CtrlAQUA

Annual Report 2022
CtrlAQUA - Centre for Closed-Containment Aquaculture

Norwegian Centre for Research-based Innovation

Front page and picture above

Front page: In 2022, Nofima opened the new RAS facilities with one tank / one RAS systems in Sunndalsøra. We managed to perform the last CtrlAQUA trials in the new systems, and together with the rest of the Nofima RAS infrastructure, these systems will enable us to continue to provide relevant RAS research for the industry.

Page 2: The CtrlAQUA consortium at the 2023 Annual Meeting in Sunndalsøra.
Photos: Terje Aamodt, © Nofima

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CONTENT

1 OVERALL PROGRESS AND SUMMARY FOR 2022

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.

CtrlAQUA is approaching the end, and the final date of the centre is 31st March 2023. This annual report will therefore be the last regular annual report, however we will also produce one final overall report in June 2023. The last annual meeting for consortium members will be dedicated to summarising project highlights from 2015 until today and we plan to print an extensive amount of factsheets of the most important results. After being offered to the consortium members, the factsheets will also be made available to the public. The annual meeting in 2022 was successfully arranged in Haugesund, after two years of Covid forced webinars. It was very nice to finally meet people face-to-face again and based on the in-depth discussions, I think everyone agreed.

In this annual report, you will be able to read about what the Chair of the board, Trond Rosten, thinks about the status of closed containment systems and how CtrlAQUA has contributed. He will reflect on CtrlAQUA's progress and how he considers the aquaculture future might look like. The centre management believes that a lot of development has taken place during the eight years that the centre has worked on the topic. The development of RAS and semi-closed systems (S-CCS) have made significant improvements, both regarding technological development and how fish perform and cope in the systems. We hope and believe that CtrlAQUA outputs are part of the positive development, but for sure other R&D and industrial partners have also contributed heavily. We have also addressed serious knowledge gaps that need to be dealt with in the coming years.

In this annual report you will also be able to read about three PhD students who defended their theses in 2022. Xiaoxue Zhang defended her thesis titled "The development of antifouling materials with potential application on sensors", on 16th March at NTNU. On 15th August, Patricia Aguilar Alarcon defended her thesis "Deciphering the composition and transformation of dissolved organic matter in recirculating aquaculture systems by high-resolution mass spectrometry", also at NTNU. Finally, Tharmini Kalananthan defended her thesis "Basic mechanisms for control of appetite and feed intake in Atlantic salmon (*Salmo salar*)" at the University of Bergen on 10th November. Tharmini was one of our students working on an associated project. We still have a few PhD students who will not finish during the CtrlAQUA centre time; however we are very satisfied with the recruitment of students in CtrlAQUA that after 2022 ended with 15 PhD, 1 Dr. philos and 60 MSc students.

Much of the experimental work is now finished and a majority of the projects have been focusing on wrap-ups, final analyses and publications. BENCHMARK II had the final sampling by the end of 2022 and the results are still in process. Also, the task on nephrocalcinosis in PREVENTIVE made some exciting progress in 2022 with comparing analytic methods (X-ray, histology and manual scoring). Work in both these projects will continue until the end of CtrlAQUA. You may read about these and more exciting findings in the reports from the different Departments.

We hope that you will enjoy reading the annual report 2022.

February 2023
Åsa Maria Espmark
Centre Director CtrlAQUA SFI

In 2022, the CtrlAQUA consortium could finally arrange the annual meeting face-to-face in sunny Haugesund. The consortium was well represented after two years of Covid forced webinars. Photo: © 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 the environment and fish health and welfare at risk. The ambitions for substantial increase in salmon production are big, but an increase depends 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 keys to solving 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:

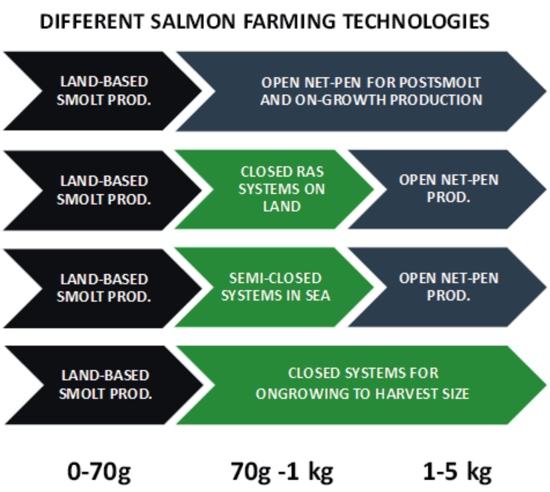

Figure 1.1. Different ways of producing Atlantic salmon: Closed-containment aquaculture systems.

"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 of the salmon 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.


Photo: Kjellrun Hoås Gannestad, Nofima


Photo: Kjellrun Hoås Gannestad, Nofima


Photo: Kirsti Hjelde, Nofima

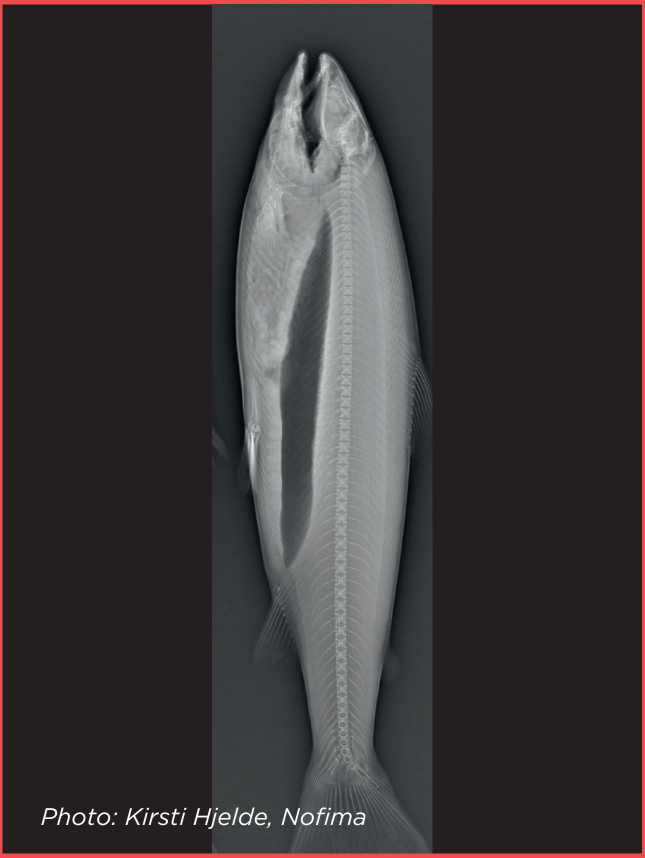
Photo: Kirsti Hjelde, Nofima

Extensive sampling at Bremnes Seashore in Trovåg with radiography and multi-sampling of the same fish.

RAS has almost become an off-the-shelf product, while semi-closed facilities at sea still have a way to go. According to Chairperson Trond W. Rosten, this is the status after eight years of intense research conducted on fish in closed fish farms in CtrlAQUA.

By Reidun Lilleholt Kraugerud, Nofima.

Partial success with closed technologies

Trond Rosten, Chair of the CtrlAQUA Board

Photo: Terje Aamodt

CtrlAQUA is a Centre for Research-based Innovation in Closed-Containment Aquaculture with 21 partners. The partners have conducted intensive research from 2015 to 2023 to develop closed-containment aquaculture systems into becoming reliable and economically viable technologies for farming salmon up to one kilogram.

The Centre is led by Nofima and Senior Scientist Åsa Espmark, while Trond W. Rosten keeps an overall view of things. As Chairperson of the Board, Rosten has many thoughts about research and development in closed-containment aquaculture technology.

Celebrating long-term collaboration

Rosten describes the process of establishing and being part of a Centre for Research-based Innovation as being part of a growing tree.

“In 2015, the Research Council of Norway formed the trunk by establishing CtrlAQUA SFI. In the consortium, the tree then gained branches as more projects were added and new ideas emerged. The tree has become stronger as research has been verified and adopted by the industry. There are now several interested parties, which gives the tree nutrients to grow further”, says Rosten.

“Long-term collaboration built around clear goals in a fixed constellation has been one of the most positive things for me.”

Rosten feels that being part of a strategically important initiative for Norway has been rewarding:

“Long-term collaboration built around clear goals in a fixed constellation has been one of the most positive things for me.
When more than 20 partners set common goals, have regular meeting points and work together over eight years, it really impacts the collaboration between research and industry."

Students are important!

As many as 60 students hold a master’s degree in the Centre and 16 have started their further work after doctoral degrees at the University of Bergen and NTNU. Several of the students have been employed by partners at the Centre and in other aquaculture, health and technology companies, to name just a few.

“The effect of the innovation the students are responsible for is invaluable. Many talented students contribute to spreading knowledge and giving a long-term perspective to research and innovation that we cannot do without.”

There is also a lot of good research being conducted abroad. Partners, such as the Freshwater Institute in the US, have been dedicated allies in CtrlAQUA right from the beginning.

“I think the Norwegian consortium, and especially the supplier industry, has really benefited from this”, says Rosten.

RAS is almost an off-the-shelf product

The CtrlAQUA Centre was formed at a time when the most important thing was to overcome lice problems and escapes. There are still important arguments for extending the time salmon spend away from open sea cages, and in recirculating systems on land or closed facilities at sea. At the same time, the high degree of control over the production process provides a good opportunity to reduce the production time for farmed salmon in net-pen facilities.

RAS is the technology that is most mature out of all the closed technologies, and the research in the Centre has contributed to the technology becoming more accessible and more sophisticated.

We have become much more skilled when it comes to the design and operation criteria than we were eight years ago. However, Rosten states that all the improvements come with a price tag:

"It is not getting any cheaper to build or operate closed systems, and it is a 24/7 task that demands a lot from the operators."

Nevertheless, RAS has been the safest financial investment for fish farmers, and it is now a relatively proven technology. As early as 2021, RAS supplier Pure Salmon Kaldnes reported that almost all new projects for smolt and post-smolt are based on RAS. They also reported that larger facilities, larger tanks and larger fish mean that new challenges are constantly emerging.

Rosten points out that for semi-closed facilities at sea, a food fish licence must be used to develop post-smolt technology at the expense of efficient production in open net-pens. This is in contrast to RAS, where the licence has been free of charge.

About the potential of semi-closed facilities at sea

"This has probably contributed to slowing down the development at sea. Those who have wanted to develop semi-closed post-smolt production at sea have not had the same economic benefits and predictability as those who have built RAS on land. It has also been difficult to obtain or maintain research licences for such technology. This is reflected in the Centre, which has been involved in more modest activity regarding semi-closed facilities at sea compared to RAS", he says.

There are several suppliers of semi-closed systems at the Centre, such as Aquafarm Equipment, FishGLOBE and FiiZK.

"The semi-closed systems have developed a lot over the eight years, but there are still some uncertainties that mean that there is higher risk associated with working on such facilities compared to both traditional nets and RAS", says Rosten.

Many of the experts in CtrlAQUA believe that semi-closed facilities at sea will play an important role in the future of salmon farming in Norway. For example, Professor Are Nylund at the University of Bergen has previously stated that the main advantage is that such facilities hardly have any lice problems, and that they have a competitive advantage by being at sea.

Water treatment is much easier than it is on land, while logistics, treatments and cleaning can be more complicated and costly. Knowledge development in CtrlAQUA regarding semi-closed facilities has really increased in the last couple of years, and Rosten is optimistic that it will continue:

"I hope and believe that everyone who uses the technologies is interested in implementing new knowledge, and documenting and validating performance in closed systems on land and at sea. In this way, we can identify new research and development needs."

"The semi-closed systems have developed a lot over the eight years, but there are still some uncertainties that mean that there is higher risk associated with working on such facilities compared to both traditional nets and RAS."

Publishing new research results in peer-reviewed journals is important to drive the knowledge further forward, and I think CtrlAQUA has contributed a great deal to this. We should be proud of that.

CtrlAQUA has contributed to obtaining much more knowledge about the biology and technology of farming fish in closed-containment systems in the phases where this is relevant. When it comes to fish welfare, the Centre has addressed major issues such as hydrogen sulphide, nephrocalcinosis and

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smolt quality; knowledge that helps increase fish welfare.

At the same time, there are still problems associated with skin and wounds that have not yet been resolved. Freshwater resources are limited, and fish farmers have learned how to produce a lot of food on limited resources in efficient facilities both on land and at sea. Rosten believes this development will continue, and that we will see expansions where resources and expertise already exist – i.e. larger facilities with increased safety and performance.

The previously mentioned tree is thus growing well, and Rosten hopes the development of new and existing production systems will not lose momentum in the years to come. He is also pleased to see that more actors are emerging and that the Norwegian Seafood Research Fund (FHF) is also funding several important research projects that are relevant to the development. Rosten says the CtrlAQUA Board and several of the partners have reflected on whether the Centre for Research-based Innovation collaboration should continue:

“The Centres for Research-based Innovation scheme has worked very well as an instrument in the CtrlAQUA context. If the Research Council of Norway announces a new call for proposals, we will sit down and discuss it and would like to get more people involved in a collaboration”, says Rosten.

Trond W. Rosten is Group Manager for Freshwater and Closed Production Technology at Mowi ASA, and has a long career in research and aquaculture. Mowi is a partner in CtrlAQUA, and Rosten has been chairperson of CtrlAQUA since 2020.

Facts about closed-containment systems

- In **closed-containment systems at sea**, most systems are still semi-closed because they do not treat all inlet water or collect waste. Many farm smolt and potentially keep them there until they weigh 500-1000 grams. In practice, they currently work as an intermediate stage for post-smolt weighing <500 grams. The advantages of such closed-containment systems at sea are that they may take in a lot of good seawater from the depths where there are less lice, less algae and fewer fish pathogens compared to the surface. A sealed wall separates the sea environment from the fish on the inside of the facility and prevents fish from escaping and lice from entering.
- Currently, **closed facilities on land** are primarily used in the production of smolt up to 250 grams, but it has become more common in Norway to expand smolt production up to 500-800 grams. A few fish farmers want to produce salmon up to slaughter size of 4.5 to 5.5 kilograms in such facilities. Such projects are also of great interest abroad, where there are limited natural geographical advantages for producing salmon in net-pen facilities. Land-based facilities often use recirculation technology for water treatment, and up to 99.9 percent of the water is purified and reused multiple times. The effluent therefore contains a higher concentration of nutrients and is less in volume.

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. A 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*

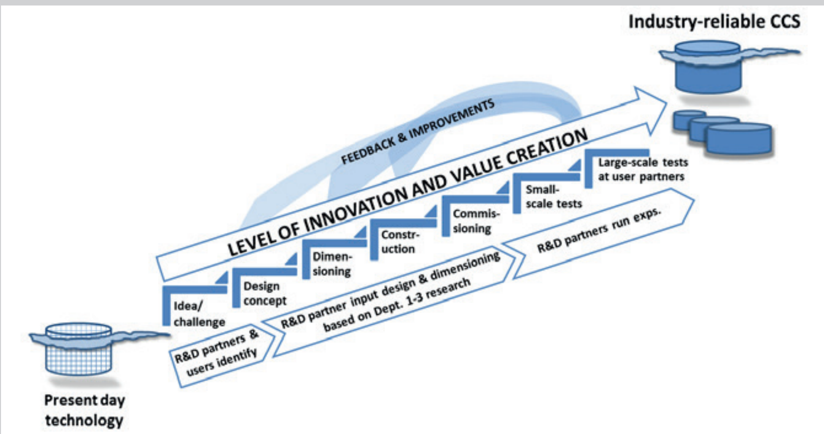
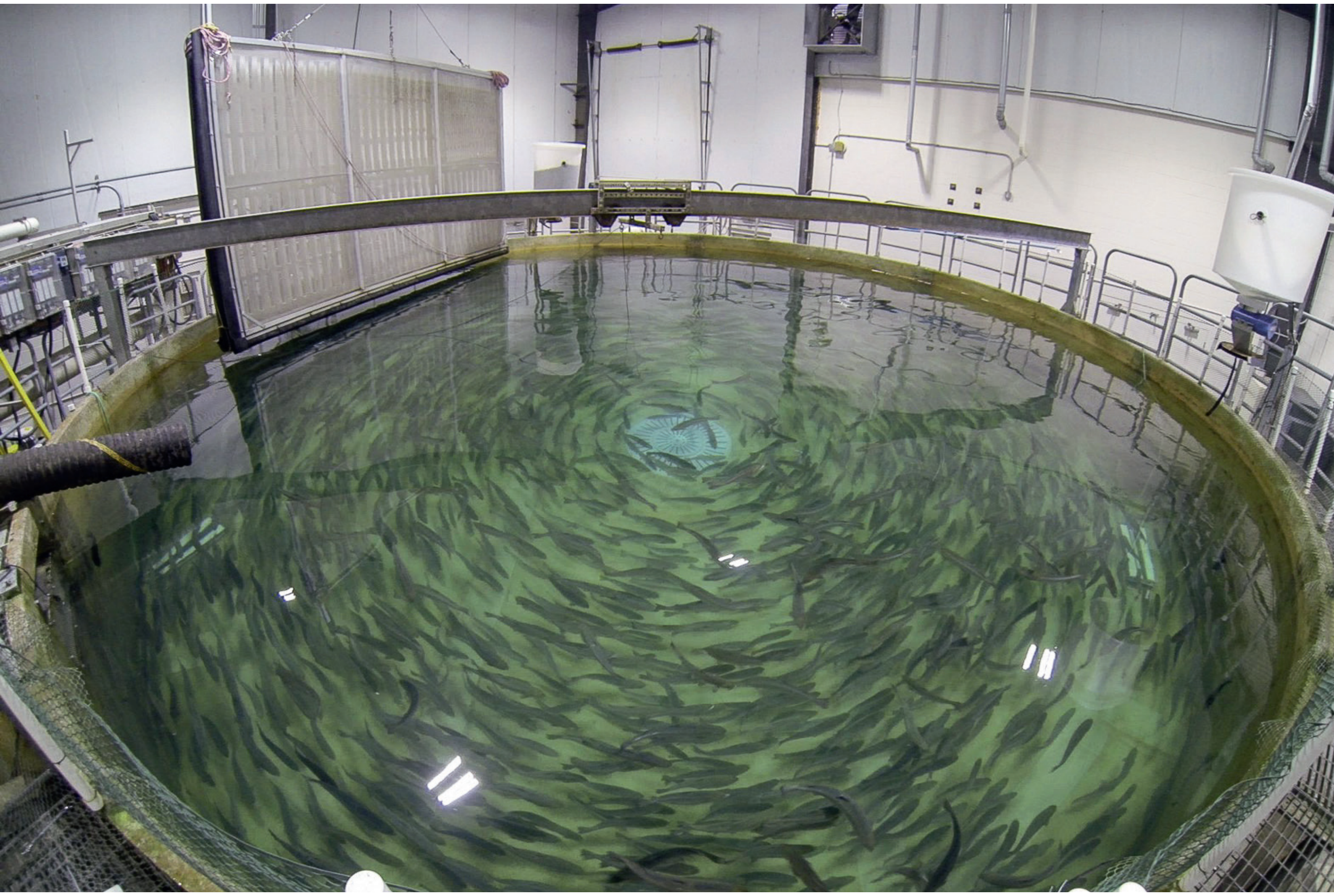


Figure 2.1. Innovation process in CtrlAQUA, from present day cage technology to establishment of industry-reliable closed-containment systems, either in-sea closed tanks or land-based RAS. Exps. = experiments.



Atlantic salmon post-smolts midway through growout to a 4 kg harvest size in a 150 m³ culture tank of a semi-commercial scale freshwater recirculating aquaculture system. Photo: Kata Sharrer, The Freshwater Institute

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 2022, the Board had two physical meetings. The Board consisted in 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 is led by the host institution.

In addition, Kjersti Turid Fjalestad, the contact

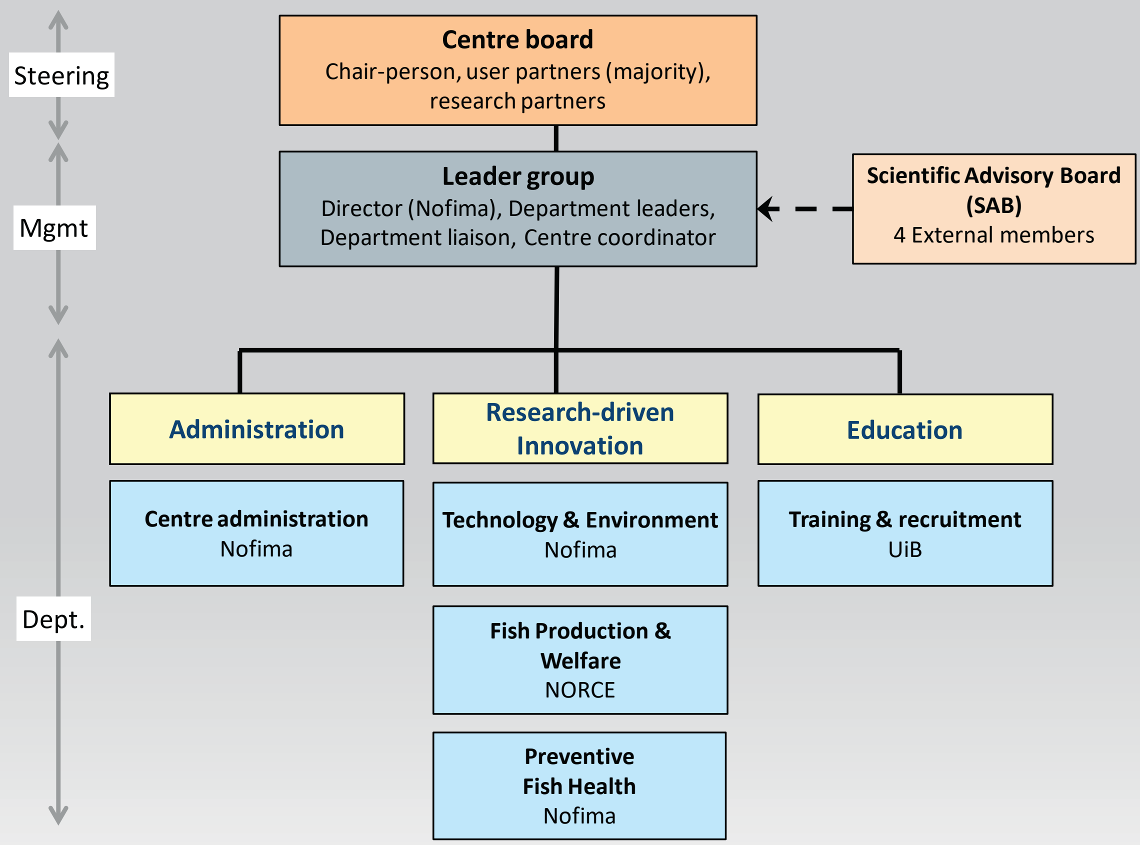


Figure 3.1. Organizational structure of CtrlAQUA.

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.

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 is 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 flow 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 2022

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
Krüger Kaldnes
Board Member

Rolf Hetlelid-Olsen
PHARMAQ
Board Member

PARTNERS

Per December 31st 2022, 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 CtrlAQUA collaboration and is now a Mowi employee. The semi closed-containment system site at Molnes in Sunnhordaland, and 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 and Coho 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 and in Finnmark 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 and innovation of production technology. 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, innovation and strategy management, fish health and production optimization. Cermaq has also contributed with their fish health group, and closed system testing facilities.

FishGLOBE AS is a company that designs, builds, and sells fully enclosed floating fish farms for sea. We are proud to have two globes in operation and so far, it proves to be working very well. We have delivered over 2 million post smolt since the start up in 2019 and have had zero lice treatment, zero escape, collecting the particle sludge and good growth ratios. The globe is built in polyethylene (HdPE). The polyethylene is a thermoplastic which works well with waves and is well-suited and well-known for fish farming. The material also has low costs for maintenance purposes (no corrosion) and has a high level of food security. The FishGLOBE technology has two patents. One of them is the unique and gentle way of delivering fish with the use of compressed air to raise the globe and let the fish gently move over to the well boat with reduced stress compared to normal delivery. The company was established in 2013 and since 2018 the organization has increased organically year by year. 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 entrepreneur and technical director Arne Berge.

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.

Grieg Seafood ASA is one of the world's leading salmon farmers. Our farms are in Finnmark and Rogaland in Norway, as well as British Columbia and Newfoundland in Canada. Our headquarter is located in Bergen, Norway. Approximately 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 world-leading seafood corporation with a history reaching back to 1899. The Group's core business is the production of salmon and trout, catches of whitefish, processing, product development, marketing, sale and distribution of seafood. We have production and packaging plants in Norway, Sweden, Denmark, Finland, France, the Netherlands, Portugal, Spain, Italy, Turkey and Shetland Islands. We also have sales offices in the USA, Japan and China. Every day, Lerøy delivers thousands of different seafood products to shops, restaurants, canteens and hotels. We are proud suppliers of seafood to customers worldwide, and our deliveries correspond to 1.75 billion meals every year. Lerøy Seafood Group's vision is to become the most profitable global supplier of sustainable high-quality seafood. In CtrlAQUA, Lerøy is represented by Technical Manager Harald Sveier, who has a long research background in fish physiology and nutrition. Sveier is head of Ocean Forest, and has lead Lerøy's work in developing the closed-containment system Preline.

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 is one of the Major recirculating aquaculture systems (RAS) supplier worldwide. Over the past 15 years, PSK has developed strong knowledge and expertise in designing, delivering, and supporting (through services) landbased Atlantic salmon production, mainly smolt and post-smolt production in Norway. PSK portfolio includes over 21 large land-based RAS facilities in Norway and Europe.

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, bacteriology and Next Generation sequencing extend the advisory and problem-solving capability which PHARMAQ Analytiq offers the aquaculture industry. In CtrlAQUA, PHARMAQ Analytiq is represented by Stian Nylund and Anne Katrine Reed, both having 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 PhD Patcharee Thongtra 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 fish health and vaccines, dedicated to support sustainable growth in the aquaculture industry. PHARMAQ is part of Zoetis, the world leader in animal health. Our innovative fish health solutions include PHARMAQ fish vaccines and therapeutics, PHARMAQ Fishteq vaccination machinery, and PHARMAQ Analytiq research and analysis. PHARMAQ's research and production facilities are based in Norway, with global operations in commercial fish farming markets. PHARMAQ has around 375 employees. To learn more, visit PHARMAQ.com. In CtrlAQUA, PHARMAQ is represented by Nils Steine, Mari Solheim, Øyvind Tønnesen, Monica Gausdal-Tingbo, Siv Tunheim, Anette Furevik and Rolf Hetlelid Olsen 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.

Neda Gilannejad from NORCE at the Benchmark II sampling linking to project Robust, investigating how photoperiod and salinity protocols affect post-smolt energy status, intestinal integrity, and performance in RAS and after seawater transfer.

Pradeep Lal (NORCE) at the Benchmark II sampling linking to Robust, Optimize and Preventive projects

Erik Heimdal, Master student (NORCE), joining the Benchmark II sampling in Sundalsøra. Investigating smolt physiology and performance: small and large smolt.

Photos: 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). The use of photoperiod in production of large smolts and post-smolts has become somewhat inconsistent, with an increasing number of farmers only applying 24 hours light, leaving out the winter signal traditionally used in a classic square wave photoperiod regime Figure 4.1). Large freshwater salmon are reported to display traits associated with smoltification, such as silvering and elevated gill Na, K-ATPase (Nka) enzyme activity when reared under constant light. This has raised questions about the use of Nka enzyme activity as a sufficient proxy for smolt development. One concern has been that larger smolts also display higher variation in gill Nka activity than smaller smolts, indicating asynchronous smolt development in larger fish. Here we demonstrate that the Nka enzyme activity, when used appropriately, can be used as a good proxy for smolt development of smolts up to at least 350 grams (Figure 4.1A, 4.1D).

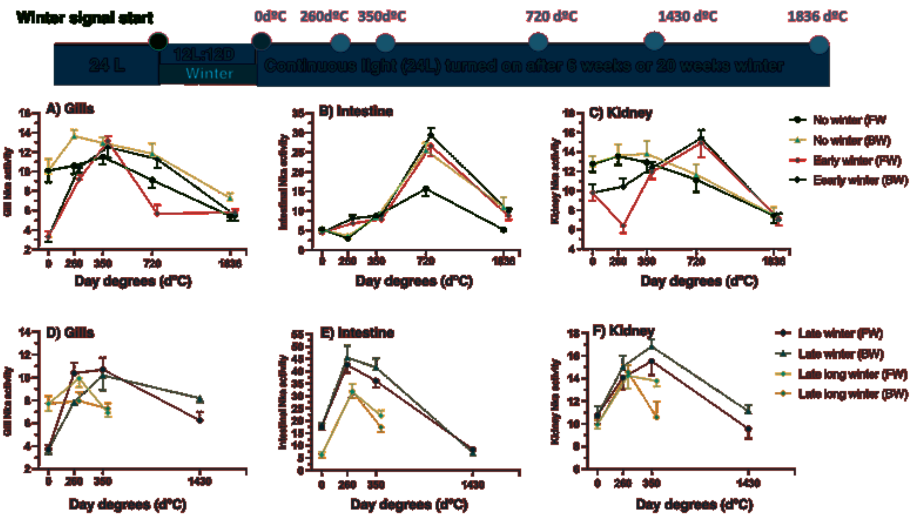


Figure 4.1. Nka enzyme activity in Atlantic salmon given either no winter (continuous light) or a 6-week winter signal (12 hours light:12 hours dark) when 40 grams (early winter group), followed by 24 hours light spring signal (A, B, C). Nka enzyme activity in salmon given a 6-week late winter signal (late winter group), or 20-week late long winter signal (late long winter group) when 120 grams, followed 24 hours light spring signal (D, E, F). Zero-day degrees indicate the first time point after 24 light was turned on after the winter signal. Fish were reared in both freshwater (FW) and brackish (BW).

Our findings demonstrate that a classic photoperiod treatment with 6 weeks winter stimulate Nka enzyme activity in gills (Fig. 1A), intestine (Figure 4.1B) and kidney (Figure 4.1C). It should be noted, however, that peak enzyme activity occurs earlier in the gill than in the intestine and kidney. Intestinal (Figure 4.1B) and kidney (Figure 4.1C) Nka activity do not peak until approximately 720-day degrees after spring signal is turned on, while gill Nka, which peaks around 350-day degrees, have already decreased to pre-smolt values at 720-day degrees (Figure 4.1A). The use of brackish water prolongs elevated gill NKA activity until at least 720-day degrees in smaller smolt around 150 grams (Figure 4.1A), while the use of brackish water is less effective in larger smolts around 350 grams (Figure 4.1D). Overall, our findings suggest that Nka activity is a good proxy for photoperiod induced smoltification in smolts up to 350 grams, despite a somewhat different developmental trajectory in larger smolts (Figure 4.1D-E) than in small smolts (Figure 4.1A-C). It is therefore important to monitor smolt development closely. Both large and small smolts experience reduced Nka activity if kept for longer periods of time in brackish water, suggesting that if smolt and post-smolts are not given a proper salinity signal after smoltification, parts of their adaptation to full strength seawater will be lost. If smolts and post-smolts are kept more than 750-day degrees in RAS after spring signal is turned on, the salinity should probably be higher than 12 ppt.

Gill Nka activity is high in juveniles kept at continuous light (Figure 4.1A). Interestingly, the winter signal results in reduced gill Nka activity in smolts up to at least 350 grams, indicating that they have responded sufficiently to the winter signal, followed by a subsequent increasing gill Nka activity after spring light is turned on. However, if the fish is larger than 800 grams, they will not show any changes in response to either a winter signal, or a subsequent spring light signal (Figure 4.2). It is recommended to start the winter signal before the fish are 200 grams, and the winter signal should not last longer than 8-10 weeks.

The rearing strategy in RAS may impact the later performance of smolt and post-smolts in sea pens. Smolts and post-smolt

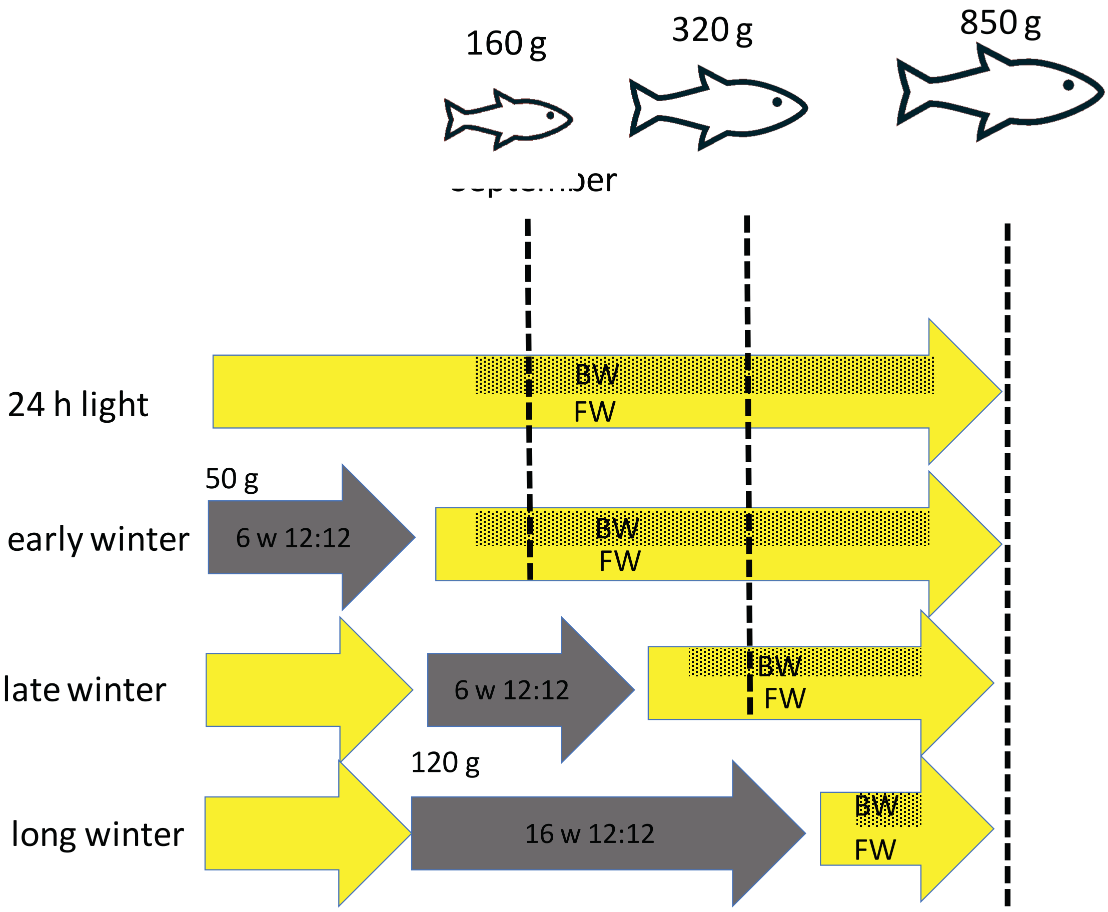


Figure 4.2. Experimental design; photoperiods in RAS and mean bodyweight at transfer to seawater pens at Gifas in September 2021, November 2021 and January 2022. Early winter revied winter signal (6 weeks) when they were 40 grams. Late winter (6 weeks) and long winter (16 weeks) groups received the winter signal when they were 120 grams.

were transferred to seawater pens at Gifas in September 2021, November 2021 and January 2022 (Figure 4.2). The group that was transferred in September had received either continuous 24 h light in RAS (no winter) or a 6-week winter signal from 50 g (early winter). All photoperiod treatments were replicated in freshwater and in brackish water (12 ppt).

Fish weight at transfer were 187 g for fish on 24 h light in RAS and 148 g for fish that were given a winter signal. In the next batch transferred in November, one group had received a late 6-week winter signal from 120 g in addition to the photoperiods mentioned. The mean bodyweight for the different photoperiods were 356 g (no winter), 275 g (early winter) and 330 g (late winter). The last group transferred in January included a treatment given a 16-week winter period from 120 g RAS (long winter). The mean bodyweight for the different photoperiods at transfer in January were 930 g (no winter), 866 g (early winter), 900 g (late winter) and 728 g (long winter).

The mortality during the seawater phase at Gifas was high, and the fish was infected with moritella viscosa and tenacibaculum and suffered heavy mortality due to winter ulcers from February until the end of April. The fish transferred in September was however only slightly affected by winter ulcers, and mortality in this group from September until the end of April was 5%. In contrast, fish transferred in November had a mortality of 35% mainly due to winter ulcers and fish transferred in January suffered 30% mortality from January to the end of April. Mortalities include fish that was found dead in the pen and fish that was euthanized due to winter ulcers. From May until the end of June the mortality was low, but it started to increase in July, and during delousing in July fish died with symptoms of circulatory heart failure, and the fish was diagnosed with HSMB. Mortality was close to zero in August, but another delousing in early September at high water temperature resulted in high mortality in all treatments, as the fish had not recovered from the HSMB infection. Mortality from April to September was 15-20% mainly due to delousing on HSMB infected fish and was not significantly different among transfer sizes. In October and until slaughter in mid-November the morality was low. Mortality in seawater was not related to photoperiod or salinity in RAS, only time of seawater transfer had a large impact on survival.

Growth rate and final bodyweight at slaughter was highest in fish transferred to sea at the lowest bodyweight in September. TGC in seawater was slightly higher in fish given an early winter signal (3.3) compared to fish on 24 h light in RAS (3.2), but final bodyweight was higher in fish on 24 h light in RAS (3681 g) compared to fish given a winter signal (3571 g). Mean bodyweight at slaughter for fish transferred in November and January were 3054 and 3058 g and TGCs were 3.0 and 2.4 respectively. A winter signal in RAS was positive for seawater growth in fish transferred in November, but there was no difference between an early or late winter signal in TGC. For fish transferred in January, highest TGC was recorded in fish given a late long winter signal whereas fish on continuous light in RAS had the lowest TGC. Final bodyweight was however similar for all treatments transferred in November and January. Growth in seawater and final bodyweight was not affected by salinity in RAS regardless of transfer size.

MSc student Danilo Carletto at H2salar sampling for Department of Preventive Fish Health. It was the very first sapling in the mini RAS landing systems at Sunndalsøra in the spring of 2022. Photo: Kevin Torben Stiller, Nofima

DEPARTMENT OF PREVENTIVE FISH HEALTH

The main objectives in Department Preventive Fish Health are inventions to prevent, detect and control diseases in closed and semi-closed containment systems.

We have evaluated the effectiveness of ozone alone or in combination with peracetic acid (PAA) as disinfectant inside a RAS system (RAS loop), to control a disease outbreak following an experimental infection with infectious pancreatic necrosis virus (IPNV). During the trial, the ozone group had moderate mortality (10-20%), while the ozone-PAA group had low mortality (<10%). Water quality did not significantly change during the treatments and following infection, but the fish was affected. In the ozone-PAA group expression of several immune-related genes were upregulated in gill and skin. The changes in gill were mirrored by the gross pathologies observed, like discolouration and increased mucus production, however, there were no differences between groups in number of mucus producing cells. Gill damage scores were mainly 3 (scale 0 - 3) three weeks post-infection. Upregulation of immune genes were documented also in the head kidney in the ozone-PAA group. While stress responses measured in blood (plasma cortisol, lactate dehydrogenase, oxygen radicals) were higher in the ozone group than in the ozone-PAA group, key stress markers in liver, including hsp90 and gpx, were upregulated in the ozone-PAA group.

The bacterium *Candidatus* Branchiomonas cysticola is considered the primary cause of epitheliocystis in farmed salmonids. So far, no genetic characterization has been done to describe potential differences associated with geographical origins, host species or reservoirs, primarily due to lack of cultivation systems for this intracellular bacterium, which complicates the sequencing of its genome. Recent identification and application of previously uncharacterized genes provided knowledge of interest. Reconstructing the evolutionary relationship of this bacterium compared to its closest related species has revealed its unique characteristics, and the genetic divergence observed has led to a proposal of a novel bacterial family to be named *Branchiomonaceae.* Results show that it is a small selection of highly similar strains/variants of the bacterium that is circulating in farmed and wild salmon in Norway. Whether the few genetic differences observed affect virulence remains uncertain and will rely on clinical field observations. Importantly, a genotyping scheme has been developed which enables the possibility to attribute observable traits (if any) of the variants that were ultimately identified.

Nephrocalsinosis (NC) in farmed 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 and at different life stages of the salmon. The benefits of using radiography for diagnosing NC would be that it is non-invasive and easily performed on live fish, it is quick and can be done on large numbers of fish at the fish production sites using portable equipment. This also enables us to follow the development in fish with a known degree of NC throughout production and study their survival, performance, and growth at sea to learn more about the consequences this diagnosis has for the fish. During the last year, several hundred Atlantic salmon from 9 to 1000 g, have been radiographed and examined for NC, many while alive. Other methods included for comparison were histology, the main diagnostic tool used today, and macroscopical scoring. In addition, some fish with varying degree of NC were sampled for blood analyses. Comparisons show that there is a correlation between histological and macroscopical scoring, and radiography (see example in Figure 4.3.). We have seen that accuracy

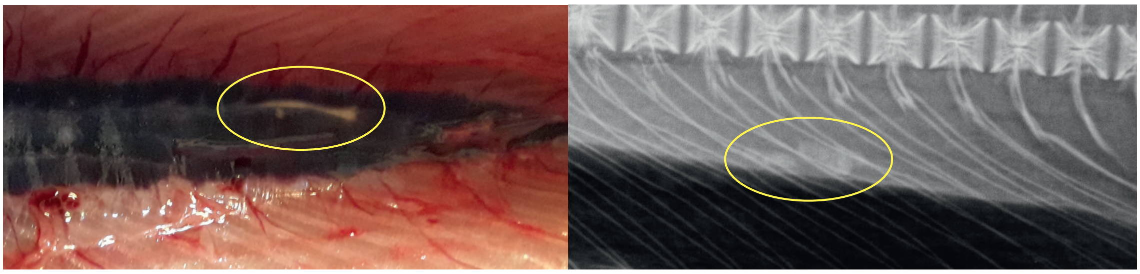


Figure 4.3. Macroscopical scoring of low degree nephrocalcinosis (NC) and radiography (mammography) of the same area in the same fish (200g) in lateral view. NC was observed only in the ureter and it was given a weighted histology score 3, which represent a scarce find.

of radiographic scoring depends on image quality, fish size, experience, and the degree of NC. Image quality improves with increasing fish size and increasing degree of NC and larger mineral deposits increases visibility on the radiograph. Stationary radiography (mammography) equipment especially designed to detect small calcifications in soft tissue, gives better images than portable x-ray systems, but smaller changes can be recognized with increasing experience by the user. Tests show that with the portable system even low-grade NC on 40 gr fish, as shown in Figure 4.4, can be detected..

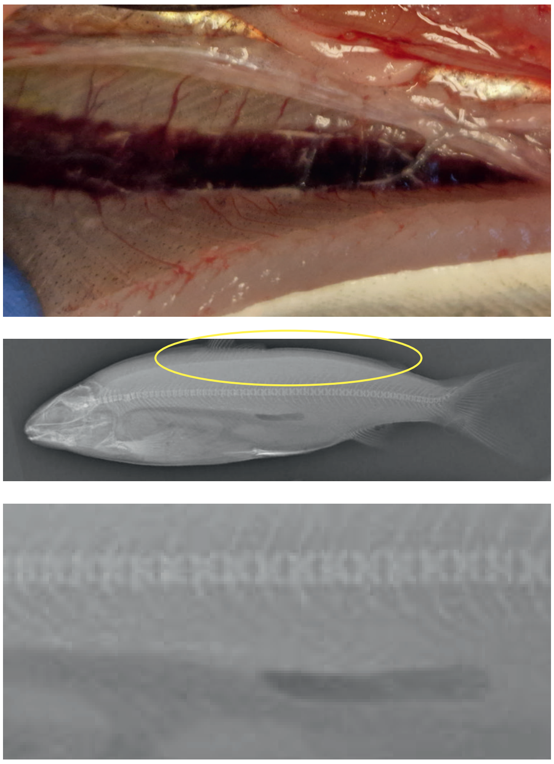


Figure 4.4. A. salmon, 42 g, with low grade NC. Macroscopical score, radiograph by portable system and enlarged part of the radiograph showing barely visible calcifications in the ventral part of the kidney.

During visits to several fish production facilities, we have seen many different macroscopic scoring systems for NC, and also detected wrongly scored NC. There is a great need for a common scoring system to get comparable scores for the understanding of the cause and effect of NC. Blood was analyzed for several compounds, including Calcium, Chloride, Glucose, Potassium, Magnesium, Sodium and Phosphorus, and it revealed that primarily the Magnesium levels were out of normal range in the NC affected fish.

The development of methods to simultaneously measure the expression of multiple genes in many samples, such as the Biomark HD (Fluidigm) platform, promises a breakthrough in aquaculture research and diagnostics. We have made significant progress in the development of multigene expression assays and they have been successfully used in a large-scale salmon production trial in CtrlAQUA studying different production protocols. Differences in protocols had no effect on the immune status of salmon. The assay allows simultaneous assessment of smoltification - and immune status is now used by the industry to evaluate groups of fish at the critical stage before and after seawater transfer.

Knowing the healing progression of different wound types when injuries occur can be used to estimate a time frame for healing, i.e. if the tissue recovers and restore or if further handling increases the risk of adding further damage to the skin. When assessing skin structure characteristics, we revealed effects and wound healing progression of different mechanically induced skin wounds (1- scale loss, 2 - superficial wounds, and 3 - deep wounds down to the underlying muscle tissue). Wound healing progression depends on the severity of damage. After 5 weeks at 10 °C, scale loss areas were in the final remodeling stage, superficial wounds were closed but only starting to develop scales, while deep wounds were still in inflammation with active tissue formation. The experiment could not verify if the different wound types influenced growth performance, intestinal morphology or serum parameters. Samples from fish reared with different production protocols in RAS were used to investigate functional and morphological characteristics of the skin and intestine. At first transfer (~100 g), epidermal skin thickness and mucosal cell numbers decreased during the end of smoltification in the group kept on 12 h light and 12 h dark (12:12). However, no effect of light treatment (12:12 vs 24h light) was observed on the barrier and transport functions of the skin. The intestinal barrier and transporting functions in the 12:12 group resembled changes previously observed during natural smoltification. Later (~300 g), including the variables constant light and early and late winter signaling, differences in skin morphometrics in neither fresh nor brackish water were seen.

A prototype system to perform automatic sample treatment, purification of DNA/RNA and amplification and detection of pathogens in water samples, now named 'FORDETECT', has been developed throughout the CtrlAQUA lifespan by the University of SouthEast Norway (USN). An international patent application on the system is pending. Tests performed in 2022 on automatic DNA purifications of water extracts were shown successful. Two detection methods, (i) PCR (polymerase chain reaction) and (ii) LAMP (loop-mediated isothermal amplification) were compared, and LAMP showed favorable outcomes. USN, together with a commercial partner, will continue to standardize and test the FORDETECT system directed towards salmon farming.

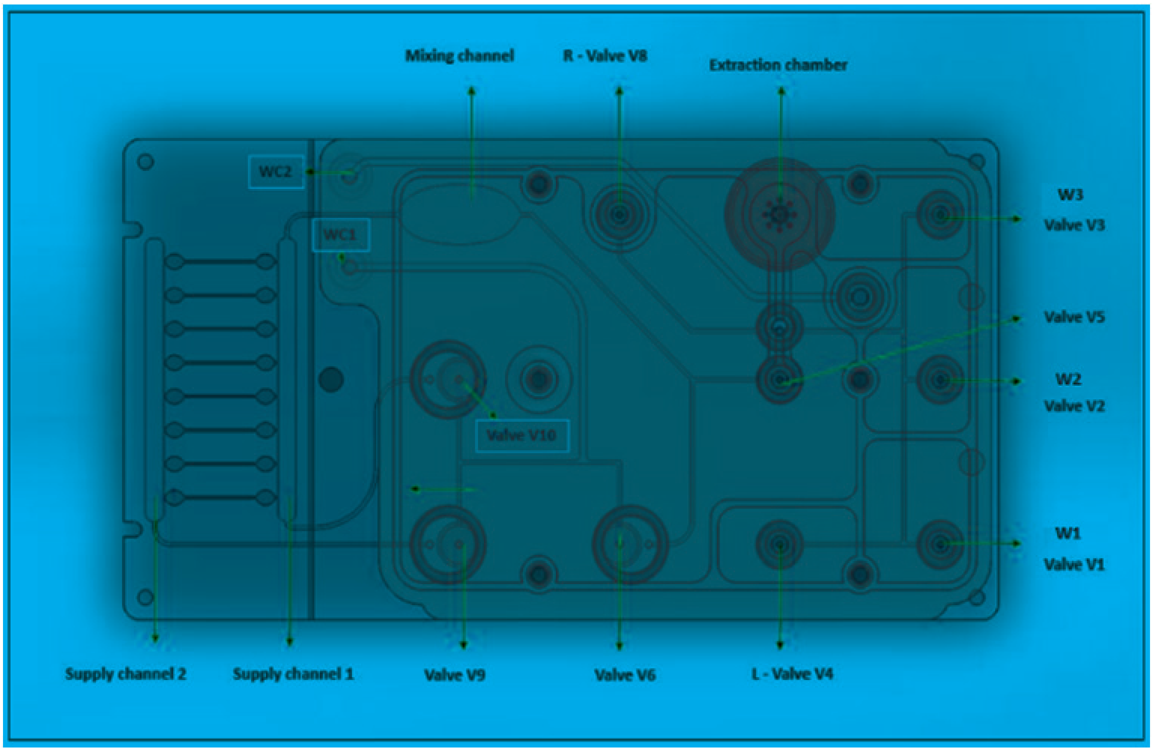


Figure 4.5. A look inside the FORDETECT cassette

Centre Director of CtrlAQUA SFI Åsa Maria Espmark and Nofima researcher and WATERQUAL project leader Andre Meriac. Photo: Terje Aamodt, © Nofima

DEPARTMENT OF TECHNOLOGY AND ENVIRONMENT

Better understanding of water quality composition and dynamics in RAS and semi-closed aquaculture systems is one of the main goals of the Department of Technology and Environment. The amount of organic matter and its composition effects key factors of water quality, like e.g., water turbidity, growth of microorganisms/biofilms and potential for toxic compounds/gaseous such as hydrogen sulphide to form. The dissolved organic matter (DOM) accumulated in the water has different origins and its composition can change over time. During the last year we have finalized a methodology for using non-targeted analyses by high-resolution mass spectrometry techniques to decipher, for the first time, the molecular composition of DOM in RAS and its transformation during the water treatment processes.

In 2022 one main achievement was high accuracy characterization of DOM molecular composition and its changes in RAS water and sludge before and after addition of disinfectant (peracetic acid) using a fast-monitoring FIA-QTOF-MS technique. The results revealed that the water matrix of RAS before the addition of peracetic acid was dominated by unsaturated and CHO type compounds, particularly those with vinylic key structures. By contrast, CHO type compounds were the lowest in abundance in the sludge samples, which were rich in CHOS, CHON, unsaturated and aliphatic type compounds particularly those with carboxyl-rich alicyclic materials and linear and branched aliphatics key structures. After the application of peracetic acid in the tank waters, a slight decrease in the unsaturated compounds, particularly those with vinylic key structures, were observed, while CHOS, CHON aliphatic and aromatic compounds, especially those CRAM-like or with linear and branched aliphatic key structures, were formed. The transformation of DOM from sludge samples with the exposure of peracetic acid followed the opposite trend, increasing unsaturated compounds, particularly with vinylic key structures and decreasing aliphatic compounds, especially with linear and branched key structures during the PAA application.

Our results show that while disinfectants are added to RAS to improve biosecurity, they also change water composition in which fish and microbiota live. The knowledge on how this change affects fish welfare and system performance is still largely unknown.

Disinfection of the new water entering closed containment systems has also been in focus of our research. Ultrafiltration (UF) membrane in aquaculture sites is used as support of ultraviolet (UV) irradiation and it was shown to eliminate waterborne microorganisms, small particles, and humic acids.

A promising use of UF membrane technology in aquaculture is a stand-alone unit to treat production facilities intake water by removing waterborne viruses and bacteria. Our study evaluated the performance of a capillary polyethersulfone UF membrane to remove two benchmark waterborne salmonids pathogens. Our results showed that the filtration of suspensions containing the infectious pancreatic necrosis virus (IPNV) and the bacterium *Aeromonas salmonicida* using a 20 nm capillary polyethersulfone membrane completely removed these microorganisms. Water temperature did not affect membrane removal efficiency in the tested range (4 - 19 °C), though lower temperatures resulted in higher membrane water pressure. The results from this bench-scale study are encouraging for the application of UF membrane technology in aquaculture water treatment to prevent virus and bacteria outbreaks.

Floating semi-closed containment systems (SCCS) inlet water is pumped from depths > 20 m, which increases their biosecurity,

0 mJ/cm2

25 mJ/cm2

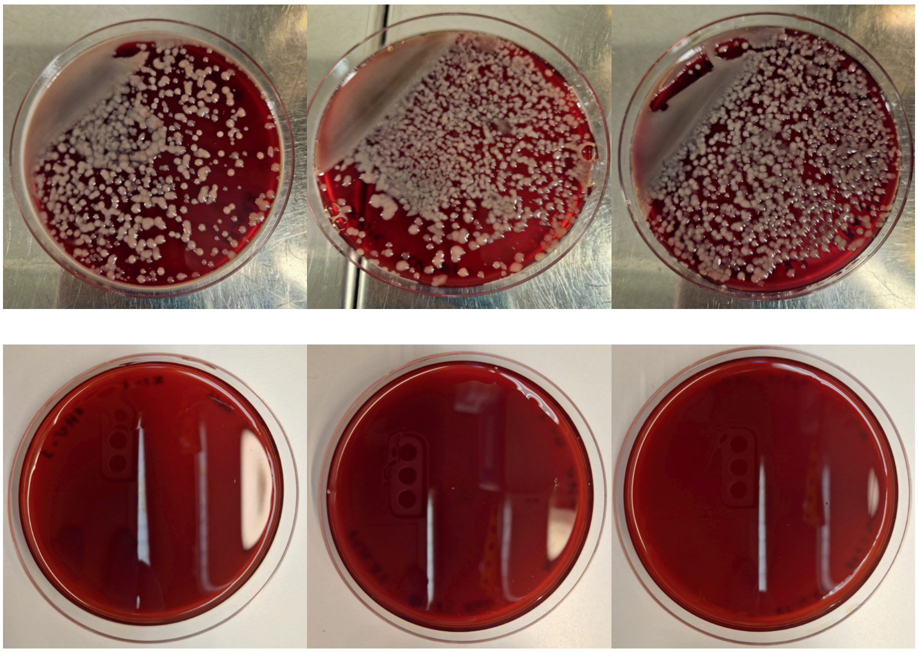


Figure 4.6. Colony-formation units (CFU) after 6 days of incubation in blood agar Petri dish plate at 12 °C. Petri dished spiked with non-treat water (0 mJ/cm2) and UV treated water (25 mJ/cm^2) of site 1 and 2.

specifically by limiting sea lice infestations. However, to prevent occasional outbreaks of bacteria and virus in SCCS it may be relevant to add a water intake treatment unit. In our study, we assessed the presence of salmon pathogens in SCCS fish gills and, in water treated by ultraviolet (UV) light filter. Fish gills and water were collected from three commercial SCCS sites and the water was exposed to UV (0 or 25 mj/cm^2). Our results show that water samples not treated with UV resulted in bacteria grow in Petri dish plates. In contrast, water treated with UV inhibited bacteria growth in plates for site 1 and 2 (Figure 4.6) and it greatly reduced bacteria growth in site 3.

Further, the samples were tested for 17 common salmon virus and bacteria. In gills, 5/17 agents were present. These were the Salmonid gill pox virus, Piscine orthoreovirus 1, *Paranucleospora theridion*, Candidatus *Branchiomonas cisticola* and Candidatus *Piscichlamydia salmonis*. In water, 3/16 agents had strong positives, these were Candidatus *Piscichlamydia salmonis*, *Tenacibaculum spp.* and *Yersinia ruckeri*. Similar results were found for samples that received UV treatment. A possible explanation for this observation is that the technique used for analysis does not differentiate between alive, dead, or non-viable microorganism. However, there were important differences between the microorganism present in fish gills and water. Viruses were underrepresented in water samples. Bacteria present in the gills were different from those present in the water, potentially indicating pre-infectious, infectious, and post-infectious phases of the process.

Since the start of CtrlAQUA we have been working to optimize tank conditions for improved welfare and performance of Atlantic salmon. Recent CtrlAQUA research indicates that increased water velocities provide performance benefits for Atlantic salmon post-smolts raised in fish tanks. New RAS facilities are built with this knowledge in mind, however already existing facilities might need to retrofit their tanks to achieve higher velocities. To do so, an additional inlet can be installed on a separate pumped loop that removes water from the fish tank and re-injects it to increase water velocities. This internally pumped “velocity assist” inlet aims to increase water velocities available to larger post-smolt and harvest-size salmon in commercial-scale fish tanks.

We aimed to evaluate the effect of the velocity assist technique in the commercial scale Cornell-style dual drain circular fish tank by testing combinations of three different water flow rates and three different nozzle headloss configurations for a velocity assist: ~30% of the main flow as velocity assist flow (1136 lpm), ~50% of the main flow as velocity assist flow (2271 lpm), ~60% of the main flow as velocity assist flow (2763 lpm) and low (0.14 bar), medium (0.33 bar), high (0.56 bar) velocity assist inlet nozzle headloss. Water velocity measurements were done at three depths across two cross-sections (Line A and Line B) at the steady state for each combination of flow and headloss. Water velocities were also characterized for the tank without the velocity assist inlet in operation. The intent was to determine optimal combinations for increasing water velocities at minimum energy.

The empirical measurements indicate that the use of the velocity assist inlet improved velocity profiles versus the baseline condition without a velocity assist inlet. The condition with the velocity assist inlet at 50% of the main flow as velocity assist flow at the highest inlet nozzle headloss provided the highest increase in water velocities over the baseline condition. Increasing velocity assist inlet flow from 50% to 60% of the main flow as velocity assist flow did not result in a better ranking for either low or medium inlet nozzle headloss conditions while the high inlet nozzle headloss condition was not achievable for the highest inlet flow due to equipment limitations.

The use of a velocity assist inlet effectively allows for more control of rotational velocities independent of the primary inlet flow. This technique can be used to provide fish with an optimal training regime. The energy use and the set-up of the velocity assist inlet will be dependent and can be adjusted to the fish size during production.

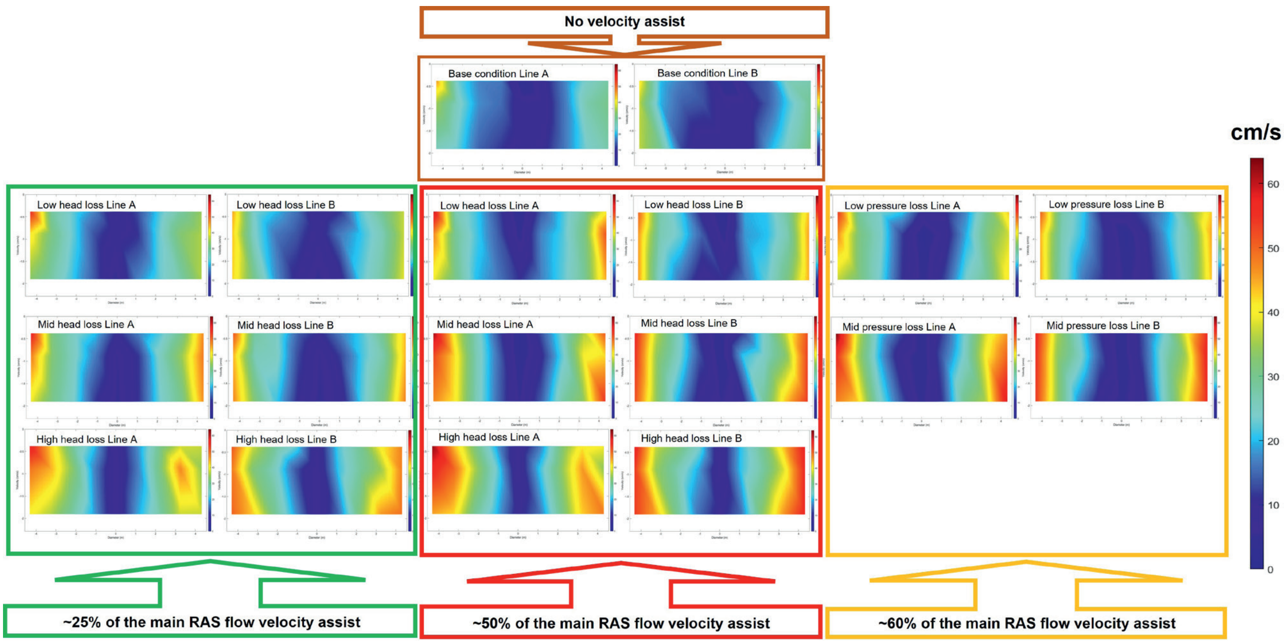


Figure 4.7. Water velocity intensity plots for all conditions evaluated indicated in the text: ~30%, 50% and 60% of the main flow as velocity assist flow. Line A and B are cross sections of the tank where water velocity was measured at 1.08m, 2.16 m, 3.24 m, and 4.32 m from the tank centre and at three different depths below water surface: 0.38 m, 0.89 m, and 1.91 m. The velocity gradient is indicated with colours, with lowest velocity indicated in blue and highest in red colour.

5 INTERNATIONAL COLLABORATION IN 2022

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

CtrlAQUA researchers are invited as speakers at different international scientific meetings, and we are often invited to host sessions at meetings. During the European Aquaculture Society (EAS) conference 2022, arranged in Rimini, several CtrlAQUA related presentations were held. During October 2022, the seventh "Smolt production in the future" conference was arranged in Sunndalsøra, Norway. Nearly 300 participants from research, government, regulatory bodies, and industries met for the international conference. CtrlAQUA has a central role in this conference, both regarding presentations and arrangement / hosting. The Centre Director presented news from CtrlAQUA at the conference. Further, the Centre Director gave a presentation during "Seafood Talks", May 2022, where CtrlAQUA was part of the theme "fish welfare and environmental challenges in closed containment systems".

There are two international R&D partners in CtrlAQUA, The University of Gothenburg (UGOT) and The Conservation Fund Freshwater Institute (FI), USA. UGOT is represented by Prof. Kristina Sundell and her research team. In 2022, they 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. FI is represented by Dr. Chris Good and Dr. Brian Vinci with colleagues. They are heavily involved in the work with sexual maturation, disinfection

At the University of Gothenburg, Kristina Sundell and the rest of the UGOT team are working in CtrlAQUA project BARRIER. Photo: Henrik Sundh, UGOT protocols and hydrodynamic modeling. Both Chris Good and John Davidson contributed with presentations at the “Smolt production in the future” conference.

CtrlAQUA opened for associated projects in 2015. Associated projects need external funding and can involve partners that are not regular CtrlAQUA partners. In 2022 we have had five associated projects that involves international partners:

1. “Microplastics in the environment”, led by UGOT and funded by the Swedish Research Council: an investigation into how microplastics affect fish and potential risks for the aquaculture industry.

2. “Prevalence and consequences of hydrogen sulphide in land-based Atlantic salmon production” (H2Salar), led 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.

3. “Water disinfection strategies to improve Atlantic salmon parr production in freshwater recirculating aquaculture systems” (RASHealth), led 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.

4. “The balancing act: Biologically driven rapid-response automation of production conditions in recirculating aquaculture systems (RAS)” (RAS 4.0), led by Nofima, funded by RCN. 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 smart algorithms that combine biological, environmental, and operational factors.

Atlantium RZB300 HOD installation for sea-water IPN protection. Photo: © Atlantium

5. “Kunnskapskartlegging - produksjon av stor laksesmolt”, led by Nofima, funded by FHF, where published and experience-based knowledge about production protocols for postsmolt that are used 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 with international partners. One example is a series of EU projects where some of the CtrlAQUA-partners helped establish “AQUAEXCEL”, then secondly “AquaExcel^{2020}” and now the ongoing “AQUAEXCEL3.0”, where 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 AQUAEXCEL3.0, as was also the case in AQUAEXCEL and AquaExcel^{2020}.

CtrlAQUA students (from left) Patrik Tang, I-Hao Chen and Marius Takvam. Patrik and Marius are now employed by CtrlAQUA R&D partner NORCE.
Photo: Terje Aamodt, © Nofima

6 RECRUITMENT, EDUCATION AND TRAINING

The aim of CtrlAQUA has been to have 15 PhD students educated throughout the lifetime of the centre. We have overachieved this target as we currently have 16 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 (2023). The PhD projects have addressed key research topics of the center and its associated projects. Six students (Takvam, Chen, Helberg, Qi, Mjølnerød and Bergstedt) were recruited to the centre in 2020/21 and these students will complete their theses after the centre period has ended. The centre has seen three candidates defend their theses during 2022: Xiaoxue Zhang "The development of antifouling materials with potential application on sensors", Patricia Aguilar Alacron "Deciphering the composition and transformation of dissolved organic matter in recirculating aquaculture systems by high-resolution mass spectrometry" and Tharmini Kalananthan "Basic mechanisms for control of appetite and feed intake in Atlantic salmon (Salmo salar). "Several master students finished in 2022 and a large group of students will finish in the first half of 2023.

As we reported in 2021, parts of 2022 have been an exceptional period for the students due to Covid-19. The restrictions caused delays for many of our students, both master and PhD. This means that there have been and will be some delays in finishing some of the 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 (see table in chapter 8). So far, we have recruited 60 Master students. 45 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 taking active part in the establishment, organization and teaching of courses, both at bachelor and master level. Within the centre, five 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 8 females and 9 males. Among the MSc students, the gender balance is approximately 50/50.

THREE STUDENTS WITH INDUSTRY RELEVANT WORK

In 2022, three students defended their Ph.D degrees in work associated with CtrlAQUA. They have contributed to increasing the knowledge about organic matter in recirculating aquaculture systems (RAS), antifouling material on sensors, and knowledge on what regulates feed uptake.

Source: uib.no and ntnu.no

Adds a new chapter to understanding the water quality of RAS

On 15th August, Patricia Aguilar Alarcon defended her thesis "Deciphering the composition and transformation of dissolved organic matter in recirculating aquaculture systems by high-resolution mass spectrometry".

Recirculating aquaculture systems (RAS) are managing the water quality to create optimal conditions for fish growth. In these systems, the water input from natural sources is recycled through different mechanisms and treated to control biological pollution, hygiene and diseases. The implementation of RAS has not been widely approved due to one of its several limitations: accumulation of dissolved organic matter (DOM). The DOM accumulated in the system have different origins and can have potential effects on water quality, fish welfare and system performance. Thus, the characterization of the compounds contained in DOM has become the primary objective in RAS to improve water quality and consequently fish productivity.

The focus of this thesis was to apply non-targeted analyses using high-resolution mass spectrometry techniques to decipher the molecular composition of DOM in RAS with Atlantic Salmon and its transformation during the water treatment processes of RAS. The work presented in this thesis adds a new chapter to understanding the water quality of RAS.

The doctoral work has been carried out at the Department of Chemistry, where Øyvind Mikkelsen was her supervisor. Associate Professor Alexandros Asimakopoulos at Department of Chemistry and Scientist Ana Rocío Borrero Santiago at Department of Biology were co-supervisors.

To the left: Patricia Aguilar Alarcon. Photo: Øyvind Mikkelsen © NTNU

Read more: NTNU or https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3017484

Contributes to more stable sensor systems within aquaculture

Xiaoxue Zhang defended her doctoral work titled “The development of antifouling materials with potential application on sensors”, 16th March at NTNU.

Unwanted biofilm is one of major unsolved problems for underwater structures including movable and stationary, such as ships, pipelines, cables, fishing nets, bridge pillars and sensors in RAS-systems. Especially for water monitoring sensors, the surface fouling can shorten sensor’s life and cause errors in the collected data. The most common ways to combat fouling on sensors today are still pure mechanical devices like wipers or scrapers, or biocide generation system.

Given the abundant research results on antifouling coatings, the nonbiocidal antifouling coatings are extremely attractive. Unlike biocidal antifouling materials, in which the antifouling property come from the toxicity of biocides, the antifouling property of nonbiocidal antifouling materials are dependent on different surface properties.

In this PhD work, Zhang and colleagues developed three kinds of nonbiocidal antifouling materials, nanocomposites-based antifouling coating, FRCs and biomimetic microstructure coatings. All the three kinds of materials demonstrated that the surface microstructure of antifouling materials determines surface properties, in turn influencing the antifouling property.

This work validates three environmentally friendly materials as competitive candidates for practical antifouling application on sensors. The work is regarded an important contribution for more stable sensor systems within aquaculture.

Most of such antifouling materials are still limited in laboratory research or having challenges in scale-up, which deserves continuing research effort in the future research.

The doctoral work has been carried out at Department of Chemistry, where Professor Øyvind Mikkelsen was supervisor and Emeritus Rudolf Schmid was co-supervisor.

Xiaoxue Zhang.
Photo: Øyvind Mikkelsen © NTNU

Read more:
https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2985205

Understands more about what regulates feed intake in salmon

Tharmini Kalananthan defended her thesis 'Basic mechanisms for control of appetite and feed intake in Atlantic salmon (Salmo salar)' at the University of Bergen on 10th November.

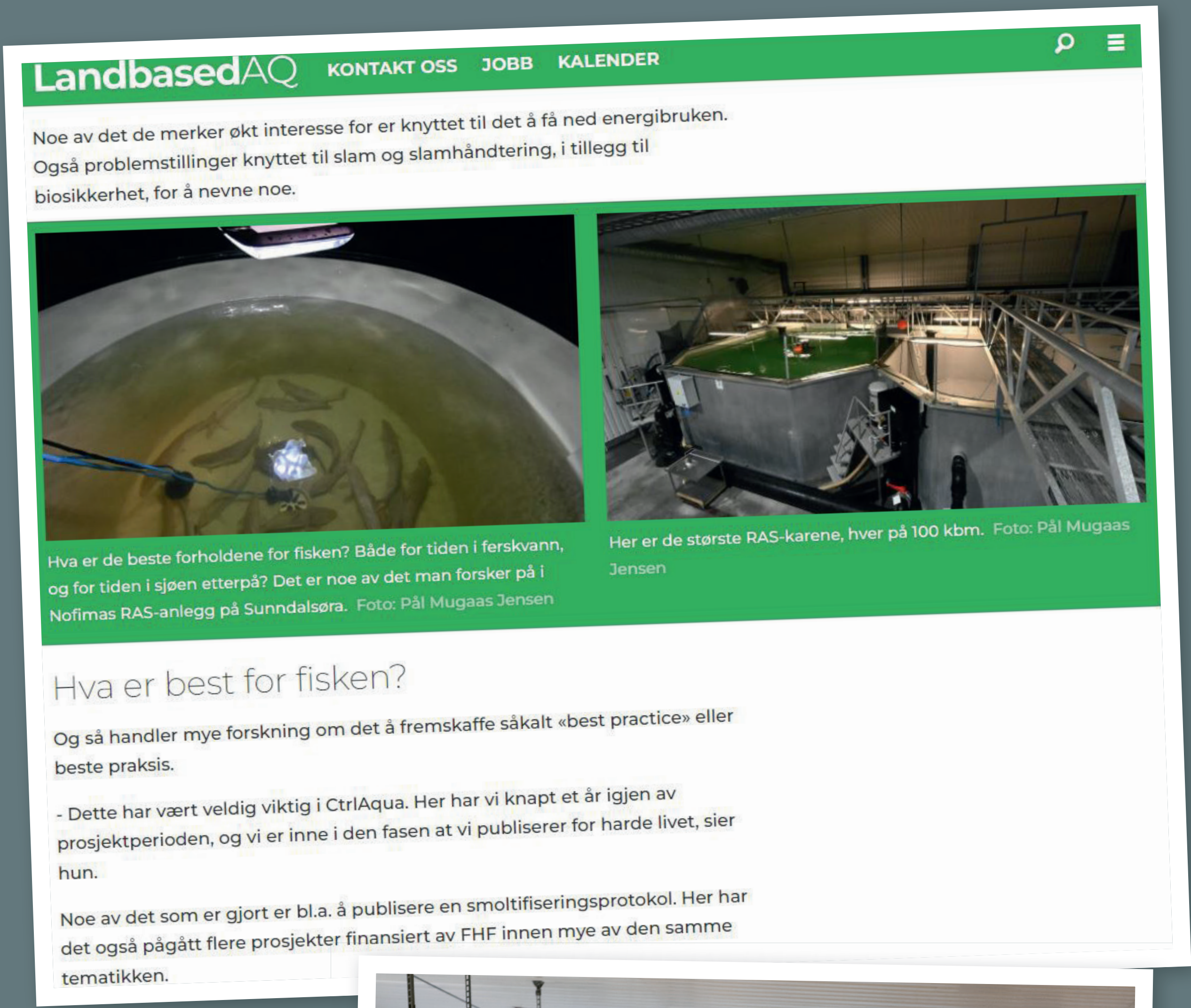
If we gain a more fundamental understanding of the biological mechanisms that control hunger, satiety, and control of feed intake in fish, we will have the opportunity to improve current feeding protocols and increase feed utilisation. In vertebrates, the interaction between the digestive system and the brain is important for managing food intake. A region of the brain called the hypothalamus plays a key role in regulating appetite and feeding behaviour. Salmon in the wild experience longer periods of fasting due to seasonal fluctuations in the food supply, migration or reproduction. Farmed salmon can be exposed to fasting periods of up to nine days. However, the mechanisms that regulate appetite under normal conditions and periods of starvation are unclear in salmonids.

Kalananthan has identified important neurotransmitters in the brain (neuropeptides) that affect appetite and feeding behaviour. She has also identified new biomarkers that can be used to assess appetite and possible growth in fish after a short period of starvation (3-4 days) and a long period of starvation (4-6 weeks). The study has confirmed that neuroendocrine factors affecting appetite and feeding behaviour are present in salmon, and has also identified newer factors (npy, cart and mc4r). It was shown that these neurotransmitters are also present in other parts of the brain, most likely having other functions. Overall, the data indicate that an agrp1 neuropeptide is a possible appetite biomarker. The dynamic interaction between the signalling factors that affect feed intake needs to be investigated further.

Professor Ivar Rønnestad (BIO) was the main academic supervisor, while Professor Sigurd Handeland (BIO/NORCE) and Dr. Floriana Lai (BIO) were co-supervisors. Kalananthan received the main part of the funding from the Greenbag and KABIS projects.

Tharmini Kalananthan.
Photo: © UiB

Read more:
Signalfaktorer som regulerer fôropptaket hos laks | Nye doktorgrader | UiB



LandbasedAQ KONTAKT OSS JOBB KALENDER

Noe av det de merker økt interesse for er knyttet til det å få ned energibruken. Også problemstillinger knyttet til slam og slamhåndtering, i tillegg til biosikkerhet, for å nevne noe.

Hva er de beste forholdene for fisken? Både for tiden i ferskvann, og for tiden i sjøen etterpå? Det er noe av det man forsker på i Nofimas RAS-anlegg på Sunndalsøra. Foto: Pål Mugaas Jensen

Her er de største RAS-karene, hver på 100 kbm. Foto: Pål Mugaas Jensen

Hva er best for fisken?

Og så handler mye forskning om det å fremskaffe såkalt «best practice» eller beste praksis.

- Dette har vært veldig viktig i CtrlAqua. Her har vi knapt et år igjen av prosjektperioden, og vi er inne i den fasen at vi publiserer for harde livet, sier hun.

Noe av det som er gjort er bl.a. å publisere en smoltifiseringsprotokol. Her har det også pågått flere prosjekter finansiert av FHF innen mye av den samme tematikken.

Excerpt from a report at the new website LandbasedAQ.no about CtrlAQUA.

At the conference "Smolt production in the future", participants from the entire value chain were invited to visit the RAS facilities of Nofima, and to hear about research in CtrlAQUA. Photo: Frode Nerland, © Nofima.

7 COMMUNICATION AND DISSEMINATION ACTIVITIES

In CtrlAQUA, the overall aim with communication is to create interest around the Centre activities, and to contribute strategically to fulfil 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 30 registered news articles in 2022 where CtrlAQUA has been mentioned. In addition, we have observed several articles and social media posts where CtrlAQUA activity plays a role.

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 meeting spots, particularly towards our main target groups in industry and research. The 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 and Facebook from the host institute and partners.

Examples of dissemination activities in 2022 are:

- Invited as presenters at forums/ conferences:
    - Featured session on RAS for the World Aquaculture Society (WAS) by Freshwater Institute in February
    - Several presentations at EAS 2022 in September
    - Several presentations at the conference "Smolt production in the future" at the Sunndalsøra where our main R&D activity is located
- Visit from the editor of the new Norwegian magazine "LandbasedAQ" to Sunndalsøra, and dissemination of several popular scientific articles in the magazine
- NTNU and UiB disseminated three doctoral degrees
- Several news stories about results from Nofima
- During 2022 the CtrlAQUA communication department has released 8 news stories about the activities in the centre, well distributed in media. All can be read at www.ctrlaqua.no.

Status of our internal and external communication platforms

The CtrlAQUA intranet is the most important channel for maintaining internal routines and systems for communication between the partners with over 100 participants involved. The intranet has a document base and an image base, it has a calendar showing important center activities, a news feed and issues internal alerts of new findings or publications as agreed upon in the consortium agreement. The various centre meetings also facilitates and strengthen our internal communication.

The website www.ctrlaqua.no, is designed for presenting results, activities, publications and innovations in the Centre.

8 ATTACHMENTS TO THE REPORT

Key R&D partners in 2022

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
Rene Alvestad	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
Valentina Tronci	NORCE
Patrik Tang	NORCE
Marius Takvam	NORCE
Simon Menanteau Ledouble	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 progress

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

PhD-students/dr. philos

Sara Calabrese	2013 - 2017	NORCE
Lene Sveen	2014 - 2018	UiB
Bernat Morro	2016 - 2019	NORCE
Xiaoxue Zhang	2016 - 2022	NTNU
Patrik Tang	2017 - 2021	NORCE/UiB
Sharada Navada	2017 - 2021	NTNU
Enrique Pino Martinez	2018 - 2021	NORCE
Gaute Helberg	2021 - 2023	UiB
Marius Takvam	2021 - 2023	NORCE/UiB
I-Hao Chen	2021 - 2023	NORCE
Patricia Aguilar Alarcon	2018 - 2022	NTNU
Tharmini Kalananthan	2018 - 2022	UiB
Ingrid Naterstad Haugen	2018 - 2023	NTNU
John Davidson	2019 - 2021	UiB
Even Mjølnerød	2020 - 2023	UiB
Wanche Qi	2020 - 2023	NFR
Julie Hansen Bergstedt	2020 - 2023	NFR

MSc students

Britt Sjöqvist	2015 - 2016	UGOT
Ida Heden	2015 - 2016	UGOT
Egor Gaidukov	2016 - 2017	NORCE
Gisle Roel Bye	2016 - 2017	NTNU
Hilde Frotjold	2016 - 2017	UiB
Ingrid Gamlem	2016 - 2017	NORCE
Simen Haaland	2016 - 2017	NTNU
Øyvind Moe	2016 - 2017	NORCE
Kamilla J. Grindedal	2016 - 2018	NTNU
Gunnar Berg	2017 - 2019	NORCE
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	NORCE
Nikko Alvin Cabillon	2018 - 2019	Nofima/Erasmus
Ross Fisher Cairnduff	2018 - 2019	NORCE
Gulbrand Stålet Nilsen	2018 - 2020	NTNU
Nefeli Simopoulou	2018 - 2020	UGOT
João Osório	2019 - 2020	University of Lisbon
Kari Anne Kamlund	2019 - 2021	NORCE
Marius Takvam	2019 - 2020	NORCE
Sigval Myren	2019 - 2020	NORCE
Sjur Øyen	2019 - 2020	UiB
Steinar Bårdsnes	2019 - 2020	UiB
Tarald Kleppa Øvrebø	2019 - 2020	NORCE
Tilde Sørstrand Haugen	2019 - 2020	NORCE
Trine Tangerås Hansen	2019 - 2021	NORCE
Bibbi Hjelle	2019 - 2021	NORCE
Kristine Kannelønning	2019 - 2021	UiB
Markus Brånås	2019 - 2021	NORCE
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
Sofie Agnethe Isaksen	2020 - 2021	UiB
Danilo Carletto	2020 - 2022	University of Messina
Ingrid Gjerde	2021 - 2022	NTNU
Siri Marie Lillebostad	2021 - 2022	UiB
August B. E. Sindre	2021 - 2022	NORCE/UiB
Erik Heimdal	2021 - 2022	NORCE/UiB
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
Anushree Mainali	2023 - 2023	NMBU
Samaneh Mousavi	2021 - 2023	UiT/Nofima
Maia Langøy Eggen	2021 - 2022	UiT/Nofima
Rolf Klokkerengen	2021 - 2022	NTNU/Nofima
Eivind Branzæg Sundfør	2021 - 2022	NTNU/Nofima
Guro Berge Lokshall	2022 - 2023	UiB
Bosco Ara Diaz	2022 - 2023	Wageningen University and Research
Bedika Ghising	2022 - 2023	UiT/Nofima

BSc students

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

MOWI's RAS tech smolt plant facility in Steinsvik, Norway. Photo: © MOWI

CtrlAQUA Dissemination and publications 2022 and 2023

Peer-reviewed publications

Aguilar-Alarcon, P., Zherebker, A., Rubekina, A., Shirshin, E., Simonsen, M.A., Kolarevic, J., Lazado, C.C., Nikolaev, E.N., Asimakopoulos, A.G., Mikkelsen, Ø (2022). Impact of ozone treatment on dissolved organic matter in land-based recirculating aquaculture systems studied by Fourier transform ion cyclotron resonance mass spectrometry. Total Environment. 843:157009.

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J Benktander, H Sundh, S Sharba, S Teneberg, SK Lindén (2022). Aeromonas salmonicida binds a2-6 linked sialic acid, which is absent among the glycosphingolipid repertoires from skin, gill, stomach, pyloric caecum, and intestine. Virulence. 13 (1), 1741-1751.

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Lazado, C.C., Espmark, Å.M., Freire, R. (2022). Biology meets technology: Aquatic animals in novel and new aquaculture production systems. Frontiers in Animal Science. 3: 102126.

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Ovrebo Kleppa, T., Balseiro, P., Stefansson, S. O., Tveteras, R., Sveier, H., Imsland, A. K. and S. O. Handeland (2022). Investigation of growth performance of post-smolt Atlantic salmon (Salmo salar L.) in semi closed containment system: A big-scale benchmark study. AQUACULTURE RESEARCH. Vol 53: 4178-4189.

P.A. Tang, S.O. Stefansson, T.O. Nilsen, N. Gharbi, F. Lai, V. Tronci, P. Balseiro, M. Gorissen, L.O.E. Ebbesson, (2022). Exposure to cold temperatures differentially modulates neural plasticity and stress responses in post-smolt Atlantic salmon (Salmo salar). Aquaculture. Volume 560, 2022.

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

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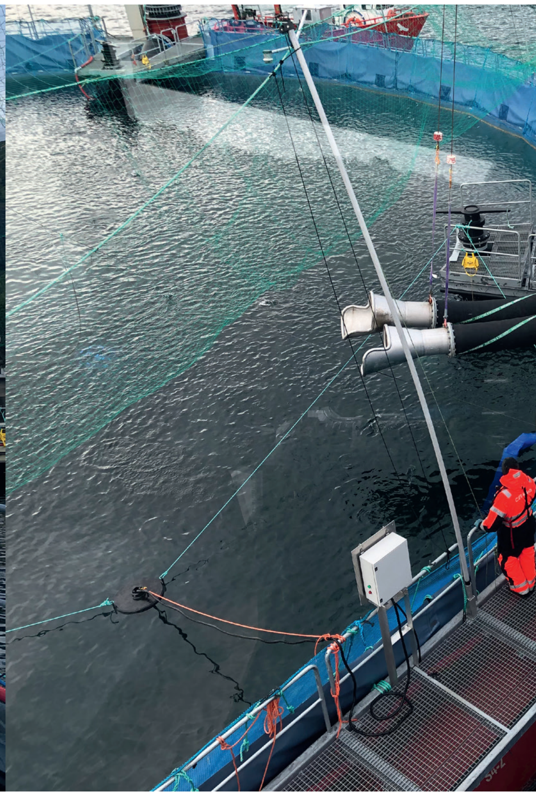
Christian Karlsen, Anette Furevik, Siv Tunheim, Monica Gausdal Tingbø, Elisabeth Ytteborg, Lene Sveen, Sergey



Afanasyev, Aleksei Krasnov (2022). Sårutfordringer - Hvordan virker vaksinen mot sårdannelse av Moritella viscosa . Havbruk 2022 Bergen, October 19-21, 2022.

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Espmark, Å. (2022). Kunnskap om fiskevelferd i lukkede oppdrettsanlegg - Erfaringer CtrlAQUA. Tekna Havbrukskonferanse. Trondheim. November 23-24, 2022.

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Haugen, I. N. (2023). Overvåking av metaller i settefisk – utvikling av nye sensorer. TEKSET, Trondheim. February 15, 2023.

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Cermaqs S-CCS facility Certus has played a key part in CtrlAQUA. Photo: © Cermaq

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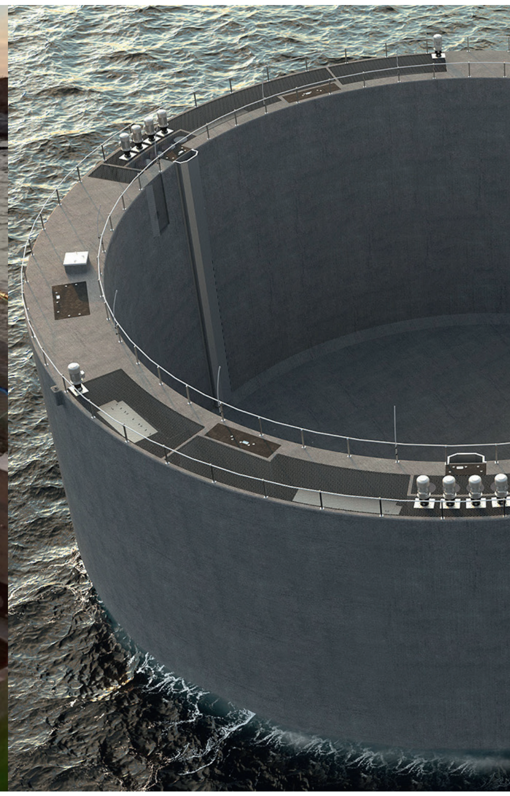

Pilot cage of 1.000 m^3 floating semi-closed concrete sea cage at Gullklakken. Photo © Nekton

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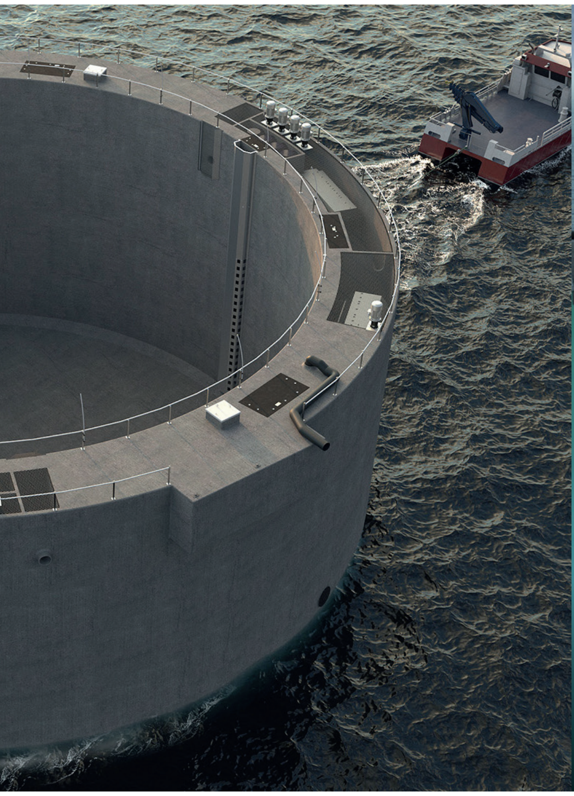

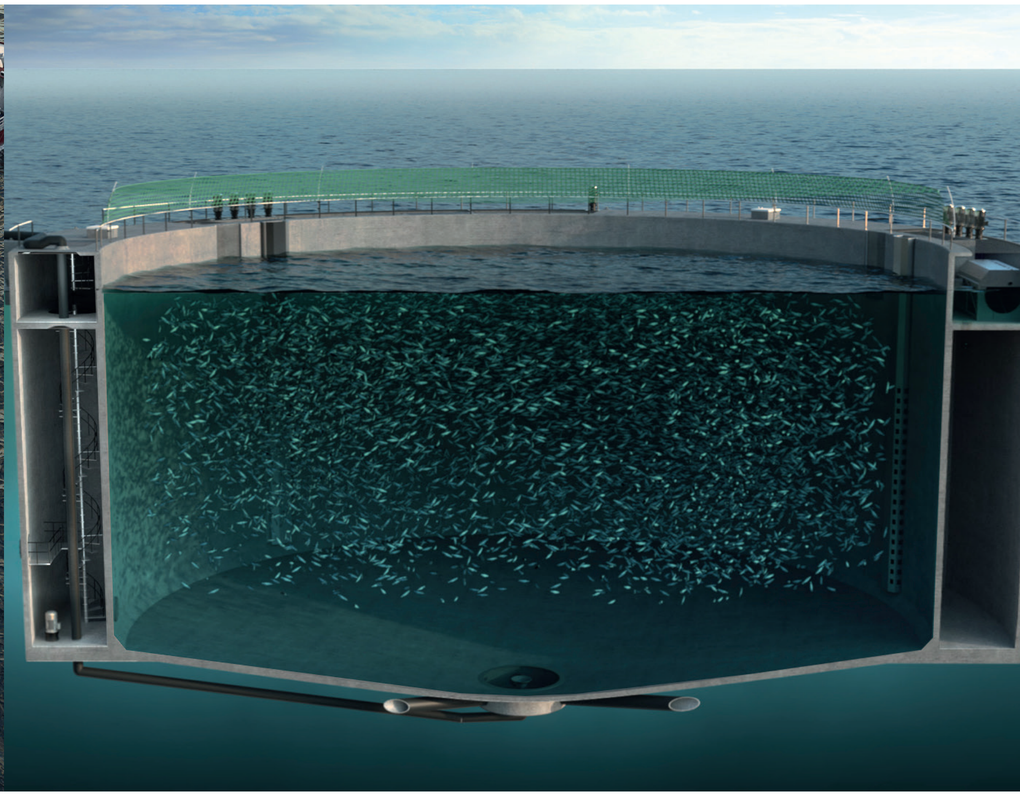

Illustrations of 20.000 m^3 floating semi-closed concrete sea cage under development. Photo: © Nekton