CtrlAQUA

Annual Report 2021
CtrlAQUA - Centre for Closed-Containment Aquaculture

sfi Centre for Research-based Innovation
The Research Council of Norway

Front page and picture above
In the picture above, Aquafarm's system Neptun 4 is getting ready for transport to hook-up at SalMar's location in Sekken while the front page shows it during. Neptun 4 is fitted with a water treatment system that includes UV as well as a sludge collection/treatment system that will be retrofitted, making Neptun 4 a state-of-the-art sustainable semi-closed production facility. Photo: ©Aquafarm.

Please use the following citation when referencing the Annual report:
Multiple Authors (2022). Annual Report 2021 CtrlAQUA – Centre for Closed-containment Aquaculture, eds.

CONTENT

1 OVERALL PROGRESS AND SUMMARY FOR 2021

CtrlAQUA SFI was kicked off in spring 2015 as a Centre for Research-based Innovation for Closed-containment Aquaculture. Our vision is to make closed-containment aquaculture systems (CCS) a reliable and economically viable technology, and we even said that the technology should become commercially available. The latter point is now the case for many of the systems used by centre partners, including for some of the partners using or producing semi-closed systems. In the annual report for 2021, we will put some focus on implementation and to what extent CtrlAQUA results have made the systems more “off the shelf”.

Are Nylund, professor at the University in Bergen has since 2015 followed pathogens associated with closed systems, dispersion, intake route and risk for accumulation in the systems. In the interview published in this annual report he gives his thoughts, based on obtained knowledge about how far from commercialization the semi-closed systems that he has followed are regarding preventing pathogens and need for further development. Are Nylund gives some good advice to the users and producers of semi-closed systems and to the regulatory bodies. Best practice and implementation are also of interest in the interviews with three of CtrlAQUA doctor students that finished in 2021: Sharada Navada, who defended her PhD thesis “Salinity acclimation strategies for nitrifying bioreactors in recirculating aquaculture systems” at NTNU, February 2021; John Davidson, who defended his thesis "Evaluating the suitability of RAS culture environment for rainbow trout and Atlantic salmon: A ten-year progression of applied research and technological advancements to optimize water quality and fish performance" for Dr. philos degree, June 2021 and Enrique Pino Martinez, who defended his PhD thesis "Influence of water temperature, photoperiod and feeding regime on early sexual maturation of Atlantic salmon (Salmo salar L.) postsmolts in freshwater", December 2021. Other students who finish in 2022 will be presented in the annual report for 2022 as well. In the third and final interview, researchers Trine Ytrestøyl (Nofima) and Tom Ole Nilsen (UiB) talk about the BENCHMARK project, where we have the possibility to investigate the effects of different smolt protocols, in terms of photoperiod and salinity until the fish reach market size. We are now running the second BENCHMARK project in CtrlAQUA and together with the associated FHF project “Kunnskapskartlegging - produksjon av stor laksesmolt” we begin to have some indications for optimal smolt protocols, the effects in RAS and of a longer run to slaughter.

BENCHMARK has been the major experiment in 2021 that will also continue in 2022. We have made efforts to utilize the comprehensive experiment as much as possible by sampling fish, water, sludge, and CO_2 for other CtrlAQUA projects. Also, fish material has been used for nephrocalcinosis investigations and multigene expression, skin quality and barrier functions. Lastly, the experiment has been used to test degassing units and for sampling sludge for H_2S monitoring.

The year 2021 was once again highly influenced by Covid-19, and we had to delay some activities where we needed to visit user partners. Fortunately, there was an opening during the autumn that gave us a long-awaited possibility to fulfil some of the tasks that required travelling. The annual meeting sadly needed to be held digitally for the second year in a row, as Covid-19 did not

High activity when researchers, students, and technicians from Norce and Nofima are sampling in project BENCHMARK at Nofima in Sunndalsøra, autumn 2021. Photo: Terje Aamodt, ©Nofima.

allow us to travel during the spring. Still, 65 participants joined the meeting that lasted for two days and provided many interesting project updates and partner contributions. By the end of 2021 we had registered 48 MSc students and 13 PhD students. However, two more PhD students that should have been in the list for 2021 were added in February 2022. We have then achieved the goal of 15 PhD students, in the centre. Many of these are now publishing and finishing, meaning that together with the project participants, the PhD students are contributing significantly to the knowledge transfer from the centre.

We hope that you will enjoy reading the annual report 2021.

March 2022
Åsa Maria Espmark
Centre Director CtrlAQUA SFI

Åsa Maria Espmark. Photo: Kevin Torben Stiller, Nofima.

Vision and objectives of CtrlAQUA SFI – Centre for Closed-Containment Aquaculture

The Norwegian salmon industry and the government are aiming to increase the production in the years to come. However, this growth must be sustainable and not put environment and fish health and welfare at risk. Previous ambitions for a five-fold increase in volume has later been modified, because the capability of growth will depend on many environmental and social factors, including how we manage sea lice, pathogens and escapes, and how increased usage of land and sea areas needed for growth will affect other businesses and the public interests. Innovations in closed-containment aquaculture systems, where the salmon is separated from the outside environment by a closed barrier, will be important for further development of aquaculture, since these technologies may be a key to solve many of the challenges. CtrlAQUA is a centre for research-based innovation (SFI) that will work on such closed-containment systems. The main goal of CtrlAQUA SFI is to:

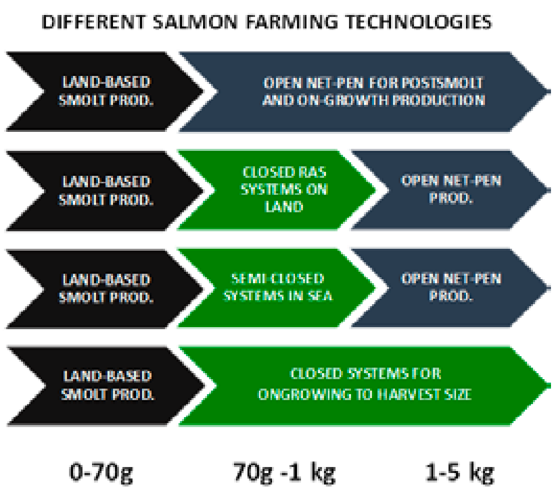


Figure 1.1. Different ways of producing Atlantic salmon: Closed-containment aquaculture systems.

"Develop technological and biological innovations to make closed-containment aquaculture systems (CCS) a reliable and economically viable technology, for use in strategic parts of the Atlantic salmon production cycle, thus contributing significantly to solving the challenges limiting the envisioned growth in aquaculture".

Closed systems can be land-based where water is recycled (RAS), or sea-based, in which large floating tanks receive clean water from depth (S-CCS). In CtrlAQUA the research deals with both approaches.

In the centre we focus primarily on the most sensitive phases for the salmon in the production cycle, such as the first seawater phase, the so-called post-smolt stage (Figure 1.1). However, the research is also highly relevant for other strategies shown in the figure. The main innovation will be reliable and efficient production of robust post-smolts in closed and semi-closed systems on land and at sea. Thus, the industry can get a good realistic alternative or supplement to the currently most common production technology with open cages. The centre will also contribute to better production control, fish health, welfare, and sustainability in closed-containment farms. We do this through development of new and reliable sensors, methods for producing and recognizing robust fish, minimizing environmental impact through water treatment, reduce the risk of escape, and disease transmission to wild stocks and optimizing tank/cage environment, amongst others. These innovations will be of value to the Norwegian society, since closed systems for strategic phases in salmon farming can contribute to the foreseen growth.

Some of the people working at Bremnes Seashore with Sigrid Johansen (lower right) representing the future generation in fish farming. In photos: upper left Eldbjørn Strand, upper right Marita Trovåg, lower left Jorunn Ånestad. Photos: Inger Lise Breivik, Bremnes.

Do semi-closed facilities in the sea protect farmed salmon against pathogens? Which production protocols in RAS provide the best health and growth of post-smolt for grow-out up in sea? These questions are answered in three articles where researchers provide knowledge that hopefully authorities, fish farmers and suppliers will find useful to support their decisions in the production of safe and healthy farmed salmon. Read the articles here, at page 20-21 and 38-41.

Article by Reidun Lilleholt Kraugerud

Two pieces of fish health advice

Are Nylund, professor at the University of Bergen

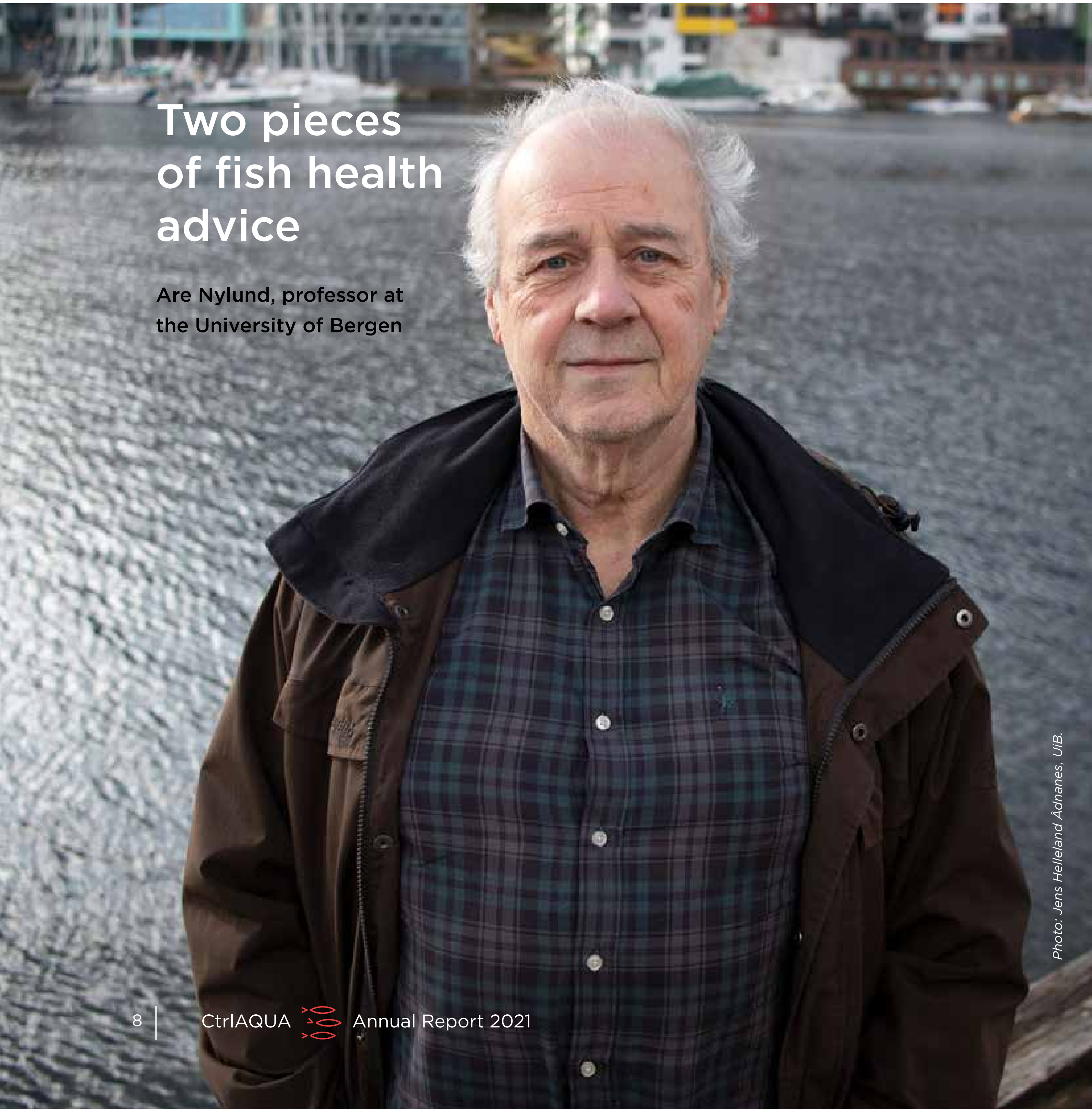


Photo: Jens Helleland Ådnanes, UiB.

"The fact that there are few salmon lice in semi-closed fish farms is the main argument for these farms having a future", says Are Nylund, a professor in fish health at the University of Bergen.

Nylund has been researching pathogenic organisms in closed fish farms since CtrlAQUA started in 2015.

“Avoiding sea lice was an important motivating factor when the industry started establishing closed facilities at sea. And the facilities are largely successful”, says Nylund.

Salmon lice are found in the upper metres of the water column, while the water intake is usually at a depth of 20 metres. This means that the salmon avoid a large part of the infestation.

In CtrlAQUA, Nylund has collaborated with Lerøy (the Preline system), Mowi (the Neptune net-pen) and Cermaq (the Certus net-pen). He has monitored many production cycles and have a good idea of the situation regarding pathogens.

However, there are several challenges that need to be addressed before the facilities can be put on the market:

“All the facilities I work with are prototypes that clearly need to be improved. They are designed for calm seas and cannot be placed anywhere. That’s just one of the challenges. And then there are some improvements that can be made to improve fish health in addition to avoiding salmon lice”, says Nylund.

Clean smolt and deeper water intakes

Nylund’s research in CtrlAQUA shows that many of the pathogens found in a semi-closed facility accompany the smolt from the hatchery, with the exception of the marine pathogens. The fish health professor’s main piece of advice to fish farmers is therefore to ensure that the smolt they release into their semi-enclosed facilities are pathogen-free.

His other piece of advice is to place the water intake at greater depths. This was originally the ambition.

“It should be possible to place the water intake at a depth greater than 20 metres. If you go deeper, you avoid more marine pathogens, despite the fact that the Tenacibaculum bacterium and the AGD amoeba will still be found there”, says Nylund.

Moving fish across zones

It is a well-known problem for fish farmers who have semi-closed facilities that these expensive installations that are intended to be more environmentally friendly are nevertheless regulated as if they were open net-pens. Among other things, it means that fish farmers are not allowed to move fish across zones. For fish farmers in some areas, keeping the fish within a zone is an operational challenge.

Nylund supports the practice from the authorities on this point, and believes that there are still too many things that are unresolved to move fish across zones.

“Our research shows that as long as you do not have smolt that are free of viruses, you will get viruses in semi-closed facilities or any other aquaculture system for that matter”, says Nylund.

However, he does not recommend having frameworks that are too strict during a developmental phase:

“Authorities must allow the industry to continue to develop semi-closed systems if they insist on keeping that kind of solution”, says Nylund.

“I think the aquaculture industry should be based at sea, except for smolt production. At least based on the knowledge we have today. We must focus on the sea, that is where the advantages lie, and we need to continue to develop semi-closed facilities to avoid salmon lice”, concludes Nylund.

2 RESEARCH PLAN/STRATEGY

The Centre for research-based innovation in closed-containment aquaculture, CtrlAQUA, commenced operations in April 2015. The Research Council of Norway's objectives in running the SFI-program are four-fold: 1) to stimulate innovation activities in strong industries in Norway, 2) to promote collaboration between innovative industries and excellent research institutions, 3) to develop industry-relevant research institutions that are leading in their field, and 4) to educate new scientists and foster knowledge- and technology transfer. These goals, in addition to the specific goals of the centre, form the basis for the work in CtrlAQUA. Through close collaboration between user partners and the R&D institutions, the centre focus on closed-containment system innovations, such as new RAS process units, development and implementation of prototypes and methods for improved fish welfare and health, shown in Figure 2.1

The work with the research annual plans is led by the leader group of CtrlAQUA, who uses several sources of information to develop the plans, including: the SFI Centre description, which was part of the proposal in 2014, the letters of intent by the user partners, meetings with the user partners, and input received from the partners during project, annual and thematic meetings. The Scientific Advisory Board (SAB) is appointed for CtrlAQUA, consisting of researchers and stakeholders with competencies in the fields of research in the centre. Important tasks of the SAB are to give advice during development of the annual plans and to evaluate the work in the centre that annually ends up in a written report.

The annual plan consists of common projects and user-specific projects. Both types of projects contribute towards the main goal of the centre. Common projects are activities that benefit all partners in the centre, such as environmental requirements of salmonids in closed systems and optimal use of sensors, securing health and welfare, and hydrodynamic modelling. User-specific projects are defined as activities that also benefit the entire centre, but are particularly important for one user partner, or a group of user partners. From 2015, we also included associated projects, defined as: "*A project*

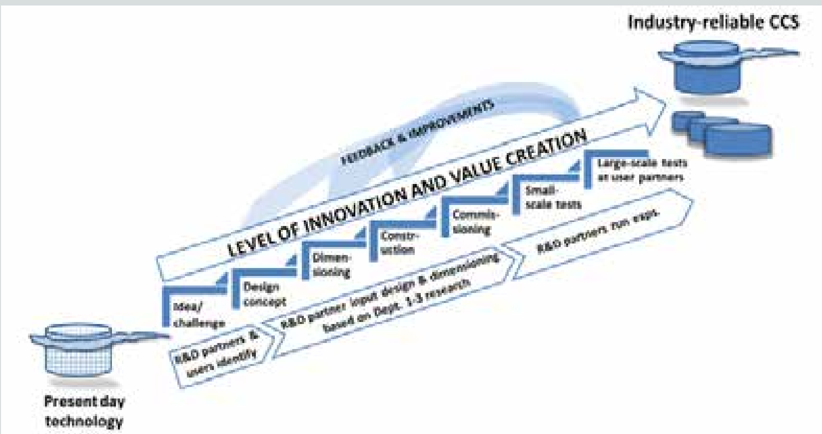


Figure 2.1. Innovation process in CtrlAQUA, from present day cage technology to establishment of industry-reliable closed-containment systems, either in-sea closed tanks or land-based RAS. Exps. = experiments.

New smolt hatchery delivered for Salten Smolt in Breivika - Smolt department. Photo: ©Pure Salmon Kaldnes.

can be termed an "Associated Project" to CtrlAQUA, and be entitled as such when applying for grants. The consortium behind this Associated Project must agree to share results with CtrlAQUA partners. The project owner of this Associated Project can participate at CtrlAQUA annual meetings, except when IPR-sensitive results are presented. CtrlAQUA partners will have no access rights or other IPR rights to results from the Associated Project, or vice versa, without written agreements similar to other third parties".

During preparation of the SFI centre description, several innovations were described and defined as innovation deliverables. These innovation deliverables are further linked to the departments and their specific research tasks. In the annual plan, each project is linked to one or more Innovation deliverables, and this is an important tool during discussions of the research plans. Innovations are also defined when user partners implement CtrlAQUA results into their businesses as improved routines or operations.

After the mid-way evaluation of CtrlAQUA in 2019, we have implemented three new focus areas that were not part of the original centre description. These are issues with hydrogen sulfide, nephrocalcinosis and early sexual maturation.

3 ORGANIZATION

Organizational structure and cooperation between the centre's partners

CtrlAQUA is organized (Figure 3.1) with a Board that oversees that obligations are fulfilled, and are responsible for finances, partnerships, and IPR issues, as well as ratifying annual research plans made by the leader group. In 2021, the Board had two physical meetings as well as digital one. The Board consisted in 2021 of the following elected members:

- Trond Rosten, Mowi, Chairperson of the CtrlAQUA Board
- Harald Takle, Cermaq, Board Member
- Hans Kleivdal, NORCE, Board Member
- Hilde Toften, Nofima, Board Member and representing the host institution
- Frederic Gaumet, Pure Salmon Kaldnes, Board Member
- Rolf Hetlelid-Olsen, PHARMAQ, Board Member

Each board member category (farming category, technology and biotechnology category, NORCE, Nofima) has a deputy. The Board members are suggested by an election committee consisting of three members and led by the host institution.

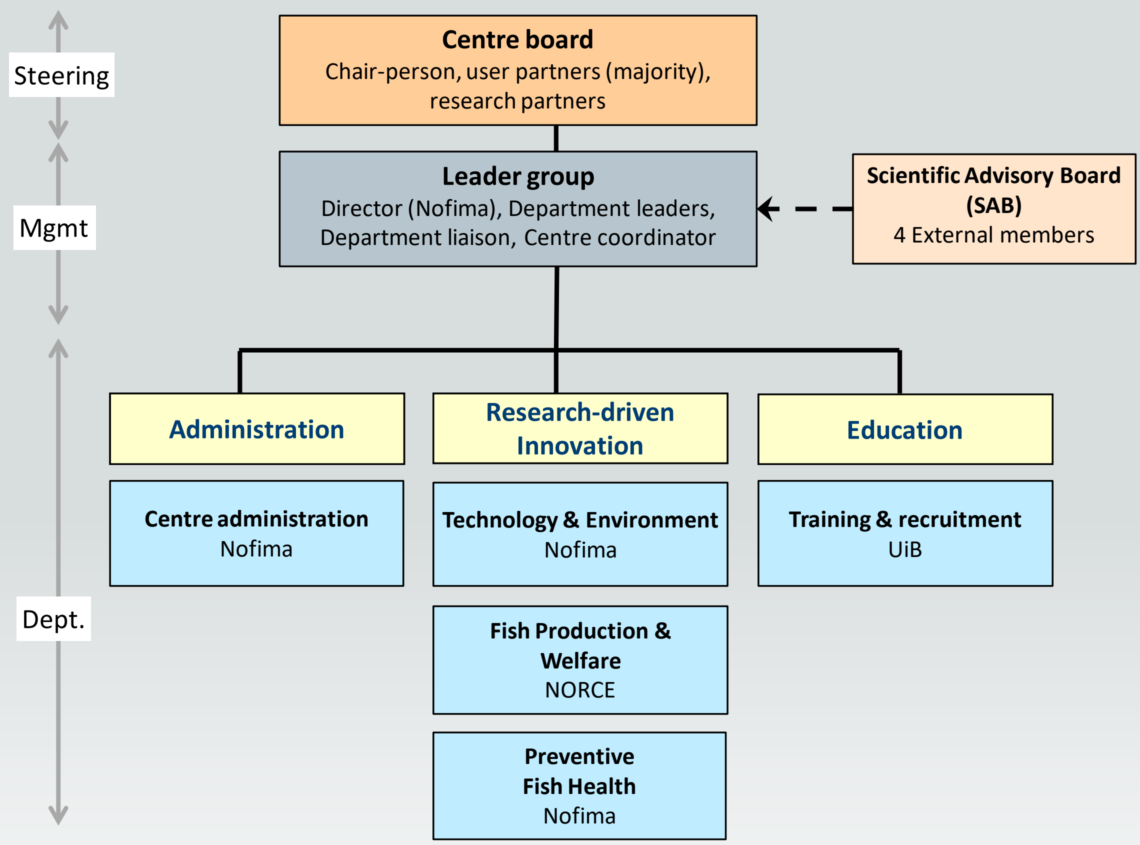


Figure 3.1. Organizational structure of CtrlAQUA.

The CtrlAQUA leader group. From left: Åsa Espmark, Sigurd Stefansson, Kasper Thøring Juul-Dam, Naouel Gharbi, Tom Ole Nilsen, Lill-Heidi Johansen and Jelena Kolarevic. Photo: Silje Katrine Robinson.

In addition, Kjersti Turid Fjalestad, the contact person for CtrlAQUA at the Research Council of Norway, is invited as observer at the Board meetings.

The centre scientific work is organised through close collaboration between three departments: Dept. Technology & Environment, Dept. Fish Production & Welfare, and Dept. Preventive Fish Health, whereas student recruitment and management are managed in Dept. Training & Recruitment. The Dept. of Liaison ensures smooth collaboration between departments and identifies subprojects and user partners for projects.

The leader group manages and leads CtrlAQUA, such as ensuring strategic planning and running of projects, recruitment of qualified personnel, and providing a good working environment and communication between partners.

In CtrlAQUA there has been a focus on collaboration and knowledge transfer between the partners from the start. This collaboration has been done within the projects, and occurred between R&D partner scientists, scientists and user partners, and between user partners. The extensive collaborations are facilitated by participation from all institutions in project workshops, thematic meetings, as well as joint experiments, sampling and analytical work. Frequent meetings are organized at Board level (each six months), centre level (annual meetings), leader group (every third week), and thematic or project level (as required). Furthermore, the intranet has a news feed where centre participants have posted e.g. news, links to documents, research plans, results, pictures and videos. In addition to a formal news channel, the centre intranet has also been used as a social media, thus contributing to build the CtrlAQUA team spirit.

THE CtrlAQUA BOARD 2021

Trond Rosten
MOWI
Chairperson of the
CtrlAQUA Board

Harald Takle
Cermaq
Harald Takle
Board Member

Hans Kleivdal
NORCE
Board Member

Hilde Toften
Nofima
Board Member and
representing the host
institution

Frederic Gaumet
Krüger Kaldnes
Board Member

Rolf Hetlelid-Olsen
PHARMAQ
Board Member

PARTNERS

Per December 31st, 2021, CtrlAQUA has 21 partners, where seven are R&D partners and 14 are user partners.

R&D PARTNERS

Mowi is the world's leading seafood company and the largest producer of farm-raised salmon in Norway and the world. As the first global seafood company with an end-to-end supply chain, Mowi brings supreme quality salmon and other seafood to consumers around the world. Mowi develops future solutions for farming and is a key driver for innovation, both in Norway and globally. Business in Norway include being the largest aquaculture company in Norway with over 2000 employees and with operations along the Norwegian coast from Flekkefjord in Agder to Kvænangen in Troms. In CtrlAQUA, Mowi is represented by Group Manager Freshwater & Closed Production Technology, Trond W. Rosten. Sara Calabrese was employed in Mowi as an industry-PhD student linked to CtrlAQUA and defended her thesis in June 2017. Marianna Sebastianpillai completed her master thesis at NTNU linked to the QtrlAQUA collaboration and is now a Mowi employee. The semi closed-containment system site at Molnes in Sunnhordaland, other Mowi RAS sites also provide input and are involved in various projects in CtrlAQUA. With headquarters in Bergen, Norway, Mowi employs approximately 15.000 people in 25 countries worldwide, and is listed on the Oslo Stock Exchange.

Cermaq is one of the world's leading fish farming companies, with operations in Norway, Chile and Canada, supplying Atlantic salmon, Coho and trout to the global market. Cermaq's vision is to be the preferred global supplier of sustainable salmon. Cermaq Norway produces Atlantic salmon with operations in Nordland (22 licenses) and in Finnmark (27 licenses) with processing plants in both regions. The four freshwater sites are all located in Nordland. Cermaq sets its operations in the context of the UN Sustainable Development goals, and Cermaq is a key driver for research and innovation as well as transparency and partnerships. Fundamental to this work is Cermaq Norway's preventative health strategy for fish. This means using the knowledge of the salmon's biology, physiology, and environment, to achieve the best fit between production, fish welfare and growth. In CtrlAQUA, Cermaq Norway is represented by Head of Strategy and Seawater Innovation, Dr. Harald Takle. He has extensive background in research, R&D and strategy management, fish health and production optimization. Cermaq will also contribute with their fish health group, and closed system testing facilities.

FishGLOBE AS is a company that designs, builds and sells fully enclosed fish farms for sea. We are proud to have a globe in operation now and everything so far proves to be working as superior as we dreamed about. The globe is built in polyethylene which is the preferred material to use at sea. The polyethylene is a thermoplastic which works well with waves and is well-suited for fish farming. The clue to hold the structure/form and make it strong and stiff, is to use the inlet and outlet pipes. To be able to use this material it holds to patents. The company was established in 2013, but the development of closed aquaculture technology has roots back to the late 80's. The company is located in Forsand, Norway. The vision of FishGLOBE is to develop new cost-effective solutions that makes it possible for the aquaculture industry to expand. The business concept is to offer a solution to the salmon farmers that make farming more profitable, more sustainable and with higher fish welfare. FishGLOBE entered CtrlAQUA in November 2015 and is represented by manager Arne Berge.

Grieg Seafood ASA is one of the world's leading salmon farmers. Our farms are in Finnmark and Rogaland in Norway, British Columbia and Newfoundland in Canada, and Shetland in the UK. Our headquarter is located in Bergen, Norway. More than 900 people are employed by the company globally. Sustainable farming practices are the foundation of Grieg Seafood's operations, as the lowest possible environmental impact and the best possible fish welfare drive economic profitability. The company is represented in CtrlAQUA by Chief Technology Officer Knut Utheim. Grieg Seafood will contribute with their long experience in salmon aquaculture and RAS, as well as running large-scale trials.

Lerøy Seafood Group is a leading exporter of seafood from Norway and is in business of meeting the demand for food and culinary experiences in Norway and internationally by supplying seafood products through selected distributors to producers, institutional households and consumers. The Group's core activities are distribution, sale and marketing of seafood, processing of seafood, production of salmon, trout and other species, as well as product development. The Group operates through subsidiaries in Norway, Sweden, France and Portugal and through a network of sales offices that ensure its presence in the most important markets. Lerøy Seafood Group's vision is to be the leading and most profitable global supplier of quality seafood. In CtrlAQUA, Lerøy is represented by Technical Manager Harald Sveier, who has a long research background in fish physiology and nutrition. Sveier will head Lerøy's work in developing closed-containment systems, and the testing-site Samnanger.

Bremnes Seashore AS is one of Norway's leading suppliers of farmed salmon. Research and development have given them their own, patented production processes, and they established SALMA as Norway's first brand for fresh fish. Bremnes Seashore currently handles the full production chain for salmon and is one of the largest privately-owned salmon farming companies in Norway. The company has farming facilities in Hardanger, Sunnhordland and Rogaland, which are spread across 23 locations in 9 different municipalities. In CtrlAQUA, Bremnes Seashore is represented by Chief Advisor Geir Magne Knutsen, and the company contributes financially and with farming expertise and large-scale facilities.

Nekton AS is a holding company placed in Smøla County, Norway. The company owns Nekton Settefisk AS that has a production capacity of 5.5 million salmon smolt per year, on two sites. Initially the company started up in 1984, and in 1999 it invested in eel farming. The farm also had a cod license, but today's activities are production of salmon smolt. Nekton Settefisk is represented in CtrlAQUA by Quality manager Maria Sørøy and contributes with expertise on RAS and floating closed-containment systems in sea, and facilities and personnel for testing new closed-containment system concepts.

Aquafarm Equipment's ambition has been to develop a cost-effective, semi-closed fish cage that prevents the escape of fish, drastically reduces the risk of salmon lice, and reduces the release of organic nutrients and waste into the surrounding environment. Since 2013 we have worked closely with Mowi to document the impact of our semi-closed fish cage prototype for post-smolt fish – and the results are very promising. Currently we are working on our first commercial deliverable, which integrates a water treatment system in the construction's water intake channels. The water treatment systems consist of UV treatment systems, oxygenation equipment and filtration of the intake water. Our fish cage concept enhances the fish welfare by virtually eliminating the need for mechanical handling of the fish, as well as the need for chemicals. As a result of these factors, mortality is extremely low – less than 1%, in addition to increased FCR to 0,85. In CtrlAQUA, Aquafarm Equipment AS is represented by engineer CEO Egil Bergersen, Business Developer Roger Thorsen and Project Engineer Håkon Lund Bondevik who contribute with their expertise in engineering of floating closed-containment systems in sea.

Pure Salmon Kaldnes AS, previously part of Krüger Kaldnes AS, is one of the leading recirculating aquaculture systems (RAS) suppliers for the Norwegian aquaculture industry. Over the past 15 years, PSK has developed strong knowledge and expertise in designing, delivering, and supporting (through services) smolt and post smolt production. Our reference list includes over 16 large land-based RAS facilities in Norway and Europe (MOWI, Lerøy seafood, Salmar, Sundfjord Smolt and Helgeland smolt, etc.).

At FiiZK we combine craftsmanship gained through more than 150 years of proud industry history with expertise in technology, computer science, economics and biology. We are a leading aquaculture supplier of semi-closed cage solutions, software development (planning, optimization, budgeting, analysis and digitization of production management) and technical tarpaulins (lice skirts, treatment tarps, freshwater tarps, disinfections tarps).

PHARMAQ Analytiq is a Norwegian biotechnology company working with preventive fish health and welfare. Since 2015 PHARMAQ Analytiq has been a part of Zoetis – the largest global animal health company. And in 2020 they acquired FishVetGroup so now they are one of the largest global fish diagnostic companies with laboratories in Norway, the UK and Chile. The company offers analytical services and consultation to solve challenges faced by intensive fish production – in a preventive way by monitoring, diagnostics and interpretation of biological data. In 2008 PHARMAQ Analytiq opened a state-of-the-art real time RT-PCR laboratory for the detection of pathogens and in 2018 the laboratory was accredited by Norwegian Accreditation. Furthermore, histology and bacteriology extend the advisory and problem solving capability which PHARMAQ Analytiq offers the aquaculture industry. In CtrlAQUA, PHARMAQ Analytiq is represented by Product Manager Renate Johansen, Stian Nylund and Director Strategic Development Siri Vike. They all have an extensive research background in fish health. PHARMAQ Analytiq will contribute in development of tools for assessment of salmon post-smolt robustness, improved fish health, reduced stress and ensure a functional immune system.

CreateView is a technology company based in Molde. CreateView develops and sells welfare sensors that monitor lice, detects fish health status and measures biomass in fish farms to optimize production. The sensors are based on artificial intelligence, data acquisition and camera technology. This allows real-time monitoring without causing stress to the fish. Combining the measured data from the sensor and machine learning, the user can, through the CreateView Analytics analysis tool, plan for good welfare, increased profitability and sustainable operations. In CtrlAQUA CreateView is represented by CEO Even Bringsdal and Kristine Steinhovden who will contribute with knowledge and experience with Artificial Intelligence, image- and sensor technology, as well as Aquaculture competence.

PHARMAQ is the global leader in vaccines and innovation for aquaculture and part of Zoetis, the world leader in animal health. The company provides environmentally sound, safe and efficacious health products to the global aquaculture industry through targeted research and the commitment of dedicated people. The vaccines are manufactured in state-of-the-art production facilities in Overhalla and Oslo, Norway. Administration and research and development activities are based in Oslo with subsidiaries in Norway, Chile, United Kingdom, Vietnam and Spain. PHARMAQ has approximately 300 employees. The company's products are marketed in Europe, North and South America, and Asia. In CtrlAQUA, PHARMAQ is represented by Nils Steine, Mari Solheim, Øyvind Tønnesen, Rolf Hetlelid Olsen and Karine Lindmo Yttredal and will contribute with expertise and vaccine development in Department Preventive Fish Health.

Atlantium is a leading global water treatment company providing reliable water disinfection solutions for the aquaculture industry through the propriety Hydro-Optic™ disinfection (HOD) technology. Major industry players - producers, engineering firms and research institutes - around the world rely on Atlantium's proven HOD technology when designing solutions for complete sustained microbial inactivation, safeguarding facilities from otherwise detrimental diseases. Atlantium's HOD technology is distinguished from any other UV system because of its comprehensive sensor configuration, setting a new standard in UV dose monitoring and control. The HOD technology employs a dedicated output sensor per lamp as well as an integrated UVT sensor for real-time accurate UV dose monitoring. The core of the HOD system is a disinfection chamber made of quartz and surrounded by an air block. This unique configuration combined with optimally engineered flow of water in a controlled, defined pattern, through the HOD system creates a uniform UV dose distribution that reaches and inactivates microorganisms and is the key to attaining sustainable and reliable water biosecurity.

Raising large salmon smolt in Recirculating Aquaculture Systems (RAS) is pioneering work. Therefore, fish farmers have requested research on how different production strategies for large smolt in RAS affect growth, survival rates, welfare and sexual maturity during the sea phase.

Article by Reidun Lilleholt Kraugerud

Time of year for sea transfer decides RAS strategy

Trine Ytrestøyl, senior scientist in Nofima about to analyse fish in RAS together with scientists Tom Ole Nilsen and students from University of Bergen.

Photo: Terje Aamodt, ©Nofima.

Scientists Trine Ytrestøyl from Nofima and Tom Ole Nilsen from the University of Bergen are trying to find answers.

Testing the effect of RAS conditions on growth at sea

In their trials, which are still ongoing, the salmon were raised in land-based RAS according to various production strategies at Nofima in Sunndalsøra. The strategies involved different photoperiods and the use of brackish water while the salmon are in tanks with recirculating water, and smolt size when transferred to sea. The sizes at transfer were just over 100 grams, 300 grams and 800 grams.

Is continuous light in RAS facilities safe?

To stimulate smoltification, the salmon are controlled by light rhythms, and the scientists have simulated nature's winter signal and compared it with continuous light in the production of large smolt.

Salmon that were exposed to continuous light in RAS grew the fastest while in the RAS facility and were therefore larger when transferred to sea compared to fish that received a winter signal. The scientists found no obvious negative effects of using continuous light in RAS on growth in tanks with seawater. These fish also had the highest weight gain during 12 weeks in seawater.

Brackish water is a method of gradually acclimatising salmon to seawater. Salmon that had been raised in brackish water in RAS until 300 grams, had better growth when transferred to sea than those raised in freshwater.

The main finding from the trial in tanks with seawater so far is that the fish also grow well at sea when exposed to continuous light in RAS facilities. The scientists see that an early winter signal in RAS facilities is very positive for growth at sea when the fish are transferred in sea conditions corresponding to the autumn season.

"The conditions that fish farmers should give the salmon in RAS facilities seem to depend on which time of year the fish are to be transferred to sea", says Ytrestøyl.

Large smolt risk becoming sexually mature too early

Early sexual maturation in male salmon is a common problem when the fish are exposed to high temperatures in RAS facilities. Very few of the fish that were transferred to sea at 100 grams became sexually mature early. When salmon were transferred to tanks with seawater at 300 grams, a larger proportion of the males were sexually mature when the sea trial ended.

Scientist Tom Ole Nilsen is not surprised that large smolt have certain challenges that traditionally smaller smolt do not have. "When you work in unison with the salmon's physiology, it is natural to assume that the risk of adverse episodes during the seawater phase is lower. We see somewhat earlier sexual maturity and also more incidents of the disease nephrocalcinosis in fish raised in RAS facilities until they are as large as 300 and 800 grams, compared to 100 grams. Therefore, it is important that we take biology into account when choosing a strategy", says Nilsen.

So far in the trial, the lowest mortality rates have been seen in net-pens at sea where the transferred salmon were 100 grams.

Read the full article at ctrlaqua.no:

Neda Gilannejad and Pradeep Lal from NORCE at the BENCHMARK trial. Photo: Terje Aamodt, ©Nofima.

4 SCIENTIFIC ACTIVITIES AND RESULTS

DEPARTMENT OF FISH PRODUCTION AND WELFARE

The main priority within Department of Fish Production and Welfare is to provide knowledge and innovations to determine environmental and biological requirements of Atlantic salmon in RAS and semi closed systems (S-CCS). Much of the focus in the Department of Fish production and welfare during the year has been linked to the Benchmarking production protocols, addressing optimal photoperiod in RAS, transfer size and time of seawater transfer. Best practice and potential adverse effects of different smolt and post-smolts size at transfer, seawater temperature and season was also addressed. A detailed overview of the BENCHMARK experiment is shown in Figure 4.1.

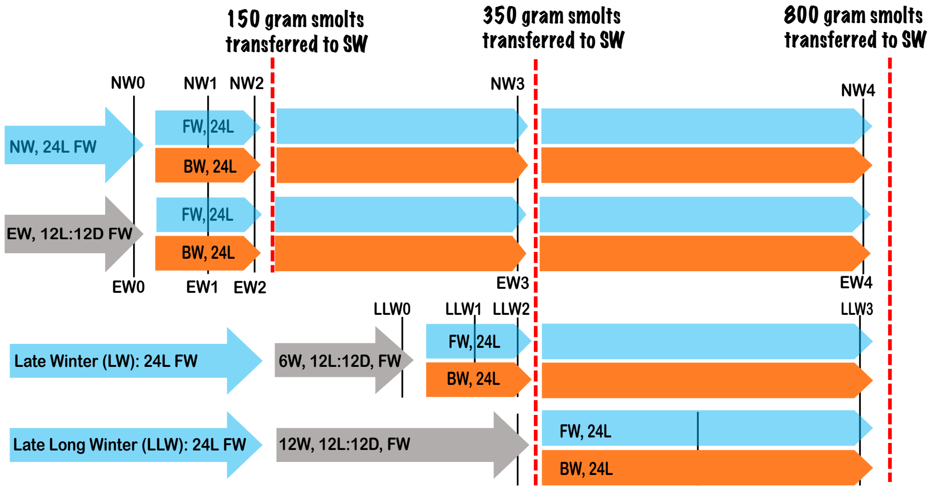


Figure 4.1: *Groups of Atlantic salmon were exposed to four different photoperiod protocols. 1) No winter signal (NW) and 2) Early winter signal (EW), resulting in 150-gram smolts transferred to seawater. 3) A delayed 6-week winter signal, Late winter (LW), resulting in 350-gram smolts transferred to seawater, and 4) a delayed prolonged 12-week winter signal, Late Long Winter (LLW), resulting in 850-gram smolts transferred to seawater. All groups were exposed to both freshwater (FW) and 12 ppt brackish water (BW) after completion of the winter signal. Post-smolt from NW and EW was also retained in RAS and transferred to seawater when reaching 350 and 850 grams, while LW post-smolt retained in RAS was transferred to seawater when reaching 850 grams. An extensive sampling program was conducted during smolt development and prior to seawater transfer. Here we will report the growth performance after 3 months in seawater for the 150- and 350-gram groups as the 850 groups are still ongoing.*

Smolts and post-smolts were transferred from RAS to flowthrough seawater common garden tanks when reaching approximately 150, 350, and 850 grams (Figure 4.1). Fish receiving no winter signal (NW) in RAS was consistently larger than all other groups during the RAS phase, reaching approximately 185, 355, and 930 grams at the time of seawater transfer. Fish receiving an early winter signal (EW) displayed the lowest growth in RAS, reaching approximately 150, 275 and 890 grams in at the time of seawater transfer. Post-smolt performance following three months in seawater was assessed under the following four environmental conditions. 12°C, decreasing daylength (simulating fall) and 12°C, constant light. 6°C,

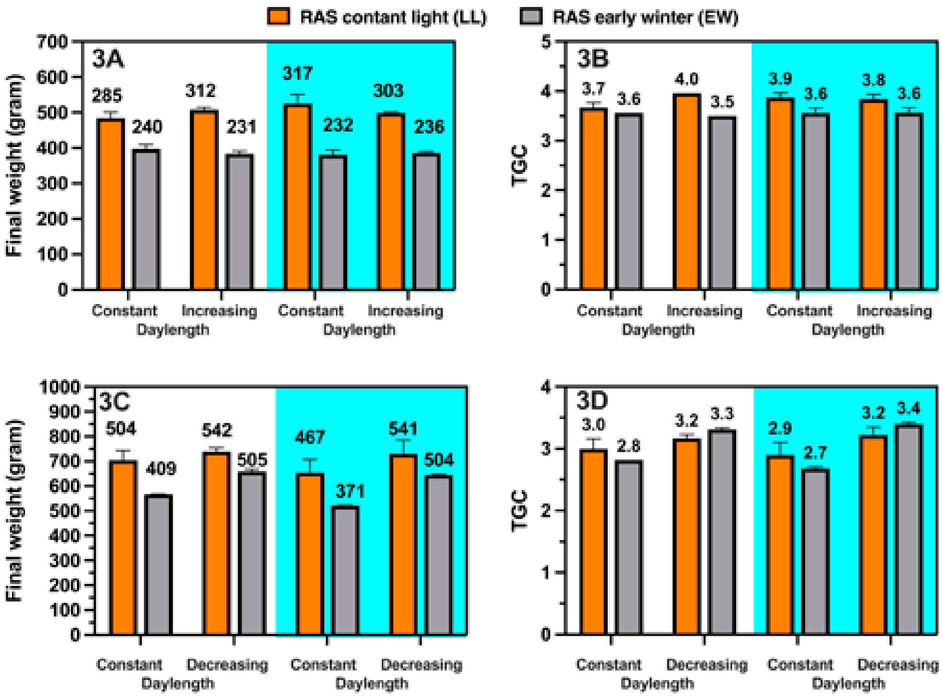
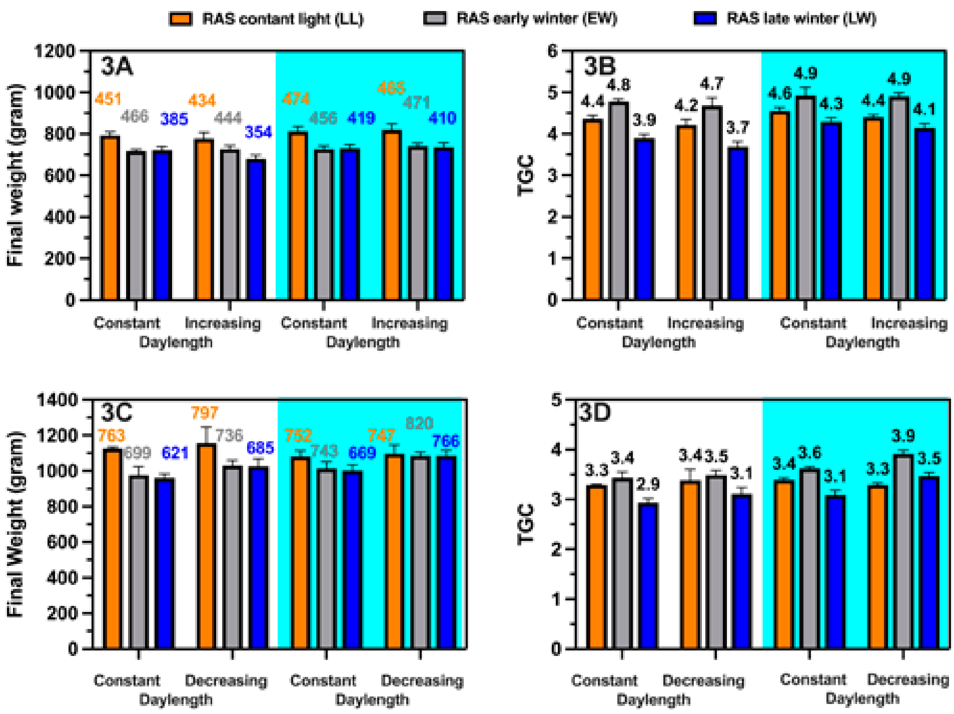


Figure 4.2: *Final weight and thermal growth coefficient (TGC) in Atlantic salmon post-smolts after 3 months in 6°C (Figure 4.2 A, B) and 12°C (Figure 4.2 C, D) full strength seawater. The weight gain in gram is written above bars for each group (Figure 4.2 A, C). TGC values are written above each bar (Figure 4.2 B, D). The weight of the No winter signal (NW) and Early winter signal (EW) when transferred from RAS were approximately 185 and 150 grams, respectively. Post-smolts in 6°C seawater was reared under constant and increasing daylength, while fish in 12°C seawater was reared under constant and decreasing daylength. The white area of each graph represents freshwater groups during the RAS phase, while cyan represents seawater groups during the RAS phase.*

increasing daylength (simulating spring) and 6°C, constant light. Despite no significant effect of photoperiod and salinity in RAS on performance after 3 months in 6°C seawater, the weight advantage was maintained as evidenced by the higher weight gain (Figure 4.2 A) and thermal growth coefficient (TGC) (Figure 4.2 B). A similar trend was observed after 3 months in 12°C seawater (Figure 4.2 C, D). Post-smolts exposed 3 months to decreasing daylength in 12°C seawater displayed a higher growth compared with the constant light groups (Figure 4.2 C, D). Interestingly, fish exposed to an early winter signal (EW) in RAS performed best under decreasing daylength in 12°C seawater.

Smolts receiving a late winter signal, LW, (Figure 4.1) were on average larger (330 grams) than the Early winter, EW, (275 grams) and no winter, NW, (355 grams) groups in RAS at the time of second seawater transfer (Figure 4.1). Post-smolts receiving no winter signal (NW) in RAS still displayed higher final weight after 3 months in 6°C seawater (Figure 4.3 A), yet the early winter signal (EW) group displayed a similar weight gain and thus higher TGC (Figure 4.3 B). Post-smolts receiving late winter signal in RAS displayed the lowest weight gain after 3 months in 6°C seawater (Figure 4.3 A). Interestingly, there appear to be a positive effect of BW versus FW in RAS on later growth performance in both 6°C seawater (Figure 4.3 A, B) and 12°C seawater. Post-smolts receiving early winter (EW) in RAS displayed highest growth performance (Figure 4.3 C, B) after 3 months in 12°C seawater under both constant and decreasing daylength. Lowest performance after 3 months in seawater was post-smolts that received late winter (LW) in RAS phase (Figure 4.3 C, D). A late long winter signal (LLW) resulted in the lowest growth in RAS, reaching 730 grams at the time of seawater transfer, which was the lowest performance of the 800 grams groups in RAS. Performance after 3 months in seawater the final seawater transfer is still pending and to be completed in late April 2022.

Adverse effects such as early puberty and nephrocalcinosis is also monitored. As part of other variables influencing maturation, water temperature appears to be a critical factor, and could explain why RAS-raised salmon, typically cultured at higher temperatures than those in sea cages, exhibit comparatively higher rates of early maturation.



To further understand this problem, we sought to investigate whether there is a size threshold after which post-smolts will sexually mature in response to an increase in water temperature. To this end, we incubated and hatched mixed-sex diploid eyed eggs and reared the fry / parr in flow-through freshwater at 12°C up to 40 gram in weight, at which point 50% of the salmon received an S_0 winter photoperiod (i.e., 6 weeks LD12:12) to induce smoltification. All fish were then transferred and comingled in 15 0.5 m^3 flow-through tanks, to be raised to 400-gram final size. Treatment groups (with n=3 replication) included: i) 12°C for the entire study duration; and ii-v) temperature elevation to 14°C at 100, 150, 250 and 350 grams, respectively. We determined that male post-smolts that underwent temperature increases at 100 and 250 grams displayed significantly ($p<0.05$) higher maturation rates than controls, based on gonadosomatic index (GSI) assessment. Those receiving temperature increase at 350 grams also had higher maturation than controls, although not significant statistically; post-smolts receiving temperature increase at 150 grams were nearly ($p=0.059$) less likely to display maturation, compared to controls. When assessing winter photo signal in conjunction with the size-at-temperature independent variables, it was determined that post-smolts that had undergone photoperiod manipulation to induce smoltification were significantly less likely to display early maturation at any size compared to post-smolts with no winter photo signal.

Figure 4.3: *Final weight and thermal growth coefficient (TGC) in Atlantic salmon post-smolts after 3 months in 6°C (Figure 4.3 A, B) and 12°C (Figure 4.3 C, D) full strength seawater. The weight gain in gram is written above bars for each group (Figure 4.3 A, C). TGC values are written above each bar (Figure 4.3 B, D). The weight of the no winter signal (NW), early winter signal (EW) and late winter signal (LW) when transferred from RAS were approximately 355, 275 and 330 grams, respectively. Post-smolts in 6°C seawater was reared under constant and increasing daylength, while fish in 12°C seawater was reared under constant and decreasing daylength. The white area of each graph represents freshwater groups during the RAS phase, while cyan represents seawater groups during the RAS phase.*

Carlo C. Lazado (in front) is collecting skin mucus from Atlantic salmon smolts that were reared in ozone-treated water and experimentally infected with IPNV. The trial aimed to determine the effects of ozone and peracetic acid as routine water disinfection following a biosecurity breach in RAS. Also in picture: Danilo Carletto and Hanne Brenne. Photo: Kevin Torben Stiller, Nofima.

DEPARTMENT OF PREVENTIVE FISH HEALTH

The main objectives in Dept. Preventive Fish Health are inventions to prevent, detect and control diseases in closed and semi-closed containment systems (CCS/S-CCS). The transfer of smolts from freshwater to seawater is a challenging period during production of Atlantic salmon. From the parr stage, contrasting diets composed of either marine or plant ingredients were used to assess how they affect the skin (epithelial) barriers during the last stage of smoltification and the first period in seawater. In smoltified fish, growth in the marine diet group was significantly faster. The deeper layer of the skin was thinner in the plant fed group and the number of genes regulated in skin was higher in this group when transferred to seawater. Many of the genes were related to the immune system. However, feed-related differences in the skin were smaller compared to environmental changes, i.e., effects of transfer from fresh- to seawater.

In the intestine, gene expression suggests that a marine diet stimulates blood flow, development and immunity. However, histological studies showed little dietary impacts on these tissues. Instead, intestinal structures were affected by the fecal consistency score that is linked to appetite or time since last feeding. This observation is in parallel with several blood parameters. Blood parameters related to stress (cortisol) or osmoregulation (Na, Cl) showed no difference between dietary groups after seawater transfer.

A controlled trial that tests the resolution of sensor-based welfare scoring of wounds was started together with CreateView at Sunndalsøra late 2021. The results will be used to assess if sensors can detect different types of wounds and if acute wounds can be distinguished from healing wounds, based on a previously made scheme to categorize skin images. Also, physiological and molecular data will be utilized to associate functional characteristics of the wounds to data from the high-resolution images.

One important task in CtrlAQUA has been to study how CCS and S-CCS perform compared to open systems related to diversity, prevalence, and load of microparasites. Surveillance has been performed in several production rounds in different types of S-CCS, and in 2021 a study was performed in Certus (S-CCS; Cermaq) and in open cages (controls) at the same locality. We found, in line with earlier studies, that the salmon may to a certain degree be protected from infection with salmon lice, but there were no significant differences in development of prevalence and densities of other microparasites in S-CCS compared to nearby control cages. The explanation could be that some microparasites are introduced into the systems via smolt delivery while others may enter via water intake. Some of them could possibly be avoided by lowering the depth of the intake water, but this could lead to introduction of other fish pathogenic bacteria present in the water column. Research is still needed for optimalization of the different S-CCS for preventing introduction of microparasites.

The knowledge generated from work with *Cand. Branchiomonas cysticola* is now being applied in the development of a genotyping scheme to describe the population structure of this bacterium associated with gill disease, in existing and novel production systems. Preliminary analysis suggests that the taxonomic ranking of the bacterium needs revision. There is significant industry interest in utilizing peracetic acid (PAA) to prevent and treat opportunistic pathogens (e.g., *Flavobacterium* spp.). Application of low dose PAA in brackish water RAS was identified as a mild stressor that posed minimal risk to health and welfare of post-smolt. Freshwater fluidized sand biofilters were dosed with PAA at different concentrations and application methods. Regardless of concentration or application method, PAA did not cause major disruption to biofilter nitrification.

Ozone treatment remains as one of the most potent water disinfection methods in RAS. We have identified and characterized the optimal dose of ozone in brackish water salmon RAS that do not cause serious concerns to health and welfare. Ozonation could be beneficial for post-smolts in RAS, particularly in improving gill health. In collaboration with associated project RASHealth we tested the effectiveness of a disinfection protocol by pH manipulation during a simulated *Yersinia ruckeri* outbreak in RAS. The protocol was effective in eliminating *Y. ruckeri* in the system.

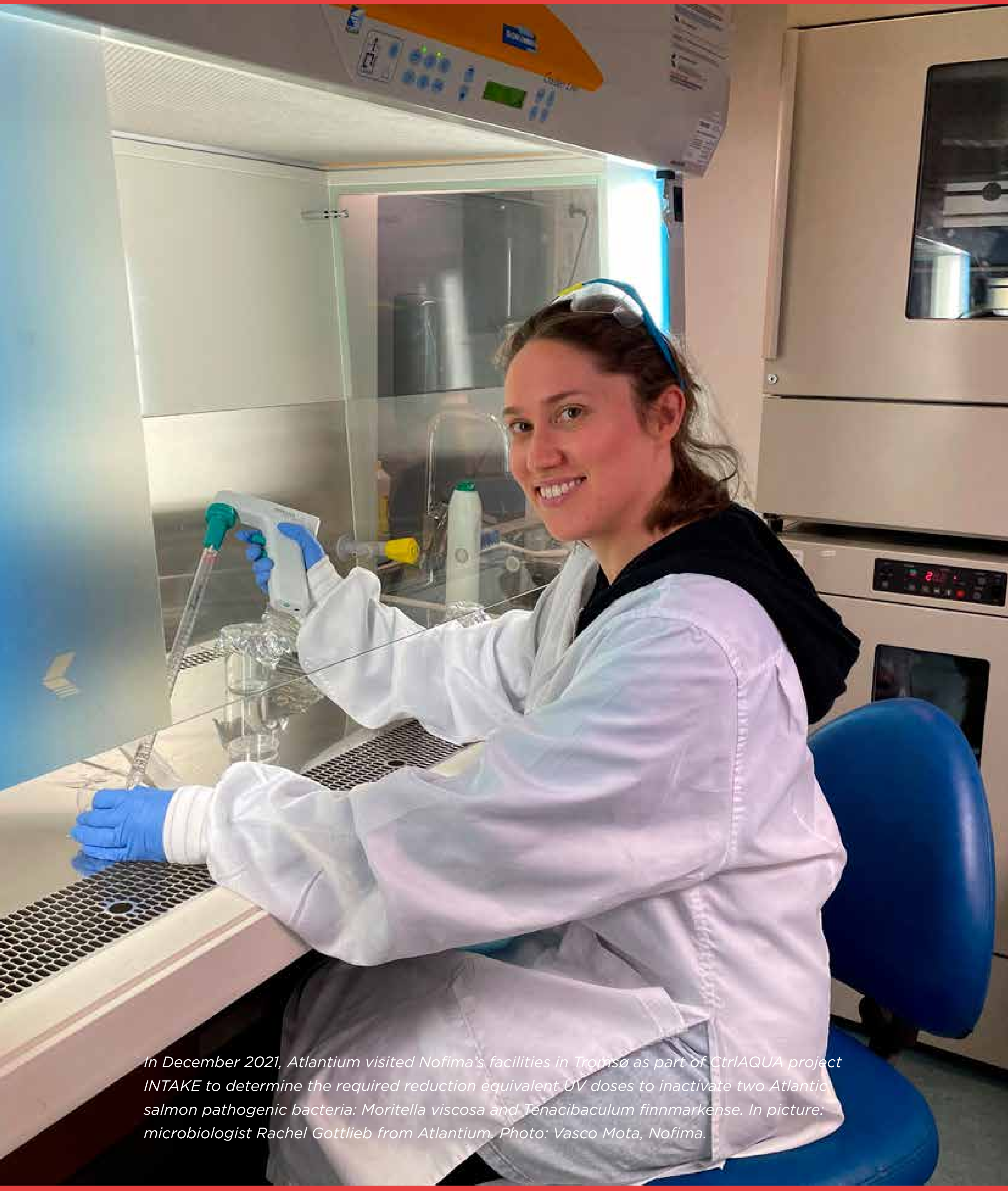
Nephrocalsinosis (NC) in A. salmon has increased the last years and we have worked to gain insight into the physiological mechanisms associated with the disease and test the suitability of radiography (X-ray) to identify NC at different developmental stages of the disease and at different life stages of the salmon. X-ray analyses were performed on fresh (recently killed) and frozen fish in different sizes delivered from industry partners. In a time-series with frozen fish, precipitates were detected with certainty in the kidney in 65-70g fish. In fresh fish histology was performed in parallel to compare the two methods. NC was detected on X-ray images when damages representing early, active disease development were detected histologically. Preliminary conclusion is that X-ray has potential as a method for non-lethal, non-invasive evaluation of NC. Possibilities and limitations of the method will further be validated in 2022.

Normal renal function and transporters for absorption and secretion of ions during

Performance of trial to test the resolution of sensor-based welfare scoring of wounds. Photo: Karoline Valseth, Nofima.

smoltification and seawater transfer were studied. Sulphate transporters and Natrium-kalium ATPase enzyme activity in normal smoltifying fish was characterized and other transporters (calcium, magnesium, phosphate) were identified and will be subject to further studies in normal vs NC positive fish to better understand the physiological disturbances in Nephrocalcinosis.

Fish sampling in Sunndalsøra with Lene Sveen and Sebastian Bucerzan. Skin and intestinal samples are collected in project BARRIER. Photo: Kevin Torben Stiller, Nofima.



In December 2021, Atlantium visited Nofima's facilities in Tromsø as part of CtrlAQUA project INTAKE to determine the required reduction equivalent UV doses to inactivate two Atlantic salmon pathogenic bacteria: Moritella viscosa and Tenacibaculum finnmarkense. In picture: microbiologist Rachel Gottlieb from Atlantium. Photo: Vasco Mota, Nofima.

DEPARTMENT OF TECHNOLOGY AND ENVIRONMENT

During 2021 we have finalized the development and testing of bio-antifouling membranes for sensors for specific use in aquaculture. A series of new environment-friendly antifouling materials for sensor surface was developed based on Polytetrafluoroethylene (PTFE) and modified PTFE surfaces. Different plasma treatment time were fabricated through O_2 plasma treatment. The plasma treatment time was proved to have significant influence on morphology, topology, and wetting-ability on PTFE surfaces, in turn influencing the antifouling property. The developed bio-antifouling membranes provides antifouling materials which can be used on sensor surface to solve fouling and long-term stability problem.

During 2021 the work on online sensor system for metals has been continued, and the main activity has been data treatment of results from earlier long-time operation of the system in real RAS system. Further, work on a more efficient flow-through system, including use of disposable sensors for easy maintenances, has been initiated.

We have continued our focus on characterization of dissolved organic matter in closed containment systems. By use of non-targeted approach using Fourier Transform Ion Cyclotron Resonance Mass Spectrometry, we have, for the first time, characterized and identified the sources of dissolved organic matter (DOM) in the RAS water matrix and effects on composition of DOM after ozonation. The molecular compositional change of the DOM in RAS waters before and after ozonation clearly reflected the removal of CHO chemicals and maintained the abundance levels of CHNO and CHNOS chemical groups steady through the water treatment processes.

In our work with hydrodynamics, we moved a step forward towards creating a two-phase CFD model that consider solids (as feed pellets and faeces) and water interactive behavior in rearing tanks. Initially we created models at the smaller scale that we validated empirically. Our model shows good agreement with the experimental data in both 'descent' behaviour of the pellets and time it was necessary for two types of particles

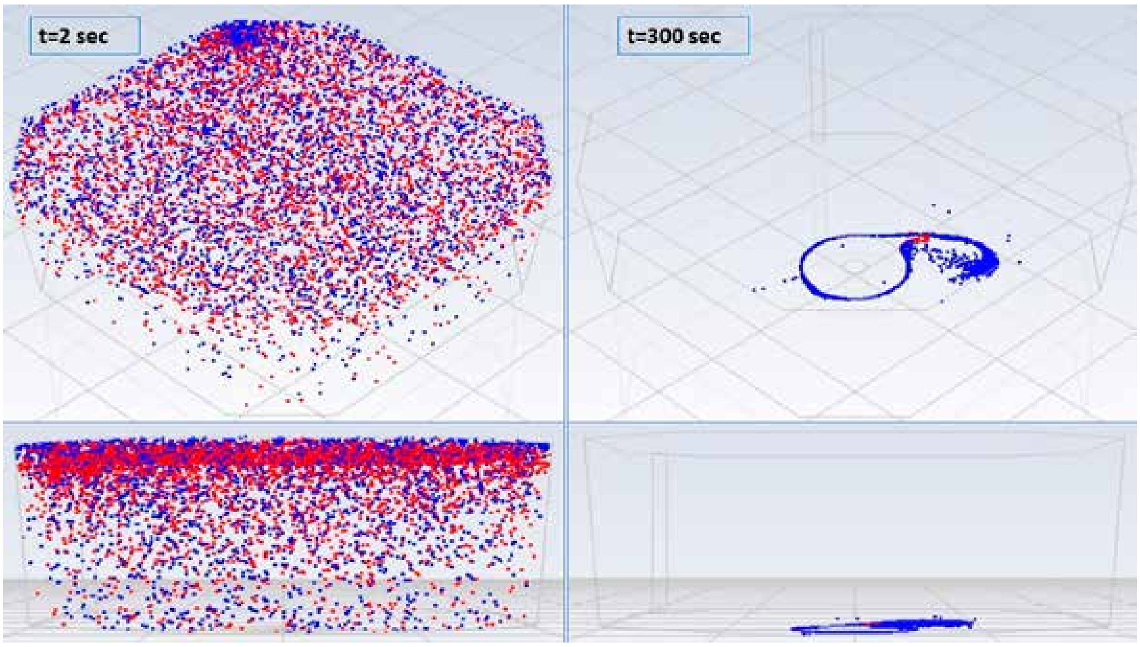


Figure 4.4. Two phase CFD model of 3 m^3 octagonal tanks over time (t=2 and 300 s): pellets (red) and faeces (blue) location.

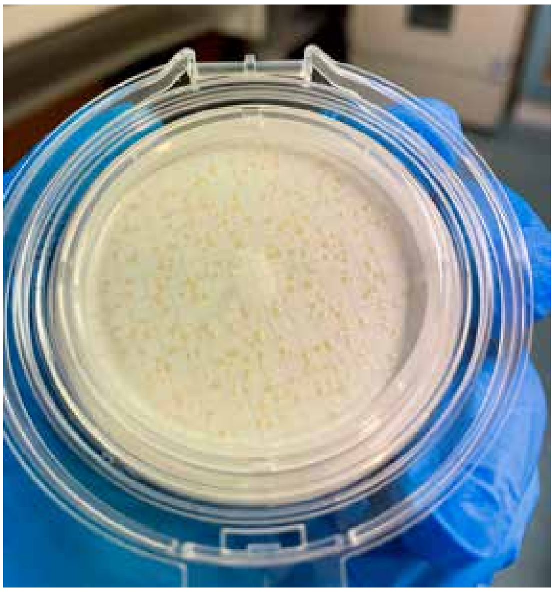
(feed and faeces) to reach the bottom of the tank (Figure 4.4).

Based on our initial tank model we successfully create the CFD model for large 1000m^3 octagonal tank. Both models can help us describe and predict the solid dynamics in different types of tanks. This will allow us to identify potential zones in the tanks with higher possibility for sludge accumulation that can increase risks for H_2S formation. Last but not the least, the self-cleaning phenomena can be verified by tracking of solids on the tank floor in those models.

Biosecurity has always been one of the main aspects of closed containment systems. The UV radiation is one of the more promising technologies for inactivation of Atlantic salmon pathogens. It is already applied in land-based facilities but can also be used in semi-closed containment systems in the sea.

The occurrence of tenacibalucosis in seawater-reared Atlantic salmon caused by *Tenacibaculum* spp. has been an increasing problem for the Norwegian farming industry. Our tests show that the minimum required UV dose to 99.9% inactivate the gram-stain negative bacteria *Tenacibaculum finnmarkense*, the causative agent of tenacibaculosis, is ≤ 3.3 mj/cm^2 for both low-pressure and medium-pressure UV. This result indicates that *T. finnmarkense* is very susceptible to UV, similar to what we found in 2020 for the two other Gram-negative bacteria *Yersinia rucker* (enteric redmouth disease) and *Moritella viscosa* (winter ulcer disease).

Sea lice or salmon louse is one of the most common parasites on farmed salmon and a current problem for the aquaculture industry. Intake water in semi-closed systems is usually taken from sea water depths below the normal occurrence of the free-living sea lice or copepodite stage. However, in occasional events this copepodite may be present in the intake water. For the first time



The objects of our UV tests: Tenacibaculum finnmarkense (upper image) and sea lice copepodit (lower image). Photos: Vasco Mota, Nofima.

we assessed the impact of UVC radiation (284 nm and 220 – 300 nm) exposure on sea lice (*Lepeophtheirus salmonis*) copepodites. Very low mortality rates (< 10 %) were documented after copepodites were exposed to typical UV doses used in aquaculture (0 – 50 mJ/cm^2). These results indicate that UV irradiation may not be an efficient method to inactivate sea lice copepodites within 24 hours of exposure.

Hydrogen sulphide (H_2S) has been indicated as one of the risk factors for production in brackish and seawater RAS for Atlantic salmon post-smolt. The production of H_2S was the topic of four MSc thesis that investigated early warning signs and evolution of H_2S, the role of redox reactions on N- and P- cycles, dissolved organic matter characterisation, and the production of nitrous oxide in sludge collected in RAS. As expected, nitrate delayed H_2S production, and manganese and iron were found to be the early detection signs towards H_2S production in batch assays.

H_2S production potential of sludge was tested with different nitrate levels in mixed batches. We found that nitrate delayed and reduced the overall production of H_2S. Our results matched theoretical stoichiometric ratios for denitrification and sulphate reduction close to 100%. Therefore, the potential for H_2S production can be estimated in an ideally mixed system, based on the amount of biodegradable carbon and nitrate. However, reaction rates and production dynamics should be fundamentally different for sediments and biofilms in RAS, due to diffusion being the rate-limiting factor.

To investigate H_2S dynamics in sediments, we have developed a procedure to collect sediments from the settleable solids fraction in RAS water, and subsequently to transfer and test the undisturbed sediments in flow cells. The results from this experiment are currently being evaluated.

In our attempts to make the use of degassers in RAS more energy efficient we have been searching for the most reliable ways to monitor their efficiency. To do so, the measures of carbon dioxide (CO_2) concentrations were done at multiple locations in the systems. Measurements of CO_2 concentrations in the air entering and leaving the degassers were compared to two different ways CO_2 is measured in the water. The measurements in the air were a fast and reliable proxy of CO_2 degassing efficiency and will be used in the further work with optimization of CO_2 removal in RAS.

Sediment collection in RAS with up flow columns and testing RAS sediments in flow cells for H_2S production. Arrows indicate the workflow from sediment collection to analysis. Photo: Andre Meriac, Nofima.

5 INTERNATIONAL COLLABORATION IN 2021

Researchers and user partners in CtrlAQUA have an extensive international network of contacts. In our Scientific Advisory Board, whose main task is to provide inputs to the annual plans and evaluate the scientific work, there are several international members, including from the European Aquaculture Society, Danish Technical University, the University of Aberdeen, and University of Maryland.

CtrlAQUA researchers are invited as speakers at different international scientific meetings, and we are often invited to host sessions at meetings. Due to the Covid-19 pandemic, the European Aquaculture Society (EAS) arranged the 2020 conference digitally during the spring of 2021, and a physical conference was held in Madeira later in autumn. CtrlAQUA researchers were session leaders at both events, and we contributed significantly with presentations. The Centre Director was also invited to the NASCO annual meeting in 2021 to talk about how to protect wild salmon against sea lice with the use of new technologies and post-smolts.

There are two international R&D partners in CtrlAQUA, Gothenburg University (UGOT) and The Conservation Fund Freshwater Institute (FI), USA. Gothenburg University is represented in CtrlAQUA by Prof. Kristina Sundell and her research team. UGOT has in 2021 contributed to important knowledge regarding skin and gut as barrier organs. They have also continued their work in an associated project on effects of microplastics in RAS. The Conservation Fund Freshwater Institute (FI) is represented by Dr. Chris Good and Dr. Brian Vinci with colleagues. They are heavily involved in the work with sexual maturation, disinfection protocols and hydrodynamic modeling. In 2021, John Davidson from FI successfully defended his thesis about rainbow trout and Atlantc salmon in RAS for a Dr. philos degree.

At University of Gothenburg, postdoctoral researcher Darragh Doyle is working in CtrlAQUA project BARRIER. Photo: UGOT.

CtrlAQUA opened for associated projects in 2015. Associated projects need external funding and can in addition to CtrlAQUA partners involve partners that are not regular CtrlAQUA partners. In 2021 we had six associated projects that involves international partners:

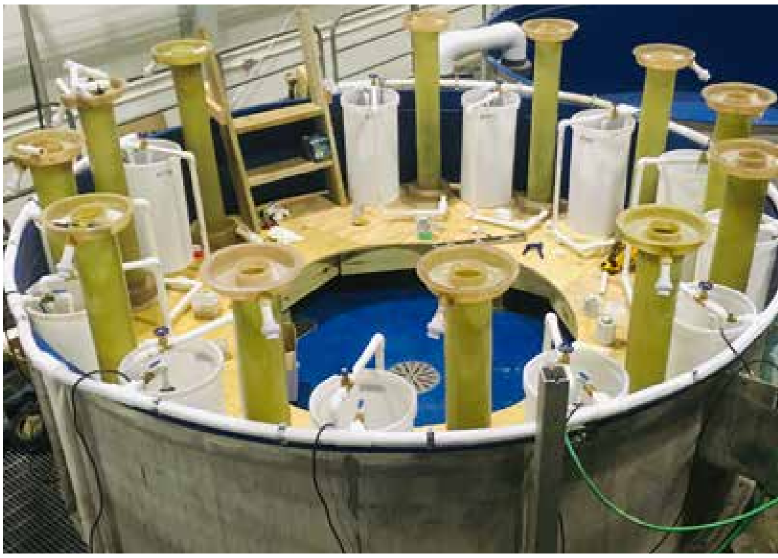
1) "Microplastics in the environment" (lead by UGOT and funded by Swedish Research Council): an investigation into how microplastics affect fish and potential risks for the aquaculture industry.

2) "Post-smolt maturation" (lead by UiB, funded by RCN). This project led to the successful PhD defense from Enrique Pino Martinez, with his thesis about early sexual maturation in Atlantic salmon, December 2021.

3) "Prevalence and consequences of hydrogen sulphide in land-based Atlantic salmon production" (H2Salar) (lead by Nofima, funded by RCN). The primary objective is to create knowledge and advance the understanding of the risks and impacts of exogenous hydrogen sulphide (H_2S) to the physiology of Atlantic salmon in recirculating aquaculture.

4) "Water disinfection strategies to improve Atlantic salmon parr production in freshwater recirculating aquaculture systems" (RASHealth) (lead by Nofima, funded by RCN). The primary objective is to optimize existing disinfection protocols and develop new water disinfection strategies to control pathogens in Atlantic salmon freshwater RAS.

5) The balancing act: Biologically driven rapid-response automation of production conditions in recirculating aquaculture systems (RAS) (RAS 4.0) (lead by Nofima, funded by RCN), where the main objective is to improve fish wellbeing and production efficiency and reduce operational risks by developing integrated control systems for water quality, feeding and energy optimization. The control systems are based on novel sensors, data integration and



Experimental-scale biofilters under construction at The Freshwater Institute, to be used for a range of experiments involving disinfection compounds and their potential effects on biofilter performance, which is vital for successful RAS operation and maintaining fish health. Photo: Christopher Good.

smart algorithms that combine biological, environmental, and operational factors.

6) "Kunnskapskartlegging - produksjon av stor laksesmolt" (lead by Nofima, funded by FHF), where published and experience-based knowledge about production protocols for postsmolt that are usen in Norwegian salmon farming and the other relevant salmon farming countries, including the Faroe Islands are collected and disseminated.

Researchers in CtrlAQUA are often involved in new project proposals where international partners are included. One example is a series of EU projects where some of the CtrlAQUA-partners have helped establishing first AQUAEXCEL, then secondly AquaExcel[2020] and now the ongoing AQUAEXCEL3. There, amongst others, Nofima Centre for Recirculation in Aquaculture (NCRA) in Sunndalsøra is included as one of the Transnational Access Points (TNA). TNA means that researchers across Europe can do experiments in NCRA funded by AQUAEXCEL3, as was also the case in AQUAEXCEL and AquaExcel[2020].

CtrlAQUA PhD student Xiaoxue Zhang defending her thesis "The development of antifouling materials with potential application on sensors" in March 2022. Photo: NTNU.

6 RECRUITMENT, EDUCATION AND TRAINING

The aim of CtrlAQUA has been to have 15 PhD students to be educated throughout the lifetime of the centre. To a large extent, we have succeeded in achieving this target as we currently have 14 PhD students and one dr. philos within the centre and its associated projects. Several of the candidates have defended their theses, and more will come during the final year of the centre. The PhD projects have addressed key research topics of the center and its associated projects. Three students (Takvam, Chen and Helberg) were recruited to the centre in 2021 and these students will complete their theses after the centre period has ended. The centre has seen three candidates defend their theses during 2021. In February 2021, Sharada Navada (industry-PhD with Krüger Kaldnes) defended her thesis “Salinity acclimation strategies for nitrifying bioreactors in recirculating aquaculture systems” at NTNU. In June, John Davidson (Freshwater Institute, USA) defended his thesis “Evaluating the suitability of RAS culture environment for rainbow trout and Atlantic salmon: A ten-year progression of applied research and technological advancements to optimize water quality and fish performance”. Finally, in December 2021 Enrique Pino Martinez (associated project KABIS) defended his thesis "Influence of water temperature, photoperiod and feeding regime on early sexual maturation of Atlantic salmon (Salmo salar L.) postsmolts in freshwater". Several master students finished in 2021 and a large group of students will finish in the first half of 2022.

As we reported in 2020, parts of 2021 have been exceptional periods for the students due to Covid-19. The restrictions have caused delays for many of our students, both master and PhD. During the pandemic, the universities have granted an extension for the students who were affected. However, this means that there have been and will be some delays in finishing both master and PhD theses. We have continued to recruit students to the centre up until the present. Still, we do expect that most students who are currently working within the centre will finish in its lifetime.

In addition to the PhD students, we are educating several master students within CtrlAQUA at the University of Bergen (UiB), Norwegian University of Science and Technology (NTNU), University of Tromsø (UiT), Norwegian University of Life Science (NMBU), University of Gothenburg (UGOT), and universities in Portugal, Italy and the Netherlands (see table in chapter 8). We have recruited more than 50 Master students in the lifetime of the centre so far. 39 of these students have completed their theses and final exam, while the other candidates are at various stages of carrying out their research in CtrlAQUA projects and preparing their theses. Several of the scientists in CtrlAQUA are acting as supervisors for PhD and master students and actively participate in the establishment, organization and teaching of courses, at both bachelor and master level. Within the centre, four post-docs have also been recruited at various points. These scientists also form an important part of the centre’s recruitment and training.

Gender balance among the PhD candidates was commented on in the 2020 annual report. The addition of Takvam, Chen and Helberg (all male) as PhD students and John Davidson as a dr. philos. candidate has helped to even out the balance with 7 females and 8 males. Among the MSc students, the gender balance is approximately 50/50.

MEET THREE CtrlAQUA STUDENTS

An important task for an SFI is to educate students. In 2021 three PhD students defended their degrees at the University of Bergen and NTNU. Three central pieces of the puzzle to make closed containment aquaculture off the shelf product, have been placed. Common for the three candidates is water quality in recirculating aquaculture systems (RAS) but seen from different angles. Let us meet them and hear their best advice for the industry, and views on future research needs.

Articles by Reidun Lilleholt Kraugerud

Photo: Geir Mogen, NTNU.

Professor Øyvind Mikkelsen at NTNU has supervised several students through the years.

John overviews RAS water quality

John Davidson is an experienced researcher who stands out from the classic research fellow. He has had a long research career at the Conservation Fund Freshwater Institute in the US. In June 2021 he defended his Dr. philos. degree through the University of Bergen.

His thesis title was "Evaluating the suitability of RAS culture environment for rainbow trout and Atlantic salmon: A ten-year progression of applied research and technological advancements to optimize water quality and fish performance".

Now that you look back, what is your best advice for the aquaculture industry?
"Successful production of Atlantic salmon and other species in RAS requires multifaceted expertise amongst a team that is well versed on a range of topics including: fish biology, water chemistry, systems engineering, operations, food science, and waste management, among others. This wide scope of understanding has kept research and development of land-based RAS constantly interesting to me. There is always something new to learn and discover. As such, additional research is constantly required to support this rapidly growing aquaculture sector."

What is your take home message for future research needs?
"Over my 20+ year career, I have seen RAS research needs shift slightly from optimizing engineering design and related water quality to other niche topics. For example, developing solutions for off-flavor and evaluating holistic effects of newly developed diets for RAS are now at the top of my list. At the Freshwater Institute, our team is also working on precision aquaculture initiatives such as fish biomass estimation through camera vision and machine learning and waste-to-value research that is focused on turning fish waste into valuable products such as biogas and compost. It's an exciting time to be involved with the RAS industry!"

John Davidson. Photo: Sam Levitan.

About John's work
His work in the Dr. philos degree summarizes ten years of knowledge gleaned from Freshwater Institute research on water quality and performance of both Atlantic salmon and rainbow trout in RAS.

The main findings from his degree are:

- Dissolved copper, potassium, and nitrate can be concentrated to potentially harmful levels for rainbow trout and salmon when farmed in minimally diluted RAS.
- Of these parameters, nitrate was identified as a limiting factor, and safe concentrations for nitrate were established for each species under the conditions at the Freshwater Institute.
- Low-dose ozone improves water quality, leading to increased growth in salmonids.
- Biological membrane reactors significantly reduce water consumption, while maintaining acceptable performance for rainbow trout.

More information (in Norwegian):

Sharada has an eye for the small workers

The goal of Sharada Navada's work was to make bacteria in the bioreactor thrive despite increasing the salt content of the water.

Sharada Navada was an industry PhD, which means she was employed by a company (now Pure Salmon Kaldnes) while doing her industry-relevant doctoral work. She defended her degree at NTNU in February 2021. Her main supervisors were Øyvind Mikkelsen (NTNU), Olav Vadstein (NTNU), Frederic Gaumet (Pure Salmon Kaldnes), and Jelena Kolarevic (Nofima). She has continued her career at Pure Salmon Kaldnes as a process engineer and has clear views on the future.

What is your best advice for the aquaculture industry?
"Invest in smart people and train them well. RAS is like a swanky kitchen, but if you want to produce 5-star food, you need 5-star chefs", she says.

What are the most important research needs for the future?
"Optimization and sustainability. There will be high focus on recovering minerals and revalorizing sludge and effluents that are currently discharged to the environment."

About Sharada's PhD work
The basis of her work is that fish produce poisonous ammonia, and in land-based fish farming facilities, biofilters are used to reduce ammonia content in the water. The effect of the bioreactor can be reduced when the salinity of the water is increased, which is ideally required to grow salmon past the smolt stage.

Sharada Navada's dissertation addresses how to "mature" the bioreactor in the most optimal way so that it can tolerate changes in the salinity, thus ensuring the best fish welfare. Frederic Gaumet at Pure Salmon Kaldnes sees Sharada's work as a milestone in terms of understanding adaptive capacities of a so-called "moving bed bioreactor" (MBBR) in challenging environments, specifically with regards to changes in salt content.

Sharada Navada. Photo: Pure Salmon Kaldnes.

"Her work is directly useful in both start-up of post smolt RAS systems, and in acclimatisation of bioreactors during production when salt levels are raised from freshwater to brackish or saltwater", he says.

Centre Director of CtrlAQUA SFI, Åsa Maria Espmark at Nofima, characterises Navada's dissertation and results as very important and directly beneficial to the environment of research and the industry as a whole.

"This field has been subject to some amount of guesswork earlier, and this is one of the first systematic works of research that has been conducted in this field. Several of Sharada's results were ready a couple of years ago, and they have already been applied by Nofima and within the industry," says Espmark.

More information:

Enrique keeps an eye on the young salmon

In a RAS facility, salmon are prone to becoming sexually mature far too early. It is bad for the fish and bad for the economy of the fish producer.

It is known that early sexual maturation is related to water temperature, light and feed regime used to increase the growth of salmon in a facility. But how?

About Enrique's work

Enrique Pino Martínez has systematically investigated how these three factors contribute to early maturation in male post-smolts reared under very intensive conditions. He defended his degree at the University of Bergen, with supervisors being Prof. Sigurd Handeland, Dr. Pablo Balseiro and Prof. Sigurd Stefansson. His main findings were:

- The use of high (18°C and 15°C) temperature and manipulation of light regime contribute to an increased risk of sexual maturation in post-smolt and suboptimal development of seawater tolerance.
- Feed regime had little impact on incidence of maturation when combined with high temperatures.
- No maturing fish were detected at low temperature (8°C) and all underwent a normal smolt development.

What is your best advice for the aquaculture industry?

"According to our findings, intensive conditions and closed systems possibly are the best way to solve key sustainability issues and improve productivity in salmon aquaculture. However, the industry needs to be cautious with intensification, avoiding pushing biological boundaries of the species to the limit, or risk of unwanted consequences such as early maturation will inevitably increase."

Enrique Pino Martínez. Photo: Private.

What is your take home message for future research needs?

"After our research, we have identified certain gaps that academia and industry may try to address. For example, we believe that the size reached by salmon upon introduction of key environmental signals during production, or temperature changes during key periods of salmon life, may have important effects on the incidence of early sexual maturation. Consequently, investigation of the effects of such variables will be among our most immediate research plans."

More information (in Norwegian):

Nofima
11,207 followers
1yr •

We wish to congratulate Sharada Navada for submitting her doctoral thesis this Thursday at Norwegian University of Science and Technology (NTNU). Her dissertation was about the biofilter in recirculating aquaculture systems, and part of the CtrlAQUA Centre for Research-based Innovation.

At CtrlAQUA she has been an industry PhD from Krüger Kaldnes AS. We at Nofima are proud for having had two scientists supervising her, Jelena Kolarevic and Bendik Fyhn Terjesen, and happy to have had her as a colleague while doing the trials at the RAS facilities at Sunndalsøra.

#KrügerKaldnes #NTNU #CtrlAQUA #recirculatingaquaculturesystems #RAS #dissertation #science #aquaculture #salmon #phd

59 comments • 1 shar

Sharada Navada was one of three PhD students that gained a lot of attention in the press for her dissertation. It was celebrated and widely shared in social media, here from LinkedIn.

IntraFish
Mine varsler

LANDBASERT
Se alle artikler
Bli varslet om Landbasert

SISTE JOBBER
Båt- og maskinkyndig akvatekniker

Smolt. Foto: Krüger Kaldnes

Smoltproduksjon: Lakseforskere deler bekymringen om at finans går foran biologi

Nofima-forsker roser laksenæringa for at den nå forsøker å sette større søkelys på biologi i smoltproduksjonen – og mindre på finans.

12. april 2021 14:30 OPPDATERT 13. april 2021 8:24

Av Bent-Are Jensen | Bodø

– Vi tror det er viktig med åpenhet rundt norsk smoltproduksjon, slik at man kan belyse utfordringer og problemer som denne type produksjon står overfor, slår seniorforsker Åsa Espmark i Nofima fast.

IntraFish intervjuet nylig seniorkonsulent/pensjonert veterinær Jan Gjerde og daglig leder/majoritetseier i Sørsmolt, Stein Helge Skjelde. De to la breisida til mot måten mesteparten av norsk laksesmolt blir produsert på i dag.

CtrlAQUA scientists in Nofima were interviewed by Intrafish about biology in smolt production in RAS, in April 2021. Image: Intrafish.no.

7 COMMUNICATION AND DISSEMINATION ACTIVITIES

In CtrlAQUA, the overall goal with communication is to create interest around the activity of the center, and to be a strategic contribution to attain the goals of CtrlAQUA. The communication shall mirror the vision of the center.

The interest from the first and second target groups (mainly industry and academia) this year has been good. This has resulted in 50 registered mentions of CtrlAQUA in news articles in 2021.

The Centre director, partners and scientists have been available for press to report on the progress of research and innovation in closed-containment aquaculture.

We have had high activity in disseminating progress and results at webinars, particularly towards our main target groups in industry and research. Social media platform LinkedIn has been particularly useful in spreading information and creating interest in what we are doing. News and webinars are spread at LinkedIn, Twitter and Facebook from the host institute and partners.

Examples of dissemination activities in 2021 are:

- Invited as presenters at several online forums/conferences:
  - EAS 2021: Åsa Espmark chairing the session «Recirculating Aquaculture Systems (RAS)".
  - RAStech connector series – Strategic partner
  - Intrafish seminar at Aqua Nor
  - Nofima seminar at Aqua Nor
- Doctoral degree of Sharada Navada (PURE Salmon Kaldnes)
- New knowledge about disinfection of RAS facilities (Nofima)

During 2021 the CtrlAQUA communication department has released 5 news stories about the activity in the centre, well distributed in media. All can be read at ctrlaqua.no.

Status of our internal and external communication platforms

The intranet is the most important channel for maintaining internal routines and systems for communication between the partners. The intranet is the main communication channel within the center with over 100 participants involved. The intranet has a document base, image base, message facilities, calendar and internal alerts of new findings or publications as agreed upon in the consortium agreement. Other systems for internal communication are regular meetings, mostly digital in 2021.

The main external communication channel is the website www.ctrlaqua.no, which is designed for presenting results, activities, publications and innovations as the centre develops. Also, template for fact sheet, guide for presentations, and readily available roll ups and folder show externally what the center is about.

8 ATTACHMENTS TO THE REPORT

Key R&D partners in 2021

Name	Institution
Åsa Maria Espmark	Nofima AS
Jelena Kolarevic	Nofima AS
Lill-Heidi Johansen	Nofima AS
Trine Ytrestøyl	Nofima AS
Christian Karlsen	Nofima AS
Per Brunsvik	Nofima AS
Elisabeth Ytteborg	Nofima AS
Gerrit Timmerhaus	Nofima AS
Aleksei Krasnov	Nofima AS
Lene Sveen	Nofima AS
Grete Bæverfjord	Nofima AS
Chris Noble	Nofima AS
Kevin Stiller	Nofima AS
Andre Meriac	Nofima AS
Khurram Shahzad	Nofina AS
Carlo Lazado	Nofima AS
Vasco Mota	Nofima AS
Tom Ole Nilsen	NORCE
Naouel Gharbi	NORCE
Neda Gilannejad	NORCE
Pradeep Lal	NORCE
Sigurd Stefansson	University of Bergen
Are Nylund	University of Bergen
Øyvind Mikkelsen	NTNU
Frank Karlsen	USN
Snuttan Sundell	UGOT, Sweden
Henrik Sundh	UGOT, Sweden
Brian Vinci	Freshwater Institute, USA
Chris Good	Freshwater Institute, USA
John Davidson	Freshwater Institute, USA

Postdoctoral researchers in process

Name	Period	Institution
Nhut Tran-Minh	2016 - 2017	Nofima
Shazia Aslam	2017 - 2022	NTNU
Nobotu Kaneko	2018 - 2019	UiB
Darragh Doyle	2020 - 2022	UGOT

PhD-students/dr. philos

Sara Calabrese	2013 - 2017	UiB
Lene Sveen	2014 - 2018	UiB
Bernat Morro	2016 - 2019	UiB

Victoria Røyseth	2016 - 2019 (avbrutt)	UiB
Xiaoxue Zhang	2016 - 2022	NTNU
Patrik Tang	2017 - 2021	UiB
Sharada Navada	2017 - 2021	NTNU
Enrique Pino Martinez	2018 - 2021	UiB
Gaute Helberg	2021 - 2023	UiB
Marius Takvam	2021 - 2023	UiB
I-Hao Chen	2021 - 2023	NORCE
Ingrid Naterstad Haugen	2018 - 2022	NTNU
Patricia Aguilar Alarcon	2018 - 2022	NTNU
Tharmini Kalananthan	2018 - 2022	UiB
John Davidson	2019 - 2021	UiB
Even Mjølnerød	2020 - 2023	UiB

MSc students

Britt Sjöqvist	2015 - 2016	UGOT
Ida Heden	2015 - 2016	UGOT
Egor Gaidukov	2016 - 2017	UiB
Gisle Roel Bye	2016 - 2017	NTNU
Hilde Frotjold	2016 - 2017	UiB
Ingrid Gamlem	2016 - 2017	UiB
Simen Haaland	2016 - 2017	NTNU
Øyvind Moe	2016 - 2017	UiB
Kamilla J. Grindedal	2016 - 2018	NTNU
Gunnar Berg	2017 - 2019	UiB
Kristin Søiland	2017 - 2019	NTNU
Marianna Sebastianpillai	2017 - 2019	NTNU
Thomas Kloster-Jensen	2017 - 2019	UiB
Caroline Berge Hansen	2018 - 2019	NTNU
Claudia Spanu	2018 - 2019	NTNU/Erasmus
Hilde Lerøy	2018 - 2019	UiB
Nikko Alvin Cabillon	2018 - 2019	Nofima/Erasmus
Ross Fisher Cairnduff	2018 - 2019	UiB
Gulbrand Stålet Nilsen	2018 - 2020	NTNU
Nefeli Simopoulou	2018 - 2020	UGOT
João Osório	2019 - 2020	University of Lisbon
Kari Anne Kamlund	2019 - 2021	UiB
Marius Takvam	2019 - 2020	UiB
Sigval Myren	2019 - 2020	UiB
Sjur Øyen	2019 - 2020	UiB
Steinar Bårdsnes	2019 - 2020	UiB
Tarald Kleppa Øvrebø	2019 - 2020	UiB
Tilde Sørstrand Haugen	2019 - 2020	UiB
Trine Tangerås Hansen	2019 - 2021	UiB
Bibbi Hjelle	2019 - 2021	UiB
Kristine Kannelønning	2019 - 2021	UiB
Markus Brånås	2019 - 2021	UiB
Miguel Guerreiro	2020 - 2020	Algarve Univ, Faro/Erasmus
Anusha Lamichane	2020 - 2021	Nofima
Kari E. Takvam Justad	2020 - 2021	UiT
Julie Elise Trovaag	2020 - 2021	NMBU
Ylva Mathilde Osdal	2020 - 2021	UiB
Bjørn Anda Estensen	2020 - 2021	NTNU

Clara Gansert	2020 - 2021	NTNU
Magne Bjørnstad Vrangen	2020 - 2021	NTNU
Yemima Tanudjaja	2020 - 2021	NTNU
Ingrid Gjerde	2021 - 2022	NTNU
Siri Marie Lillebostad	2021 - 2022	UiB
August B. E. Sindre	2021 - 2022	UiB
Erik Heimdal	2021 - 2022	UiB
Sofie Agnethe Isaksen	2020 - 2021	UiB
Danilo Carletto	2020 - 2022	University of Messina
Lena Hovda Aas	2021 - 2022	UiT
Hanna Ross Alipio	2021 - 2022	Wageningen University and Research
Giuseppe Scaduto	2022 - 2023	University of Messina
Ilona Nicolaysen	2022 - 2023	UiB

BSc students

Matilda Svensson	2016 - 2016	UGOT
Karin Sivard	2019 - 2020	UGOT

Tytlandsvik Aqua is located in Hjelmeland and is owned by CtrlAQUA user partners Bremnes Seashore and Grieg Seafood in addition to Vesthavsbruk. In 2019, the facility opened with two production halls as seen in the picture while the plan is to have six production halls fully operational in 2025. Photo: Tommy Ellingsen.

CtrlAQUA Dissemination and publications 2021

Peer reviewed publications

Cabillon, N.A.R., Lazado, C.C (2022). Exogenous sulphide donors modify the gene expression patterns of Atlantic salmon nasal leukocytes. Fish & Shellfish Immunology. 120, p 1-10.

Karlsen, C., Tzimorotas, D., Robertsen, E.M., Kirste, K.H., Bogevig, A.S., Rud, I. (2022). Feed microbiome: confounding factor affecting fish gut microbiome studies. ISME COMMUN. 2, 14, 2022.

Ytrestøyl, T., Hjelle, E., Takle, H., Kolarevic, J., Rebl, A., Afanasyev, S., Krasnov, A., Brunsvik, P., Terjesen, B.F. (2022). Photoperiod in recirculation aquaculture systems and timing of seawater transfer affect seawater growth performance of Atlantic salmon (Salmo salar). Journal of the World Aquaculture Society. 1– 23, 2022.

Benktander J., Sundt H., Sundell, K., Mohana Murugan A.V., Venkatakrishnan V., Padra J.T., Kolarevic J., Terjesen B.F., Gorissen M., Lindén S.K. (2021). Stress impairs skin barrier function and induces α 2-3 linked N-acetyl neuraminic acid and core 1 O-glycans on skin mucins in Atlantic salmon, Salmo salar . Int. J. Mol. Sci. 2021, 22(3), 1488.

Davidson, J., Summerfelt, S., Mota, V., Espmark, A.M.O., Good, C. (2021). Effects of ozone on post-smolt Atlantic salmon Salmo salar performance, health, and maturation in freshwater recirculation aquaculture systems. Aquaculture. vol. 533, p. 12.

Lazado C. C., Stiller K. T., Megård Reiten M.K., Osório J., Kolarevic J., Johansen L.H. (2021). Consequences of continuous ozonation on the health and welfare of Atlantic salmon post-smolts in a brackish water recirculating aquaculture system. Aquatic Toxicology. Volume 238, September 2021, 105935.

Navada, S., Gaumet, F., Tveten, A.K., Kolarevic, J., Vadstein, O. (2021). Seeding as a start-up strategy for improving the acclimation of freshwater nitrifying bioreactors to salinity stress. Aquaculture. Volume 540, 15 July 2021, 736663.

Osório, J., Stiller, K.T., Reiten, B.K., Kolarevic, J., Johansen, L.H., Afonso, F., Lazado, C.C. (2021). Intermittent administration of peracetic acid is a mild environmental stressor that elicits mucosal and systemic adaptive responses from Atlantic salmon post-smolts. BMC Zoology. 7, Art. no. 1 (2022).

Takvam, M., Denker, E., Gharbi, N., Kryvi, H., Nilsen, T.O. (2021). Sulfate homeostasis in Atlantic salmon is associated with differential regulation of salmonid-specific paralogs in gill and kidney. Physiological Reports. Volume 9, Issue 19.

Takvam, M., Wood, C. M., Kryvi, H., Nilsen, T. O. (2021). Ion Transporters and Osmoregulation in the Kidney of Teleost Fishes as a Function of Salinity. Front. Physiol., 20.04.2021.

Zhang, X., Mikkelsen, Ø. (2021). Graphene Oxide/ Silver Nanocomposites as Antifouling Coating on Sensor Housing Materials. Journal of Cluster Science, 28 January. 33, 627–635.

Reports/abstracts/articles/media contributions

Johansen, A-M. (2022). Mye å spare med målrettet UV-lys. Norsk Fiskeoppdrett, nr. 2, 2022.

Espmark Å. M. (2021). How to protect wild salmon against sea lice with the use of new technologies and post-smolts. NASCO. CNL (21)48, Agenda item: 5(a).

Espmark Å. M. (2021). What are the key elements to promote and ensure fish welfare in a RAS environment?. RAStech magazine, June 21, 2021.

Espmark, Å.M.O. (2021). How to protect wild salmon against sea lice with the use of new technologies and post-smolts? In: NASCO. 2021. Minimising Impacts of Salmon Farming on Wild Atlantic Salmon:

Supporting Meaningful and More Rapid Progress Towards Achievement of the International Goals for Sea Lice and Containment. Report of a Theme-based Special Session of the Council of NASCO. CNL (21)65. 124 pp.

Espmark, Å.M.O. (2021). What are the key elements to promote and ensure fish welfare in a RAS environment?. Guest column RAStech. June, 2021.

Good, C. and Lazado, C.C. (2021). RAS disinfection strategies. Hatchery International. Vol 22, Issue 1, p. 28.

Lazado C.C., Stiller K. T. (2021). Ask The Experts: Risks and benefits of using ozone. RAStech magazine, August 10, 2021.

Lazado, C., Stiller, K.T. (2021). Risks and benefits of using ozone. RASTech, August 10, 2021.

Stiller, K.T. (2021). Fire viktige faktorer i landbasert oppdrett. NFE nr. 4 2021 årgang 46, Tema: Risiko i RAS.

Presentations (oral and poster)

Espmark, Å.M.O. (2021). How to protect wild salmon against sea lice with the use of new technologies and post-smolts. NASCO annual meeting 2021, May 31 - June 4, 2021.

Good, C., Crouse, C., May, T., DiCocco, A., Davidson, J., Nilsen, T.O., Espmark, A.M. (2021). Investigating the impact of water temperature on sexual maturation in Atlantic salmon post-smolts. Aquaculture Europe 2021, Madeira, Portugal, October 3-7, 2021.

Good, C., Nilsen, T.O., May, T., Crouse, C., DiCocco, A., Davidson, J., Espmark, A.M. (2021). Assessing

FishGLOBE producing post-smolts in their uniquely designed closed-containment aquaculture systems in Lysefjorden. In the picture, the 2021 system can be seen to closest to the left, while the 2019 system is to the right. Photo: Meyer Media, ©FishGLOBE.

the effects of water temperature on precocious maturation in Atlantic salmon Salmo salar post-smolts. Aquaculture American 2021, San Antonio, USA, August 11-14, 2021.

Karlsen, C. (2021). Moritella viscosa - egenskaper, interaksjoner og sykdom. Pharmaq webinar, February 28, 2021.

Lazado, C.C. (2021). Ozone use in Atlantic salmon brackish water RAS. RAS Connector Series (web). June 9, 2021.

Lazado, C.C., Carletto, D., Stiller, K.T., Mota, V., Osório, J., Verstege, G.C., Kolarevic, J., Aas, L.H., Reiten, B.K.M., Hansen, R.I., Good, C., Johansen, L.H. (2021). Disinfection, biosecurity and fish health in Atlantic salmon RAS. Aquaculture Europe 2021, Madeira, Portugal, October 3-7, 2021.

Lazado, C.C., Osorio, J., Stiller, K., Kolarevic, J., Reiten, B.K., Johansen, L.H. (2021). Potent oxidising agents as routine water disinfectants in Atlantic salmon brackishwater RAS – can mucosal health status support their potential?. GHI2021: Gill Health Initiative, Stirling, Scotland, Oct 26-27, 2021.

Lazado, C.C., Timmerhaus, G., Voldvik, V., Cabillon, N.A., Karlsen, C.R., Andersen, Ø (2021). Fish cells can “smell” rotten eggs: Molecular insights into the responses of Atlantic salmon to exogenous hydrogen sulphide. Aquaculture Europe 2021, Madeira, Portugal, October 3-7, 2021.

Stiller, K.T. (2021). Industrial testing of a new Norwegian ozone reactor and skimmer system. Research plaze at Aqua Nor, "How to ensure a healthy and robust fish?", August 25, 2021.


FishGLOBE 3.5K under production in 2021 at Bluegreen Fusion in Bamble, Vestfold & Telemark. Photo: ©FishGLOBE.

Lerøy Seafoods facility at Kjærelva, Norway. Photo: ©Lerøy Seafood Group ASA.

Stiller, K.T. (2021). Fire viktige faktorer i landbasert oppdrett - kjønnsmodning, salinitet, geosmin og karbondioksid. Morefish konferanse: Risiko og kompetanse i landbasert oppdrett, Oslo, 2th of November.

Stiller, K.T., Johansen, S., Vadseth, M., Brunsvik, P. (2021). Industrial testing of a new Norwegian ozone reactor and skimmer system. AquaNOR 2021, Trondheim, Norway.

Stiller, K.T., Johansen, S., Vadseth, M., Brunsvik, P. (2021). Industrial testing of a new Norwegian ozone reactor and skimmer system. EAS 2021, Madeira, Portugal, 7th of October 2021.

Theses

Carletto, D.(2021). Physiological hallmarks of Atlantic salmon (Salmo salar) parr responses to an oxidant. Master thesis, University of Messina.

Estensen, B. A. (2021). The impact of redox reactions on the N- and P-cycle in recirculating aquaculture system. Master thesis, NTNU.

Gansert, C. (2021). Characterization of changes in dissolved organic matter (DOM) composition of recirculating aquaculture systems (RAS) sludge at different redox stages. Master thesis, NTNU.

Takvam Justad, K. E. (2021). Atlantic salmon water pathogens inactivation by UV irradiation. Master thesis, University of Tromsø, Norway.

Tanudjaja, Y. (2021). Early Warning Signs and Dynamics of H2S production in Recirculating Aquaculture Systems. Master thesis, NTNU.

Trovaag, J. E. (2021). Dietary effects on skin morphology and stress marker genes of Atlantic salmon smolts. Master of Science in Aquaculture, NMBU.

Vrangen, M. B. (2021). Nitrous oxide and hydrogen sulfide production in sludge from a recirculating aquaculture system (RAS). Master thesis, NTNU.

Photo: ©MOWI.

Photo: ©MOWI.