impacts from uneaten food and faeces. Optimal fallowing times and the factors that can influence the rate of benthic community recovery remain key knowledge gaps in the environmental management of the industry.

This project seeks to examine the recovery processes at predominantly hard-bottom aquaculture sites undergoing fallowing by evaluating how the fallowing duration influences the distribution of visual bioindicators of organic disposition such as bacterial mats and Opportunistic Polychaete Complexes (OPC). This study will also examine changes in the presence of flocculent matter and non-indicator species (epifauna) during fallowing. The biological basis for changes in the distribution of bacterial mats and OPC during fallowing will be examined to improve our understanding of the processes of benthic recovery in the Newfoundland and Labrador Region. The results will shed light on the degree of benthic recovery associated with various lengths of fallowing, the biological processes underlying OPC dynamics in association with organic matter degradation, and the effectiveness of fallowing as a mitigation strategy.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Dounia Hamoutene (DFO)

PROJECT TEAM: Kimberley Burt, Flora Salvo (DFO)

COLLABORATORS: Suzanne Dufour (MUN); Robert Sweeney (SIMCorp)

CONTACT: Dounia.Hamoutene@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-NL-07-eng.html

Characterization of Pesticide Post-Deposit Exposure Zones

The finfish aquaculture industry within Canada can make use of pesticide bath treatments to manage sea lice infestations on netpen farmed salmon. Once each treatment is completed, the pesticide bath water is released into the ambient water where the pesticide is transported and diluted by the ambient hydrographic conditions. Non-target organisms and habitats within the spatial and temporal domain occupied by the pesticide may experience exposure to the pesticide. The deposition activities are authorized and guided by the *Aquaculture Activity Regulations* under the *Fisheries Act*. This project builds on earlier modelling and field work aimed at defining the exposure zones by refining vertical dispersion estimates and incorporating baroclinicity in the circulation models, and by exploring how model exposure zones vary with fish production husbandry factors such as treatment method, net pen size, and frequency of bath treatment. This project will also explore to what extent the zones include exposure of benthic environments. The work will be conducted in relation to salmon farming in the Bay of Fundy and will contribute to a foundation of knowledge that can be used to design a post-deposit pesticide monitoring approach. The work also complements other projects focused on biochemical oxygen demanding (BOD) matter dispersal from fish farms.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Fred Page (DFO)

PROJECT TEAM: Susan Haigh, Yongshen Wu, Brent Law, Stacey Paul, Mitchell O'Flerhaty-Sproul, Sean Corrigan, Sarah Scouten, Monica Lyons, David Wong (DFO)

COLLABORATORS: Michael Beattie (NBDAAF); Kevin Wickens (Health Canada)

CONTACT: Fred.Page@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-M-12-eng.html

Effects of Cage Aquaculture on Freshwater Benthic Communities

Cage aquaculture results in the release of organic matter to the lake with the greatest deposition under the cages. Organic matter deposition can lead to alterations of the benthic invertebrate populations exposed. Total abundance, richness, and biomass are classical proxies for benthic community succession during exposure to organic matter enrichment. Measures of total abundance, richness, and biomass of benthos from three commercial freshwater finfish aquaculture farms in Lake Huron were presented spatially to measure the net effect of aquaculture waste. In 2009 and 2012, sediment cores were collected from under the cages to 110 m distance away, as well as at six distant reference sites. Our data showed that total abundance, richness and biomass of benthos were suppressed under and in close proximity to the farm, while further afield invertebrate abundance and biomass of some taxa were elevated above reference values. We quantified the total biomass per m^2 and initial results found that total biomass loss was comparable amongst all three farms. However, reference sites are the determinant for calculating the net gain or loss of benthic invertebrates at a farm and net biomass results differed among farms. Farm three measured a net gain as compared to the other two farms that experienced a smaller net loss. Net biomass is a simplistic metric and does not completely present the dynamic change in diversity or functional groups by benthic invertebrates. Rather, net biomass represents the recycling of energy from aquaculture farm waste into invertebrates and potentially to higher trophic levels like wild fish.

DATE: APR. 2011–APR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Cheryl Podemski (DFO)

PROJECT TEAM: Jian Zhang, Megan Otu (DFO)

CONTACT: Cheryl.Podemski@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2011-CA-07-eng.html

Comparing the Impact of Bottom and Suspended Oyster Culture on Bay-Scale Food Resources (Foxley/ Trout River, PEI)

Bottom cultured oyster (Foxley, PEI). Photo: Luc Comeau (DFO)

Floating cages for suspended oyster culture (Foxley, PEI). Photo: Luc Comeau (DFO)

Bivalve aquaculture is extractive rather than fed and there is inherent sustainability assuming one can manage the limiting resource, i.e., phytoplankton. Oyster aquaculture is gradually evolving from a traditional use of the benthic environment (bottom culture) to a novel use of the three-dimensional water column (suspended culture). Both industry and regulators recognize the need to evaluate the ecological impact of growing oysters in the water column. Specifically, the project addressed three objectives: 1) assessing the bottom vs. suspended oysters diet overlap; 2) determining filtration rates of oysters from the two culture types (bottom and suspended); and 3) incorporating the latter results into a simple bay-scale model and quantify the impact of different culture scenarios on available food resources. The 2013-2014 results on quantitative comparison of suspended and bottom oyster culture in PEI suggested that a transition from bottom to suspended culture results in an actual reduction in oyster stock densities and grazing rates.

DATE: APR. 2012–APR. 2015

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEADS: Luc Comeau, Rémi Sonier (DFO)

PROJECT TEAM: Réjean Tremblay (UQAR-ISMER)

CONTACT: Luc.Comeau@dfo-mpo.gc.ca, Remi.Sonier@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2012-G-05-eng.html

CIMTAN

2010–2017: Seven Productive Years for the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN)

After seven years of intense activities, between 2010 and 2017, the NSERC strategic network, the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN), is finished.

The aim of CIMTAN's research was to ecologically engineer systems for increased environmental sustainability (ecosystem services and green technologies for improved ecosystem health), economic stability (improved output, lower costs, product diversification, risk reduction, and job creation in coastal and rural communities), and societal acceptability (better management practices, improved regulatory governance, nutrient trading credit incentives, and appreciation of differentiated and safe products).

The Network was organized into three linked Domains: 1) environmental system performance and species interactions; 2) system design and engineering; and 3) economic analyses and social implications. Each Domain was co-led by one scientist at an academic institution and one at a Fisheries and Oceans Canada (DFO) laboratory. The entire Network was comprised of 28 scientists from 8 universities, 6 DFO laboratories, 1 provincial government laboratory (New Brunswick Research and Productivity Council), and 4 industrial partners. The Network was hosted by the University of New Brunswick in Saint John (UNBSJ), where the Scientific Director of the Network was located.

The budget for CIMTAN was nearly $12.8 M over the 7 years of its existence. This was consequential as it enabled the Network to obtain far-reaching achievements along the continuum R&D&C (commercialization). Of this, over $5 M was received from NSERC with the rest leveraged through both cash and in-kind contributions from government, academic, and industrial partners.

Training of highly qualified personnel (HQP) was a very high priority for CIMTAN and 137 HQP (120% of the initial target) were trained: 76 undergraduate students, 35 Masters students, 6 PhD students, 7 postdoctoral fellows, 12 technicians, and 1 research scientist. CIMTAN enabled the priming of young talents so they could enter a highly skilled labour force well-prepared, capable of thinking critically and independently, and well-versed in the interdisciplinary approach to problem solving. Our CIMTAN HQP have either pursued higher academic degrees or found jobs in a variety of sectors (academic, industrial, regulatory or non-governmental). It is interesting to see how these HQP have become respected professionals and remarkable agents of knowledge dissemination and technology transfer in several sectors, to the extent that it is no longer necessary to re-explain what IMTA is about at each meeting.

An IMTA site in the Bay of Fundy, New Brunswick, Canada: two salmon cages on the left, one mussel raft on the right and two seaweed rafts in the background. Photo: Thierry Chopin (UNBSJ)

CIMTAN was always interested in disseminating and translating its scientific research, results, and perspectives. CIMTAN produced a substantial number of publications (617), testifying to the accomplishments and vitality of the Network. More than 1150 contacts were made with 232 media outlets across 42 countries, through interviews or citations. The deliberate choice to use a diverse array of documents and media platforms (scientific papers, papers and abstracts in conference proceedings, book chapters, theses, reports, professional magazines articles, newspapers/radio/TV interviews and documentaries, public school activities, Google Scholar, ResearchGate, LinkedIn, YouTube videos, *CIMTAN Snippets* newsletter, Wikipedia, etc.) has enabled the Network to reach varied targeted fields and audiences in Canada and beyond, and to spread the IMTA message widely with researchers, federal and provincial agencies, the industry, professional associations, coastal and rural communities, First Nations, national and international environmental non-governmental organizations (ENGOs), and the general and school public.

Two media were very successful at reaching audiences beyond those associated with the traditional scientific dissemination tools: the Network newsletter *CIMTAN Snippets* and 15 videos posted on YouTube. There were 40 issues of *CIMTAN Snippets* over 6 years, totaling 331 pages of information about the activities of the Network, sent to 842 subscribers, some of whom are known to have redistributed *CIMTAN Snippets* to others. YouTube has been a very efficient dissemination platform for the IMTA concept and the principles on which it is based. By December 31, 2016, the IMTA YouTube channel (https://www.youtube.com/user/imtacanada/videos) had reached 85,334 total views of its 15 videos.

The following research articles in this section describe each of the 16 projects of CIMTAN.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Thierry Chopin (UNBSJ)

PROJECT TEAM: Bruce MacDonald, Adrian Hamer (UNBSJ); Gregor Reid (UNBSJ; DFO); Shawn Robinson, Chris Pearce, Saleem Rahman (DFO); Maycira Costa (UVic); Duncan Knowler (SFU)

COLLABORATORS: DFO; NBRPC; Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

CONTACT: tchopin@unbsj.ca

WEBSITE: http://www.cimtan.ca/

Quantifying the Capture and Conversion Efficiencies of Species Being Considered for Organic Extraction in Open-Water IMTA Systems

This project assessed the capability of different invertebrate species to capture, absorb, and convert particulate fish-farm waste into new production.

On the east coast, Blue Mussels (*Mytilus edulis*) were capable of ingesting and efficiently absorbing small organic material from both fish food and faeces. After a variety of feeding trials using artificial diets in the laboratory and natural particles at IMTA sites, we determined that the Orange-Footed Sea Cucumber (*Cucumaria frondosa*) could also efficiently extract larger organic material from farm waste. Biodeposition techniques and flume feeding trials revealed that *C. frondosa* fed equally among all particle sizes monitored (200-1200 µm) but rates of clearance in the field (7.2 L day^{-1}) were relatively low compared to other species being considered for mitigation.

On the west coast, species assessed for extractive capabilities include filter feeders such as Basket Cockles (*Clinocardium nuttallii*) and Blue Mussels (*M. edulis*), as well as deposit feeders such as Green Sea Urchins (*Strongylocentrotus droebachiensis*), California Sea Cucumbers (*Parastichopus californicus*), and Pacific Prawns (*Pandalus platyceros*). Green Sea Urchins and California Sea Cucumbers ingest and absorb Sablefish (*Anoplopoma fimbria*) faeces at rates comparable to or higher than those for traditional diets such as kelps and natural sediment, respectively.

This research has enabled the assessment of nutritional responses for a variety of shellfish and deposit-feeder species on diets of fish-farm organics, thereby providing crucial insight into co-cultured species selection and IMTA system efficiency.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited.; Grieg Seafood BC Ltd.

PROJECT LEAD: Bruce MacDonald (UNBSJ)

PROJECT TEAM: Shawn Robinson, Chris Pearce, Dan Curtis (DFO); Gregor Reid, Emily Nelson, Kurt Simmons (UNBSJ); Stephen Cross, Lindsay Orr, Sarah Sprague (UVic); Helen Gurney-Smith (VIU); Shannon Balfry (UBC); Vancouver Aquarium); Steve Pace (UBC)

COLLABORATORS: Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.

CONTACT: bmacdon@unb.ca

WEBSITE: http://www.cimtan.ca/

California Sea Cucumber, *Parastichopus californicus*. Photo: Dominique Bureau (DFO)

Cultivation of Complementary Inorganic Extractive Species for Increased System Performance

This project investigates the red alga *Palmaria palmata* (Dulse) for increased inorganic biomitigation of IMTA systems when kelps are not present at the sites. Large-scale cultivation of this species has been hampered by a complex life history, in which *P. palmata* alternates between sexual (with macroscopic male and microscopic female gametophytes) and asexual (with macroscopic tetrasporophytes) reproduction. One of the current challenges is that male gametophytes are indistinguishable from tetrasporophytes by conventional microscopy when they are not reproductive.

We took two approaches (molecular and spectroscopic) to make identification easier. We designed and tested primers to target DNA in an intron region in an actin gene that is expressed in tetrasporophytes, but not in males, in an attempt to identify a sex-linked molecular marker, however, the intron region showed no difference. Individual ratios, or combinations of ratios, of spectral bands obtained by Raman and near infrared (NIR) spectroscopy allowed for classification between male gametophytes and tetrasporophytes.

The cultivation of *P. palmata* in the laboratory has progressed (design and testing of new substrates/panels; increased light irradiance and photoperiod). The best timing of transfer to the sites remains to be better understood to reduce biofouling.

The cultivation, harvesting, and processing of the two kelps (*Saccharina latissima* and *Alaria esculenta*) continue to be improved. They have continuously been organically certified since 2014.

The project is also looking at the development of appropriate and efficient regulations for seaweeds and the management of inorganic nutrient loading, within an integrated coastal area management strategy and scale.

This research has developed a better understanding of the issues related to the management of the inorganic load from aquaculture operations. It has highlighted the ecosystem functions and services provided by the inorganic extractive component of IMTA. It has brought understanding to the need to consider IMTA within the context of an integrated coastal area management strategy. Integration should be understood as cultivation in proximity, not considering absolute distances but connectivity in terms of ecosystemic functionalities, which means that entire bays/coastal areas/regions could be the units of IMTA management.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Thierry Chopin (UNBSJ)

PROJECT TEAM: Constanza Chianale, Caroline Longtin, Ellen Belyea, Adrian Hamer, Samuel Backman (UNBSJ)

COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: tchopin@unbsj.ca

WEBSITE: http://www.cimtan.ca/

Line of Sugar Kelp (*Saccharina latissima*) at an IMTA site in the Bay of Fundy, New Brunswick, Canada. Photo: Thierry Chopin (UNBSJ)

Quantifying the Role of Microbes in the Nutrient Recycling of Organic Material from IMTA Sites

Miniature respiration chamber holding a filter (0.2 µm pore size) coated with bacteria and seston from a sample. The pink dot is an oxygen optode that reads oxygen levels over time inside the vial when pulsed with blue light from outside the vial with the black fibre optic probe. Photo: Shawn Robinson (DFO)

Understanding the various paths and processes by which energy flows through an IMTA site is one of the main objectives in the creation of sustainable aquaculture systems using ecosystem-based approaches. As food from one trophic level is recycled through another, the energy associated with the organic particles is stripped out and is converted to inorganic waste products such as ammonia, carbon dioxide, or heat. This transfer process occurs between all trophic levels right down to the lowest where the bacteria and other microbes reside.

The objective of this project was to evaluate and quantify the role that bacteria play in nutrient recycling at a salmon aquaculture site and to evaluate the relative scale of their ability to convert organic particles into inorganic components. Specifically, we enumerated bacteria and their respiration rates on and away from finfish aquaculture farms in both the water column and the benthos on a seasonal basis at IMTA sites in the Bay of Fundy. Additionally, we identified prominent members of the benthic and pelagic bacterial communities associated with the aquaculture sites and how they varied with depth, distance, and time.

The results are demonstrating that these non-pathogenic bacteria are playing a very large role in carbon conversion on a farm lease and should be considered in the design of aquaculture sites in the future. This information is also contributing to a model being prepared on energy flow through an IMTA site.

This research provided insight into the role heterotrophic bacteria are playing in the recycling of organic wastes near salmon aquaculture farms. This will provide much needed guidance on what the carrying capacity is for benthic and pelagic microbes to convert organic carbon which will have direct implications on feeding rates of the fish and time required for fallowing the site after a production cycle. The research may also provide insights on what proactive measures might be taken before fish production starts.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Bruce MacDonald, Thierry Chopin, David Thumbi, Hannah Bradford, Kelli Mitchell, Leslie-Marie MacArthur-Britt, Eric Manuel (UNBSJ); Ben Forward (NBRPC); Terralynn Lander, Craig Smith (DFO)

COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: http://www.cimtan.ca/

Quantifying Energy and Nutrient Dispersal and Scales of Influence on Wild Species from Open-Water IMTA Sites

This research, on methods to quantify the effect of mid-water nutrients in wild species, revealed that site-specific hydrographic conditions are critical components for colonization, growth, and quality of many nutrient extracting wild species that inhabit the coastal zone near aquaculture farms.

One approach has been to sample wild species biocolonization to measure changes in diversity and growth in the “near-field” and “far-field”. This revealed that introduced habitats placed near and far from aquaculture sites attract very different species rather than altered growth of any one dominant organism. Differences in mid-water physical environment and the presence of appropriate habitat substrates, from cage structure or coastal topography, are as important to wild species colonization as the availability of nutrients alone.

Another approach has sought to measure changing colour characteristics of wild algal species as a proxy to current analytical laboratory techniques to measure nitrogen concentrations in the water column or nitrogen content in algal tissues. Several species of naturally occurring algae (some of which may also be commercially important) exhibited

Biocollector plates used to measure natural biocolonization of wild species at an IMTA aquaculture site. Photo: Andrew Cooper (DFO)

changes in colour characteristics throughout their growing season. Within a relatively confined geographic location and season, the relationship between colour and tissue nutrient content (% nitrogen) is small. However, differences in colour and the relationship with % nitrogen is more pronounced among different locations and time periods and could be a potential tool to monitor changes in nutrient availability on a larger scale.

This is key information to support the design of IMTA sites using nutrient extracting species, as well as to understand IMTA performance measures for those species integrated for the purpose of extracting aquaculture-related nutrients.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Andrew Cooper (DFO)

PROJECT TEAM: Thierry Chopin, Jonathan Day (UNBSJ)

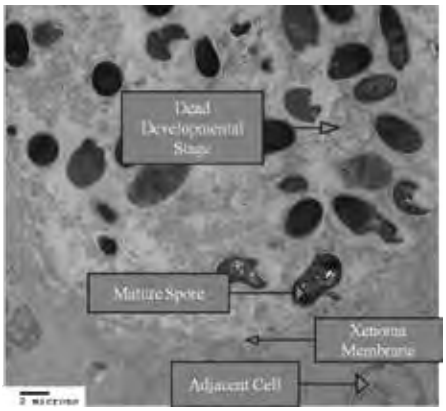
COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: Andrew.Cooper@dfo-mpo.gc.ca

WEBSITE: http://www.cimtan.ca/

Loma salmonae: A Microsporidian Model to Help Assess Transmission Dynamics to Pathogens within an IMTA Setting

Our goal has been to modify an infection model for the microsporidian pathogen *Loma salmonae*, and use this model to evaluate the role that Blue Mussels may have in extracting environmentally released spores within an IMTA setting. Specifically, asking the question of whether Blue Mussels may serve to mitigate disease transmission by deactivating spores that they encounter during feeding. The model has been successfully developed and now allows us to modify various environmental and temporal parameters. A very useful and unexpected outcome was the establishment of *L. salmonae* within cell culture. This advance will allow far greater flexibility in our studies, both as a tool for producing spores, but also for detecting them within environmental niches under study. To date, we have determined that Blue Mussels are very effective in extracting microsporidial spores from the environment; spores are subsequently released in pseudofeces, or feces, and small proportion of them stored for several weeks within mussel viscera. Spores are not rendered defective whether they are retained, or passed within egesta; *in vitro* tests of spore viability have been evaluated against the gold standard *in vivo* measures of infectivity.



Microsporidial spores developing within a cell-cultured xenoma. Photo: Sarah McConnachie (UPEI–AVC)

The introduction of a bivalve component alongside a salmon growing operation may provide beneficial disease reduction services. A greater understanding of disease dynamics between trophic levels is a key part of health management within integrated settings.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Dave Speare (UPEI–AVC)

PROJECT TEAM: Sarah McConnachie, Nicole Guselle (UPEI–AVC)

CONTACT: speare@upei.ca

WEBSITE: http://www.cimtan.ca/

Can Filter-Feeding Bivalves Ingest Planktonic Sea Lice, Leading to Reduced Sea Lice Numbers on Cultivated Salmon?

Cleaning biofouling from Pacific Oyster trays at a salmon farm in the Broughton Archipelago, British Columbia. Photo: Allison Byrne (UVic; DFO)

The close proximity of salmon farms and wild Pacific salmon stocks in British Columbia (BC) is an important incentive for precautionary, environmentally-friendly sea lice management strategies.

A field trial was conducted to determine whether IMTA filter-feeding bivalves can provide preventative, natural sea louse control by ingesting sea lice larvae (nauplii and copepodids) from the water column; a system that exploits the sea louse life cycle and the natural filtration capabilities of bivalves. Pacific Oysters, one of several bivalve species that consumed sea lice larvae in previous laboratory experiments, were grown at a commercial Atlantic Salmon farm in BC for 13 months. The 30,000 experimental oysters were deployed in trays at 1, 3, and 6 m around one end of the farm's 2x7 square-cage array, and at a nearby reference site.

Bivalve growth (both shell size and tissue biomass) was significantly affected by depth and side of the fish cage. Oysters from select sides were consistently, significantly larger than those from other sides and from the reference site. Sea lice mitigation by oysters was assessed by comparing monthly sea lice larval densities inside bivalve and non-bivalve fish cages, and by analyzing preserved oyster digestive tracts for presence of sea lice DNA. Using these methods, no significant evidence of sea lice mitigation was detected. Planktonic sea lice densities inside of the cages were low (typically < 1 m^{-3}), and sea louse mitigation by bivalves may, therefore, require the larvae be concentrated using light or other means and/or the strategic placement of a higher density of bivalves.

The development of non-chemical sea lice mitigation techniques, such as IMTA filter-feeding bivalves, may help improve the environmental, social, and economic performance of salmon farms.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Chris Pearce (DFO)

PROJECT TEAM: Allison Byrne, Janis Webb (UVic; DFO); Stephen Cross (UVic); Simon Jones, Shawn Robinson (DFO); Matt Miller, Devan Johnson, Colleen Haddad (VIU; DFO)

COLLABORATORS: Grieg Seafood BC Ltd.; Marine Harvest Canada Limited

CONTACT: Chris.Pearce@dfo-mpo.gc.ca

WEBSITE: http://www.cimtan.ca/

Presence, Effect, and Bioaccumulation of Therapeutants in Polychaetes

Ecto-parasites are common on Atlantic Salmon under cage culture conditions. Severe infestations require treatment with drugs and pesticides. Considerable research has been conducted to assess the risk of these compounds to non-target species, mostly focusing on indigenous species of known commercial or ecological value.

In this project, the non-target species of interest is one being considered as a co-cultured species in an IMTA setting, the Sand Worm *Nereis virens*. As a co-cultured species, the worms would be exposed to compounds during routine anti-parasitic treatments. Worms were exposed, in treated water, sediment, or sand, to one drug (Slice®, active ingredient emamectin benzoate (EB)) and one pesticide (AlphaMax®, active ingredient deltamethrin). Survival was monitored, as well as sublethal indicators of "wellness".

Worms exposed to Slice® survived exposure to environmentally-relevant concentrations (~360 µg/kg dry sand) of the product; however, in 30-day studies worms stopped burrowing in the treated substrate and showed signs of poor condition including loss of weight. Worms exposed to AlphaMax® died at concentrations

Preparing *Nereis virens* worms for a 30-day sublethal exposure. Photo: Geoffrey McBriarty (UNBSJ)

well above the recommended dose, but survived exposures in sediment. Worms exposed to as little as 11 µg/g of wet sediment in 30-day trials stopped burrowing and showed poor condition, including loss of weight. Anti-sea louse treatment could be hazardous to *N. virens*; however, in the absence of data regarding concentrations of EB or deltamethrin near cage sites, it is difficult to assess the potential risk to cultured worms.

While the two anti-sea louse products are not particularly lethal to *N. virens*, worms were affected by exposure to these products and results indicate that anti-sea louse treatments have the potential to negatively affect this species. These negative effects could affect the suitability of this species to be co-cultured in IMTA.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Karen Kidd (UNBSJ)

PROJECT TEAM: Les Burridge (DFO); Jordana van Geest (DFO; UNBSJ); Geoffrey McBriarty (UNBSJ)

COLLABORATORS: Cooke Aquaculture Inc.

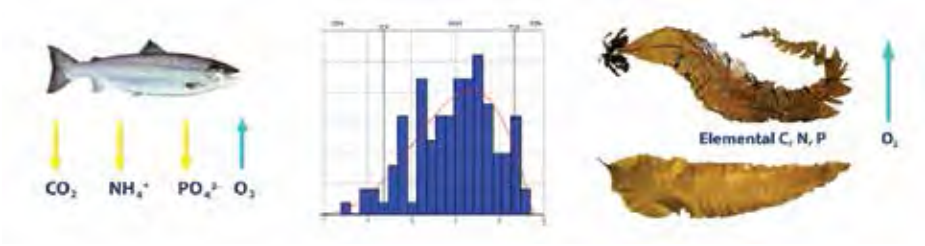
CONTACT: kiddk@unb.ca

WEBSITE: http://www.cimtan.ca/

Mathematical Modelling for Open-Water IMTA: Developing Tools to Support System Design and Measures of Sustainability

This project aimed to quantify efficiency of nutrient recovery and augmented growth in open-water IMTA systems. One study explored the seaweed biomass required to remove soluble nutrients from salmon culture. The mean weight ratios of the seaweeds *Alaria esculenta* and *Saccharina latissima* required to sequester all soluble nutrients excreted per unit weight of salmon range from 4:1 to 13:1, depending on the nutrient. Another study reported the proportion of fish farm solids ingested by mussels needed to reduce site-wide organic loading at an IMTA site, which ranged between 10% and 20%. A third study suggested the biomitigation potential of mussels will be greatest where seston abundance is low, organic dietary content high, and that achieving maximal waste extraction by mussel co-culture entails food particle depletion that may limit mussel production.

Commercial Sablefish growth and nutrient loading were also modelled. Results suggested that the predicted peak nutrient loading in year two of production was only 1.7 times greater than the peak loading in year one, less than half the annual loading difference reported for cultured Atlantic Salmon. The slower relative growth rate of large Sablefish reduces the



Schematic representation of model elements to estimate weight ratios of seaweeds needed to sequester nutrients from salmon.

discrepancies between annual peak loading periods, enabling better matches of co-cultured species biomass with nutrient supply compared to more rapidly growing fish.

Some field data were recently combined with Norwegian field data to publish a report on discrete water quality sampling at open-water aquaculture sites, their limitations and recommended strategies. Finally, project results are providing valuable inputs for an IMTA bio-economic model under development.

This work has led to a better understanding of overall system efficiencies and has guided the effective development of open-water IMTA farms, through such mechanisms as the Canadian Science Advisory Secretariat review process to support policy development and management for Fisheries and Oceans Canada.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Gregor Reid (UNBSJ; DFO)

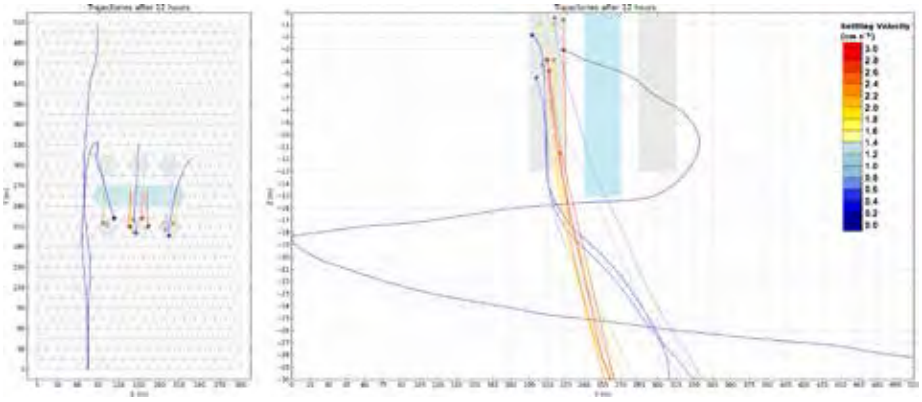
PROJECT TEAM: Bruce MacDonald, Thierry Chopin (UNBSJ); Shawn Robinson, Peter Cranford (DFO); Margaret Quinton (U Guelph)

COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: Gregor.Reid@dfo-mpo.gc.ca

WEBSITE: http://www.cimtan.ca/

Evaluating the Performance of Proposed and Existing IMTA Sites Using an Ecosystem Modelling Approach



Plan view and vertical profile trajectories after 12 hours of a subset of particles with different settling velocities released at random positions in three finfish cages (light grey). Mussel longlines are represented in light blue. Note that the vertical and horizontal scales in the vertical profile are different for visualization purposes.

Maximizing the mitigation potential of open-water finfish-shellfish IMTA farms is complex in terms of co-locating the trophic components. Both the dispersal of finfish aquaculture wastes and biological processes are highly influenced by water circulation. Consequently, the evaluation of shellfish-finfish synergy requires a combined study of biological and physical processes, which can be achieved by the implementation and coupling of mathematical models.

In the context of this project, a highly configurable mathematical model that can be applied at the apparent spatial scale of IMTA sites has been developed. The model tracks different components of the seston, including feed wastes, fish faeces, shellfish faeces, natural detritus, and phytoplankton. Based on the specific characterization of these fluxes to local conditions, the model can be used to explore different spatial arrangements of IMTA farms for evaluating finfish-shellfish farm mitigation efficiency. A hypothetical IMTA site was used as a testing ground of the model to explore mitigation efficiency under a broad range of environmental conditions and farm arrangements.

The model predicts that: (1) mitigation efficiency is highly dependent on the background environmental conditions, obtaining maximal mitigation under oligotrophic conditions that stimulate shellfish filtration activity; (2) the dominance of vertical fluxes of particulate matter triggered by the high settling velocity of finfish aquaculture wastes suggests that suspended shellfish aquaculture cannot significantly reduce organic loading of the seabed; and consequently, (3) waste mitigation at IMTA sites should be best achieved by placing organic extractive species (e.g., deposit feeders) on the seabed directly beneath finfish cages rather than in suspension in the water column.

DATE: SEP. 2012–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Jonathan Grant (Dalhousie U)

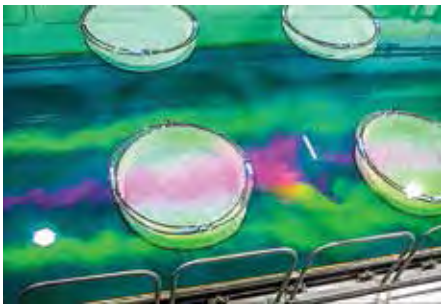
PROJECT TEAM: Ramón Filgueira (Dalhousie U); Peter Cranford, Thomas Guyondet (DFO); Gregor Reid (UNBSJ; DFO)

COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: Jon.Grant@dal.ca

WEBSITE: http://www.cimtan.ca/

Extensive Versus Intensive IMTA Systems – Hydrographic Influences and the Implications to Infrastructure Design and Operational Efficiency



Dye release study with 1:15 scale model cage-array, at the Flume Tank facility of Memorial University of Newfoundland. Photo: Adam Turner (UNBF)

This project helped to quantify near and far-field hydrodynamics of square and circular cage arrays to guide in the placement of co-cultured species. Initial project work utilized the Finite-Volume primitive equation Community Ocean Model (FVCOM) to model localized currents around an IMTA site in Kyuquot Sound, Vancouver Island, to explore influences at the bay-scale. This was followed by the development of 1:15 scale model cage-arrays, which were deployed in the Flume Tank facility at Memorial University of Newfoundland. Current meters measured wake, velocity, and turbulence around circular and square aquaculture cage-arrays, deployed in common configurations used on the west and east coasts. Dye release studies showed how flow fields in and around cages behaved within and down-stream from the array. Results quantified large velocity deficits in cages wakes, flow forcing around and below cages, and unsteadiness of large scale turbulence in array wakes. The dye release data agree well with wake velocity measurements.

This work has led to a better understanding of overall system efficiencies and has guided the effective development of open-water IMTA farms, through such mechanisms as the Canadian Science Advisory Secretariat review process to support policy development and management for Fisheries and Oceans Canada.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Gregor Reid (UNBSJ; DFO)

PROJECT TEAM: Tiger Jeans, Adam Turner (UNBF); Mike Foreman (DFO); Stephen Cross, Di Wan (UVic)

COLLABORATORS: SEA Vision Group Ltd.; GMG Fish Services Ltd.; Marine Harvest Canada Limited

CONTACT: Gregor.Reid@dfo-mpo.gc.ca

WEBSITE: http://www.cimtan.ca/

A Variation on the IMTA Theme for Land-Based, Freshwater Aquaculture Operations: The Development of Freshwater IMTA (FIMTA) for Salmon and Aquaponic Plants

Freshwater IMTA (FIMTA) applies the same principles as those used in marine IMTA, but in a freshwater setting. Aquaponics is a form of FIMTA that combines animal aquaculture and plant culture, through a microbial link and in a symbiotic relationship. Wastes produced from the fish are either absorbed directly by the plants or converted by microbes and then consumed by the plants.

The development of our FIMTA system involved a two-part investigation. The first part was to identify a suitable freshwater salmon hatchery. This was done with routine water testing at a number of sampling locations within eight hatcheries (4 flow-through and 4 recirculating). The data were used to select a hatchery for further development and to also create a software program that can be used by hatchery managers to quickly identify inadequacies in their water treatment systems and effluent discharge. The second part of the investigation was to collect effluent water from the selected hatchery and use it in a temperature and light controlled pilot-scale FIMTA/aquaponic system to test potential plant species in terms of growth and nutrient removal capabilities. Biochar produced from IMTA grown kelps was used as a substrate.

A total of 13 plant species were tested at temperatures of 10-15°C, as this is the optimal water temperature range for growing salmon in freshwater hatcheries. The ability of the system to remove nutrients from the collected salmon effluent varied depending on the species selected and the biomass they produced, as well as the variability of nutrient levels in the collected effluent.

The analyses indicated that recirculating hatcheries are more valuable candidates for FIMTA systems than conventional flow-through hatcheries. The development of FIMTA for commercial salmon hatcheries will aid in the completion of IMTA from egg to plate. Not only can this be useful for branding purposes, but it can also aid farmers in waste reduction, increased water reuse, increased product diversification, and improvement of societal acceptance of the industry. In particular, reducing phosphorus levels in effluents can help farmers meet water quality guidelines and prevent eutrophication in the environment.

IMTA and FIMTA are included in the Canadian Organic Aquaculture Standard.

The principles of marine IMTA can also be applied to land-based, freshwater systems, also called aquaponics. Yarrow, mint, lettuce, chamomile, and nasturtium after six weeks of growth at 13-15°C in effluent collected at a commercial salmon hatchery. Photo: Thierry Chopin (UNBSJ)

DATE: SEP. 2012–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Thierry Chopin (UNBSJ)

PROJECT TEAM: Stacy Murray, Hamid Khoda Bakhsh, Ellen Belyea, Adrian Hamer (UNBSJ)

COLLABORATORS: Cooke Aquaculture Inc.

CONTACT: tchopin@unbsj.ca

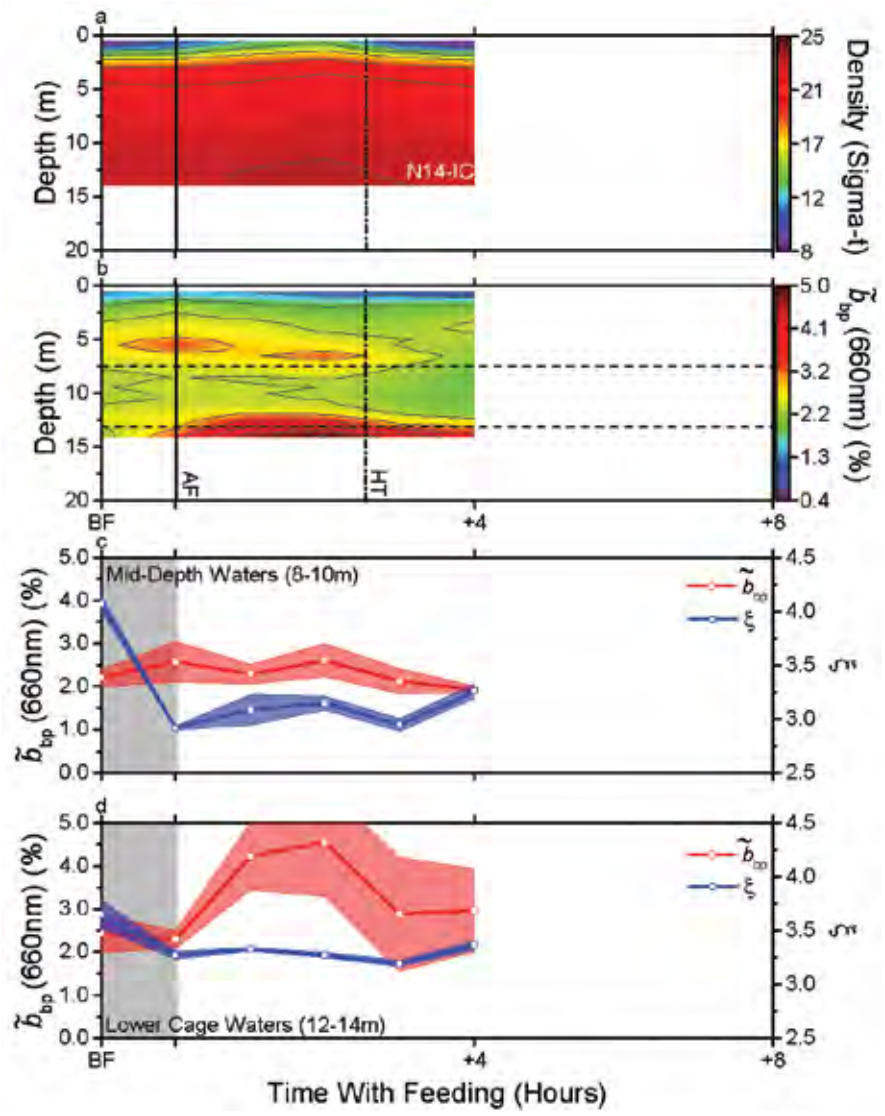
WEBSITE: http://www.cimtan.ca/

Spatial and Temporal Particulate Dynamics and Their Influence on Update Species Placement at an IMTA Site

Environmental concerns about the location of open-water aquaculture sites are based on issues such as organic wastes, primarily made up of uneaten feed and fecal material. IMTA can potentially minimize this issue by placing species that capture the produced organic matter. The main goal of this project was to investigate the open-water daily temporal and vertical dispersal of waste particles for better defining the placement of extractive species and the required background environmental conditions at an IMTA site on the west coast of Vancouver Island. We conducted *in situ* measurements, before and after fish feeding, of bio-optical properties, such as particle light scattering and backscattering as proxies for organic particle concentrations, and particulate backscattering ratio and estimated particle index of refraction as indicators of particle compositions, along with discrete measurements of high performance liquid chromatography (HPLC) derived pigments and particulate organic carbon, within and beside a finfish cage in the autumn, spring, and summer.

During autumn, lower-cage post feeding optical measurements suggest the dominance of large particles with high indices of refraction, possibly due to the influence of fish fecal particles. Optical variability in spring was driven by diatom bloom conditions (*Chaetoceros* and *Skeletonema*) with the optical proxies suggesting dominance by large particles with low indices of refraction. Summer conditions displayed noticeably high and persistent particulate backscattering in surface waters, suggesting the presence of an *Emiliania huxleyi* bloom. Optical characterization of particulate waste dispersal is constrained to low ambient seston conditions, and would be beneficial for environmental monitoring of ambient particles moving through aquaculture systems.

Tracking and quantifying particulate wastes in these sites generally relies on time consuming, expensive, and low temporal and spatial resolution discrete sampling methods. We utilized *in situ* bio-optical sensors to collect data at high temporal and vertical resolutions to track particulates within and beside a finfish aquaculture cage.



2011 conditions colour map time series of a) density (sigma-t) and b) backscattering ratio, $\tilde{b}_{bp}$ (660nm) (%). Times are normalized to feeding starting at before-feeding (BF), followed by after-feeding (AF) and then one hour intervals through the day from the AF time-step. After-feeding times are shown by the vertical solid line and high tide (HT) times are shown by the dashed-dotted vertical line. The horizontal lines represent the central depths, 9 m and 13 m, of the averaged time series data presented in c) and d), respectively. In order to reduce the influence of spikes in the data at a single depth, data were averaged from 8–10 m and 12–14 m, with one standard deviation shown as shaded colours. On these plots $\tilde{b}_{bp}$ (660 nm) (%) (primary y-axis) and ξ (right y-axis) are plotted at the same time scales as the colour maps, with the grey shading representing feeding duration.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Maycira Costa (UVic)

PROJECT TEAM: Stephen Cross, Justin Del Bel Belluz (UVic); Gregor Reid (UNBSJ; DFO)

COLLABORATORS: Kyuquot SEAfoods Ltd.

CONTACT: maycira@uvic.ca

WEBSITE: http://www.cimtan.ca/

Design and Demonstration of a Renewable Energy System Powering an IMTA Site

Installed renewable energy system components at Kyuquot SEAFoods Ltd. site: modular solar panels on dock (left and middle) with battery storage and power electronics in locker (right). Photo: Stephen Cross (UVic)

IMTA aims to reduce the environmental impacts of seafood production. However, as most sites are quite remote, diesel fuel is the primary fuel but is clearly non-sustainable from climate change and fuel spill risk perspectives. This project demonstrated a renewable energy system starting with a detailed assessment of the solar, wind, tidal, and wave resources on-site along with the loads associated with dockside operations (primarily for extractive species hoists). The site is purposely sheltered from the open sea, and therefore only solar was found to be viable, although this is likely different at other IMTA sites. A solar-battery system was optimized with particular emphasis on fine-grained temporal resolution to ensure the peak loads, as well as average energy, were satisfied throughout the year. Diesel genset back-up was also considered alongside full battery systems. Mounting of the solar panels and battery bank was also investigated on-board the dockside tram and in stationary locations on the docks. In the end, a system with genset backup was found to be most cost effective to meet extreme power loads in case of protracted low solar irradiation during winter. The system has been installed on site for long term *in situ* testing and validation of the design, and the modeling tool is available for optimizing such renewable energy systems at other IMTA sites.

Renewable energy provision on site is both viable and critical to achieving truly sustainable operations by avoiding the burning of fossil fuel, as well as associated environmental contamination risks of spills. This project developed a tool for designing such systems and implemented a field demonstration of the system components.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Curran Crawford (UVic)

PROJECT TEAM: Stephen Cross, Adam Gray, Nima Tehrani, Pouya Amid (UVic)

COLLABORATORS: Kyuquot SEAfoods Ltd.

CONTACT: curranc@uvic.ca

WEBSITE: http://www.cimtan.ca/

Optimizing IMTA Species Components Stocking Densities and Infrastructure Orientation to Maximize Overall System Efficiency

To improve the sustainability of IMTA systems, extractive species stocking densities and infrastructure orientations need to be optimised such that they maximise the interception of excess fish-farm nutrients and IMTA efficiency. In order to achieve this objective, the dynamics of nutrient transfer within the site needs to be understood to choose the best configuration and species mix. On the east coast, empirical studies were done on flow patterns and organic particle dilution rates and their potential utilization by farmed and wild species was studied on conventional and IMTA salmon sites to provide input on a model for site efficiency. Results indicated substantial spatial and temporal variation in flows around the farm. On the west coast, the project was focused on optimizing the benthic extraction of nutrients within an IMTA system using the detritus-feeding California Sea Cucumber, *Parastichopus californicus*. The California Sea Cucumber has been established as a promising candidate for IMTA due to its ability to extract benthic nutrients and its high market value. This study confirmed the potential for cultivation of juvenile *P. californicus* within suspended trays of an IMTA system. The results of a six-month field trial indicated a positive effect of co-culture with oysters with greater food availability and higher containment success compared to a control site 320 m away. In examining different suspended tray designs, we determined that reduced food availability increases the occurrence of visceral atrophy, reduces sea cucumber growth, and decreases overall IMTA system nutrient recycling efficiency. A trade-off between containment and food availability was found for the co-cultured sea cucumbers.

Taryn Minch (UNBSJ) and Adena Peters (UNBSJ) monitoring an acoustic Doppler current profiler (ADCP) while it measures the current speed and direction of the water in the water column around an aquaculture farm in the Bay of Fundy. Photo: Shawn Robinson (DFO)

Expanding our knowledge of nutrient transfer within current IMTA site designs will help the industry develop their infrastructure and also provide inputs into future designs of aquaculture farms. These studies will also contribute to the understanding of the risk of various materials advecting away from the farm point-source in relation to the dilution rates. Expanding our knowledge of *P. californicus* as a benthic extractive species within IMTA systems and addressing issues such as containment of this species will be mutually beneficial to resource managers and industry partners.

DATE: JAN. 2013–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Bruce MacDonald, Taryn Minch, Thierry Chopin (UNBSJ); Gregor Reid (UNBSJ; DFO); Chris Pearce (DFO); Stephen Cross, Angela Fortune, Hailey Davies (UVic); Colleen Haddad (VIU)

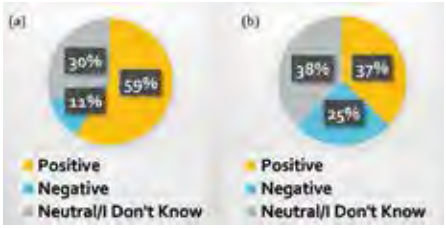
COLLABORATORS: Cooke Aquaculture Inc.; Effingham Oysters Ltd.; Kyuquot SEAfoods Ltd.

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: http://www.cimtan.ca/

Economic Implications of IMTA

Our research has addressed key economic aspects of the aquaculture commercialization process in Canada, namely benefits for consumers of aquaculture products and society at large, as well as potential producer benefits. In the first case, extensive household surveying in the major consuming region (west coast, USA) demonstrated a clear willingness to pay more for IMTA products (e.g., salmon, shellfish)–averaging 9% more for IMTA versus conventional farmed salmon. Salmon consumers were also willing to pay more for IMTA products versus those from closed containment aquaculture (CCA). The reverse was true in the producing region (British Columbia, Canada) when the general public was asked about their willingness to pay to support the development of IMTA versus CCA: CCA attracted greater levels of support. In general, preferences for IMTA were stronger in the USA than in Canada (see figure attached), while preferences for CCA were stronger in Canada than in the USA, where a small segment of consumers actually see CCA negatively.



Support for IMTA as expressed in survey responses by (a) salmon consumers in USA west coast markets, and (b) the general public in British Columbia, Canada.

On the producer side, the results are only just emerging. Earlier economic studies suggested IMTA is more profitable than conventional salmon farming. But if this is true, why has it not been adopted more extensively? Earlier studies likely underestimated the added costs of IMTA production, such as the extra management costs and risk associated with a more complex production system. We are carrying out more rigorous modelling to factor in real world constraints, such as effluent standards and site licensing limits, and to investigate policy tools to promote IMTA.

Our main impact will be on how policymakers respond to the problems associated with monoculture salmon farming and on how to help assess the role IMTA should play in the process. This can influence the design of programs and incentives to help the industry better align its activities to benefit society.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Duncan Knowler (SFU)

PROJECT TEAM: Patrick Kitchen, Winnie Yip, Kim Irwin, Stefan Crampton, Hossein Ayouqi, Mark Carras (SFU)

CONTACT: djk@sfu.ca

WEBSITE: http://www.cimtan.ca/

Social Implications of IMTA: Coastal Communities and the Appetite for Aquaculture

Our work has continued along the tenets of social license and perceptions of IMTA in Canada. In 2015, we co-hosted information workshops where an exchange of dialogue and knowledge explored the particular and nuanced interests of British Columbia First Nations communities. Building on this work we sought to further explore perceptions of IMTA amongst coastal communities of the west and east coasts of Canada, and to situate these perceptions amongst finfish, shellfish, and seaweed aquaculture, as well as seafood consumption and purchase preferences. Survey teams were dispatched to the small coastal communities (populations < 5,000 inhabitants) of Vancouver Island in British Columbia, and to the Maritime communities along the coast of Prince Edward Island, New Brunswick, and Nova Scotia. Together, the teams collected 657 survey interviews.

Erin Latham (UVic) helping with scallop lantern nets. Photo: David Schmidt (Gwa'sala-'Nakwaxda'xw First Nation)

Preliminary findings indicate significant differences in awareness of aquaculture and in perceptions, and between the two coasts. The overall response to IMTA was favourable. In British Columbia and the Maritimes, the majority of respondents thought the government should encourage the present finfish aquaculture industry to adopt IMTA methods (54% and 71%, respectively), and over 65% of respondents from both coasts would support the development of new aquaculture farms based on the IMTA production system. Notably, 44% of British Columbia respondents and 35% of east coast respondents said they would pay more for products certified as IMTA; however, almost half of all respondents also identified that they do not purchase farmed seafood, citing their ability to access and obtain wild seafood through personal means or social networks.

Our research indicates that the adaptability of the IMTA system is its greatest asset in its future development. Different interest groups will express different values in the design, scale and operations of a system amidst a variegated geographic and often contentious political landscape that has characterized much of Canada's aquaculture development. In the new era of participatory governance, the undermining or absence of including significant interest groups may pre-emptively determine the future of IMTA development.

DATE: JAN. 2010–JAN. 2017

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program

CO-FUNDED BY: Fisheries and Oceans Canada (DFO); University of New Brunswick (UNB); New Brunswick Research Productivity Council (NBRPC); Cooke Aquaculture Inc.; Kyuquot SEAfoods Ltd.; Marine Harvest Canada Limited; Grieg Seafood BC Ltd.

PROJECT LEAD: Mark Flaherty (UVic)

PROJECT TEAM: Stephen Cross, Erin Latham, Katie Tebutt (UVic); Grant Murray (VIU)

CONTACT: flaherty@mail.geog.uvic.ca

WEBSITE: http://www.cimtan.ca/

SHELLFISH: MUSSELS

Effects of Husbandry Practices and Mitigation Treatments on the Long-Term Control of Tunicate Infestation in PEI Mussel Farms

Assessing the Effect of Climate-Change-Related Summer Heat Wave on the Condition and Physiology of the Cultured Blue Mussel (*Mytilus edulis*) and Monitoring of the Carbonate System within Prince Edward Island Bays

Identification of Mussel Spat Supply Strategies in the Magdalen Islands

A Study of the Reproductive Patterns of Blue Mussel, *Mytilus edulis*, Grown in Deep and Shallow Water Sites in Notre Dame Bay, Newfoundland and Labrador

Assessment of Strategies to Prevent Farmed Mussel Predation by Sea Ducks

Mussel Stock Structure and Density in Longline Culture

Serial Knots in Mussel Culture Ropes Increase Spat Collection and Reduce Duck-Related Mortality

Comparison of the Health and Condition of Cultured Mussels from Deep and Shallow Water Sites in Newfoundland with Reference to Environmental Conditions, Condition Index, Physiological Stress, and Lipid Biochemistry

Passive Protection of Mussel Production Through Use of Exclusion Cages to Prevent Duck Predation in the Gaspé, Quebec

Monitoring Variability of Environmental Factors Impacting Tunicate Infestation on Coastal Shellfish Farms in Nova Scotia

Characterization of Lobster Habitat and Fishery's Spatial Use in Relation to Shellfish Aquaculture Leases in Malpeque Bay, PEI

Develop Diagnostic Markers to Assess Mussel Population Health in Response to Environmental Stress

Sub-Lethal Biological Effects on the Blue Mussel (*Mytilus edulis*) from Chronic Exposure to Three Types of Conventional and Unconventional Oil under Ice Cover in Winter

Characterization of Interactions Between Mussel Aquaculture and Adult American Lobsters

Impact of Mussel Culture on Infauna and Sediment Biogeochemistry

Effects of Husbandry Practices and Mitigation Treatments on the Long-Term Control of Tunicate Infestation in PEI Mussel Farms

Tunicate infestations have severely impacted the shellfish aquaculture industry in Atlantic Canada, particularly the mussel aquaculture industry in PEI. Floating or submerged substrates such as shellfish aquaculture structures, gear, and mussel lines provide ideal surfaces for the colonization of invasive tunicates. While current mitigation practices (e.g., pressure washing) address the immediate removal of tunicates from mussel lines and substrate, they do not prevent re-infestation. Past research has focused primarily on the timing, frequency, and ecological sustainability of these practices; however, there have been no long-term assessments of these treatments or of alternative measures. Examining the role of bay-wide mussel stocking densities and related effects on tunicate recruitment could provide insights into alternative options for managing tunicates on shellfish farms.

In the case of tunicates, it is recognized that unused space or substrate availability facilitates the settling of these invasive species in a new environment. This project investigates the relationship between available recruitment space and levels of infestation by the invasive Vase Tunicate, *Ciona intestinalis*, on PEI mussel culture sites. The study will be conducted at the scale of a typical mussel aquaculture site, and will entail multi-year simulations to assess the overwintering potential of tunicates. The effect of different mussel stocking densities on infestation levels will be assessed, and numerical models developed to simulate the effects of fallowing of culture leases. The results from this study are intended to inform long-term tunicate management strategies at both farm and bay-scale levels.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEADS: Thomas Landry, Thomas Guyondet (DFO)

COLLABORATORS: Aaron Ramsay (DFARD); Jeffrey Davidson, Thitiwan Patanasatienkul (UPEI–AVC)

CONTACT: Thomas.Landry@dfo-mpo.gc.ca, Thomas.Guyondet@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-G-03-eng.html

Assessing the Effect of Climate-Change-Related Summer Heat Wave on the Condition and Physiology of the Cultured Blue Mussel (*Mytilus edulis*) and Monitoring of the Carbonate System within Prince Edward Island Bays

Climate change is an issue that will impact the shellfish aquaculture industry in Atlantic Canada. There are a number of questions related to the impact of the physical effects of climate change on the environment (such as ocean acidification) in which the shellfish aquaculture industry operates, which would consequently affect the health and health management of farmed animals.

This project will quantify the physiological stress (shellfish health impact) associated with increased water temperature for extended periods of time. In relation to ocean acidification, parameters of the carbonate system will be measured within the shellfish aquaculture environment to assess current levels. Results from this project will offer guidance on maintaining healthy mussel populations in the face of climate change and sustainable management of shellfish aquaculture in the present and future.

START DATE: APR. 2015–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Prince Edward Island Aquaculture Alliance

PROJECT LEAD: Carla Hicks (DFO)

PROJECT TEAM: Luc Comeau, Kumiko Azetsu-Scott (DFO); Aaron Ramsay [PEI–Department of Fisheries, Aquaculture and Rural Development (PEI-DFARD)]; Sarah Stewart-Clark (Dalhousie U)

COLLABORATORS: Peter Warris (PEIAA)

CONTACT: Carla.Hicks@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-G-02-eng.html

Blue Mussels. Photo: DFO

Identification of Mussel Spat Supply Strategies in the Magdalen Islands

For more than 20 years, Magdalen Islands mussel farmers have collected most of their mussel spat in Bassin du Havre Aubert (BHA), where the stock is more resistant to episodes of summer mortality than stocks in other water bodies. However, the space available for collecting spat is limited in BHA, and it is essential that the potential supply in other Magdalen Island water bodies be assessed to ensure active and future supply. The main objective of this project is to identify the various strategies for Blue Mussel (*Mytilus edulis*) spat supply in the Magdalen Islands. The project contains two specific components and sub-objectives: 1) collection yield at three other sites; and 2) performance (survival and growth) of stocks from these sites (stock site design).

Preliminary results indicate that, although alternative stocks appear to be more resilient than in the 1990s, the BHA stock is still the most resilient. Genetic analyses will be performed to study the basis of this adaptation. Stock performance (survival and growth) differs among grow-out sites, reflecting a variation in local conditions. Correlation analyses will be performed with environmental parameters to identify the most important parameters.

The outcome of the project will profile alternative collection scenarios, enabling current and future companies to meet their production and profitability targets. The proposed strategies will support the proposals made at the end of the marine aquaculture fisheries project (Merinov) and mariculture development approaches in the Magdalen Islands.

DATE: APR. 2014–DEC. 2017

FUNDED BY: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)

CO-FUNDED BY: MITACS; Merinov

PROJECT LEAD: Nicolas Toupoint (Merinov)

PROJECT TEAM: Carole Cyr, Jean-François Laplante (Merinov); François Bourque (MAPAQ); Réjean Tremblay (ISMER)

COLLABORATORS: UQAR; Moules de Cultures des Îles inc.; Grande-Entrée Aquaculture inc.

CONTACT: Nicolas.Toupoint@merinov.ca

WEBSITE: www.merinov.ca

Collection yield–collector analysis. Photo: Nicolas Toupoint (Merinov)

Stock performance–*in situ* measurement process. Photo: Nicolas Toupoint (Merinov)

A Study of the Reproductive Patterns of Blue Mussel, *Mytilus edulis*, Grown in Deep and Shallow Water Sites in Notre Dame Bay, Newfoundland and Labrador

Notre Dame Bay, Newfoundland and Labrador, traditionally uses shallow water sites for mussel aquaculture, but changing spawning patterns have had a direct effect on sustainability. Offshore and deeper sites may provide a more stable deep water environment that might help to reduce physical and environmental stresses. This can include mitigating temperature and salinity changes, less mechanical disturbance due to wave action, or different concentrations of phytoplankton, all of which are thought to influence the frequency of spawning events. Offshore sites would also have lesser impacts on the benthic environment, enabling enhanced environmental sustainability.

Preliminary results have suggested that: 1) Blue Mussels from deep water sites can show improved conditions versus shallow water sites; 2) spawning events are more infrequent and predictable; and 3) meat yield is maintained.

This project will document, characterize, and compare the gonadal development in mussels cultured in deep vs. shallow water sites to determine differences in spawning frequency. The project will also monitor environmental factors that might affect gonadal development in Blue Mussels.

Results from this project will assist the mussel industry to enhance environmentally responsible operations by optimizing the utilization of resources on leases. Industry will be provided with important information on the reproductive condition and patterns of farmed mussels, leading to better overall management. The success of this project would also help reduce the impact of mussel farming in the near-shore environment.

DATE: SEP. 2015–JUN. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Norlantic Processors Ltd.

PROJECT LEAD: Harry Murray (DFO)

PROJECT TEAM: Sharon Kenny, Dwight Drover (DFO)

COLLABORATORS: Terry Mills (Norlantic Processors Ltd.)

CONTACT: Harry.Murray@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-N-03-eng.html

Assessment of Strategies to Prevent Farmed Mussel Predation by Sea Ducks

Buoy system, installed around the mussel lines, to keep protective netting out of the water. Photo: Lise Chevarie (Merinov)

High-density mussel sock when transferred to a wild duck-free environment. Photo: Lise Chevarie (Merinov)

Predation by wild ducks has affected the mussel industry for several years and causes considerable damage at some production sites. The various scaring techniques tested to date (e.g., chasing by boat, sound recordings, etc.) have been unsuccessful because they require a lot of energy and sometimes become ineffective in harsh weather conditions or when the birds become habituated.

In the Magdalen Islands, Grande-Entrée lagoon is a Quebec mussel site that is greatly affected by this problem. In order to protect mussels from predation, Merinov installed vertical nets that surround production lines and cover the entire water column to keep ducks from landing near the lines. Unfortunately, some environmental conditions prevented the netting from staying in its optimal position.

Other Merinov initiatives included transferring young mussel socks at different high densities to two sites currently not visited by ducks: a lagoon and an open environment. When the mussels reached a size less favoured by eiders and scoter ducks, they were returned to the producer's site to continue growing to commercial size. The inter-site transfers worked well. The results demonstrate that high-density socking is an option under certain conditions. Analysis of the economic data will be completed in the winter of 2016–2017 and will help determine the real effectiveness of these transfer scenarios.

The purpose of this research project is to prevent predation of mussels by sea ducks and protect mussel farmers' production.

DATE: OCT. 2013–DEC. 2016

CO-FUNDED BY: Merinov; Grande-Entrée Aquaculture Inc.; Culti-mer Inc.; Biomer

PROJECT LEAD: Lise Chevarie (Merinov)

COLLABORATORS: Grande-Entrée Aquaculture Inc.; Culti-mer Inc.; Biomer

CONTACT: Lise.Chevarie@merinov.ca

WEBSITE: www.merinov.ca

Mussel Stock Structure and Density in Longline Culture

With the proposed increase in mussel production in Malpeque Bay, PEI, there is a need to determine the amount of aquaculture production that can be supported by the aquatic environment without causing permanent changes in ecosystem function, species populations, communities, or habitats; this is also known as the Ecological Carrying Capacity (ECC). ECC is typically estimated using mathematical models which combine and describe complex interactions among shellfish aquaculture, natural shellfish populations, and the environment (e.g., currents, water exchange, nutrient dynamics, etc.). For example, the size and density of cultured mussels will determine the amount of phytoplankton being removed from the water column which, in turn, influences the overall ability of the system to sustainably support both cultured and natural shellfish populations. In PEI, leaseholders provide stock information to DFO on an annual basis, which is useful for assessing whether or not leases are used, but has little value in informing the estimate of ECC. To address this gap, a survey of the PEI Blue Mussel (*Mytilus edulis*) longline system will be carried out to generate information on mussel lease use. Specifically, the survey will focus on seasonal trends in stock composition, densities, and the degree of fouling by invasive tunicates. Characteristics such as size and weight will also be recorded and used to calculate rates of filtration and waste production (i.e., biodeposition). This new information will contribute to improving the accuracy of model simulations and predictions of the overall capacity of an area to support changes in shellfish aquaculture production.

DATE: APR. 2015–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Luc Comeau (DFO)

PROJECT TEAM: Peter Warris (PEIAA); André Nadeau, John Davidson (DFO); Jonathan Hill (UPEI)

COLLABORATORS: Jeffrey Davidson (UPEI)

CONTACT: Luc.Comeau@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-G-06-eng.html

Serial Knots in Mussel Culture Ropes Increase Spat Collection and Reduce Duck-Related Mortality

Predation by sea ducks is a threat to mussel culture in many sites. In many natural situations, however, mussel survivorship is enhanced by crevices and substrate features because predators have reduced access to their prey. We mimicked the effect of crevices by using loosely knotted spat collector ropes. The knots used were the chain sinnet and variants thereof. These are serial knots which can be knotted easily for spat collection and socking, and undone easily at harvest.

The knots were tested against regular unknotted ropes for their efficiency at collecting spat and providing anti-duck refuges in Cascapédia Bay, Quebec. Two suspended culture variants were used, the standard autocollector method used in Cascapédia Bay in 2015 and U-shaped collectors hanging from long lines in 2016.

In the 2015 experiment, control ropes collected about 2700 individual spat per 30.5 cm (October 2015; mussels smaller than 0.5 cm not included). Knotted ropes collected roughly 4000 individual spat per 30.5 cm. This is a 1.5-fold increase as compared to controls. Survivorship in June 2016 was roughly 10-15% in knotted ropes but was less than 5% on control ropes. Survivors and spat smaller than 0.5 cm in spring provided a residual population which grew during the summer and reached about 1500 individuals per 30.5 cm in Oct. 2016 (versus roughly 400 on control ropes). Size-related effects on survivorship will be examined in June 2017.

In the 2016 experiment, control ropes collected about 1300 individual spat per 30.5 cm. The chain sinnet and its variants collected 2900 and roughly 5900 individuals per 30.5 cm, respectively, with slight differences between variants. This is a two to four-fold increase as compared to controls.

Adding serial knots in spat collectors ropes increases spat collection, which is useful wherever spat are in short supply. Survivorship also increases, thus providing a potential method for reducing duck predation.

START DATE: JUN. 2013–DEC. 2017

FUNDED BY: R-D Mytis Ltée

CO-FUNDED BY: La Ferme Maricole du Grand Large

PROJECT LEAD: Marcel Fréchette (R-D Mytis Ltée)

COLLABORATORS: Éric Bujold (La Ferme Maricole du Grand Large)

CONTACT: rdmytis@gmail.com

Comparison of the Health and Condition of Cultured Mussels from Deep and Shallow Water Sites in Newfoundland with Reference to Environmental Conditions, Condition Index, Physiological Stress, and Lipid Biochemistry

Deep water mussel site near Pleasantview, Notre Dame Bay, NL. Photo: Harry Murray (DFO)

Mussels are typically cultured in sheltered nearshore areas. Traditional shallow water coastal areas (estuaries, harbours, and shallow bays) can be affected by land runoff and contaminants, especially during precipitation. Increased pressure for lease space in these areas has raised concerns regarding carrying capacity (maximum population without affecting the environment) and thus sustainability.

Industry has recently begun to develop offshore and deep water bivalve culture in Newfoundland's Notre Dame Bay region. However, little is understood about how deep water environments affect mussel health and condition. This project characterizes and compares seasonal changes in environmental conditions between shallow versus deep sites, and investigates potential correlations between environment and mussel condition, physiological stress, and lipid biochemistry. This information will help industry make decisions regarding whether expanding production to deep water sites will add increased sustainability for Newfoundland mussel culture.

Specifically, the following results were found:

- Mussels grown in deep sites demonstrate higher Omega-3 and essential fatty acids, which are key factors contributing to food quality in mussels and seafood.
- Deep water sites in Notre Dame Bay generally demonstrated increased overall condition after 12 months when compared to shallow sites.
- Under temperate conditions, mussels grown in shallow sites do as well or slightly better than those grown in deep water sites. However, under extreme environmental and surface weather conditions (i.e., abnormally cold water, wind, and ice), mussels have better overall condition over long term in deeper water, which offers more stable environmental conditions compared to shallow sites.

It is recommended that farmers in the Notre Dame Bay region take advantage of the benefits of growing in both deep and shallow water sites within a bay or lease to maintain consistent accessibility to high quality product regardless of the weather conditions.

DATE: JUL. 2012–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Norlantic Processors Ltd.

PROJECT LEAD: Harry Murray (DFO)

PROJECT TEAM: Kim Hobbs, Sharon Kenny (DFO)

COLLABORATORS: Terry Mills (Norlantic Processors Ltd.)

CONTACT: Harry.Murray@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/N-12-01-001-eng.html

Passive Protection of Mussel Production Through Use of Exclusion Cages to Prevent Duck Predation in the Gaspé, Quebec

Migrating ducks that feed on farmed mussels cause significant economic losses for the mussel aquaculture industry and current deterrent systems are becoming increasingly ineffective at keeping the ducks away. The aquaculture industry in Chaleur Bay, Québec, normally uses self-regulating mussel collector techniques. It is believed that mussels grown in this way would be best protected from diving ducks by deploying a passive, physical deterrent system of underwater duck exclusion cages around the mussels.

The project aims to develop protective cage prototypes made with common and locally-available materials to keep costs as low as possible. It will determine the optimal type of netting to prevent duck bycatch and biofouling, while measuring the effectiveness of the exclusion cages in preventing duck predation compared to the traditional methods used for self-regulating mussel collectors.

The results of this project will increase the knowledge surrounding diving duck predation on mussel farms in Québec (and elsewhere) and how this impact may be responsibly mitigated while adhering to the *Migratory Birds Convention Act* (1994). The results will also improve the economic situation of the Québec mussel industry and provide the industry and authorized management bodies with effective and conservation-oriented mitigation tools. This will benefit the mussel aquaculture industry as a whole by allowing it to better understand and mitigate potential wild-farmed interactions concerning duck predation to improve the sustainability of the shellfish culture industry.

DATE: MAY 2015–DEC. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: La Ferme Maricole du Grand Large; Moules Tracadigash Inc.

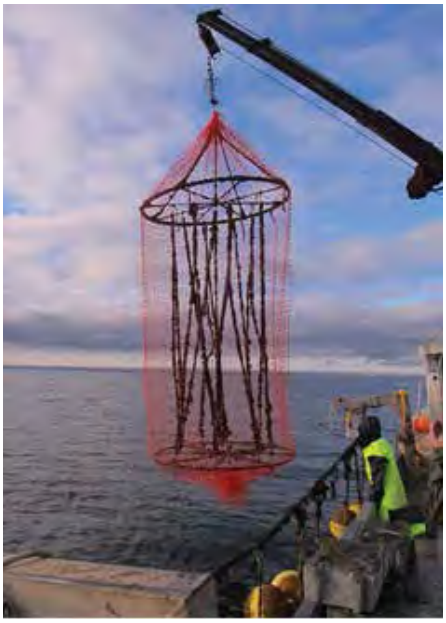
PROJECT LEAD: Chris McKindsey (DFO)

PROJECT TEAM: Annick Drouin, Marie-France Lavoie, Paul Robichaud, François Roy, Anne-Sara Sean, Émilie Simard, Andréa Weise (DFO); Élisabeth Varennes (UQAR)

COLLABORATORS: Éric Bujold (La Ferme Maricole du Grand Large); Manon Deslauriers (Moules Tracadigash Inc.)

CONTACT: Chris.McKindsey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-Q-01-eng.html



Deployment of a cage structure to protect the mussels on the lines within it from diving ducks. Photo: Paul Robichaud (DFO)

Retrieval of mussel lines that had been deployed to collect mussel spat (juvenile mussels) for grow-out for aquaculture. Photo: Paul Robichaud (DFO)

Monitoring Variability of Environmental Factors Impacting Tunicate Infestation on Coastal Shellfish Farms in Nova Scotia

Vase Tunicate (*Ciona intestinalis*) is an invasive species negatively impacting mussel farm productivity in Nova Scotia and Prince Edward Island. They grow in dense groups on mussel ropes, nets, and the mussels themselves, competing for resources and resulting in crop losses. They are difficult to remove and remain persistent even after pressure washing, brine dips, liming, UV treatment, and electric shocks.

The spatial distribution of tunicates is highly heterogeneous and could be the result of variation in environmental factors among sites. This study examines the effect of variability of environmental factors (salinity, temperature, pH, and water movement) on the establishment and proliferation of tunicates. Research results may suggest an environmental factor as an indicator to assess aquaculture sites (either current or future proposed sites) for their risk of tunicate infestation and inform siting decisions by the government. This study may also help reduce further spread of tunicates and the need for control treatments through the identification of sites less vulnerable to infestation.

This project supports the DFO objective of environmental performance. Specifically, the following results were found:

- Of the four environmental factors considered (i.e., salinity, temperature, pH, and water movement), temperature and salinity have the most influence on Vase Tunicate population dynamics. This suggests that coastal sites with generally cooler water or with greater or more frequent freshwater inputs may be less susceptible to heavy tunicate fouling. At cooler sites, initial tunicate settlement may be delayed and growth may be slower throughout the season, resulting in smaller populations, while their abundance can be reduced further if salinity is lower.
- Predictive NMLE (non-linear mixed effects) model is under development to aid in future aquaculture siting and management decisions.

DATE: JUN. 2013–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Aquaculture Association of Nova Scotia (AANS)

PROJECT LEAD: Dawn Sephton (DFO)

PROJECT TEAM: Danielle Goodfellow, Bruce Hancock (AANS); Benedikte Vercaemer (DFO); Cory Bishop, Russell Wyeth (StFX)

COLLABORATORS: Danielle Goodfellow (AANS)

CONTACT: Dawn.Sephton@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/M-13-01-002-eng.html

Characterization of Lobster Habitat and Fishery's Spatial Use in Relation to Shellfish Aquaculture Leases in Malpeque Bay, PEI

Shellfish aquaculture is an important economic activity for coastal communities in Atlantic Canada. The Blue Mussel industry emerged on the east coast during the 1970s and expanded rapidly in PEI during the 1990s. Today, Blue Mussels are the nation's leading cultured shellfish species by weight and value. In 2013, Fisheries and Oceans Canada (DFO) identified the need to develop a detailed spatial plan to accommodate a possible increase in leases for mussel aquaculture in Malpeque Bay, PEI. In addition to considering the scale of shellfish aquaculture that can be sustainably cultured in Malpeque Bay, there also remain questions related to interactions between lobster and cultured mussels. In making decisions or proposing potential increases in the number of leases in Malpeque Bay, aquaculture managers have to consider complex coastal zone management issues, including the potential for habitat overlap between lobsters and aquaculture mussel leases.

This project addresses management questions related to the interactions between lobster and cultured mussels by investigating the potential overlap between proposed mussel aquaculture sites with lobster rearing grounds and fishing activities in Malpeque Bay. The outcomes of this study will inform departmental and provincial decision-makers in their marine spatial planning processes and contribute to a sustainable aquaculture industry.

DATE: APR. 2015–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Marc Ouellette (DFO)

PROJECT TEAM: Michel Comeau, Denis Gagnon, Angeline LeBlanc, Bruno Comeau, Deryck Mills (DFO)

CONTACT: Marc.Ouellette@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-G-02-eng.html

Develop Diagnostic Markers to Assess Mussel Population Health in Response to Environmental Stress

This project is focused on generating better tools to enable industry to determine and analyse the stressors that impact cultured Blue Mussels and what effects these can have on their condition and health. This project aims to be proactive in managing health issues that may arise for cultured shellfish species in relation to climate change (water temperature and pH), tunicate treatment (high pressure water spray and hydrated lime) and other environmental stressors (food availability, hypoxia and salinity).

This project will identify genetic markers that can be used: 1) to investigate the causes of stress within underperforming mussel populations; and 2) to develop mitigating strategies to minimize the impacts of the underlying environmental/mechanical stressors on the long term viability of the mussel aquaculture industry in PEI.

The stress response (heartbeat, lysosomal destabilization) in mussel populations after an event challenge (food availability, hypoxia, salinity, thermal, pH, tunicate (*Ciona intestinalis*) recruitment/removal) will be evaluated. At the same time, transcriptomic data will be collected to develop molecular markers related to a specific stressor. We plan on using RT-qPCR markers identified via RNA-Seq to evaluate stress responses.

START DATE: OCT. 2016–MAR. 2020

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Prince Edward Island Aquaculture Alliance (PEIAA)

PROJECT LEAD: Denise Méthé (DFO)

PROJECT TEAM: Sarah Stewart-Clark, Stephanie Hall (Dalhousie U); Carla Hicks (DFO); Fraser Clark (Mount Allison U)

COLLABORATORS: PEIAA

CONTACT: Denise.Methe@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-G-04-eng.html

Left to right: Sarah Stewart-Clark (Dalhousie U), Denise Méthé (DFO), and Stephanie Hall (Dalhousie U). Photo: Scott Jeffrey (Dalhousie U)

Sub-Lethal Biological Effects on the Blue Mussel (*Mytilus edulis*) from Chronic Exposure to Three Types of Conventional and Unconventional Oil under Ice Cover in Winter

Western Canada has huge bitumen deposits, a source of unconventional oil. Once diluted, it is easily exported, which suggests it will be a leading component of future Canadian exports. The Estuary and Gulf of St. Lawrence are highly coveted shipping points given their adequate port infrastructure and strategic access to foreign markets. In addition to its extreme winter weather conditions, the St. Lawrence supports vital economic operations such as shellfish farming in outlying areas. Dilbit's (diluted bitumen) behaviour and biological effects are still unknown in the event of a spill occurring in winter under ice cover in the marine environment, not to mention the adverse economic repercussions if a spill were to occur near aquaculture facilities. We quantified the immediate and delayed biological effects by reproducing such a scenario and exposing commercial size mussels *Mytilus edulis* to dilbit and conventional crude oil for seven days. After a 72-hour exposure, bioaccumulation of the hydrocarbons as well as cellular and physiological stress were observed. A depuration period was observed after exposure during which the mussels eliminated the accumulated hydrocarbons. Several months after winter exposure and despite the depuration period, negative effects on spring spawning were evident mainly in larval survival and development. Our experiments revealed immediate toxicity (bioaccumulation, cellular and physiological stress) in addition to delayed toxicity (reproductive success). A more pronounced biological response to exposure to unconventional crude oil was also demonstrated.

This study investigated the consequences of an oil spill in the cold northern marine environment on the *Mytilus edulis* farmed mussel.

DATE: AUG. 2015–AUG. 2017

FUNDED BY: DFO–National Contaminants Advisory Group (NCAG)

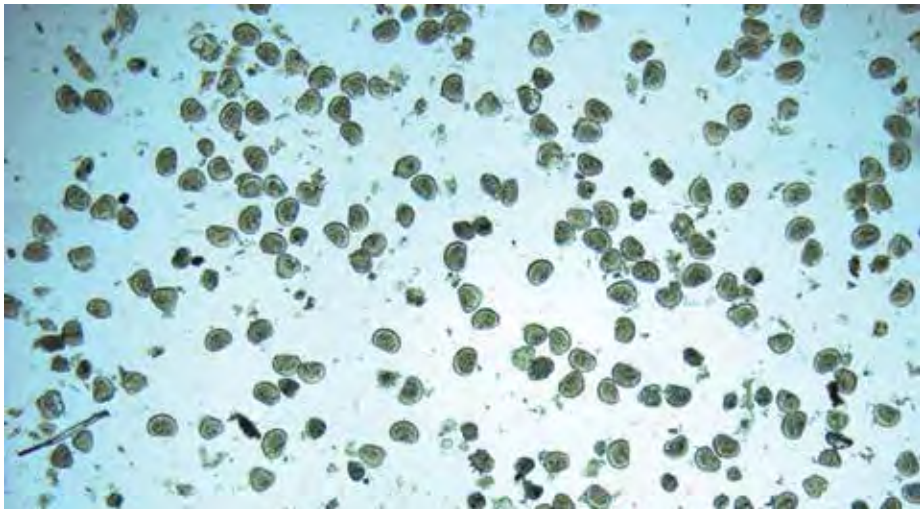
CO-FUNDED BY: Fonds de Recherche du Québec en Nature et Technologies (FRQNT)

PROJECT LEAD: Anthony Schmutz (UQAR-ISMER)

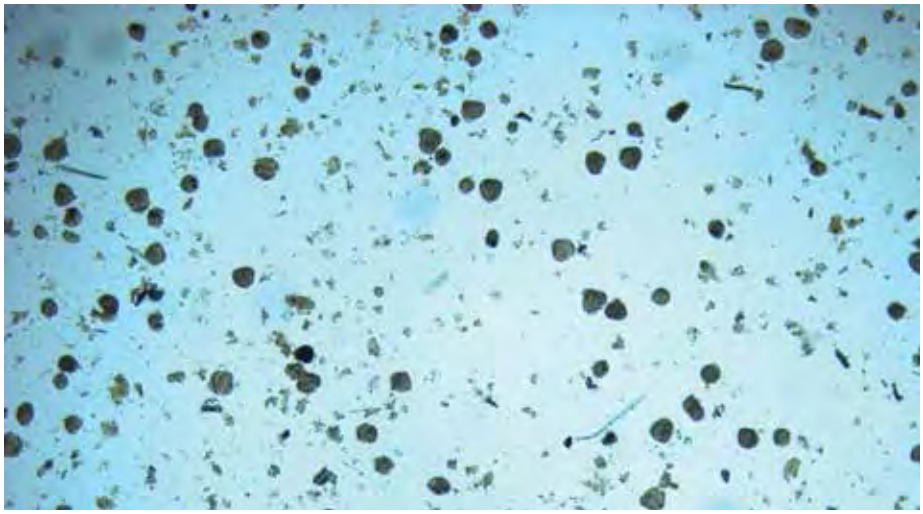
PROJECT TEAM: Richard St-Louis (UQAR); Réjean Tremblay, Céline Audet, Jean-Pierre Gagné; Émilien Pelletier, Mickaël Barthe (UQAR-ISMER)

COLLABORATORS: Richard St-Louis (UQAR), Réjean Tremblay, Céline Audet, Jean-Pierre Gagné, Émilien Pelletier, Mickaël Barthe (UQAR-ISMER)

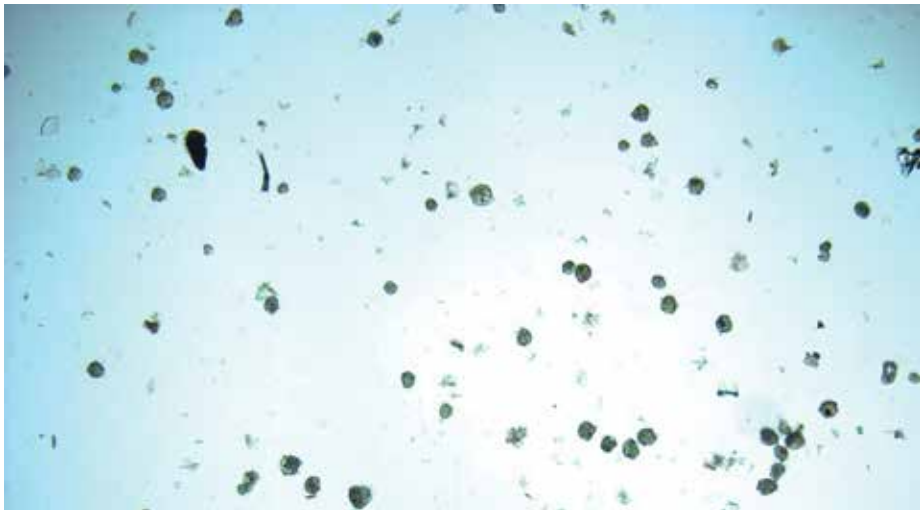
CONTACT: Schmutzanthony@hotmail.fr



Photograph of larval production (day two) in adults exposed to the control treatment.
Photo: Anthony Schmutz (UQAR-ISMER)



Photograph of larval production (day two) in adults exposed to unconventional oil treatment.
Photo: Anthony Schmutz (UQAR-ISMER)



Photograph of larval production (day two) in adults exposed to conventional oil treatment.
Photo: Anthony Schmutz (UQAR-ISMER)

Characterization of Interactions Between Mussel Aquaculture and Adult American Lobsters

Understanding the influence of mussel culture sites on the distribution and condition of lobsters is an important question for managers who evaluate requests for new mussel farms as there is limited scientific information on the subject. Additionally, it is widely perceived by lobster fishers that lobsters that congregate around aquaculture sites may become sedentary and are therefore less available to the lobster fishery. Known environmental interactions between mussel (and other shellfish) aquaculture include water column-related effects on plankton and nutrients due to mussel filter-feeding, as well as localized effects on infaunal (benthic) communities from increased organic loading on the seafloor. In the case of suspended mussel culture, organic loading comes from faeces, pseudofaeces (biodeposits), and from large quantities of farmed mussels (and the organisms that grow on them) that fall from the suspended culture structures as the mussels grow. The physical structures of aquaculture equipment also provide potential habitat for organisms that need solid substrate to grow, which may attract a variety of predatory and scavenging species. As a result, there may be ecological effects because of changes in the productivity, distribution, or catchability of target (fishery) species.

The goal of this project is to describe the extent and effect of interactions between mussel aquaculture activities and adult American Lobsters, including the spatial distribution and movement of lobsters within and around mussel aquaculture sites, and their availability to the fishery. The influence of mussel aquaculture on the condition of lobsters and their diet will also be evaluated. The results of the study will help Fisheries and Oceans Canada (DFO) aquaculture managers make scientifically sound decisions in support of ecologically and economically sustainable aquaculture.

DATE: APR. 2015–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Chris McKindsey (DFO)

PROJECT TEAM: Rénald Belley, Luc Comeau, Catherine Couillard, John Davidson, Annick Drouin, Jonathan Hill, Marie-France Lavoie, Domynick Maltais, François Roy, Paul Robichaud, Émilie Simard, Anne-Sara Sean (DFO)

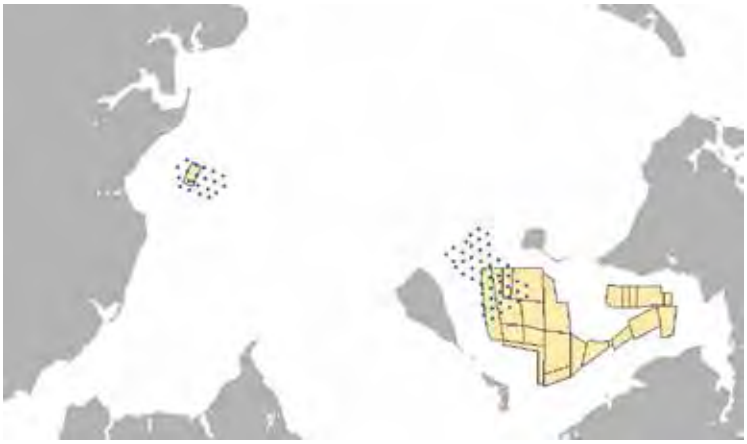
COLLABORATORS: Ocean Tracking Network (OTN); Philippe Archambault (ISMER); Jeffrey Davidson (UPEI)

CONTACT: Chris.McKindsey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-QC-01-eng.html

Annick Drouin and Marie-France Lavoie (DFO) take tissue samples of a lobster to determine its condition in a study on the influence of mussel farms on lobster condition and movement. Photo: Chris McKindsey (DFO)

Mussel socks with a hydro-acoustic receiver used to detect ultrasonic signals emitted by acoustic transmitters affixed to lobsters and crabs in Malpeque Bay. Photo: Chris McKindsey (DFO)



Map of arrays of acoustic receivers (blue points) deployed around mussel farms in Richmond Bay (left, 0.9 km^2 coverage) and Marchwater (right, 2.0 km^2 coverage) to detect lobster movements inside and outside of mussel farms (orange polygons) in Malpeque Bay, Prince Edward Island.

Impact of Mussel Culture on Infauna and Sediment Biogeochemistry

Interactions between bivalve aquaculture and the environment are complex.

In suspended mussel culture, great quantities of waste (digested and undigested planktonic food, or biodeposists) may fall from culture structures and this may impact benthic communities, particularly those living in bottom sediments. Different biogeochemical methods have been developed as proxies to monitor the health of benthic communities. While some work has examined dose (biodeposition) – response (benthic conditions) relationships, these studies often suffer from procedural issues or have been done over limited levels of biodeposition and mechanisms have not been evaluated, making the determination of benthic ecological carrying capacity difficult. This study evaluates the dose-response relationship between mussel biodeposition and benthic conditions over a wide range of deposition levels and over more than one year. Measurements will be taken to determine the processes by which bottom sediments and communities are impacted with the aim of determining the ecological carrying capacity of the benthic environment of Malpeque Bay, PEI, for mussel aquaculture.

Combining the results of this study with ongoing organic loading models for bivalve aquaculture will inform managers on how many mussels may be farmed in an area while protecting the benthic environment.

DATE: APR. 2016–MAR. 2019

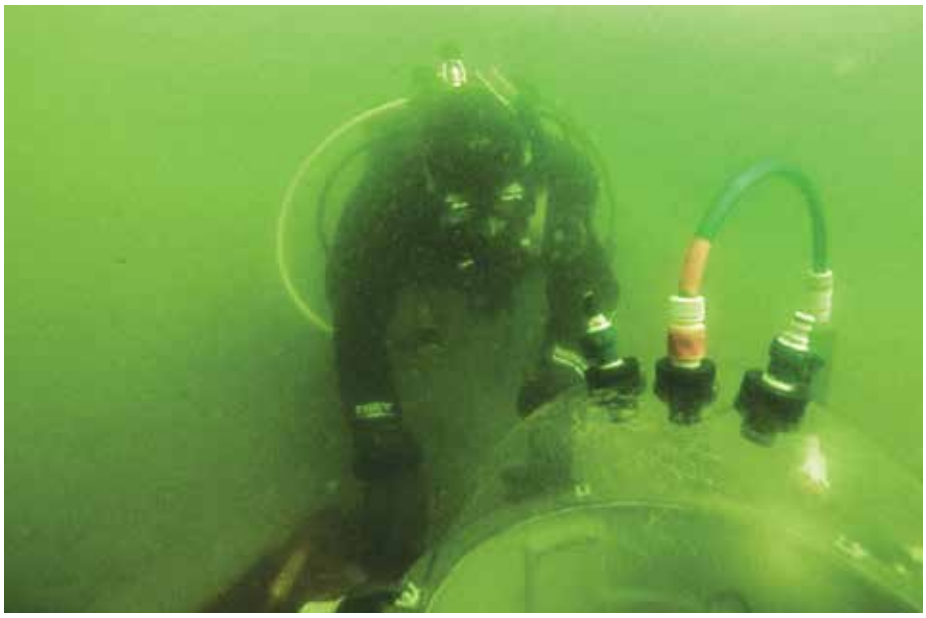
FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Chris McKindsey (DFO)

PROJECT TEAM: Luc Comeau, Annick Drouin, Nathalie Forget, Frédéric Hartog, Élise Lacoste, Marie-France Lavoie, François Roy, Émilie Simard, Anne-Sara Sean, Andrea Weise (DFO)

CONTACT: Chris.McKindsey@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-Q-01-eng.html



A diver examines a benthic mesocosm to evaluate benthic respiration and nutrient fluxes around mussel lines in Havre-aux-Maisons Lagoon, îles-de-la-Madeleine. Photo: Anne-Sara Sean (DFO)

Marie-France Lavoie and François Roy (DFO) prepare sediment traps and sample jars to evaluate sedimentation around mussel lines in îles-de-la-Madeleine. Photo: Andrea Weise (DFO)

SHELLFISH: OYSTERS

Investigating *Polydora* Outbreak in New Brunswick Off-Bottom Cultured Oysters

Assessment of Oyster Spat Collection Potential in Bouctouche Bay, New Brunswick

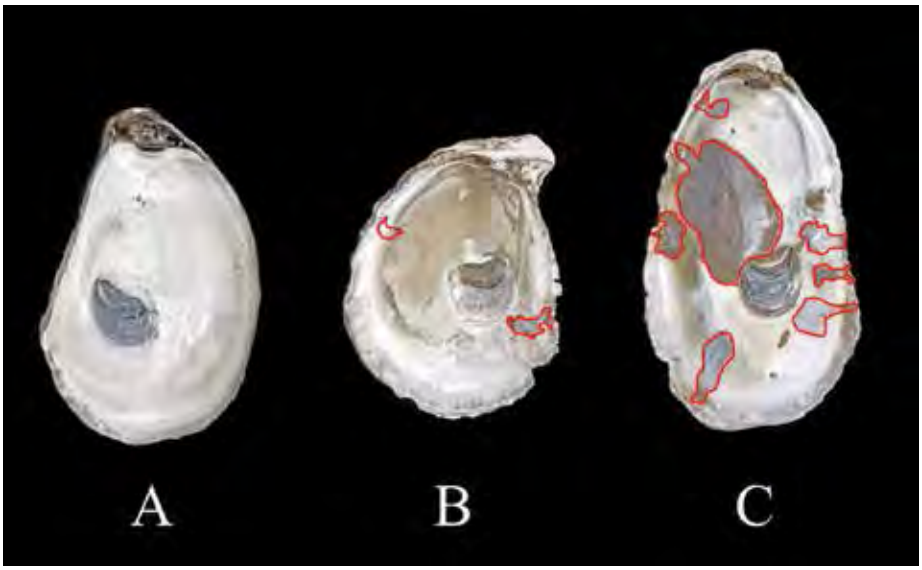
Impacts of Aquaculture Operations on the Genetic Health of Natural Populations of the Eastern Oyster, *Crassostrea virginica*

Quantifying the Effect of Winter Siltation and Burial on *Crassostrea virginica*'s Health

Improving Physiological Health of Oysters by Selecting Seed for Stress Resilience

Eastern Oyster, *Crassostrea virginica*, Response to Environmental, Physiological, and Mechanical Stressors

Investigating *Polydora* Outbreak in New Brunswick Off-Bottom Cultured Oysters



Crassostrea virginica shells with varying degrees of mud blister impact from *Polydora websteri*. (A) shells not impacted, (B) shells mildly impacted , and (C) shells severely impacted. Mud blisters are outlined in red. Photo: Jeffery Clements (DFO)

A better understanding of the increased intensity and prevalence of *Polydora* related to environmental conditions and their impact on oyster health would assist industry in developing management and mitigation strategies.

Known simply as a "mudworm" or "blisterworm", *Polydora websteri* has the ability to bore into the shells of live and dead shellfish. Commonly found in intertidal and subtidal areas in Atlantic Canada, its presence among New Brunswick oyster populations has normally been minor and usually of low intensity with burrows containing little or no mud. However, there have been sporadic increases of infestation rates observed in off-bottom (or suspension) oyster growing sites in New Brunswick.

Some reports have indicated that heavy infestations can result in low meat quality, abscesses, alteration of growth patterns, and weakened shells (increasing predator susceptibility). This unusual increase could ultimately lead to serious impacts on oyster populations and result in economic losses for the aquaculture industry. To help identify the current impact of *Polydora* on New Brunswick oyster growing areas, this project aims to: 1) document the presentation and level of the infestation of *Polydora*; 2) document the impact of *Polydora* on overall oyster health; and 3) document distribution and infestation level of *Polydora* in relation to environmental conditions.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Huîtres Aquador Oysters Inc.

PROJECT LEAD: Daniel Bourque, Mary Stephenson (DFO)

PROJECT TEAM: Daniel Bourque, Mary Stephenson, Janelle McLaughlin, Jeff Clements (DFO)

COLLABORATORS: Serge Gaudet (Huîtres Aquador Oysters Inc.)

CONTACT: Daniel.Bourque@dfo-mpo.gc.ca, Mary.Stephenson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-14-01-002-eng.html

Assessment of Oyster Spat Collection Potential in Bouctouche Bay, New Brunswick

The oyster culture industry in New Brunswick depends on the oyster spat collected at four sites–Bouctouche Bay, Cocagne Bay, Caraquet Bay, and Miramichi Bay. In 2009, lower than average oyster spat collection rates were a source of concern for producers. To properly manage these fluctuations, an in-depth understanding of the various factors influencing collection rates and recruitment numbers within the system is needed.

This project studied the factors influencing oyster spat collection in Bouctouche Bay, New Brunswick by using modelling techniques to reproduce the oyster larval transport from spawning to recruitment for environmental conditions observed *in situ* (in the field) and assessing the relative contribution of the various larval sources (wild versus cultured stock). This modelling will also help researchers evaluate the possible repercussions of one (or more) spat evolution scenarios on the hydrodynamics (examining the erosion effects on the flow of water and nutrients) and overall spat collection potential within the bay.

The results from this experiment showed that the seed collection area is located in a retention zone of the bay where renewal by Northumberland Strait waters is slowest and indicated that water circulation within Bouctouche Bay is sensitive to meteorological forcing (wind and atmospheric pressure). A particle tracking module was coupled with the hydrodynamic model in order to investigate in more detail the transport of oyster larvae within Bouctouche Bay. Further analysis of the particle tracking results is underway to provide the relative contribution of each area of the bay, the effects of meteorological and river forcing on these contributions, and potential modifications to this pattern in the context of a scenario where a storm would result in breaching of the sand dune in front of the seed collection area.

DATE MAY 2013–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Entreprise Baie Acadienne Inc.

PROJECT LEAD: Thomas Guyondet (DFO)

PROJECT TEAM: Marie-Josée Maillet (DAAF); Serge Jolicoeur (U Moncton); Dominique Bérubé (New Brunswick Department of Energy and Resource Development)

COLLABORATORS: Entreprise Baie Acadienne Inc.

CONTACT: Thomas.Guyondet@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-13-01-002-eng.html

Impacts of Aquaculture Operations on the Genetic Health of Natural Populations of the Eastern Oyster, *Crassostrea virginica*

This information will allow for both a better assessment of the genetic health of *Crassostrea virginica* populations in the Maritimes, and for the establishment of hatchery-based breeding programs.

Oyster farmers currently rely on wild-caught seed (also known as spat) to stock their aquaculture sites. The number and quality of seed, however, is highly variable from year-to-year and juvenile oysters must often be sold and transported from regions with a high seed set (abundance) to regions with a poor seed set. To address this issue, a commercial-scale hatchery in New Brunswick is currently being developed to provide adequate oyster seed to oyster farms within the Maritimes. The potential impact of hatchery-spawned oysters, as well as transplanted wild-caught spat, on the genetic integrity of neighbouring wild oyster beds greatly depends on the factors underlying the genetic structure of natural populations. Conversely, the health and vigour of cultured oysters depends on the quality of available spat, whether from wild-caught sources or hatchery production.

This project will examine genetic diversity between populations of the Eastern Oyster, identify functional diversity in terms of health indicators such as condition index, growth, survival, and reproduction, as well as evaluate the potential impacts of gene flow between wild and cultivated oyster populations. The goal of this project is to evaluate the genetic sequence of natural oyster populations through the creation of a high-density linkage map for the molecular markers associated with functional diversity in the Eastern Oyster.

DATE: APR. 2013–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: L'Étang Ruisseau Bar Ltd.

PROJECT LEAD: Mark LaFlamme (DFO)

PROJECT TEAM: Jean-René Arseneau, Royce Steeves (DFO); Martin Mallet (L'Étang Ruisseau Bar Ltd.)

COLLABORATORS: André Mallet (L'Étang Ruisseau Bar Ltd.)

CONTACT: Mark.LaFlamme@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-13-01-001-eng.html

Quantifying the Effect of Winter Siltation and Burial on *Crassostrea virginica*'s Health

In commercial shellfish aquaculture operations located within the Gulf of St. Lawrence estuaries, mesh bags containing cultivated Eastern Oysters (*Crassostrea virginica*) are lowered onto soft seabeds in the autumn and recovered in the spring. Occasional mortalities suggest that oysters are vulnerable to sedimentation and burial during winter.

This study explored the cause-effect relationship of winter siltation and burial on oyster health and productivity. It provides the first complete assessment of winter quiescence (extended period of valve closure) in oysters. Specifically, this project found the following results:

- The autumnal burial of Eastern Oysters into the sediment disrupts their quiescent behaviour and leads to irreversible and potentially lethal consequences, occurring approximately five months following burial. The risk of winter death from burial is real, and, consequently, overwintering oysters in deeper channel waters (soft-bottom sediments) is not recommended.
- Burial had no effect on the tissue concentration of lipids, proteins, and glycogen, nor did it impact the energy content index that was developed from these biochemical constituents. Oysters had their valves completely closed most of the time, operating anaerobically, regardless of whether they were buried in the sediment or lying on top of it.
- Buried oysters were likely physiologically stressed during quiescence. Early "rescue" unburying of quiescent oysters did not improve survival rates; instead, unearthing provoked stress and accelerated the depletion of energy reserves, suspected to be the result of oysters burning energy to remove excess silt clogging their gills. Because resuspending mesh bags in early spring would have minimal mitigation effect on survival rates, avoiding soft bottoms altogether (to avoid burial) remains best for oyster health and survival.

DATE: JUL. 2014–JUN. 2016

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO– ACRDP)

CO-FUNDED BY: L'Étang Ruisseau Bar Ltd.

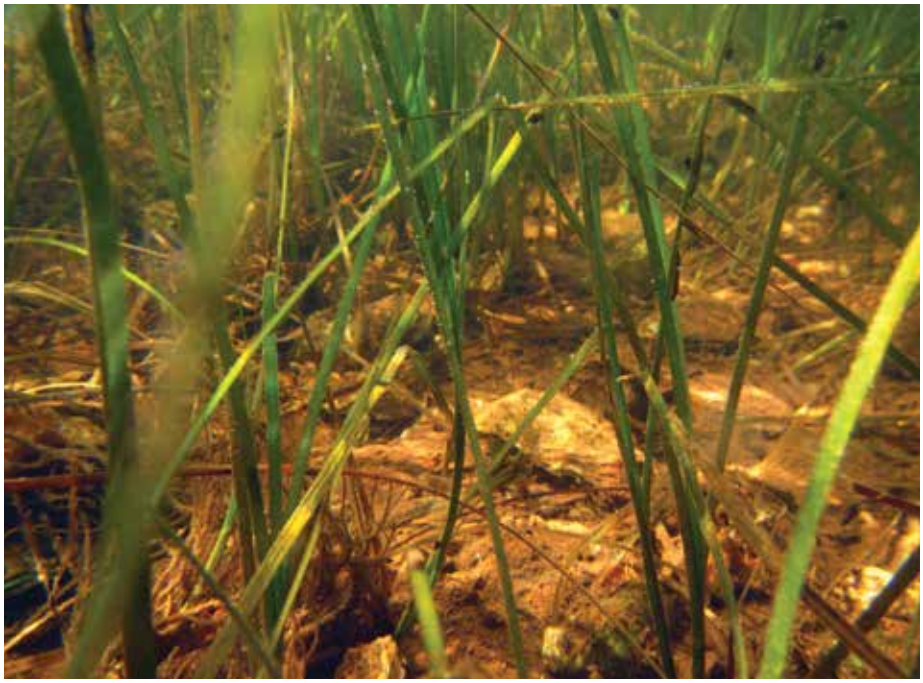
PROJECT LEAD: Luc Comeau (DFO)

PROJECT TEAM: Claire Carver (Carver Marine Consulting); Jeffrey Davidson (UPEI); Jean-Bruno Nadalini, Réjean Tremblay (UQAR)

COLLABORATORS: André Mallet (L'Étang Ruisseau Bar Ltd.)

CONTACT: Luc.Comeau@dfo-mpo.gc.ca

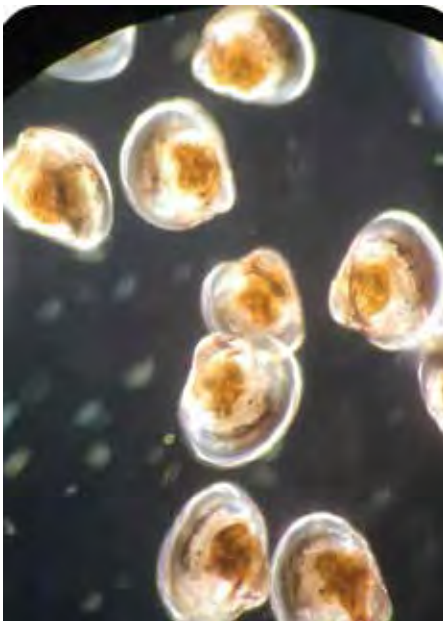
WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-14-02-001-eng.html



Oysters on the sea floor in an eelgrass bed. Photo: Luc Comeau (DFO)

Improving Physiological Health of Oysters by Selecting Seed for Stress Resilience

Gillian Huxley-Tobin (DFO) sieving oyster larvae produced from selected broodstock. Photo: Denise Méthé (DFO)



Oyster larvae ready to set. Photo: Denise Méthé (DFO)

Access to a consistent supply of high quality and resilient seed stocks (i.e., those with the capacity to launch an immune response when faced with pathogens or withstand fluctuations in salinity and temperature associated with climate change) has been identified as a key constraint for the continued viability and expansion of the Eastern Oyster industry in Atlantic Canada. Selecting oysters that are more efficient (lower metabolic need, better feed conversion, and lower reproductive effort) and have increased resistance to deal with stressful events (lower stress response) will ultimately be healthier and thus have greater resilience to pathogens and environmental changes. This project identified genetic markers in the Eastern Oyster associated with metabolic and feed absorption efficiency (10 SNPs and 14 SNPs. respectively) and produced a first generation crop of oysters. In 2017, the progeny will be monitored (and genotyped) to verify if they display these particular traits.

This project is focused on generating efficient and resilient oysters to ensure that if faced with a pathogen or environmental stressor, they will have an increased capacity to launch an immune response.

DATE: JAN. 2015–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: L'Écloserie Acadienne Ltd.

PROJECT LEAD: Denise Méthé (DFO)

PROJECT TEAM: Sarah Stewart-Clark, Stephanie Hall (Dalhousie U); Gillian Tobin-Huxley (DFO); Fraser Clark (Mount Allison U)

COLLABORATORS: Maurice Daigle (L'Écloserie Acadienne Ltd.)

CONTACT: Denise.Methe@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-14-03-001-eng.html

Eastern Oyster, *Crassostrea virginica*, Response to Environmental, Physiological, and Mechanical Stressors

In New Brunswick, oyster mortalities appear to be closely related to environmental factors (e.g., temperature, salinity, etc.) and husbandry (rearing) practices. The physiological health of the animal can determine how well it adapts to, and recovers from, exposure to potential stressors. This study investigated the relationship between oyster health and environmental changes to identify critical periods of physiological stress.

In 2013, the physiological health of oysters (phagocytosis, hemocyte viability, oxidative stress, lysosomal destabilization, condition index, tubule atrophy) from two culture sites in Richibucto estuary (Aldouane River, Indian Island) were evaluated monthly (10 oysters/site). Additional samples were taken during periods of expected stress (i.e., pre- and post-spawning, air drying). Air drying is a technique used by oyster growers to control fouling on culture gear and oysters.

Hemocyte mortality (8.4%) and lysosomal destabilization (40%) remained slightly above that reported in literature (5% and 30%, respectively). Phagocytic activity was normal, hovering around 20% with greater fluctuations at the Indian Island site. Oxidative stress was most apparent during summer months (June-Sept), as expected. Likewise, tubule atrophy indices were 5X higher during winter months (December–April) compared to the growing season (May–November).

Condition index remained above 30%, except in July–August (25%), due to spawning event—as confirmed through histology. Likewise, tubule atrophy was noticeably higher in pre-spawned individuals, indicative of no feeding activity. Interestingly, the other biomarkers showed no stress response to spawning. Finally, air drying was identified as a stressful event for oysters, but based solely on lysosomal destabilization. Lysosomal destabilization remains a sensitive biomarker of stress response in oysters.

Field monitoring established seasonal baseline levels for a number of physiological biomarkers of stress for oysters.

DATE: OCT. 2012–JUN. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: La Maison BeauSoleil Inc.

PROJECT LEAD: Daniel Bourque (DFO)

PROJECT TEAM: Denise Méthé, Janelle McLaughlin (DFO)

COLLABORATORS: Amédée Savoie (La Maison BeauSoleil Inc.)

CONTACT: Denise.Methe@dfo-mpo.gc.ca

WEBSITE: http://www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/index-eng.html

SHELLFISH: OTHER

Developing an Ecological Carrying Capacity for Shellfish Aquaculture in Baynes Sound, British Columbia

In British Columbia (BC), shellfish culture is located primarily on the west coast of Vancouver Island and the Strait of Georgia, with the most prolific production sites associated with Baynes Sound, Cortez Island, and Okeover Inlet. Although the culture of shellfish was developed over 100 years ago in BC, little research exists pertaining to the ecological capacity of shellfish production in these prolific, sheltered bays. Shellfish production is influenced by a balance of water quality, hydrodynamics (bay flushing), and food supply (plankton). A carrying capacity assessment is required to assess this balance and identify any bay-wide limitations due to a potential competition for resources or shift in ecosystem functioning. A high-resolution, spatially-explicit hydrodynamic-biogeochemical coupled model [e.g., Finite Volume Community Ocean Model (FVCOM)–Bivalve Culture Ecosystem Model] is being developed to assess the ecological carrying capacity of shellfish aquaculture in Baynes Sound. These mathematical models, groundtruthed with local data, will integrate the complex interactions among aquaculture activities, shellfish physiology, and the ecosystem.

DATE: OCT. 2011–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Terri Sutherland (DFO)

PROJECT TEAM: Peter Cranford, Chris Pearce, Hannah Stewart (DFO)

COLLABORATORS: BC Shellfish Growers Association; Mac's Oysters Ltd.; Hollie Wood Oysters Ltd.

CONTACT: Terri.Sutherland@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2011-P-21-eng.html

Juvenile oyster seed in culture trays in Baynes Sound, British Columbia. Photo: Terri Sutherland (DFO)

Understanding the Distribution of a Nemertean Predator, *Cerebratulus lacteus*, in Clam Flats: Implications for Control Measures

The results of this project will provide information to better understand the factors involved in the patchy distribution and abundance of *Cerebratulus lacteus*. This information will aid in the development of efficient management strategies to minimize the effect of this predator on clam populations.

Clams have been identified as an important alternate species for the future development of aquaculture in Atlantic Canada. One of the major obstacles in the development of clam culture has been controlling predators on culture sites, particularly endobenthic species (those that live in the sediment). In recent years, commercial size Quahaug and Soft-shell Clam densities have reportedly been lower. While the cause for these declines has not yet been documented, harvesters have noted the important presence of predatory worms at clam harvesting sites. The Milky Ribbon Worm, *C. lacteus*, is an important predator of many endobenthic bivalve species and its presence has been correlated to high field mortality in Soft-shell Clams. Very little, however, is known about the factors regulating the patchy distribution of this predator. The present study will examine the factors regulating the patchy distribution and abundance of *C. lacteus* to allow for the development of predator management strategies.

DATE: APR. 2014–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Innovation Fisheries Products Inc.; Mills Seafood Ltd.

PROJECT LEADS: Daniel Bourque, Angeline LeBlanc (DFO)

PROJECT TEAM: Jeffery Clements (DFO)

COLLABORATORS: Doug Bertram (Innovative Fisheries Products Inc.); Tim Williston (Mills Seafood Ltd.)

CONTACT: Daniel.Bourque@dfo-mpo.gc.ca, Angeline.LeBlanc@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-14-01-001-eng.html

Improving Ecological Models for a Sustainable Development of Bivalve Culture in Eutrophic Estuarine Complexes

Carrying capacity of coastal systems for bivalve culture has typically been investigated using mathematical models restricted to a Nutrient-Phytoplankton-Zooplankton-Detritus-Cultured Bivalve representation. The present project aims to generate a more detailed understanding of nutrient dynamics in order to accurately gauge the influence exerted by cultured bivalves. Specifically, macroalgae, a primary producer whose contribution can be significant, especially in eutrophic systems and wild bivalve population modules, will be coupled to an existing ecosystem carrying capacity model. These new ecophysiological modules will be built using the Dynamic Energy Budget theory to account for the use of resources by bivalves and macroalgae and also reproduce the effects of various aquaculture scenarios in terms of wild bivalve productivity. Model development will be supported by field and experimental work to characterize distribution, abundance, and growth for both macroalgae and wild bivalves. Model application will be performed for Malpeque Bay (Prince Edward Island); however, the model will be given a generic structure allowing future applications to other coastal embayments. Adding these new modules will increase model veracity and provide new insights into aquaculture-coastal ecosystem interactions, especially in quantifying the influence on species with commercial, recreational, and aboriginal fishery value.

Results of this project should further our understanding of interactions between bivalve aquaculture and coastal ecosystems.

The model developed will provide relevant information and a generic tool to improve the management of bivalve culture activities.

DATE: NOV. 2015–APR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Thomas Guyondet (DFO)

PROJECT TEAM: Luc Comeau, Romain Lavaud, Marc Ouellette (DFO)

COLLABORATORS: Ramón Filgueira (Dalhousie U); Cindy Crane (PEI Department of Communities, Land and Environment); Jeff Davidson (UPEI–AVC); Réjean Tremblay (UQAR–ISMER)

CONTACT: Thomas.Guyondet@dfo-mpo.gc.ca

The Effects of a Hydraulic Dredge and Adding Shells on the Environment and Soft-Shell Clam Population Dynamics

To improve the profitability of Soft-shell Clam farms in Atlantic Canada, growers want to use hydraulic dredging as a means of harvesting clams. The effects of dredging, however, are variable across sites. Concerns regarding mechanical clam harvesting include shell damage, impacts on recruitment and survival of juveniles, impacts on biodiversity, and the release of buried organic matter and reduced metabolites. In the presence of oxygen, this matter oxidizes, thereby lowering the pH, which can reduce growth and survival of bivalves.

Successful methods of increasing post-seeding survival rates, crucial to bivalve farming, have been demonstrated in U.S. east coast Quahog farming and Canadian west coast Manila Clam farming.

Several studies show that:

1) Hydraulic dredging enhances settlement and/or survival of bivalves–it will be important to understand the effects of mechanical harvesting on clams and the environment.
2) The presence of adults or shells increases recruitment of juvenile bivalves–thus, the addition of shells to the sediment may increase survival of juveniles.

Adding shells to the sediment acts as a buffer by raising the pH and the saturation states, and has been shown to increase Quahog and Soft-shell Clam recruitment. Results from this project (i.e., the addition of shells) may mitigate the potential negative effects of dredging.

The project seeks to compare the effects of hydraulic dredging and addition of shells to the sediment on the survival of juvenile Soft-shell Clams, and on the depth profile of physical and chemical parameters of the sediment (including grain size, sediment compaction, pH, carbonate/aragonite saturation states, and sulphides). In addition, this project will provide insights related to the potential environmental effects from shelling activity on surrounding areas (habitats) which are currently not well understood.

DATE: OCT. 2015–JUN. 2018
FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)
CO-FUNDED BY: Mills Seafood Ltd.
PROJECT LEAD: Angeline LeBlanc (DFO)
PROJECT TEAM: Jeffery Clements (DFO)
COLLABORATORS: Marilyn Clark (Mills Seafood Ltd.)
CONTACT: Angeline.LeBlanc@dfo-mpo.gc.ca
WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-2-G-02-eng.html

Bay Characterization for Nova Scotia Shellfish Aquaculture

In the Gulf Region waters of Nova Scotia, shellfish aquaculture remains in its early stages of development. A recent report based on an independent aquaculture regulatory review concluded, among other things, that licencing decisions needed to consider compatibility between aquaculture and other uses of coastal waters. Balance between sustainable development of shellfish aquaculture, fisheries, and other resource uses (e.g., harbours, marinas, cottages, etc.) can be achieved through marine spatial planning and the implementation of a bay management plan designed to protect valued species in fisheries and conservations areas, while avoiding conflicts with other users of the marine resource. Although Nova Scotia has not yet developed such a plan, describing and mapping of coastal areas identified for aquaculture would provide critical information for planning and science-based decisions making, and could provide the basis for a bay-scale management plan.

Fisheries and Oceans Canada (DFO) has identified a number of bays in Nova Scotia where future aquaculture development may be likely. Key variables including hydrodynamic characteristics, fisheries, and ecologically sensitive species' habitat and distribution, as well as aquaculture-specific activities and mitigation options will be described for these bays. The results from this project will support departmental regulatory decisions that are consistent with the ecosystem-based approach to managing the shellfish aquaculture industry.

DATE: APR. 2015–MAR. 2018
FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)
PROJECT LEAD: Monique Niles (DFO)
PROJECT TEAM: Marc Ouellette, Thomas Guyondet, Thomas Landry (DFO); Andrew Bagnall (NSDFA); Tim Webster, Kate Collins (AGRG–NSCC)
CONTACT: Monique.Niles@dfo-mpo.gc.ca
WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-G-08-eng.html

The Ecological Effects of Clam Harvesting by Mechanical Means in St. Mary's Bay, Nova Scotia

The clam aquaculture industry has experienced major challenges recruiting and retaining clam diggers, and the disinterest from the younger employable generation has resulted in an aging employee-base. Traditional hand harvesting is not considered to be socially nor economically sustainable due to being very labour-intensive, involving the manual use of a clam hake with tines that measure 15 cm in length to dig up and turn over the sediment. There is interest in using mechanical clam harvesters to complement hand harvesting of quahogs (*Mercenaria mercenaria*) in St. Mary's Bay, Nova Scotia.

This study compared the ecological effects of manual digging versus a mechanical clam harvester. It investigated the effects of both techniques on the ecological health and production of the area by monitoring the clam population, associated fauna and flora, and various physical and chemical parameters. Methods for mitigating the ecological impact of harvesting, such as replanting pre-recruits on size-class plots and reducing repeated harvesting efforts, were also investigated. Specifically, the following results were found: 1) no difference was found in physical or chemical characteristics of the sediment between non-harvested, manually, or mechanically harvested plots; 2) no differences were found before and after harvesting; and 3) both harvesting techniques either have no impact on the sediment and on faunal assemblages, or that recovery is rapid.

Neither harvesting technique was better or worse than the other regarding its effects on sediment characteristics. While manual digging is possible in any sediment type, the prototype harvester used in this project was better suited for firm sandy bottoms and some mud, but did not perform very well in soft mud. It will need to be improved to be commercially useful.

DATE: APR. 2012–JUN. 2015
FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)
CO-FUNDED BY: Innovative Fisheries Products Inc.
PROJECT LEAD: Thomas Landry (DFO)
PROJECT TEAM: Angeline LeBlanc (DFO)
COLLABORATORS: Doug Bertram (Innovative Fisheries Products Inc.)
CONTACT: Thomas.Landry@dfo-mpo.gc.ca
WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/G-12-01-001-eng.html

Microplastics and Shellfish Aquaculture: Investigating Presence, Extent, and Potential Impacts and Mitigation Measures

Microplastics (i.e., plastics < 5 mm) are an emerging contaminant of increasing concern to industry, scientists, and the general public. Microplastics are ubiquitous in the marine environment and come from a wide range of sources including sewage effluent and general degradation of larger plastics. There are several types of microplastics such as microbeads, fibres, and fragments which are ingested by a wide range of organisms. Ingestion of microplastics can have negative physical and chemical impacts on the organisms that consume them. Because of this, the aquaculture industry has the potential to be negatively affected by microplastic pollution. Conversely, because of the use of plastics in the aquaculture industry there is also the potential to contribute to microplastic pollution. To address these issues, we are conducting a collaborative study with VIU, DFO, BCSGA, Vancouver Aquarium, and UVic. This research will: 1) determine the concentration of microplastics in clams and oysters cultured in coastal British Columbia; 2) determine the concentration of microplastics in the surrounding environment; 3) characterize the type of microplastics found and identify potential sources; 4) evaluate depuration as a potential mechanism to eliminate microplastics; and 5) investigate the impact of microplastics on shellfish health and resilience.

This research will show the level of microplastic pollution within commercial shellfish and their surrounding environment. It will also indicate the efficacy of depuration to remove this contaminant, the implications of microplastic ingestion on shellfish health, and potential microplastic sources.

DATE: JUL. 2016–MAR. 2018

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: BC Shellfish Grower's Association (BCSGA)

PROJECT LEADS: Sarah Dudas (VIU); Helen Gurney-Smith, Chris Pearce (DFO)

PROJECT TEAM: Chris Pearce (DFO); Peter Ross (Vancouver Aquarium); Garth Covernton, Maggie Dietterle, Matt Miller, Kayla Balmer, Monique Raap (VIU)

COLLABORATORS: Darlene Winterburn (BCSGA); Yves Perreault (Little Wing Oysters); Andre Comeau, Chris Roberts (Okeover Organic Oysters); Dave Ritchie, Steve Pocock (Sawmill Bay Shellfish); Brian Yip (Taylor Shellfish); Keith Reid (Stellar Bay Shellfish); Andrew Dryden (Evening Cove Oysters); Pete McLellan (Nanoose Bay Oysters)

CONTACT: Sarah.Dudas@viu.ca; Helen.Gurney-Smith@dfo-mpo.gc.ca; Chris.Pearce@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-P-01-eng.html, http://www.ecologicalinteractions.com/

Oyster up close. Photo: Kayla Mohns (DFO)

Netting. Photo: Kayla Mohns (DFO)

The Effect of Cultured Shellfish on Eelgrass Productivity in Estuaries of New Brunswick

Canada's *Oceans Act* promotes an ecosystem-based approach in managing human activities in coastal and marine environments. As such, enhanced protection should be provided to species, such as eelgrass (*Zostera marina*), and community properties that are particularly significant to maintaining ecosystem structure and function, while allowing sustainable activities to be pursued. One of the human activities considered is shellfish aquaculture, an increasingly important economic driver in coastal communities. Recent studies have documented some negative effects on eelgrass from oyster aquaculture, in some areas and at a local scale, mostly linked with shading effects from aquaculture gear. However, another important aspect to also consider in the overall risk characterization is the potential off-setting effects from the cultured bivalve biomass, as filter feeders, on eelgrass productivity by influencing turbidity patterns of natural and cumulative anthropogenic sources.

This study is investigating the effects of cultured shellfish on eelgrass productivity at the bay scale. This will be achieved through field studies that describe the seascapes of study bays, with a focus on the distribution of shellfish populations (wild and cultured) and eelgrass beds, using novel remote sensing tools and strategies, and turbidity patterns of the water column. A laboratory study will evaluate the resulting effects of oyster filtration on turbidity (water clarity) and light attenuation. Finally, bay scale hydrodynamic computer models will be developed for two study bays to include a turbidity module and clearing coefficients of cultured oysters, allowing for improved assessments of bay-scale effects from existing (or proposed) shellfish leases on eelgrass productivity.

DATE: APR. 2014–MAR. 2018

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Marc Ouellette (DFO)

PROJECT TEAM: Monique Niles, Thomas Guyondet, Michael Coffin (DFO)

COLLABORATORS: Tim Webster, Kate Collins (AGRG–NSCC)

CONTACT: Marc.Ouellette@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-G-10-eng.html

MISCELLANEOUS

Integrating Individual Bioenergetics into Aquaculture Management

Science-Industry Partnership Leading to a Better Understanding of Ocean Acidification in British Columbia, Canada

Algae-Based Ingredients for Aquaculture Feeds in Canada

Development of a Brown Alga *Chorda filum* Culture Method

Assessing the Efficiency of a Macroalgae Biofilter in Regulating Nitrate and Phosphate Concentrations in Tanks at the Montreal Biodome Mimicking the Gulf of St. Lawrence Ecosystem

Biotic and Abiotic Determinants Influencing Winter Flounder Feeding Behaviour and Larval Growth

Lumpfish and Atlantic Halibut Aquaculture Operations Optimization

Physiology of Triploid Fish

Antifouling Control: Development of Non-Biocidal Techniques for Mariculture

Engineering Project in Support of the Fishing and Aquaculture Industry

Service *Viviers-Conseils*: Innovation Service in Support of the Lobster Industry

Identification of Growth Stanzas and the Modification of the Body Weight Exponent in the Thermal-Unit Growth Coefficient (TGC) Model for Nile Tilapia (*Oreochromis niloticus*)

The Feasibility of Using Bacterial Community Profiling with Next-Generation DNA Sequencing to Assess Temporal and Spatial Environmental Disturbances

Metagenomic Approach to the Characterization of Microflora in Aquaculture Effluents that Induce Phytoprotection and Growth Promotion of Aquaponic and Hydroponic Plants

NSERC-Cooke Industrial Research Chair in Sustainable Aquaculture

Evaluation of Different Biomasses for a Pilot Project to Breed Fly Larvae, an Alternative Source of Protein and Lipids in Animal Feed

The Development of an FVCOM Hydrodynamic Model to Support Aquaculture on the West Coast of Vancouver Island

Fish Farm Site-to-Site Connectivity Using GPS Tracked Surface Drifters and FVCOM-Based Particle Tracking Model

Contribution to the Identification of a Locally Available Food Source for Sustainable Tilapia (*Oreochromis niloticus*) Production in the Democratic Republic of Congo

Benthic Culture of Sea Cucumbers: Assessing Interactions Between Cultured and Wild Populations and the Mitigation of Environmental Impacts in Shellfish Co-Culture

Optimization of Fly Co-Product Processing Methods for Repurposing Organic Waste in Quebec

Comparative Genomics of the Salmonid Brook Charr for Identifying Physiological/Expression QTL and Conserved Gene Regulatory Networks

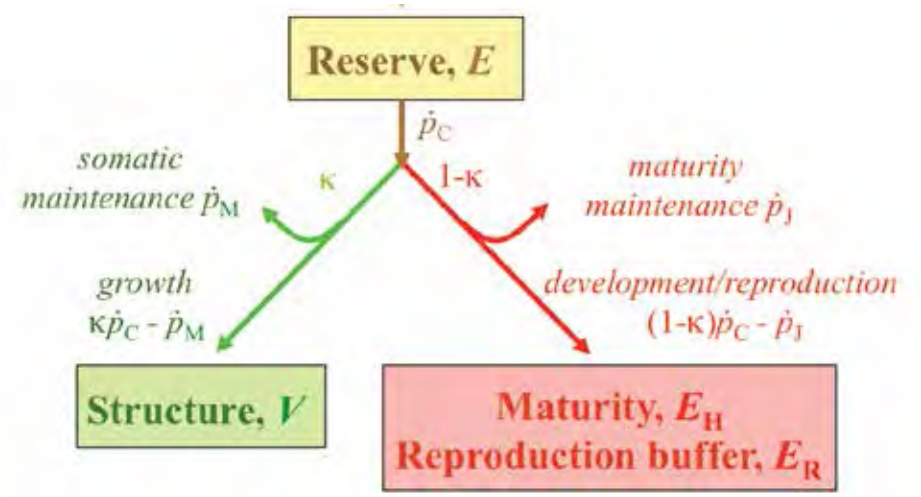
Establishing Zones for Managing Risks Related to Pathogens and/or Pollutants Originating on Finfish Aquaculture Facilities in the Broughton Archipelago and Discovery Islands

Development of Environmental DNA (eDNA)-Based Biosurveillance for Aquatic Invasive Species (AIS) to Inform Management and Policy Decision-Making Associated with Shellfish Aquaculture Movements

Assimilation Capacity of Organic Matter from Salmon Aquaculture (ACOM): Improving Model Predictions of Benthic Impacts

Evaluation of Genetic Structuring of California Sea Cucumber (*Parastichopus californicus*) Across Transfer Zones in British Columbia

Integrating Individual Bioenergetics into Aquaculture Management



Standard Dynamic Energy Budget (DEB) model scheme (Modified from Kooijman 2010).

Understanding individual bioenergetics is critical for assessing how environmental drivers (e.g., temperature, food availability, oxygen, currents, etc.) affect the performance of cultured species. Dynamic Energy Budget (DEB) has become the most cutting-edge theory on the organization of metabolism of individual organisms. The mechanistic nature of DEB allows its application to the full range of environmental conditions, which is vital to quantify the role of cultured species in ecosystem functioning and predict their responses to anthropogenic changes and/or changes in climate. Despite the individual-based approach of DEB, the most recent ecosystem models rely on DEB theory to simulate individual bioenergetics and extrapolate the results to the ecosystem level.

This research program focuses on individual bioenergetics of cultured species, ranging from Atlantic Salmon to mussels and oysters, as well as invasive tunicates that are relevant to the management of aquaculture sites. State-of-the-art technology, such as acoustic tags and laser particle counters, will be key for the success of the program. In this program we will explore the effects of extrinsic drivers such as diseases, parasites, temperature, and food availability, as well as intrinsic factors such as the internal state of the organism. Moreover, the resulting refined and state-of-the-art individual models will be coupled to larger scale models to contextualize aquaculture at the ecosystem level with the ultimate goal of adopting an ecosystem-based management approach.

This research program will generate fundamental scientific knowledge that will: 1) inform industry on key processes of individual behaviour and bioenergetics; and 2) assist policy makers and managers in dealing with current and future issues such as invasive species and aquaculture management.

DATE: MAR. 2016–MAR. 2021

FUNDED BY: Cooke Aquaculture Inc.

CO-FUNDED BY: Dalhousie University

PROJECT LEAD: Ramón Filgueira (Dalhousie U)

COLLABORATORS: Luc Comeau, Peter Cranford, Thomas Guyondet (DFO); Jon Grant (Dalhousie U); Cooke Aquaculture Inc.; Vemco

CONTACT: ramon.filgueira@dal.ca

Science-Industry Partnership Leading to a Better Understanding of Ocean Acidification in British Columbia, Canada

The goal of this study is to investigate the spatial and temporal variability of Ocean Acidification (OA) parameters at two sites in the northern Salish Sea; one being a continuous monitoring system at a research station and the other being a partnering local shellfish producer's farm site. Increased anthropogenic carbon dioxide (CO_2) uptake by the surface ocean is driving a reduction in oceanic pH. This acidification alters the carbonate chemistry of the seawater, decreasing the saturation state of carbonate minerals essential to shell-forming organisms. Consequently, OA will have major implications for the shellfish aquaculture industry in the long-term. Currently, key information is lacking for coastal settings, hindering identification of near-term effects. It is critical to monitor coastal areas to determine the current status and plan mitigation strategies for the impact of increasing OA on the shellfish industry.

In this study, weekly OA samples were collected at the farm site and compared them with the high resolution data collected at the research station. Preliminary analyses reveal two important features: 1) OA signals are coherent across both sites, suggesting that they are influenced by similar processes and that broadcast high resolution data available on a public web portal (Global Ocean Acidification Observing Network data portal: http://portal.goa-on.org/Explorer?action=oiw:fixed_platform:HAKAI_Quadra1) is an important diagnostic for the industry partner; and 2) the OA data fluctuated across a large range between sampling events at the farm site indicating the importance of short time scale variability in setting conditions.

The information produced in this study demonstrates the critical importance of science-industry partnerships for filling the extensive OA data gap present in coastal settings. Ultimately the information garnered by studies like this will aid in the development of adaptation strategies for the regional impacts of this significant global problem.

DATE: MAY 2016–ONGOING

FUNDED BY: Hakai Institute

PROJECT LEAD: Wiley Evans (Hakai Institute)

PROJECT TEAM: Katie Pocock, Alex Hare (Hakai Institute)

COLLABORATORS: Sawmill Bay Shellfish Co.

CONTACT: Wiley.Evans@hakai.org

WEBSITE: www.hakai.org

Stephen Pocock (Sawmill Bay Shellfish) collects a discrete seawater sample at his aquaculture site on Read Island, BC. Photo: Wiley Evans (Hakai Institute)

Algae-Based Ingredients for Aquaculture Feeds in Canada

Conventional aquaculture feed resources are becoming increasingly costly and ecologically unsustainable. In an effort to develop more sustainable feeds based on 'lower-trophic' ingredients, certain algae have been proposed as promising candidates based on their perceived supply of well-balanced amino acids, essential fatty acids, and bioactive compounds. However, despite this encouraging trend, many of the nutritional claims for aquaculture feeds are unsubstantiated because their required biochemical profiles, digestibility data, and effects on animal performance are either inadequate or non-existent. Take for example *Chlorella* spp., which is one of the most highly studied microalgae for industrial applications. While these algae have been proposed for large-scale cultivation for bioremediation, renewable energies, health food supplements, and sustainable animal feeds, there has never been an adequate strategic assessment of their nutritional quality as feed ingredients for Atlantic Salmon; the most widely farmed fish in Canada. This is the case for virtually all algal species presently considered for industrial mass algaculture.

At the National Research Council of Canada and in partnership with industry and academia, a major focus is to evaluate the potential for algal products and co-products for use in aquaculture feeds as a means to valorize the algal crop produced as a result of industrial CO_2 conversion. To do this, we use a suite of existing and emerging technologies such as, photobioreactor algal cultivation and harvesting, chemical and biochemical profiling, *in vitro* digestibility, biomass processing and feed production technologies, and *in vivo* biological performance evaluation with target species.

In addition to valorization of the algal crop resulting from industrial CO_2 conversion, we expect that this applied, industrially-relevant research will also help to provide essential nutritional data for national regulatory approval and industry adoption of novel dietary ingredients of algal origin in Canada. To date, we have generated biochemical profiles and digestibility data (*in vitro* and *in vivo*) for 13 microalgae species and 9 seaweed species.

DATE: SEP. 2013–MAR. 2017

FUNDED BY: NRC–National Bioproducts Program (NBP); NRC–Algal Carbon Conversion (ACC) Program

PROJECT LEAD: Sean Tibbetts (NRC)

PROJECT TEAM: Patrick McGinn, Stephen O'Leary (NRC)

COLLABORATORS: André Dumas (CATC); Daniel Lemos (University of São Paulo); Jason Mann (EWOS; Cargill Canada)

CONTACT: Sean.Tibbetts@nrc-cnrc.gc.ca

WEBSITE: http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/algal_index.html

NRC Technical Officer, Jenny MacPherson, poses with NRC-developed "Brite-Box" photobioreactors (>10,000 L production capacity).
Photo: Scott MacQuarrie (NRC)

Example of chlorophytic microalgal biomass for nutritional evaluation as a potential novel ingredient for aquaculture feeds. Photo: NRC

Development of a Brown Alga *Chorda filum* Culture Method

Magdalen Islands mussel farming companies want to diversify their marine lagoon production and are interested in growing macroalgae. *Chorda filum*, a fast growing brown alga that occurs naturally in the lagoons of the region, could be a good candidate since there are markets for this edible alga. The general purpose of the project was to develop an understanding of the steps involved in growing *C. filum*, i.e., cultivating gametophytes *in vitro*, growing sporophytes on ropes, in tanks, and growing sporophytes on a sea farm in lagoons. The project was also designed to establish the nutritional and sensory profile of this alga. Fertile fronds were harvested in September. Two types of lights (white and red) and three temperatures (5, 10, and 15°C) were tested for growing gametophytes. Vegetative growth of *in vitro* gametophytes appeared to be optimal at 10°C in white light. Two methods were used to grow sporophytes on ropes: by directly seeding the ropes with spores and by spraying gametophytes on kuralon ropes. In both cases, sporophytes were produced by keeping cultures at 10°C in white light and gradually reducing the water temperature to 5°C. In tanks, the average growth of the fronds was 1.3 cm/day and the largest fronds reached 191 cm. Undesirable opportunistic macrophytes such as *Ulva* sp. were always present in the cultures despite the fact that the fertile fronds of *C. filum* had been disinfected prior to sporulation.

The project diversified the portfolio of cultivable edible macroalgae species with a summer tubular species distinct from leaf kelp.

DATE: SEP. 2014–OCT. 2016

FUNDED BY: Ministère de l'éducation et de l'enseignement supérieur du Québec (MÉES) [Québec Ministry of Higher Education and Training]

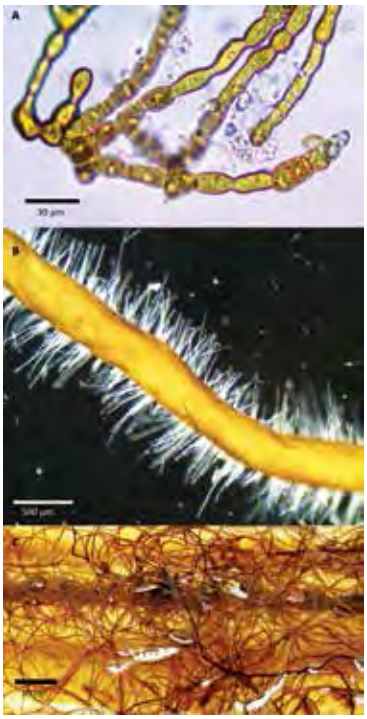
PROJECT LEAD: Lisandre Gilmore-Solomon (Merinov)

PROJECT TEAM: Isabelle Gendron-Lemieux, Karine Berger, Éric Tamigneaux (Merinov)

COLLABORATORS: Michel Fournier (Les moules de culture des Îles inc.)

CONTACT: Isabelle.Gendron-Lemieux@merinov.ca

WEBSITE: http://alguequebec.org/



A. Female *Chorda filum* with a developing sporophyte embryo; B. Young *C. filum* sporophyte; C. *C. filum* sporophytes on culture ropes in a tank.
Photo: Isabelle Gendron-Lemieux (Merinov)

Assessing the Efficiency of a Macroalgae Biofilter in Regulating Nitrate and Phosphate Concentrations in Tanks at the Montreal Biodome Mimicking the Gulf of St. Lawrence Ecosystem

To improve the quality of recycled water in the exhibition's tanks housing the Montreal Biodome live collections, it is necessary to search for a complementary method for controlling nitrate and phosphate build-up simultaneously. In excessive concentrations, these nutrients can become an important source of stress for aquatic organisms. Based on integrated multi-trophic aquaculture systems, we wish to design a macroalgae biofilter adapted to absorb nitrates and phosphates under conditions similar to those of the Montreal Biodome's marine ecosystem.

The performance of native species, *Ulva lactuca* and *Palmaria palmata*, were assessed for six days at École des Pêches et de l'Aquaculture du Québec (EPAQ) in Grande-Rivière. The average daily nitrate absorption rate for *P. palmata* was found to be 0.65 mg·N·g MS^{-1} versus 1.76 mg·N·g MS^{-1} for *U. lactuca*. The average daily phosphate absorption rates for *P. palmata* were 0.14 mg·P·g MS^{-1} versus 0.32 mg·P·g MS^{-1} for *U. lactuca*. Seven to 12% of nitrates and four to 24% of phosphates were removed by *P. palmata* while *U. lactuca* removed eight to 18% of nitrates and five to 24% of phosphates.

After the *P. palmata* culture was introduced at the Montreal Biodome, other trials led to an improvement in biofiltration performance. In addition, the excess biomass is used to fertilize the exhibition tanks.

This research project has improved the water quality of the Montreal Biodome exhibition tanks, and led to the enrichment of exhibition tank by providing natural shelter and food for aquatic animals.

DATE: JAN. 2014–APR. 2017

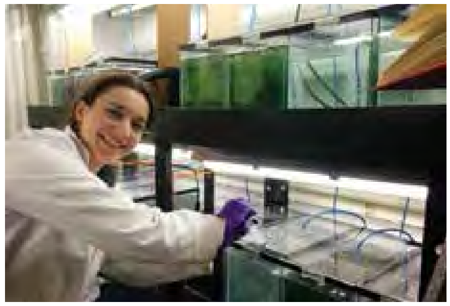
FUNDED BY: MITACS; Société des amis du Biodôme de Montréal (SABM); Natural Sciences and Engineering Research Council of Canada (NSERC)–Industrial Research Chair

CO-FUNDED BY: Fonds d'amorçage UQAR; Mérinov Inc.; Ressources Aquatiques Québec (RAQ)

PROJECT LEAD: Nathalie Le François (Montreal Biodome; U Laval)

PROJECT TEAM: Anne Tremblay-Gratton (U Laval); Grant Vandenberg (U Laval); Éric Tamigneaux (EPAQ)

CONTACT: nle_francois@ville.montreal.qc.ca



Anne Tremblay-Gratton in plant science room (EPAQ). Photo: Nathalie Le François (Biodome de Montréal)

Seaweed culture aquarium for the master's project in the plant science room (EPAQ). Photo: Anne Tremblay-Gratton (U Laval)

Ulva lactuca (EPAQ). Photo: Anne Tremblay-Gratton (U Laval)

Palmaria palmata. Biodome de Montréal. Photo: Anne Tremblay-Gratton (U Laval)

Palmaria palmata. Biodome de Montréal. Photo: Anne Tremblay-Gratton (U Laval)

Palmaria palmata. Biodome de Montréal. Photo: Anne Tremblay-Gratton (U Laval)

Palmaria palmata. Biodome de Montréal. Photo: Anne Tremblay-Gratton (U Laval)

Palmaria palmata. Biodome de Montréal. Photo: Anne Tremblay-Gratton (U Laval)

Biotic and Abiotic Determinants Influencing Winter Flounder Feeding Behaviour and Larval Growth

Winter Flounder (*Pseudopleuronectes americanus*) is a fish species that occurs off the east coast of North America. This species is of great interest for temperate aquaculture and recreational fishing, which requires seed production in order sustain stocks in coastal habitats. However, development of aquaculture production is limited by high mortalities in the initial benthic phase. Feed quality plays an important role in limiting these mortalities. The purpose of this project is to verify the nutritional quality (in terms of fatty acids) of copepod nauplii as alternative live prey and compare it with traditional aquaculture feed (rotifers). In addition, flounder use shallow habitats where significant human activities occur. Another objective of the project is to assess whether boat noise affects feeding behaviour in this species, particularly during the larval period, while individuals are still pelagic. Such information could assist in the selection of seeding areas.

This study defines the impact of biotic parameters such as prey quality on Winter Flounder larval growth and the impact of anthropogenic noise on this species' feeding behaviour.

DATE: APR. 2015–MAR. 2018

FUNDED BY: Fonds de Recherche du Québec en Nature et Technologies (FRQNT) team research project

PROJECT LEAD: Réjean Tremblay (UQAR-ISMER)

PROJECT TEAM: Gilberte Gendron, Maria Martínez-Silva, Céline Audet, Gesche Winkler (UQAR-ISMER)

COLLABORATORS: Aurélie Jolivet (CNRS Research Unit 6539; TBM environnement); Fréderic Olivier (BOREA Research Unit 7208; CNRS; MNHN; UPMC; IRD)

CONTACT: Rejean.Tremblay@uqar.ca

Lumpfish and Atlantic Halibut Aquaculture Operations Optimization

Farming Atlantic Halibut (*Hippoglossus hippoglossus*) and Lumpfish (*Cyclopterus lumpus*) represents an opportunity for Quebec's aquaculture industry to diversify its activities and markets with native species that tolerate captivity well. The project aims to improve the survival rate of these two marine fish species.

For Atlantic Halibut, the project focuses on the period between egg incubation and juvenile rearing because proficiency in larval rearing of flatfish is a critical step influencing performance in subsequent stages of the development cycle.

As lumpfish is a new farmed species, the project covers all stages of its life cycle.

A method has been developed to breed Lumpfish. From the first cohort of farmed Lumpfish, Merinov performed breeding trials from the larval stage to sexual maturity. The organization is now producing 3rd generation farmed larvae. Current trials are designed to optimize the various stages of production. The 4th generation should be produced in winter.

Merinov trials have produced halibut eggs and larvae. To date, it has been impossible to maintain larvae beyond metamorphosis. Further trials are scheduled for January 2017.

The project has contributed to the advancement of marine fish culture and the training of highly qualified staff.

DATE: JUN. 2014–JUN. 2017

FUNDED BY: Fonds de Recherche du Québec en Nature et Technologies (FRQNT)

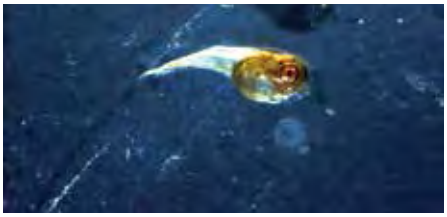
PROJECT LEAD: Marie-Hélène Fournier (Merinov; CÉGEP de la Gaspésie des et Îles)

PROJECT TEAM: Tony Grenier (Merinov)

CONTACT: mhfournier@cegepgim.ca

WEBSITE: www.merinov.ca

Lumpfish spawners. Photo: Marie-Hélène Fournier (Merinov; CÉGEP de la Gaspésie des et Îles)



A Lumpfish larva. Photo: Marie-Hélène Fournier (Merinov; CÉGEP de la Gaspésie des et Îles)

Physiology of Triploid Fish

Triploidy is the only management tool currently available for ensuring reproductive sterility of farmed fish. Sterile populations can be of direct benefit to industry since sexually mature fish often have reduced flesh quality and disease resistance. Sterility also addresses the risk of escaped fish breeding in the wild. However, triploids are rarely used in aquaculture because of performance limitations. We are investigating the effects of triploidy on key physiological processes to determine whether changes in cell size and number, associated with triploidy, affect the ability of these animals to withstand chronic stress. Our research currently focuses on red blood cell structure and function, aerobic capacity, bioenergetics, and environmental tolerances (high temperature and hypoxia). We have adopted zebrafish as a model species for some of this research because of the availability of stocks with fluorescent cells that are ideal biomarkers for cell location and function. Additional research is being done with Brook Charr, as a model salmonid that is easy to keep in our small-scale aquatic facility at the University of New Brunswick (UNB) campus. Research results will be translated to Atlantic Salmon through industry partnerships.

Understanding the physiological limitations of triploidy will allow for improvements in their culture protocols for commercial production. This will benefit the aquaculture industry in two ways: by eliminating early maturation of production fish and by ensuring that escaped fish cannot breed in the wild.

DATE: ONGOING

FUNDED BY: NSERC–Discovery Grants Program

CO-FUNDED BY: New Brunswick Innovation Foundation (NBIF)–Research Assistantships Initiative

PROJECT LEAD: Tillmann Benfey (UNB)

PROJECT TEAM: Chris Small, Nicole Nader, Krista Latimer, Tillmann Benfey (UNB)

CONTACT: benfey@unb.ca

WEBSITE: www2.unb.ca/biology/Faculty/Benfey.html

Adult male Brook Charr in a swim flume used for measuring oxygen uptake at various temperatures. Photo: Krista Latimer (UNB)

Antifouling Control: Development of Non-Biocidal Techniques for Mariculture

Increased proliferation of biofouling (amalgam of algae, bivalves, crustaceans, or other invertebrates) on breeding structures and organisms is a major challenge for sea farmers, particularly oyster and scallop farmers. In the Magdalen Islands, this problem is amplified by the proliferation of invasive aquatic species: Golden Star Tunicate (*Botryllus schlosseri*) and Violet Tunicate (*Botrylloides violaceus*). This colonization is having a significant economic impact on the industry: additional costs for maintaining and cleaning structures, premature structural degradation, deterioration in the quality of breeding stock organisms, etc.

Current techniques used to attenuate the impact of biofouling are often very inefficient. In response to a growing phenomenon catalyzed by climate change, producers must identify new, more efficient processes, without risk to farmed organisms and consumers. This is why Merinov is working on this project to improve management of mariculture structures and survival of the breeding organisms, oysters, and scallops. The techniques tested are non-biocidal antifouling paints and natural competitors such as Periwinkle (*Littorina littorea*) and Hermit Crab (*Pagurus spp.*). Tests are performed in a natural and a controlled environment to compare the anti-fouling effectiveness of these treatments under different conditions.

This project provides an opportunity to test several innovative techniques to stop or reduce the development of biofouling on stock structures. In the long term, these advances will make companies more cost-effective and competitive. They may also provide benefits for other marine industries.

DATE: SEP. 2016–MAR. 2017

FUNDED BY: DFO–Partnership Fund

CO-FUNDED BY: Merinov

PROJECT LEAD: Madeleine Nadeau (Merinov)

PROJECT TEAM: Nicolas Toupoint (Merinov)

COLLABORATORS: Nathalie Simard (DFO); Biomer consortium

CONTACT: Nicolas.Toupoint@merinov.ca

WEBSITE: www.merinov.ca

Control structure, no treatment. Photo: Merinov

Structure which received an antifouling coating treatment. Photo: Merinov

Engineering Project in Support of the Fishing and Aquaculture Industry

In order to be as efficient as possible and remain competitive, marine aquaculture companies need to meet significant adaptation or technological development needs. Merinov's engineering team provides various services such as computer-assisted design, 3D modelling, and system and process optimization.

Among one if its many accomplishments, Merinov modified an outdoor mussel spat collector by adding a rotating drum with a hydraulic motor. This change significantly reduced labour costs. A job that once required three employees now requires two.

At a mussel farmer's request, Merinov also designed a mussel spat collection system for conventional collectors. The collection system was modelled. The mussel stripping system was modified to improve worker ergonomics and reduce physical effort. This work greatly reduces travel time during operations. Mechanizing this work sped up operations and provided a significant increase in performance.

Many other initiatives by the Merinov engineering team have helped marine aquaculture companies in the Gaspé, Magdalen Islands, and North Shore areas optimize their farming methods.

From time to time, Merinov engineering projects also cover some fishing industry needs. For example, a recently developed underwater camera housing is now used to produce images of crab movement near a cage for 20 to 24 hours.

Thanks to the new equipment and technologies installed in company facilities, sea farmers will become more cost-effective.

DATE: APR. 2015–MAR. 2017

FUNDED BY: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ); Ministère du Développement Économique, de l'Innovation et Exportation du Québec (MDEIE)

PROJECT LEAD: Lise Chevarie (Merinov)

PROJECT TEAM: Lise Chevarie, Daniel Leblanc, Hubert Murray (Merinov)

COLLABORATORS: Private companies

CONTACT: Lise.Chevarie@merinov.ca

WEBSITE: www.merinov.ca

System for mussel sock dismantlement. Video: Merinov

Mussel spat collector. Photo: Daniel Leblanc (Merinov)

Design drawings of a rotating drum with a hydraulic motor. Photo: Daniel Leblanc (Merinov)

Service *Viviers-Conseils*: Innovation Service in Support of the Lobster Industry

In recent years, lobster landings have increased. Since the fishing season is open for only about 10 weeks, lobster marketing companies have to process and market large volumes in a very short time. During this time, various issues arise: labour shortages, insufficient storage capacity, reduced ability to obtain better prices from buyers, quality management issues, etc.

Service *Viviers-conseils*, created by Merinov–Centre collégial de transfert de technologie des pêches du CÉGEP de la Gaspésie et des Îles, is addressing this industry problem by helping companies innovate in order to optimize their systems and containment conditions.

It is necessary to innovate in this field since 60% of Quebec lobster is marketed live. For instance, producers can consult Merinov to diagnose mechanical and biological parameters, set up new tanks, and monitor lobster quality status prior to marketing. In, they also offer support for setting up an automation system, implementing research and development projects, and custom training.

Service *Viviers-conseils* promotes the marketing of very high quality lobster, several months after the fishing season. It makes companies more productive and competitive by increasing their containment capacity, providing superior product quality, and modernizing their equipment.

DATE: APR. 2016–MAR. 2021

FUNDED BY: Natural Sciences and Engineering Research Council of Canada (NSERC)

CO-FUNDED BY: Emploi Québec; Private Sector

PROJECT LEAD: Jean-François Laplante (Merinov)

PROJECT TEAM: Marie-Claude Côté-Laurin, Francis Coulombe, Madeleine Nadeau (Merinov);Marie-Hélène Bénard, Lisandre Solomon-Gilmore (Merinov; CÉGEP de la Gaspésie et des Îles); Marie-Hélène Fournier (EPAQ); Jacinthe Bourgeois (Cégep de la Gaspésie et des Îles)

COLLABORATORS: Private Sector

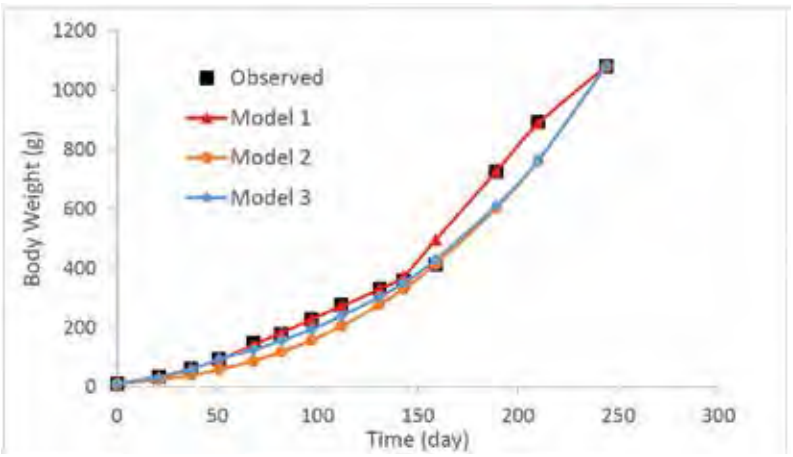
CONTACT: Jean-François.Laplante@merinov.ca

WEBSITE: www.merinov.ca

Hemolymph sampling for blood protein analysis to verify lobster quality. Photo: Jean-François Laplante (Merinov)

Extended lobster containment. Photo: Jean-François Laplante (Merinov)

Identification of Growth Stanzas and the Modification of the Body Weight Exponent in the Thermal-Unit Growth Coefficient (TGC) Model for Nile Tilapia (*Oreochromis niloticus*)



Resulting growth trajectories from Model 1, 2, and 3 compared to observed sampled body weight values from one production lot of Nile Tilapia. Photo: Christopher Powell (U Guelph)

The ability to predict growth of aquaculture species has improved with the adoption of the thermal-unit growth coefficient (TGC) model. However, the TGC model does not account for changes in growth patterns across life stages by assuming a constant body weight exponent (b=1/3). The objective of this study is to improve the predicative ability of the TGC growth model through the identification of growth stanzas and modification of the body weight exponent in Nile Tilapia (*Oreochromis niloticus*).

Growth data were collected from commercial tilapia culture operations (329 observations); growth rates were calculated using the TGC model and regressed against body weights. Three growth stanzas, representing changes in growth patterns across life stages, were identified using spline and broken-line analysis. A non-linear model was applied to growth data and body weight exponents iteratively solved for in each identified growth stanza. Analysis resulted in a modified TGC model with body weight exponents (b) of 0.405, 0.798, and 0.956 in each growth stanza. The modified TGC model (Model 1) was compared to the traditional TGC growth model (Model 2), and the TGC model (b=1/3) modified to include three growth stanzas (Model 3). Goodness-of-fit statistics (R2, CCC, RSS, etc.) and model selection criteria (AIC) determined Model 1 was superior to Model 3; Models 1 & 3 were superior to Model 2. The inclusion of growth stanzas improved the fit of the TGC model, with modification of the body weight exponent further improving the fit, resulted in a more realistic and biologically sound growth model.

Growth functions are integral in farm production management, current growth functions used in aquaculture overlook the potential of difference in growth pattern (stanzas) during the production cycle. The proposed model incorporates growth stanzas, and differing body weight exponents in each growth stanza, in an effort to better represent growth at any given life stage of a fish.

DATE: SEP. 2015–ONGOING

FUNDED BY: MITACS Canada

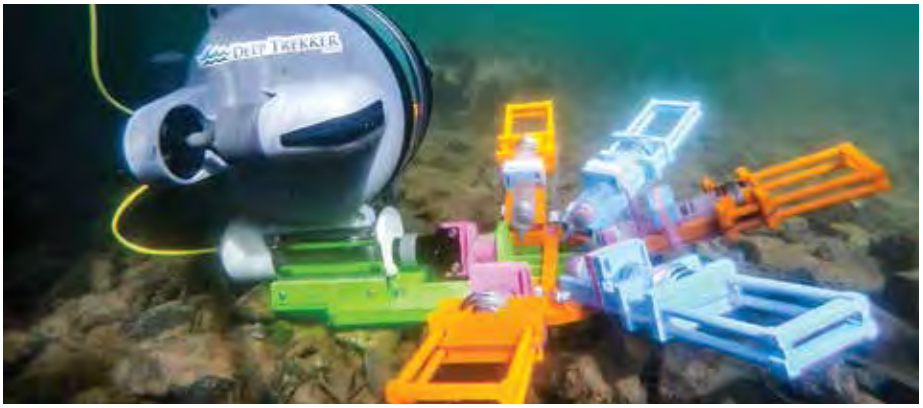
CO-FUNDED BY: Ontario Graduate Scholarship (OGS)

PROJECT LEADS: Christopher Powell, Dominique Bureau (U Guelph)

PROJECT TEAM: James France, Owen Skipper-Horton, Fiona Tansil (U Guelph)

CONTACT: cpowell@uoguelph.ca, dbureau@uoguelph.ca

The Feasibility of Using Bacterial Community Profiling with Next-Generation DNA Sequencing to Assess Temporal and Spatial Environmental Disturbances



Remotely operated vehicle (ROV) and bacterial syringe sampler taking a surface sediment sample on a rocky bottom in the Bay of Fundy. Photo: Shawn Robinson (DFO)

Changes to marine habitats, either from natural or anthropogenic sources, will be reflected in the species diversity and the physiological traits of the organisms. This characteristic profile of species by habitat is reflected at many different size scales ranging from bacteria to large mobile marine animals. The goal of this study is to test the concept that benthic conditions can be easily and cost-effectively monitored via bacterial populations using MiSeq, a rapid DNA sequencing technology that is being adopted internationally and setting new standards for environmental monitoring.

We feel that this new technique could be applicable to all bottom types, in all depths of water, and may give an accurate overview of the current benthic oxygen level that drives much of the biodiversity of interest for the management of industrial activities. Because we will be sampling from the surface layers where the turnover of bacteria can be very rapid, the technique will allow us a view of the current environmental conditions of the bottom. We propose to test this concept in the Bay of Fundy to develop an understanding of the spatial and temporal limitations of this technique. Ultimately, we envision this as a broad-based tool that can be used across the country, in both marine and freshwater habitats, and on all bottom types. It is designed to mesh well with other techniques being developed in separate research initiatives, both nationally and internationally.

We are entering a new era in biology where genetic technologies are allowing us insights, which were not available previously, into biological processes and characteristics of animals and the habitats they inhabit. If successful, this project will add another tool for scientists and managers to assess impacts of various practices and potentially a mechanism to provide baseline information for longer term climate change impacts to the ecosystem.

DATE: JUN. 2016–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Shawn Robinson (DFO)

PROJECT TEAM: Helen Gurney-Smith, Jonathan Day, Steve Neil, Craig Smith (DFO)

COLLABORATORS: Ben Forward (RPC)

CONTACT: Shawn.Robinson@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-M-10-eng.html

Metagenomic Approach to the Characterization of Microflora in Aquaculture Effluents that Induce Phytoprotection and Growth Promotion of Aquaponic and Hydroponic Plants

Environmental protection concerns are growing in the agri-food sector, particularly in the aquaculture industry, where effluent capture and recovery have become priorities. At the same time, the hydroponics sector is seeking more sustainable nutrient sources and biological methods for fighting specific pathogens. Aquaponics technology can be used in this context to produce vegetable plants from fish excrement, which microorganisms convert into digestible nutrients. In return, the plants clean the water by catching elements that are toxic to fish, so that 99% of the water can be recycled. Aquaculture effluents promote the growth and performance of a wide range of hydroponic plants. We recently demonstrated that the microflora present in aquaculture effluents induces phytoprotection against *Pythium ultimum* and *Fusarium oxysporum*, two significant pathogens in agriculture. However, there is little information providing a taxonomic description of this specific microflora. This research project will identify, through metagenomic methods, microorganisms promoting plant growth and phytoprotection in hydroponics and aquaponics. This will allow the development of a better understanding of their interactions with plants and the impact they have on them. The characterization of a hydroponic system's unique microflora will allow for the identification of beneficial species, and foster their development and marketing as phytopathogenic biocontrol agents or even organic fertilizers.

DATE: APR. 2015–MAR. 2018

FUNDED BY: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)

PROJECT LEAD: Grant Vandenberg (U Laval)

PROJECT TEAM: Benjamin Laramée, Nicolas Derome, (U Laval); Martine Dorais (AAC)

COLLABORATORS: Youbin Zheng (U Guelph)

CONTACT: Grant.Vandenberg@fsaa.ulaval.ca

WEBSITE: http://www.vrrc.ulaval.ca/fileadmin/ulaval_ca/Images/recherche/bd/chercheur/fiche/424160.html

Benjamin Laramée in front of his aquaponic system. Photo: Benjamin Laramée (U Laval)

NSERC-Cooke Industrial Research Chair in Sustainable Aquaculture

Farming of fish and shellfish in the ocean is equal in importance to harvest fisheries as a means of seafood production. Concerns about disease and waste management as well as interaction with commercial fisheries have led to controversy among the industry, government regulators, and coastal communities. There are, however, many avenues of environmental improvement feasible for ocean culture of salmon in net pens. Cooke Aquaculture, the largest locally owned aquaculture company in North America, has partnered with Dalhousie University, in a research program on aquaculture sustainability. Professor Jon Grant is the NSERC-Cooke Industrial Research Chair in Sustainable Aquaculture.

An approach involving simulation modelling is being employed using computer models and mapping of aquaculture ecosystems to predict the transport of diseases and waste particles by ocean currents. A field program of oceanographic instruments and sampling at coastal sites, including Cooke Aquaculture farm operations, is being used to check the reliability of the predictions. Various planning scenarios are explored with this method, which can be used to arrange farm sites to minimize the spread of disease or accumulation of waste. Dalhousie's inclusion of training of highly qualified personnel in the research program furthers this cooperation with the aquaculture industry in a new chapter in the practice of environmentally conscious fish farming.

This research into the sustainability of salmon farming includes an ecosystem approach to aquaculture and marine spatial planning.

DATE: JAN. 2014–DEC. 2018

FUNDED BY: Natural Sciences and Engineering Research Council (NSERC)–Industrial Research Chairs Grants

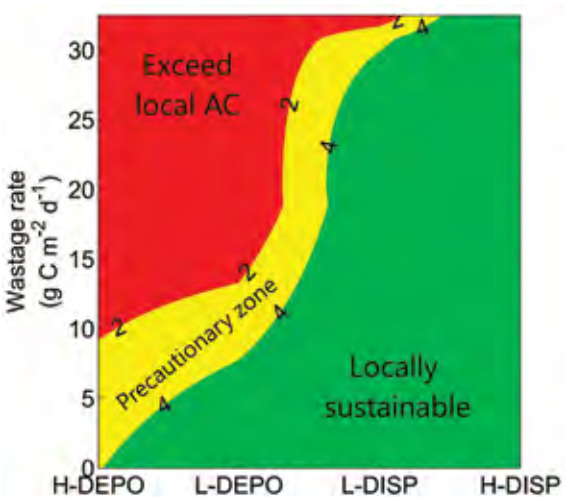
CO-FUNDED BY: Cooke Aquaculture Inc.

PROJECT LEAD: Jon Grant (Dalhousie U)

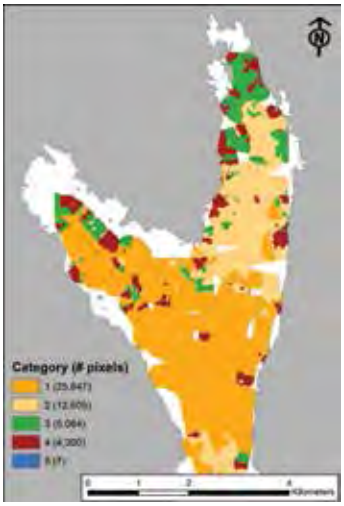
PROJECT TEAM: Ramon Filgueira (Dalhousie U)

COLLABORATORS: Tom Taylor (Cooke Aquaculture Inc.)

CONTACT: jon.grant@dal.ca



Simulation of benthic process allows estimation of assimilative capacity (AC) of sediments near aquaculture sites. Sediment oxygen is contoured as a function of waste deposition (fish feed and pellets) relative to hydrodynamic regime from highly depositional to highly dispersive. Red regions are low sediment oxygen due to high deposition and low dispersion.



Habitat map based on echosounder surveys of Shelburne Harbour. Colours correspond to different bottom types as separated statistically and groundtruthed with bottom video. The most widespread colour is sand.

Drone used for mapping salmon habitat in Upper Salmon River, Fundy National Park.
Photo: Jon Grant (Dalhousie U)

Sensor collaboration with Vemco Amirix (realtimeaquaculture.com) on cage-specific oxygen and temperature data, with wireless acoustic data logging and smartphone monitoring.

Evaluation of Different Biomasses for a Pilot Project to Breed Fly Larvae, an Alternative Source of Protein and Lipids in Animal Feed

In Quebec, the management of organic waste recycling, aimed at reducing landfill use, is currently challenging. There is also a critical need for alternative cost-effective and environmentally-friendly ingredients for livestock feed. Fish meal derived from the overexploitation of marine ecosystems is not sustainable, and the volumes produced cannot keep up with the growing demand from the aquaculture industry.

Our approach combines the two issues, using fly larvae to recycle organic waste into quality feed that is high in protein and other nutrients. Fly larvae production is simple, low-cost, and environmentally friendly.

The goal of this project in the first year is to evaluate various ratios of feed substrates produced from fruit and vegetable waste and microbrewery grains on the growth and nutritional composition of two species of fly larvae (i.e., Black Soldier and Domestic Fly). The second year will focus on incorporating marine waste to assess its impacts on larval omega-3 content to enhance the nutritional quality of fish meal for carnivorous species. Larval meal and oil production costs will also be assessed to determine whether they meet the constraints of aquaculture feed producers.

This project will thereby validate the success of establishing fly larva production to recycle organic waste and make it fit for inclusion in fish feed for aquaculture species in Canada.

DATE: MAY 2015–DEC. 2017

FUNDED BY: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ); Mitacs

PROJECT LEAD: Grant Vandenberg (U Laval)

PROJECT TEAM: Justine Richard-Giroux, Marie-Hélène Deschamps (U Laval); Marie-Pier Aubin, Charles Lavigne (CDBQ)

CONTACT: Grant.Vandenberg@fsaa.ulaval.ca

WEBSITE: http://www.vrrc.ulaval.ca/fileadmin/ulaval_ca/Images/recherche/bd/chercheur/fiche/424160.html

Adult Black Soldier Flies mating.
Photo: Justine Richard-Giroux (U Laval)

The Development of an FVCOM Hydrodynamic Model to Support Aquaculture on the West Coast of Vancouver Island

Previous hydrodynamic modelling in the Broughton Archipelago and the Discovery Islands has demonstrated the advantage of having a computer (numerical) model that provides accurate three dimensional information on current flow, temperature, and salinity. FVCOM (Finite Volume Coastal Ocean Model), when fully developed for this area, promises to provide accurate 3D information. Since FVCOM's development process is complex, this research project is using existing information and new data collected specifically for this project in order to further develop the model.

The ultimate goal of the project is to be able to apply the accurate FVCOM 3D information to examine particle tracking, virus dispersion, and sea lice behaviour in the waters off the West Coast of Vancouver Island in and around aquaculture sites in the area.

The results of this project (the developed model) will be important for the sustainable management of the aquaculture industry. The data will inform mitigation actions that can be recommended by management bodies in response to well characterized risk. From an industry perspective, these results can inform best management practices in order to offset possible impacts.

DATE: MAY 2015–JUN. 2017

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Cermaq Canada Ltd.; Grieg Seafood BC Ltd.

PROJECT LEAD: Peter Chandler (DFO)

PROJECT TEAM: Mike Foreman, Darren Tuele, John Morrison, Pramod Thupaki, Di Wan, Ming Guo, Maxin Krassovski (DFO)

COLLABORATORS: Kathleen Frisch (Cermaq Canada Ltd.); Barry Milligan (Grieg Seafood BC Ltd.)

CONTACT: Peter.Chandler@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/15-1-P-03-eng.html

Final checks prior to the deployment of a current meter mooring from the CCGS *John P. Tully* off the west coast of Vancouver Island are made by Lucius Perreault and Roger Savoie. Data collected by a network of moorings are used to validate the currents simulated by the FVCOM hydrodynamic model.
Photo: David Spear (DFO)

Fish Farm Site-to-Site Connectivity Using GPS Tracked Surface Drifters and FVCOM-Based Particle Tracking Model

Aquaculture Bay Management Areas (ABMAs) were implemented in southwest New Brunswick in 2006 as part of a multi-faceted effort to manage disease within fish farms and reduce the potential for the spread of disease between farms and geographic areas. The boundaries of the ABMAs were chosen so that the estimated exchange of water and associated water borne pathogens between ABMAs on a tidal time scale (~12.5 h) was minimized. Although the ABMA approach to disease management seems to have been successful, the original ABMA structure imposed some limitations that have operational and socio-economic consequences. Splitting some of the ABMAs will increase the total number of ABMAs in the southwest New Brunswick area and may increase water exchange between the new ABMAs but it could help provide more operational flexibility to the industry. This approach could also offer more socio-economic stability to the residents of the area by providing more consistent and stable employment. This is particularly relevant to the island of Grand Manan in the mouth of the Bay of Fundy where employees sometimes need to travel by ferry to and from work on the island because of the lack of a third ABMA. Both industry and provincial government desire a better understanding of the potential for water exchange between the farm sites within the existing ABMAs and the risk potential for disease-spread between fish farms prior to decision making. A more advanced water circulation model, Finite Volume Coastal Ocean Model (FVCOM), new particle tracking models, and new current meter data from the offshore area of Eastern Grand Manan will soon be available. When these data are combined with the new drifter data collected under this project, a more substantial examination of the potential for water exchange between the fish farms in the ABMAs will be possible.

DATE: APR. 2016–JUN. 2019

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Atlantic Canada Fish Farmers Association (ACFFA)

PROJECT LEAD: Fred Page (DFO)

PROJECT TEAM: Susan Haigh, Sean Corrigan, Sarah Scouten, Frederick (Jack) Fife (DFO); Mike Beattie, Pat Mowatt (DAAF); Betty House (ACFFA)

COLLABORATORS: Sue Farquharson (ACFFA)

CONTACT: Fred.Page@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/16-1-M-03-eng.html

Contribution to the Identification of a Locally Available Food Source for Sustainable Tilapia (*Oreochromis niloticus*) Production in the Democratic Republic of Congo

Final sampling of tilapia (*O. niloticus*) on day 28. Photo: Albert Tshinyama (U Laval)

Collection of feces by syphoning for tilapia digestibility study. Photo: Albert Tshinyama (U Laval)

Tilapia farming is one alternative that can contribute to reducing food insecurity in the Democratic Republic of Congo and in Africa as a whole, as this fish species is highly productive and adapts better to low inputs in fish farming. However, the use of optimized feed with a high content of fish meal is not encouraged, given their high costs and their very limited availability to farmers. Identifying locally available resources would make it possible to develop fish farming and reduce production costs. This study involved evaluating the effects that substituting fish meal with vegetable protein sources would have on zootechnical and nutritional performances (e.g., growth, food use), as well as the cost of fish production. Tests were conducted on juvenile tilapia (*Oreochromis niloticus*) (~ 15-20 g) at the aquatic sciences lab at Université Laval. Three diets were tested: 1) *Rcongo*: the main substitution test food made with African ingredients; 2) *Rcanada*: the second test food made with the same ingredients but acquired in Canada; and 3) *Rcommercial*: a commercial control feed made with fish meal. Although the commercial feed had a higher zootechnical performances compared to the *Rcongo* test feed, the cost-benefit analysis indicated that it was more economically advantageous because it reduced fish production costs by 36% compared to commercial feed.

The project allowed the reduction of fish production costs through the informed use of vegetable protein sources and a food source that is easily accessible by farmers.

DATE: JUN. 2015–AUG. 2015

FUNDED BY: Fonds Forestier pour le Bassin du Congo (FFBC); African Development Bank (AfDB)

CO-FUNDED BY: Programme Élargi de Formation en Gestion des Ressources Naturelles dans le Bassin du Congo (PEFOGRN-BC)

PROJECT LEAD: Grant Vandenberg (U Laval)

PROJECT TEAM: Albert Tshinyama, Emilie Proulx, Marie-Hélène Deschamps, Damase Khasa (U Laval); Freddy Okitayela (University of Kinshasa)

COLLABORATORS: Mélodie Richard, Corina Nagy (U Laval)

CONTACT: Grant.Vandenberg@fsaa.ulaval.ca

WEBSITE: http://www.vrrc.ulaval.ca/fileadmin/ulaval_ca/Images/recherche/bd/chercheur/fiche/424160.html

Benthic Culture of Sea Cucumbers: Assessing Interactions Between Cultured and Wild Populations and the Mitigation of Environmental Impacts in Shellfish Co-Culture

Juvenile California Sea Cucumber, *Parastichopus californicus*, perched on an oyster clump amid a forest of oyster culture strings. Photo: Dan Curtis (DFO)

High market demand has resulted in a great deal of interest in culturing the California Sea Cucumber (*Parastichopus californicus*) in British Columbia (BC). However, before these operations can proceed to full scale production, additional base-line data are needed to determine the viability and potential impacts of culturing sea cucumbers. The primary aims of this project are to determine: 1) the growth and survival of sea cucumbers in benthic culture; 2) the environmental impact of sea cucumber aquaculture; and 3) the potential interactions between wild and benthic-ranched individuals. The results of this project show promise for the development of sea cucumber aquaculture in BC. Juveniles have shown good growth and survival when raised in benthic cages both on and away from an existing deep-water oyster farm. When co-cultured with oysters, the nutrient rich benthic habitat at these sites may allow for higher growth rates and stocking densities. High densities of sea cucumbers often found at existing aquaculture sites may help to ameliorate some of the nutrient loading and associated environmental impacts of shellfish aquaculture. However, seasonal changes in sea cucumber density at our study site suggest that if preventing mixing of wild and cultured stocks is desired, some form of containment may be necessary.

Expanding our knowledge of benthic ranching techniques for *P. californicus* and addressing issues such as containment of this species will be mutually beneficial to resource managers and industry partners.

DATE: APR. 2012–MAR. 2015

FUNDED BY: DFO–Aquaculture Collaborative Research and Development Program (DFO–ACRDP)

CO-FUNDED BY: Fan Seafoods Ltd.; Klahoose First Nation; Pacific Sea Cucumbers Harvesters Association; Viking Bay Ventures

PROJECT LEAD: Chris Pearce (DFO)

PROJECT TEAM: Dan Curtis, Nick Duprey, Claudia Hand (DFO); Scott McKinley (UBC)

COLLABORATORS: Fan Seafoods Ltd.; Klahoose First Nation; Pacific Sea Cucumbers Harvesters Association; Viking Bay Ventures

CONTACT: Chris.Pearce@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/acrdp-pcrda/projects-projets/P-14-02-003-eng.html

Optimization of Fly Co-Product Processing Methods for Repurposing Organic Waste in Quebec

The production of insects from organic waste is a sustainable approach that would allow the production of alternative proteins and lipids meeting the needs of animal production. The goal of this project is to improve the techniques for culling Black Soldier Fly larvae, as well as fish meal processing processes, to optimize the nutritional value, safety, and digestibility of fish and chicken feed.

Black Soldier Fly larvae will be produced at the Centre de développement bioalimentaire du Québec (CDBQ), and various culling techniques (i.e., CO_2 anaesthesia, by oxygen deprivation and/or freezing) will be tested. The larvae will then be transferred to Université Laval where various packaging techniques will be tested (i.e., pasteurization and Ultra-high temperature processing (UHT) or High pressure homogenization (HPH)) aimed at reducing/controlling the microbial load of the larvae. HPH optimization will facilitate the extraction techniques of co-products such as protein, lipid, and chitin from fly larvae meal. Costs, performance, and product quality, such as lipid and amino acid profiles, will be rigorously monitored at each stage of processing to determine the optimal processes to be retained. Finally, two protein meals obtained through the optimal techniques will be incorporated into experimental diets, and their digestibility and palatability compared to control diets during nutritional testing in fish and chickens.

This project will include the development of insect products meeting nutritional needs of Canadian farmed fish as well as the Canadian safety and hygiene criteria of alternative feeds.

DATE: JUN. 2016–MAY 2019

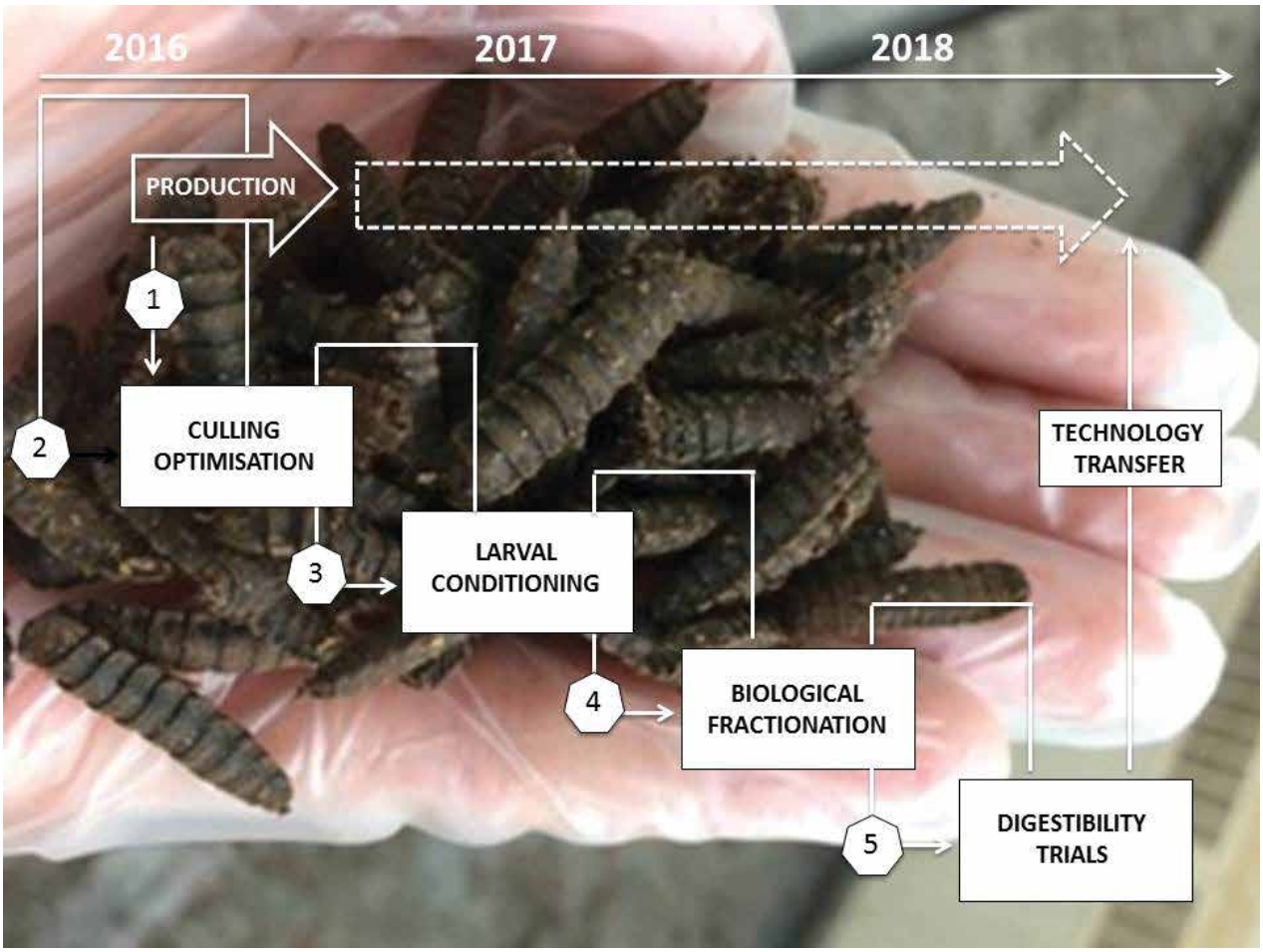
FUNDED BY: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)

PROJECT LEAD: Grant Vandenberg (U Laval)

PROJECT TEAM: Marie-Hélène Deschamps, Jennifer Larouche, Justine Richard, Linda Saucier, Cristina Ratti, Alain Doyen, Lucie Beaulieu, Marie-Pierre Létourneau Montminy (U Laval); Marie-Pier Aubin, Charles Lavigne (CBDQ)

CONTACT: Grant.Vandenberg@fsaa.ulaval.ca

WEBSITE: http://www.vrrc.ulaval.ca/fileadmin/ulaval_ca/Images/recherche/bd/chercheur/fiche/424160.html



Operational diagram of Black Soldier Fly meal optimization. Photo: Marie-Hélène Deschamps (U Laval)

Comparative Genomics of the Salmonid Brook Charr for Identifying Physiological/Expression QTL and Conserved Gene Regulatory Networks

In addition to their ecological, cultural and commercial importance, salmonids are of great interest for genetics research and evolutionary biology due to their evolutionary success and the occurrence of an ancestral whole-genome duplication at the base of the lineage. Much research has been conducted in salmonid genetics, and there exist high-density genetic maps for at least eight species, chromosome-level genome assemblies for two species, and many transcriptome studies. However, most of this work has been conducted on two genera, *Salmo* and *Oncorhynchus*. The Brook Charr (*Salvelinus fontinalis*) is of great importance commercially (both from an aquaculture and an angling perspective) but remains much less characterized. This project aims to improve the genetic tools and characterization of Brook Charr.

First, we developed a high-density genetic map with 3826 single nucleotide polymorphism (SNP) markers and a new bioinformatics method to compare the map to all other published high-density salmonid maps, as well as to a non-duplicated outgroup, to identify chromosome correspondence among the species. Second, we identified quantitative trait loci (QTL) associated with growth, reproductive and stress-resistance traits. We also identified the sex chromosome and confirmed striking recombination rate differences between the sexes. Third, we will use RNA-sequencing to perform expression QTL (eQTL) analysis and characterize gene expression networks and central hub genes. Finally, we will anchor assembled genomic scaffolds on the newly developed genetic map and compare with other species. Collectively, this work will identify regions of the genome important for ecologically and evolutionary important traits, and bring Brook Charr genetics into the genomic era.

This work will develop genomic tools for Brook Charr, including a high-density genetic map, a draft genome assembly, and growth and stress-resistance markers to be used for selective breeding. Additionally, this work will put Brook Charr genomics into the context of the broader study of evolution post whole genome duplication, specifically in terms of sex determination, important genomic regions, and gene expression regulation.

DATE: SEP. 2013–SEP. 2017

FUNDED BY: Fonds de recherche du Québec–Nature et Technologies (FRQNT)–Projets de recherché en équipe

CO-FUNDED BY: Société de recherche et de développement en aquaculture continentale Inc. (SORDAC)

PROJECT LEAD: Louis Bernatchez (U Laval); Céline Audet (UQAR)

PROJECT TEAM: Ben Sutherland (U Laval)

CONTACT: Louis.Bernatchez@bio.ulaval.ca; Celine_Audet@uqar.ca

Brook Charr alevins. Photo: Céline Audet (UQAR)

Establishing Zones for Managing Risks Related to Pathogens and/or Pollutants Originating on Finfish Aquaculture Facilities in the Broughton Archipelago and Discovery Islands

Fish farming in coastal waters characterized by strong and variable currents makes understanding the water circulation important to sustain a healthy environment, both on and away from the farm. When many farms share a common environment, the cumulative impacts may be surprisingly complex, especially in an environment that changes daily (tides and winds), seasonally (snowmelt and river runoff), and yearly (climate change). A high precision model (FVCOM) that can represent temperature, salinity, and water flow in three dimensions has been developed. The results of the model simulations (April to October 2010) are stored as 3D data fields at hourly intervals for 21 depth levels, at each of the 36,000 nodes that comprise the model grid. Particle tracking models use the modelled currents to determine the area of influence due to the release of virtual particles from fish farm locations. A field program using surface drifters designed at DFO has been used to validate the model results with observed surface currents. Tracked by a GPS (global positioning system), the drifters provided weeks of positional information to compare with corresponding circulation and particle tracking model simulations. The hydrodynamic connectivity between fish farms in regions such as the Broughton Archipelago and Discovery Islands has been used to contribute to decisions involving pathogen transfer among fish farms, and from fish farms to wild fish. Management zones can then be established based on these criteria.

DATE: APR. 2011–APR. 2016

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Peter Chandler (DFO)

PROJECT TEAM: Mike Foreman, Diane Masson, Kyle Garver, Dario Stucchi, Darren Tuele, Michael Ikonomou, Stewart Johnson, Marc Trudel (DFO)

CONTACT: Peter.Chandler@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2011-P-08-eng.html

Development of Environmental DNA (eDNA)-Based Biosurveillance for Aquatic Invasive Species (AIS) to Inform Management and Policy Decision-Making Associated with Shellfish Aquaculture Movements

Shellfish movements associated with aquaculture activities are a known vector for aquatic invasive species (AIS) introduction and spread. For example, the transfer of harvested shellfish has been established as a vector for the spread of invasive tunicates, bryozoans, and European Green Crab. Even with mitigation measures like rinsing in place, which is currently used for Green Crab areas, some degree of risk of translocating invasive species is intrinsic to all shellfish movements. As such, informed decision-making around shellfish movements is an important management activity to mitigate risk of new invasions in geographic areas in BC that currently lack AIS that are present at other locations. Along the coast of British Columbia, collecting spatial data on AIS distributions is challenged by high variability in the geographic distribution of AIS at relatively small spatial scales. These patchy AIS distributions also create a challenge for management because it is not feasible to manage shellfish movements in BC at the level of individual AIS or individual bays.

DNA metabarcoding of complex (i.e., mixed-species or environmental DNA) samples generates millions of sequence reads from the majority of species present within the sample simultaneously and with high sensitivity. Using reference DNA sequence libraries, metabarcoding reads can be translated into biodiversity data with a relatively high level of taxonomic resolution and can be used for detection of cryptic, rare, and small taxa, including AIS. The main objective of this project is to transfer into DFO an eDNA-based metabarcoding tool developed by the Canadian Aquatic Invasive Species Network (CAISN) and perform optimization and field-validation for its use as an AIS biosurveillance tool to aid decision-making, including around shellfish aquaculture movements in BC.

DATE: APR. 2016–MAR. 2019

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Cathryn Abbott (DFO)

PROJECT TEAM: Kristen Marie Westfall, Tom Therriault, Kristi Miller-Saunders, Kara Aschenbrenner, Geoff Lowe, Scott Gilmore (DFO); Melania Cristescu (McGill U); Guang Zhang (McGill U; DFO)

CONTACT: Cathryn.Abbott@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2016-P-03-eng.html

Assimilation Capacity of Organic Matter from Salmon Aquaculture (ACOM): Improving Model Predictions of Benthic Impacts

The spatial scale, magnitude and persistence of benthic, or seabed, effects from the release of organic wastes are influenced by a range of factors that control waste deposition, recycling, and transport. Previous research has shown that a relationship exists between the deposition rate of organic matter from salmon net-pens and benthic community effects. However, this simple cause-effect relationship neglects to consider many important physical, chemical, and biological processes that are responsible for the manifestation of benthic effects. An important, but poorly understood factor is the inherent capacity of different benthic habitats to mineralize (recycle) this material without significantly altering the natural state of the seabed. This organic enrichment threshold is commonly referred to as the "assimilative capacity". Ongoing multidisciplinary research in Canada and Norway aims to increase scientific expertise and knowledge on the major processes that determine benthic assimilative capacity under a range of environmental settings and seabed types (mud, sand, and mixed substrate). This work includes studies on waste deposition and dispersion dynamics, the decay rates of organic matter, and oxygen exchanges with the seabed. A separate objective of this research is the development of a model that will provide increased accuracy in predicting the spatial scale and the magnitude of benthic community effects from ocean-based finfish farms.

DATE: APR. 2014–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Peter Cranford (DFO)

PROJECT TEAM: Brent Law, Fred Page, Terri Sutherland, Shawn Robinson, Herb Vandermeulen, Susan Haigh (DFO)

COLLABORATORS: Raymond Bannister (Institute of Marine Research, Norway)

CONTACT: Peter.Cranford@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2014-M-06-eng.html

Evaluation of Genetic Structuring of California Sea Cucumber (*Parastichopus californicus*) Across Transfer Zones in British Columbia

Fisheries and Oceans Canada (DFO) regulates the introduction and transfer of fish and shellfish into and between facilities in British Columbia so as not to adversely affect local aquatic species and habitats. Requests for introductions and transfers to and from aquaculture facilities are risk-assessed for possible disease, ecological and and genetic effects on native species and ecosystems, and to ensure the regulations are met. There may be a requirement for mitigation measures to minimize any risks associated with transfer activities (e.g., egg disinfection, quarantine of stock).

In British Columbia, five distinct shellfish transfer zones (STZs) span the Pacific Region. STZs are used to manage the movement of cultured shellfish to prevent gene flow between farmed and wild populations, and to manage the transfer of potential parasites/pathogens. Introducing or translocating cultured individuals can lead to gene flow with wild populations, and can result in a loss of genetic variation or adaptive genes found in the wild populations. Therefore, understanding the spatial scales at which shellfish populations are genetically distinct can help to optimize the boundaries of STZs to meet both ecological and socio-economic objectives.

Currently, an Introductions and Transfers Licence is required for both between and within zone transfer activities of sea cucumbers in British Columbia. This study will assess the genetic structure of the California Sea Cucumber (*Parastichopus californicus*) and compare the location of genetic discontinuities with current STZ boundaries. Information on their genetic structure will also contribute important spatial information for informing fisheries management and the design of Marine Protected Area (MPA) networks. The results of this project will contribute to science advice that can be used to enhance the scientific basic for STZs and the sustainable management of the shellfish aquaculture industry.

DATE: APR. 2015–MAR. 2017

FUNDED BY: DFO–Program for Aquaculture Regulatory Research (DFO–PARR)

PROJECT LEAD: Janelle Curtis (DFO)

PROJECT TEAM: Nicholas Duprey, Chris Pearce, Dan Curtis (DFO)

COLLABORATORS: Marie-Josée Fortin, Amanda Xuereb (U of T); Louis Bernatchez (U Laval)

CONTACT: Janelle.Curtis@dfo-mpo.gc.ca

WEBSITE: www.dfo-mpo.gc.ca/aquaculture/rp-pr/parr-prra/projects-projets/2015-P-03-eng.html

ORGANIZATIONS

Atlantic Canada Opportunities Agency (ACOA)

- Atlantic Innovation Fund (AIF)

British Columbia Salmon Farmers Association (BCSFA) – Marine Environmental Research Program (MERP)

Fisheries and Oceans Canada (DFO)

- Aquaculture Collaborative Research and Development Program (ACRDP)
- Centre for Aquatic Animal Health Research and Diagnostics (CAAHRD)
- Genomics Research and Development Initiative (GRDI)
- National Contaminants Advisory Group (NCAG)
- Partnership Fund
- Program for Aquaculture Regulatory Research (PARR)

Fonds de recherche du Québec – Nature et Technologies (FRQNT)

Genome Canada (GC)

- Genome Atlantic
- Genome British Columbia
- Genome Québec
- Ontario Genomics

Hakai Institute

Ministere de l'Agriculture, des Pecheries et de l'Alimentation du Québec (MAPAQ)

National Research Council (NRC) Canada

- Industrial Research Assistance Program (IRAP)
- Algal Carbon Conversion (ACC) Program

National Sciences and Engineering Research Council (NSERC)

- Discovery Grants Program
- Industrial Research Chairs (IRC) Grants
- Industrial Research Chairs for Colleges (IRCC) Grants
- Postdoctoral Fellowship (PDF) Program
- Strategic Partnership Grants for Networks (SPG-N)

Pacific Salmon Commission (PSC)

Pacific Salmon Foundation (PSF)

Ressources Aquatiques Québec (RAQ)

Sea Pact

Social Sciences and Humanities Research Council of Canada (SSHRC)

Atlantic Canada Opportunities Agency (ACOA)

The Atlantic Canada Opportunities Agency works to create opportunities for economic growth in Atlantic Canada by helping businesses become more competitive, innovative and productive, by working with diverse communities to develop and diversify local economies, and by championing the strengths of Atlantic Canada. Together, with Atlantic Canadians, we are building a stronger economy.

With our many partners in economic development, ACOA works to strengthen the Atlantic economy through:

- Enterprise development – helping improve the business climate and lending a hand for individual business start-ups, modernizations and expansions;
- Community development – working with communities to nurture economic growth, improve local infrastructure and develop opportunities in the local economy; and
- Policy, advocacy and co-ordination – being a champion for Atlantic Canada by representing the region's interests at the national level in areas like policy development, research and analysis and in work with other departments to ensure coordination of policies and programs.

We will also continue to play an essential role in the co-ordination and development of the Atlantic Gateway and lead trade development initiatives that increase the exposure of Atlantic Canadian firms in foreign markets, thereby generating new economic opportunities.

Atlantic Innovation Fund (AIF)

As part of the Government of Canada's commitment to increasing business productivity, growth and competitiveness, the AIF is helping Atlantic Canada compete at home and abroad by supporting the development of innovative products and services that lead to commercial success.

The AIF helps Atlantic Canadians develop and bring to market new products and services that lead to market success, help grow strategic sectors, or lead to the creation of research and commercialization partnerships. (2017, www.acoa-apeca.gc.ca)

Atlantic Canada Opportunities Agency
Agence de promotion économique du Canada atlantique
Canada

Aerial view of salmon net-pens in Doctor's Cove, New Brunswick. (Photo: Kobb Media)

British Columbia Salmon Farmers Association (BCSFA) – Marine Environmental Research Program (MERP)

The BC Salmon Farmers Association (BCSFA) is a forum for communication and cooperation within the salmon farming sector, and the focal point for liaison between the industry and government. BCSFA also provides information to the public and stakeholders about salmon farming, and coordinates industry-wide activities, research, and community events. Our members include both farmed salmon producers and many of the companies who provide services and supplies to them. The BCSFA was established in 1984 and is based in Campbell River, British Columbia.

The BCSFA holds research and development as one of the top priorities in maintaining a sustainable industry. In December 2014, the BCSFA developed the Marine Environmental Research Program (MERP) and committed $1.5 million in funding to the program between 2015 and 2020 to be utilized in partnership with government, academic and independent research institutions. The program was created with the aim to gain a better understanding of the marine environment and BC's wild marine species, particularly wild salmon stocks. The BCSFA has developed a formalized Call for Proposals process, overseen by an external body – the BCSFA Science Advisory Council.

Annually, the BCSFA hosts the Collaborations on the Coast workshop in Nanaimo, BC which brings together representatives from the industry, scientific community, government and conservation groups to discuss and review current research (including MERP funded research) to further improve the industry's understanding of both wild and farm-raised fish health, as well as the changing coastal environment.

For further information, please visit www.bcsalmonfarmers.ca/research-innovation

Fisheries and Oceans Canada (DFO)

Fisheries and Oceans Canada (DFO) delivers programs and services that support the sustainable use and development of Canada's waterways and aquatic resources. On behalf of the Government of Canada, DFO is responsible for developing and implementing policies and programs in support of Canada's scientific, ecological, social, and economic interests in oceans and fresh waters. It is DFO's mission to deliver to Canadians the following outcomes:

- Economically Prosperous Maritime Sectors and Fisheries;
- Sustainable Aquatic Ecosystems; and
- Safe and Secure Waters.

In working toward these outcomes, the Department is guided by the principles of sound scientific knowledge and effective management.

DFO is the lead federal department for the sustainable management of fisheries and aquaculture. Responsibility for aquaculture management and development (governance) is shared between the federal, provincial, and territorial governments. We work together, with many other partners, to ensure that the legislative and regulatory framework for aquaculture is responsive to the public's and industry's needs.

DFO's aquaculture research aims to address regulatory knowledge gaps, and collaborative research and development with the aquaculture industry. Collaborative research facilitates the transfer of the latest technologies to the aquaculture industry. Research on the environmental effects of aquaculture also provides a solid scientific foundation for the conservation and protection of fish and fish habitat in marine or freshwater ecosystems. On-going research contributes to scientific certainty with respect to aquaculture operations and how they interact with the aquatic environment.

In recent years, DFO's research effort has been directed at understanding environmental effects of aquaculture on freshwater and marine habitat and ecosystems. We also invest in aquatic animal health research to understand how best to prevent, mitigate, and treat disease. As species diversification is often seen as a means of increasing Canada's global market share, DFO scientists also play a key role in innovative research. (2017, www.dfo-mpo.gc.ca)

The following DFO programs are currently supporting Canadian aquaculture research:

Fisheries and Oceans Canada | Pêches et Océans Canada

A CTD (conductivity, temperature, and depth) rosette taking water samples in Baynes Sound, British Columbia. Photo: Dan McPhee (DFO)

Aquaculture Collaborative Research and Development Program (ACRDP)

The Aquaculture Collaborative Research and Development Program (ACRDP) is a DFO initiative that promotes collaborative research and development activities between the aquaculture industry and the department. The Program teams industry representatives with DFO researchers. The projects are primarily conducted within DFO research facilities but field work may also take place at industry or other partner facilities. Potential projects are proposed by aquaculture producers and funded jointly through the ACRDP as well as the participating aquaculture producer partners.

The key goals of the program are to: Improve the competitiveness and sustainability of the Canadian aquaculture industry; Increase collaborative research between the department and industry; Facilitate the process of technology transfer and knowledge mobilization; and Increase scientific capacity of the Canadian aquaculture industry for essential aquaculture research and development.

The program has two broad Research and Development Objectives. The first is Optimal Fish Health. The sustainability of the marine and freshwater aquaculture industry in Canada is dependent on the health and proper health management of the farmed aquatic animals (fish, shellfish, and seaweed). Funded research is intended to assist the aquaculture sector in improving fish health management practices and better understand pathogen and disease interactions. The second objective is Environmental Performance. This objective is aimed at supporting research that will enhance the overall environmental sustainability of aquaculture operations in Canada with the goal of enhancing environmental responsibility while ensuring economic viability and optimal product quality.

Since the program's inception in 2001, approximately 460 projects have been approved and funded. Over the last five years, DFO and collaborators have invested approximately $10 M into research collaborations for the ACRDP.

For more information, please go to: www.dfo-mpo.gc.ca/aquaculture/acrdp-pcrda/index-eng.htm

Centre for Aquatic Animal Health Research and Diagnostics (CAAHRD)

The Centre for Aquatic Animal Health Research and Diagnostics (CAAHRD) oversees DFO's research in support of the National Aquatic Animal Health Program (NAAHP). The centre directs and coordinates targeted research, the development of quality diagnostics and the provision of sound scientific advice in support of the Government of Canada's efforts to protect our aquatic resources from the introduction or spread of serious infectious diseases.

The Canadian Food Inspection Agency (CFIA) has listed 42 aquatic animal diseases of concern — for which Canada has potential host species — that could severely impact wild and cultured finfish, shellfish, and crustaceans. Some of these aquatic diseases occur throughout Canada, others are endemic to specific regions and watersheds, while others are exotic (foreign) to Canada.

CAAHRD's three main areas of research are: 1) development and validation of diagnostic tests (e.g., validation as per OIE guidelines, prioritization of regulated diseases, development of molecular tests, and others); 2) improvement of laboratory processes (e.g., mitigation measures for false positives, comparability studies, optimisation, etc.); and 3) knowledge generation (e.g., host susceptibility, host-pathogen interactions, etc.). This research enables DFO's National Aquatic Animal Health Laboratory System (NAAHLS) to meet the Department's obligations as a partner in the NAAHP.

CAAHRD research is conducted by scientists at the four NAAHLS facilities: the Gulf Biosecurity Unit – Aquatic Animal Health Lab (AAHL) in Charlottetown PEI, the Gulf Fisheries Centre – AAHL (Moncton, New Brunswick), the Freshwater Institute – AAHL (Winnipeg, Manitoba), and the Pacific Biological Station – AAHL (Nanaimo, British Columbia).

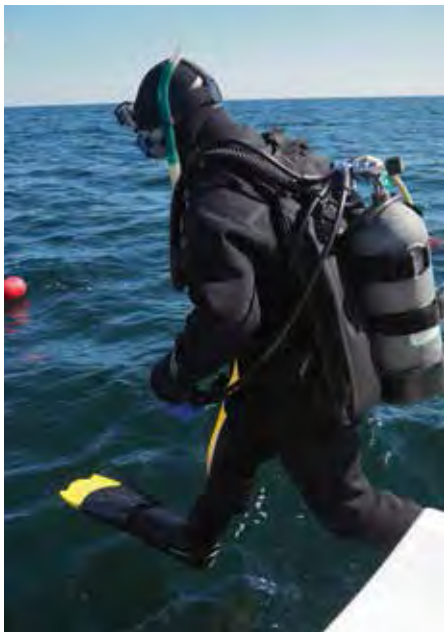
For more information please visit www.dfo-mpo.gc.ca/science/coe-cde/caahrd-cesaard/index-eng.html

Genomics Research and Development Initiative (GRDI)

DFO uses genomics for the aquaculture industry and in the management of the wild fishery. These tools lead to better disease identification and control, development of techniques to accurately determine the population structure of wild marine fish, and to identify invasive or endangered species as well as minimize illegal or unregulated harvesting. As an enabling technology, genomics provides powerful tools and precise information to support operational mandates and upon which policy and regulatory decisions can be based.

The GRDI was established for the purpose of building and maintaining capacity inside government departments to do genomics research. Through targeted investments the Initiative has enabled the establishment of critical mass in genomics research that supports innovation in key Canadian sectors, and ensures that federal departments can mobilize their support for the overall, national genomics effort (e.g., projects funded by Genome Canada, Canadian Institutes of Health Research, etc.). Programs funded under the GRDI are also used to augment human resources and help create partnerships with other government departments, universities, and industry (where applicable) through the sharing of technology platforms and by collaborating in research areas that cut across traditional departmental sectors.

For information visit www.dfo-mpo.gc.ca/science/biotech-genom/index-eng.htm



A Fisheries and Oceans Canada (DFO) diver entering the water to collect samples in the Magdalen Islands. Photo: Dan McPhee (DFO)

National Contaminants Advisory Group (NCAG)

As a science-based federal government department, DFO requires scientific evidence to inform the management of Canada's fisheries, and to advance sustainable aquatic ecosystems while fostering economic prosperity across maritime sectors and fisheries. The National Contaminants Advisory Group (NCAG) facilitates the provision of scientific information and advice to DFO on priority issues specific to the biological effects of contaminants on aquatic ecosystems. The main functions of the group are to fund external research projects that are aligned with NCAG's priorities, to synthesize results, and to develop science advice in support of DFO decision-making. Current priority research themes are: 1) oil and gas; 2) pesticides; 3) aquaculture therapeutants; and 4) contaminants and issues of emerging concern. The NCAG has funded a variety of multiyear research projects at Canadian universities and not-for-profit research institutions.

Partnership Fund

As part of the Government of Canada's new investments in science, DFO has established a Partnership Fund that provides $5 million per year in support of collaborative research and increasing collective understanding of our oceans and freshwater.

This is managed by the Department's Office of Partnership and Collaboration. It will support new partnerships and collaborations within the ocean and freshwater sciences community (including universities, aquatic research networks, environmental organizations, Indigenous groups and other stakeholders, both in Canada and abroad). These partnerships will contribute to the best available science that will support decision-making about Canada's oceans, lakes, and rivers.

Fisheries and Oceans Canada is committed to fostering and leveraging these important partnerships and the fund will support a number of scientific research projects and activities across the country, including those related to: science data collection and integration; ocean and freshwater monitoring; and science in support of ocean literacy, and the management, conservation, protection, and promotion of ocean and freshwater resources.
http://www.dfo-mpo.gc.ca/science/collaboration/partnership-fund-eng.html

Program for Aquaculture Regulatory Research (PARR)

The Program for Aquaculture Regulatory Research (PARR) funds research projects within the Department to advance our understanding of environmental and biological interactions between aquaculture and the aquatic environment. The Program is designed to increase our scientific knowledge in order to inform regulatory decision-making and policy development.

First established in 2008, this program forms one of three pillars under the Sustainable Aquaculture Program at DFO. The PARR' s research priorities are driven by knowledge gaps and research recommendations identified in DFO' s Aquaculture Pathways of Effects, which describes the linkages between aquaculture related activities and their impacts in the aquatic environment, and by specific regulatory and policy questions from federal and provincial aquaculture regulators and policy makers.

There are five broad themes or topics that the scientific research projects that are funded through PARR address:

- **Fish Pest and Pathogen Treatment and Management**
  Research that furthers our understanding of diseases and infestations, the mechanism of on-farm infection and spread, and the effect on the environment and other fish species from different treatment options.
- **Interactions with Wild Populations**
  Research related to characterizing the ecological and genetic interactions between farmed and wild fish populations in order to better understand the risks and inform policies and regulatory decisions, improving the overall sustainability of the industry.
- **Release of Organic Matter**
  Research aimed at characterizing the impact of released organic matter from aquaculture (e.g., unconsumed feed, fecal matter), developing and validating methods and performance indicators to predict and measure these impacts in different marine and freshwater environments.
- **Other Habitat Impacts**
  Research examining the relationships between aquaculture and marine habitats to better inform both management and regulatory decisions, particularly related to siting of aquaculture facilities.
- **Cumulative Effects and Ecosystem Management**
  Research to characterize and predict the cumulative impacts from aquaculture activities, including developing models to evaluate and predict the amount of aquaculture activities that the aquatic ecosystem can sustainably accommodate, and identify indicators that can be used to monitor whether an ecosystem is at or near this carrying capacity.

www.dfo-mpo.gc.ca/aquaculture/parr-prra/index-eng.html

Fonds de recherche du Québec – Nature et Technologies (FRQNT)

The Fonds de recherche du Québec – Nature et technologies (FRQNT) is a non-profit agency, administered by a board of directors whose members are appointed by the Cabinet.

Since July 1, 2011, the FRQNT has worked with the Fonds de recherche du Québec – Santé (FRQS) and the Fonds de recherche du Québec – Société et culture (FRQSC) under the banner Fonds de recherche du Québec. Their mandates are as follows:

- To promote and provide financial support for research in the fields of natural sciences, mathematical sciences and engineering.
- To promote and provide financial support for the dissemination of scientific knowledge in fields of research relating to natural sciences, mathematical sciences and engineering.
- To promote and provide financial support for the training of researchers through achievement scholarships for graduate and postgraduate students and to persons who engage in postdoctoral research, through professional development scholarships to persons who wish to re-enter the research community, and through grants that allow the teaching duties of college level professors engaging in research activities to be reduced.
- To create any necessary partnerships, in particular with universities, colleges, and industry, and the government departments and public and private bodies concerned.

(2017, adapted from www.frqnt.gouv.qc.ca/en/accueil)

Genome Canada (GC)

Genome Canada is a not-for-profit organization, funded by the Government of Canada. We act as a catalyst for developing and applying genomics and genomic-based technologies to create economic and social benefits for Canadians. We: connect ideas and people across public and private sectors to find new uses for genomics; invest in large-scale science and technology to fuel innovation; and translate discoveries into solutions across key sectors of national importance, including health, agriculture and agri-food, forestry, fisheries and aquaculture, the environment, energy, and mining.

Genome Canada aims to harness the transformative power of genomics for the benefit of all Canadians. We make strategic investments in large-scale science, leading-edge technology and translation programs and initiatives to ensure genomics knowledge is applied to maximum benefit for Canada.

Our programs are designed based on engagement with a broad range of stakeholders, including sector-specific users of genomics, especially in the private sector. They are implemented through a rigorous international peer-review system, which ensures only the highest-quality research proposals with the greatest potential for impact are funded.

Partnerships are an integral component of our model. We do nothing alone. We insist on partnership both at the program and research project levels. In this way, Genome Canada catalyzes a collaborative, thriving genomics enterprise across the country and internationally.

(2017, adapted from www.genomecanada.ca)

Genome Atlantic

Genome Atlantic is a not-for-profit corporation with a mission to help Atlantic Canada reap the economic and social benefits of genomics and associated technologies. Since our inception in 2000, we have worked with a range of partners to enable over $90 million in new genomics R&D in the region.

We aim to develop genomics R&D projects in seven key sectors – agriculture, fisheries and aquaculture, energy, the environment, forestry, mining, and human health. We work with a range of public and private partners to help companies and organisations use genomics to solve problems in these sectors. Our services are diverse and highly flexible, but are generally focused on helping teams identify, develop or manage results-focused genomics R&D projects.

We have extensive connections to Genome Canada, the Genome Centres (Genome BC, Genome Alberta, Genome Prairie, Ontario Genomics, and Genome Québec) and the network of universities, research institutions, companies, government departments, and other agencies that are involved in genomics and related research.

We receive financial support from the Government of Canada through Genome Canada, the National Research Council – Industrial Research Assistance Program, and the Atlantic Canada Opportunities Agency – Business Development Program. We are always interested in working with strategic partners to increase the impact of genomics innovation.

We help companies, government departments and researchers pursue genomics-based solutions to real-world problems.

(2017, www.genomeatlantic.ca)

Genome British Columbia

Genome British Columbia is a non-profit research organization that invests in and manages large-scale genomics and proteomics research projects and enabling technologies focused on areas of strategic importance such as human health, forestry, fisheries and aquaculture, energy and mining, and agri-food.

Our research projects have attracted over 300 major international co-funders and partner organizations, including many multinational corporations, pharmaceutical and biotechnology companies, worldwide charitable foundations, and top-tier research institutions. Such investments have helped us build internationally recognized enabling technologies; recruit, train, and retain high quality personnel; and deliver socio-economic benefits to BC, Canada, and other parts of the world.

Our major investors are the Province of British Columbia and the Government of Canada through Genome Canada and Western Economic Diversification Canada. This funding is complemented by other private and public investments.

Our Mission:

Genome BC leads academia, government, and industry to develop a world-class genome sciences region that will deliver social and economic benefits to British Columbia, Canada, and beyond, through: excellent projects and technology platforms; innovative applications for the life sciences cluster; strategic international collaborations; and proactive leadership in exploring societal impacts of genome sciences.

(2017, www.genomebc.ca)

Genome Québec

Genome Québec is an economic development organization that contributes to strengthening the competitiveness of the genomics innovation system in order to maximize its socioeconomic impact in Québec. It does so by funding major genomic research initiatives and putting in place the tools necessary for scientific and strategic development in the field.

Genome Québec is helping to accelerate the discovery of new applications for genomics in strategic areas such as health, forestry, the environment, and agrifood.

The funds invested by Genome Québec are provided by the ministère de l'Économie, de la Science et de l'Innovation du Québec (MESI), the Government of Canada through Genome Canada, and private partners. (2017, www.genomequebec.com)

GenomeQuébec

Dan McPhee setting the firing mechanism on a CTD rosette to collect samples in Baynes Sound, British Columbia. Photo: Terri Sutherland (DFO)

Ontario Genomics

Ontario Genomics (formerly the Ontario Genomics Institute) is a not-for-profit intermediary organization funded by the Ontario government and the federal research funding agency Genome Canada.

Established in 2000, Ontario Genomics is the only entity focused solely on stimulating, enabling, and nurturing genomics innovation in the province of Ontario. We act as a catalyst for developing and applying genomic technologies across seven key sectors – agriculture, bioproducts, energy, forestry, health, mining, and water – to grow the province's knowledge-based economy and create jobs and social benefits for all Ontarians.

Our Vision

- More funds for genomics research in Ontario;
- Genomics contributing to the establishment of effective and cost-conscious public services, such as healthcare;
- Established genomics companies investing and operating in Ontario; and
- An innovative milieu in which genomics start-ups develop, mature, and accelerate along the business growth pipeline, creating jobs and wealth in Ontario

(2017, www.ontariogenomics.ca)

Ontario Genomics

Hakai Institute

The Hakai Institute is a scientific research institution that conducts long-term research at remote locations on the coastal margin of British Columbia, Canada.

The name Hakai is inspired by the Hakai Lúxvbálís Conservancy, the largest marine protected area on the BC coast, located about 400 kilometers north of Vancouver.

The Hakai Institute includes the following elements: the original field station on Calvert Island on the BC Central Coast; a second field station on Quadra Island at the north end of the Strait of Georgia; the Institute's own scientific research staff and equipment; and a large network of affiliated faculty and other collaborators at universities, government agencies, and First Nations.

Our research is inspired by Long Term Ecological Research (LTER) network, originally launched by the US National Science Foundation in 1980. We pool our information with other coastal research sites—most notably in BC, Alaska, Washington, and Oregon—to gain an understanding of the dynamics of the broader landscape.

Given the unique nature of our study area on the coastal margins of British Columbia, our scope includes the history of ecological change since the region became ice-free roughly 15,000 years ago and the influence of humans on the landscape.

The coastal margins of British Columbia, Canada are among the most productive areas in the world. Water flowing from the glaciers, snow packs, forests, and bogs of the temperate rainforest pours massive quantities of inorganic and organic nutrients into the surrounding estuaries and inlets. This nutrient-rich cocktail drives primary production, which in turn fuels complex marine food webs.

Coastal productivity and biodiversity have also served as a magnet for settlement since humans first came to the coast. For millennia, humans have depended on the coast for travel, work, and sustenance – all the elements of life – which remains true today.
(2017, www.hakai.org)

Hakai
Science on the Coastal Margin

Ministere de l'Agriculture, des Pecheries et de l'Alimentation du Québec (MAPAQ)

Innovamer Program

By supporting research and innovation in the commercial fisheries and aquaculture sector, the program aims to:

- Increase the industry's ability to use the knowledge at its disposal to design or significantly improve technologies, products, processes or services;
- Improve business competitiveness, meet requirements, take advantage of business opportunities or solve a business-specific problem;
- Promote the acquisition of new scientific and technological knowledge and design generic products and processes to make them accessible to all companies and partners in the sector;
- Stimulate networking between innovation agents and private sector actors to foster knowledge acquisition and dissemination; and
- Improve the innovation capacity of the sector and support the reinforcement of the complementary actions of the Ministry and its partners in this field.

The Innovamer program has four components:

Strand 1 – Business innovation projects – Eligible customers: business.

Strand 2 – Targeted calls for sectoral innovation projects – Eligible customers: research organizations; and business associations using the necessary scientific experts; and

Strand 3 – Networking, Dissemination and Monitoring – Eligible clients: research Institutes; business associations; and networking organizations

Strand 4 – Partnership Initiatives – Eligible customers: research institutes; and networking organizations

(2017, adapted from www.mapaq.gouv.qc.ca/fr/Peche/md/Programmes/Pages/innovamer.aspx)

National Research Council (NRC) Canada

The National Research Council (NRC) is the Government of Canada's premier organization for research and development.

NRC partners with Canadian industry to take research impacts from the lab to the marketplace, where people can experience the benefits. This market-driven focus delivers innovation faster, enhances people's lives, and addresses some of the world's most pressing problems. We are responsive, creative, and uniquely placed to partner with Canadian industry, to invest in strategic R&D programming that will address critical issues for our future.

Each year our scientists, engineers, and business experts work closely with thousands of Canadian firms, helping them bring new technologies to market. We have the people, expertise, services, licensing opportunities, national facilities, and global networks to support Canadian businesses.

In this section, you will find more information about how NRC is organized and governed, where we are located across Canada, and links to our corporate publications and financial statements.

Our vision

To be the most effective research and technology organization in the world, stimulating sustainable domestic prosperity.

Our mission

Working with clients and partners, we provide innovation support, strategic research, and scientific and technical services to develop and deploy solutions to meet Canada's current and future industrial and societal needs.

(2017, www.nrc-cnrc.gc.ca)

The following NRC programs are currently supporting Canadian aquaculture research:

Algal Carbon Conversion (ACC) Program

The Government of Canada is committed to addressing the issue of CO_2 emissions while simultaneously generating economically and environmentally-sustainable opportunities for Canadian companies. The Algal Carbon Conversion (ACC) flagship program positions Canada as a world leader in converting carbon dioxide emissions into algal biomass, renewable biofuels, and other value-added products through integrated algal biorefineries.

The ACC program addresses a number of factors which influence the commercial potential of ACC technology, including identifying the most appropriate algae strains for industrial deployment, increasing the productivity and reducing energy costs of photobioreactors, identifying ways to reduce energy costs for processing algal biomass, and assisting in the development of high-value, sustainable products from algal biomass. The full impacts of this initiative are projected to lead the deployment of enough algal biorefinery facilities to divert up to 20% of Canadian carbon dioxide emissions from large final emitters by 2060.

(2017, www.nrc-cnrc.gc.ca/eng/solutions/collaborative/algal_index.html)

Industrial Research Assistance Program (IRAP)

The National Research Council-Industrial Research Assistance Program (NRC-IRAP) is Canada's premier innovation assistance program for small and medium-sized enterprises (SMEs). It is a vital component of the NRC, a cornerstone in Canada's innovation system, regarded world-wide as one of the best programs of its kind.

For nearly 70 years, the NRC-IRAP has been stimulating wealth creation for Canada through technological innovation. This is largely accomplished by providing technology assistance to small and medium-sized enterprises (SMEs), at all stages of the innovation process, to build their innovation capacity and successfully take their ideas to market. NRC-IRAP helps SMEs identify and understand technology issues and opportunities and provides linkages to the best business and R&D expertise in Canada.

Our strategic objectives

- Provide support to small and medium-sized enterprises in Canada in the development and commercialization of technologies.
- Collaborate in initiatives within regional and national organizations that support the development and commercialization of technologies by small and medium-sized enterprises.

(2017, www.nrc-cnrc.gc.ca/eng/irap/index.html)

National Sciences and Engineering Research Council (NSERC)

NSERC aims to make Canada a country of discoverers and innovators for the benefit of all Canadians. The agency supports university students in their advanced studies, promotes and supports discovery research, and fosters innovation by encouraging Canadian companies to participate and invest in postsecondary research projects. NSERC researchers are on the vanguard of science, building on Canada's long tradition of scientific excellence.

NSERC's role is to make investments in people, discovery, and innovation to increase Canada's scientific and technological capabilities for the benefit of all Canadians. NSERC invests in people by supporting postsecondary students and postdoctoral fellows in their advanced studies. We promote discovery by funding research conducted by postsecondary professors and foster innovation by encouraging Canadian companies to participate and invest in postsecondary research and training.

Over the last 10 years, NSERC has invested more than $7 billion in basic research, projects involving partnerships between postsecondary institutions and industry, and the training of Canada's next generation of scientists and engineers. (2017, www.nserc-crsng.gc.ca)

The following NSERC programs are currently supporting Canadian aquaculture research:

Discovery Grants Program

The Discovery Grants Program assists in: promoting and maintaining a diversified base of high-quality research capability in the natural sciences and engineering in Canadian universities; fostering research excellence; and providing a stimulating environment for research training.

The Discovery Grants Program supports ongoing programs of research (with long-term goals) rather than a single short-term project or collection of projects. These grants recognize the creativity and innovation that are at the heart of all research advances. Discovery Grants are considered 'grants in aid' of research as they provide long term operating funds to support the costs of a research program. As a grant in aid of research, Discovery Grants are not meant to support the full costs of a research program and they can facilitate access to funding from other programs. NSERC recognizes that, while being of a grant in aid nature, Discovery Grants must be sufficient to support a program of quality research that can have a meaningful impact on the field of study.

Recipients of Discovery Grants are not restricted to the specific activities described in their applications, but may pursue new research interests, provided they are within NSERC's mandate. This provides researchers with the flexibility to pursue promising research avenues as they emerge and the opportunity to address higher-risk (higher reward) topics. Researchers can use their grants to participate in collaborative efforts. (2017, www.nserc-crsng.gc.ca/Professors-Professeurs/Grants-Subs/DGIGP-PSIGP_eng.asp)

Industrial Research Chairs (IRC) Grants

Industrial Research Chairs (IRC) are intended to: assist universities in building on existing strengths to achieve the critical mass required for a major research endeavour in natural sciences and engineering of interest to industry; and/or assist in the development of research efforts in fields that have not yet been developed in Canadian universities but for which there is an important industrial need; and provide an enhanced training environment for graduate students and, where appropriate, postdoctoral fellows by exposing them to research challenges unique to industry and the opportunity for significant ongoing interactions with the industrial partner(s).

NSERC offers three types of IRCs:

- **Senior Industrial Research Chairs** for distinguished senior researchers (five-year appointment, renewable);
- **Associate Industrial Research Chairs** for early-stage researchers demonstrating exceptional promise (five-year appointment, renewable once); and
- **Executive Industrial Research Chairs** for outstanding R&D professionals (five-year appointment, non-renewable).

An IRC grant provides funding for the salary of the Chairholder, infrastructure, research tools, instruments, and general expenses related to the Chair's program of research. Chairholders are expected to focus their activities on conducting research and training highly qualified personnel, while carrying a reduced administrative and teaching load.

IRCs are funded jointly by NSERC and industry. Provincial or federal government departments and agencies may also co-sponsor/support an IRC, but only the industrial contributions are taken into account when NSERC determines its funding level.
(2017, adapted from www.nserc-crsng.gc.ca/professors-professeurs/cfs-pcp/irc-pci_eng.asp)

Industrial Research Chairs for Colleges (IRCC) Grants

Industrial Research Chairs for Colleges (IRCC) Grants support Chair programs across the spectrum of natural and social sciences, engineering, humanities, and/or health sciences fields. Grants are given by NSERC, with the exception of funded proposals exclusively in the social sciences, humanities, and/or health sciences, which will be given by SSHRC or CIHR, as appropriate.

IRCC Grants support applied research leaders and their development of business-focused applied research programs at colleges. It is expected that the establishment of applied research leaders will enable the realization of the following objectives:

- Increased delivery of innovative applied research solutions to local companies at the community and/or regional level;
- Enhanced teaching and curricula;
- Increased participation of faculty and other college staff in applied research activities;
- Increased opportunities for students to gain industrial problem-solving experience; and
- Increased knowledge and technology transfer between colleges and companies, with the objective of increasing the productivity and competitiveness of local companies, particularly small and medium-sized enterprises (SMEs).

IRCC Grants assist colleges to develop new or significantly enhance existing applied research efforts and capacity in areas that meet local or regional socio-economic needs. Chairholders are expected to conduct a program of applied research with partner companies. Candidates should therefore have a strong track record in conducting and managing industry-focused applied research projects. The applied research projects will provide an enhanced training environment for students and college personnel by giving them the opportunity to address applied research challenges with the private sector and to participate in significant ongoing interactions with business partners.
(2017, adapted from www.nserc-crsng.gc.ca/Professors-Professeurs/RPP-PP/IRCC-CRIC_eng.asp)

Postdoctoral Fellowship (PDF) Program

The Postdoctoral Fellowships (PDF) Program provides support to a core of the most promising researchers at a pivotal time in their careers. The fellowships are also intended to secure a supply of highly qualified Canadians with leading edge scientific and research skills for Canadian industry, government and universities.
(2017, www.nserc-crsng.gc.ca/Students-Etudiants/PD-NP/PDF-BP_eng.asp)

Strategic Partnership Grants for Networks (SPG-N)

Strategic Partnership Grants for Networks (SPG-N) fund large-scale, multidisciplinary research projects in targeted research areas that require a network approach and that involve collaboration between academic researchers and Canadian-based organizations. The applicant should be an established researcher with a solid track record in collaborative research, student training, and grant management, and who demonstrates the leadership and other skills necessary for managing a complex, interdisciplinary, multi-institutional project.

It is expected that these grants will:

- Generate new knowledge/technology with the strong potential to strengthen Canada's industrial base, generate wealth, create employment, and/or influence Canadian public policy;
- Increase the number of highly qualified personnel in the specified target areas; and
- Enable the transfer of knowledge/technology and expertise to Canadian-based companies that are well-positioned to apply the results for economic gain or to government organizations to strengthen public policy.

(2017, adapted from www.nserc-crsng.gc.ca/Professors-Professeurs/RPP-PP/SPG-SPS_eng.asp)

Pacific Salmon Commission (PSC)

The Pacific Salmon Commission (PSC) is an international decision-making organization, composed of four Commissioners (and four alternates) from the United States and Canada. This body handles ongoing administration of the Pacific Salmon Treaty through advice from four regional Panels of fisheries experts. Scientific advice on salmon populations and appropriate fishery controls comes from several joint technical committees of salmon scientists from each country.

As a treaty organization, the PSC facilitates implementation of the Treaty through research and regular meetings between national, provincial/state, First Nation, and U.S. tribal delegates to manage commercial, sport, and subsistence fisheries in both countries.

It has responsibility for all salmon originating in the waters of one country which are subject to interception by the other, affect management of the other country's salmon, or affect biologically the stocks of the other country. In addition, the Pacific Salmon Commission is charged with taking into account the conservation of steelhead trout while fulfilling its other functions.
(2017, www.psc.org)

Pacific Salmon Foundation (PSF)

The Pacific Salmon Foundation, founded in 1987, is a federally incorporated non-profit charitable organization dedicated to the conservation and restoration of wild Pacific Salmon and their natural habitats in British Columbia and the Yukon. Operating independently from government, The Foundation facilitates dialogue and undertakes positive initiatives in support of Pacific salmon amongst all levels of government including First Nations; as well as industry, communities, individual volunteers, and all fishing interests.

The Pacific Salmon Foundation exists to support 'salmon communities' in their efforts, promote awareness of this keystone species, and guide the sustainable future of wild Pacific Salmon and their habitat.

The Foundation partnered with British Columbia MP's to secure $1 million more in funds for community projects by increasing its share of Salmon Stamp user fees and worked with Fisheries and Oceans Canada on creation of the federal Recreational Fisheries Conservation Partnerships Program.

We steward the investment of our available resources – both human and financial – to optimize our collective return. We are a vocal advocate, speaking as the voice of the salmon community to articulate the issues affecting our mandate.

With ongoing education, partnership and collaboration, we will positively transform people's outlook to realize the connection wild Pacific Salmon have with everything that is British Columbia.
(2017, www.psf.ca)

Ressources Aquatiques Québec (RAQ)

Ressources Aquatiques Québec is an interinstitutional grouping for the sustainable development of the aquaculture and fisheries industry in Québec. It brings together about forty Québec researchers with a large network of collaborators at the provincial, national and international levels.

The regular members of RAQ are from nine universities (Université du Québec à Rimouski, Université Laval, Université de Montréal, Université de Sherbrooke, Institut National de la Recherche Scientifique The École Polytechnique de Montréal, the Université du Québec à Chicoutimi and the Université du Québec à Montréal), a college-level institution (Cégep de la Gaspésie et des Îles), the Ministère des Forêts, Faune et Parks, Fisheries and Oceans Canada, Agriculture and Agri-Food Canada and the Canadian Museum of Nature, Merinov, the Montreal Biodome and the MBRC.

RAQ has been financially supported since 2006 by the Québec Research Fund – Nature and Technologies (Strategic Grouping Program). RAQ is the only inter-institutional organization in Québec whose objective is to participate actively in the sustainable development of the aquaculture industry and the fishing industry in Québec. It brings together Québec's freshwater and coastal expertise, as well as the skills on shellfish and fish, in a single forum involving industry and decision-makers, biotechnology, economic, legal, and ethical issues.
(2017, raq.uqar.ca)

Sea Pact

Sea Pact will improve the sustainability of global seafood by using the collective power of like-minded North American seafood companies to improve the fishing and fish farming systems we procure from. Sea Pact was created by the six founding members: Albion Fisheries, Fortune Fish & Gourmet, Ipswich Shellfish Group, Santa Monica Seafood, Seacore Seafood and Seattle Fish Co. Sea Pact now consists of nine members.

Sea Pact is a group of leading North American Seafood Companies dedicated to driving stewardship and continuous improvement of social, economic, and environmental responsibility throughout the global seafood supply chain.

Sea Pact strives to advance environmentally sustainable fisheries and aquaculture practices and provide the building blocks for a long term and sustainable seafood industry. To accomplish this, Sea Pact has pledged to financially contribute to selected projects that are aligned with Sea Pact's mission. Sea Pact wishes to place an emphasis on projects that are engaging in efforts relating to bycatch reduction, innovations in aquaculture, or social responsibility within the seafood supply chain. Projects impacting the top seafood species consumed on a global level are preferred.
(2017, www.seapact.org)

Social Sciences and Humanities Research Council of Canada (SSHRC)

SSHRC CRSH
Social Sciences and Humanities Research Council of Canada
Conseil de recherches en sciences humaines du Canada

The Social Sciences and Humanities Research Council of Canada (SSHRC) is the federal research funding agency that promotes and supports postsecondary-based research and research training in the humanities and social sciences. By focusing on developing Talent, generating Insights, and forging Connections across campuses and communities, SSHRC strategically supports world-leading initiatives that reflect a commitment to ensuring a better future for Canada and the world.

SSHRC-supported research in the social sciences and humanities enhances our understanding of modern social, cultural, technological, environmental, economic, and wellness issues. It raises profound questions about who we are as human beings, what we need in order to thrive in complex and challenging times, and where we are headed in the new millennium.

The work SSHRC supports encourages the deepest levels of inquiry. It spurs innovative researchers to learn from one another's disciplines, delve into multiparty collaborations, and achieve common goals for the betterment of Canadian society. Research outcomes are shared with communities, businesses, and governments, who use this new knowledge to innovate and improve people's lives.

SSHRC also invests directly in Canada's future. Through the social sciences and humanities, students receive the best possible training in critical thinking, complex decision-making, and creative exploration. By investing in scholarships, fellowships, and research training, SSHRC helps develop Canada's best and brightest scholars and researchers into Canada's future leaders.

SSHRC-funded research builds understanding that can help change the world. As such, it has taken its place as a central component of Canadian innovation. (2017, www.sshrc-crsh.gc.ca/)

A seaside boardwalk in the Madgalen Islands, Quebec. Photo: Ingrid Burgetz (DFO)

GLOSSARY

AAFC	Agriculture and Agri-Food Canada
AAR	Aquaculture Activity Regulations
AARS	Alma Aquaculture Research Station (U Guelph)
AC	Assimilative Capacity
ACC	Algal Carbon Conversion
ACFFA	Atlantic Canada Fish Farmers Association
ACOA	Atlantic Canada Opportunities Agency
ACOA-AIF	Atlantic Canada Opportunities Agency – Atlantic Innovation Fund
ACRDP	Aquaculture Collaborative Research and Development Program (DFO)
ADCP	Acoustic Doppler Current Profiler
AGD	Amoebic Gill Disease
AIF	Atlantic Innovation Fund
AIS	Aquatic Invasive Species
Al	Aluminum
APC	Artificial Positive Control
ARM	Artificial Reference Material
As	Arsenic
AVC	Atlantic Veterinary College (UPEI)
BC	British Columbia
BCSFA	British Columbia Salmon Farmers Association
BCSGA	British Columbia Shellfish Grower's Association
BDP	Business Development Program
BHA	Bassin du Havre Aubert
BKD	Bacterial Kidney Disease
BOD	Biochemical Oxygen Demand / Biochemical Oxygen Demanding
Ca	Calcium
CAAHRD	Centre for Aquatic Animal Health Research and Diagnostics (DFO)
CAISN	Canadian Aquatic Invasive Species Network
CARTI	Centre for Applied Research, Technology, and Innovation (NIC)
CAT	Center for Aquaculture Technologies
CATC	Center for Aquaculture Technologies Canada
CCA	Closed Containment Aquaculture
CCGS	Canadian Coast Guard Ship
CCH	Centre for Coastal Health
CCI	College and Community Innovation Program (NSERC)
Cd	Cadmium
CDBQ	Centre de développement Bioalimentaire du Québec
CÉGEP	General and Vocational College (Québec)
CERC	Canada Excellence Research Chair
CFIA	Canadian Food Inspection Agency
CIHR	Canadian Institutes of Health Research
CIMTAN	Canadian Integrated Multi-Trophic Aquaculture Network
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRCP	Canada Research Chairs Program
CTD	Conductivity, Temperature, and Depth
Cu	Copper
CyHV-3	Cyprinid Herpesvirus 3
CZRI	Coastal Zones Research Institute
DAAF	Department of Agriculture, Aquaculture, and Fisheries (New Brunswick)
Dalhousie U	Dalhousie University
DEB	Dynamic Energy Budget
DELG	Department of the Environment and Local Government (New Brunswick)
DFA	Department of Fisheries and Aquaculture of Newfoundland and Labrador
DFARD	Department of Fisheries, Aquaculture, and Rural Development (PEI)
DFO	Fisheries and Oceans Canada
DIDSON	Dual frequency IDentification SONar
DNA	Deoxyribonucleic Acid
Duke U	Duke University
EB	Emamectin Benzoate
ECC	Ecological Carrying Capacity
ECCC	Environment and Climate Change Canada
eDNA	Environmental DNA
Eh	Redox Potential
ELISA	Enzyme-Linked Immunosorbent Assay
ENGO	Environmental Non-Governmental Organization
EPAQ	École des Pêches de l'Aquaculture et du Québec
FAP	Fonds d'Amorçage de Partenariat
Fe	Iron
FFAW	Fish, Food, and Allied Workers Union
FIMTA	Freshwater Integrated Multi-Trophic Aquaculture
FL	Fork Length
FRQNT	Fonds de recherche du Québec – Nature et technologies
FRQS	Fonds de recherche du Québec – Santé
FRQSC	Fonds de recherche du Québec – Société et culture
FSWEP	Federal Student Work Experience Program
FVCOM	Finite Volume Coastal Ocean Model
Glasgow U	Glasgow University
GPS	Global Positioning System
GRDI	Genomics Research and Development Initiative (DFO)
GWAS	Genome-Wide Association Studies
HC	Health Canada
HMSC	Huntsman Marine Science Centre
HPLC	High Performance Liquid Chromatography
HQP	Highly Qualified Personnel
HSMI	Heart and Skeletal Muscle Inflamation
iBoF	Inner Bay of Fundy
ICAM	Integrated Coastal Area Management
IFREMER	French Research Institute for Exploration of the Sea
IHN	Infectious Haematopoietic Necrosis
IHNV	Infectious Haematopoietic Necrosis Virus
IMTA	Integrated Multi-Trophic Aquaculture
IPC	Internal positive control
IPMP	Integrated Pest Management Practices
IRAP	Industrial Research Assistance Program (NRC)
IRC	Industrial Research Chairs (NSERC)
IRCC	Industrial Research Chairs for Colleges (NSERC)
ISA	Infectious Salmon Anemia
ISAV	Infectious Salmon Anemia Virus
ISMER	Institut des Sciences de la Mer de Rimouski (UQAR)
ISO	International Organization for Standards
ITC	Introductions and Transfers Committee
K	Potassium
KCS	Kelly Cove Salmon Ltd.
KHVD	Koi Herpes Virus Disease
LED	Light Emitting Diode
LTER	Long Term Ecological Research
MAPAQ	Quebec Department of Agriculture, Fisheries, and Food
MAS	Marker Assisted Selection
McGill U	McGill University
MDEIE	Ministère du Développement économique, de l'Innovation et de l'Exportation, Québec
MÉES	Ministère de l'éducation et de l'enseignement supérieur du Québec [Québec Ministry of Higher Education and Training]
MERP	Marine Environmental Research Program (BCSFA)
Mg	Magnesium
MIMTA	Marine Integrated Multi-Trophic Aquaculture

MITACS	Mathematics of Information Technology and Complex Systems
Mn	Manganese
MNRF	Ontario Ministry of Natural Resources and Forestry
Mount Allison U	Mount Allison University
MPA	Marine Protected Area
MSX	Multinucleate Sphere X
MUN	Memorial University of Newfoundland
Na	Sodium
NAAHLS	National Aquatic Animal Health Laboratory System (DFO)
NAAHP	National Aquatic Animal Health Program (DFO)
NaPi	Sodium phosphate
NB	New Brunswick
NBDAAF	New Brunswick Department of Agriculture, Aquaculture, and Fisheries
NBIF	New Brunswick Innovation Foundation
NBRPC	New Brunswick Research Productivity Council
NCAG	National Contaminants Advisory Group (DFO)
NCLDV	Nucleo-Cytoplasmic Large DNA Virus
NCP	National Conservation Plan
NIC	North Island College
NL	Newfoundland and Labrador
NOAA	US National Oceanographic and Atmospheric Administration
Nord U	Nord University
NRC	National Research Council
NSCC	Nova Scotia Community College
NSDFA	Nova Scotia Department of Fisheries and Aquaculture
NSERC	Natural Sciences and Engineering Research Council
NV	Namao Virus
OA	Ocean Acidification
OGS	Ontario Graduate Scholarship
OIE	World Organization for Animal Health
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs (now Ontario Ministry of Agriculture and Food)
OPC	Opportunistic Polychaete Complex
OTN	Ocean Tracking Network
P	Phosphorus
PARR	Program for Aquaculture Regulatory Research
Pb	Lead
PCR	Polymerase Chain Reaction
PDF	Postdoctoral Fellowship
PEI	Prince Edward Island
PEIAA	Prince Edward Island Aquaculture Alliance
PEI-DFARD	Prince Edward Island Department of Fisheries, Aquaculture, and Rural Development
PGD	Proliferative Gill Disease/Disorder
PGI	Proliferative Gill Inflammation
ppm	Parts per million
ppt	Parts per thousand
PRV	Piscine Reovirus
PSC	Pacific Salmon Commission
PSF	Pacific Salmon Foundation
qPCR	Quantitative (Real-Time) Polymerase Chain Reaction
QTL	Quantitative Trait Loci
RAQ	Ressources Aquatiques Québec
RAS	Recirculating Aquaculture System
RNA	Ribonucleic Acid
ROV	Remotely Operated Vehicle
RPC	Research and Productivity Council (NB)
RT-qPCR	Reverse Transcriptase Quantitative Polymerase Chain Reaction
SABM	Société des Amis du Biodôme de Montréal
SAV	Salmon Alphavirus
SFU	Simon Fraser University
SGPV	Salmon Gill Poxvirus
SIMCorp	Sweeney International Marine Corp.
SME	Small and Medium-Sized Enterprises
sNCLDV	Sturgeon Nucleo-Cytoplasmic Large DNA Virus
SNP	Single Nucleotide Polymorphism
SODIM	Société de Développement de l'Industrie Maricole Inc.
SORDAC	Société de Recherche et de Développement en Aquaculture Continentale Inc.
SPDV	Salmon Pancreas Disease Virus
SSHRC	Social Sciences and Humanities Research Council of Canada
StFX	St. Francis Xavier University
STZ	Shellfish Transfer Zone
SVCV	Spring Veremia of Carp Virus
TFM	3-trifluoromethyl-4-nitrophenol
Trent U	Trent University
U Geneva	University of Geneva
U Guelph	University of Guelph
U Laval	University of Laval
U Maine	University of Maine
U Moncton	University of Moncton
U of M	University of Manitoba
U of T	University of Toronto
U Turku	University of Turku
U Washington	University of Washington
U Waterloo	University of Waterloo
U Windsor	University of Windsor
UBC	Univeristy of British Columbia
UBO	University of Western Brittany Brest
UdeM	University of Montréal
UNB	University of New Brunswick
UNBF	University of New Brunswick – Fredericton
UNBSJ	University of New Brunswick – Saint John
UPEI	Univeristy of Prince Edward Island
UPEI – AVC	University of Prince Edward Island – Atlantic Veterinary College
UQAC	University of Quebec – Chicoutimi
UQAR	University of Quebec – Rimouski
US-EPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Services
USGS	United States Geological Survey
UV	Ultraviolet
UVic	University of Victoria
UW	University Centre of the Westfjords (Iceland)
VHS	Viral Hemorrhagic Septicemia
VHSV	Viral Hemorrhagic Septicemia Virus
VIU	Vancouver Island University
WLU	Wilfrid Laurier University
WSIV	White Sturgeon iridovirus
WSSV	White Spot Syndrome Virus
Zn	Zinc

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