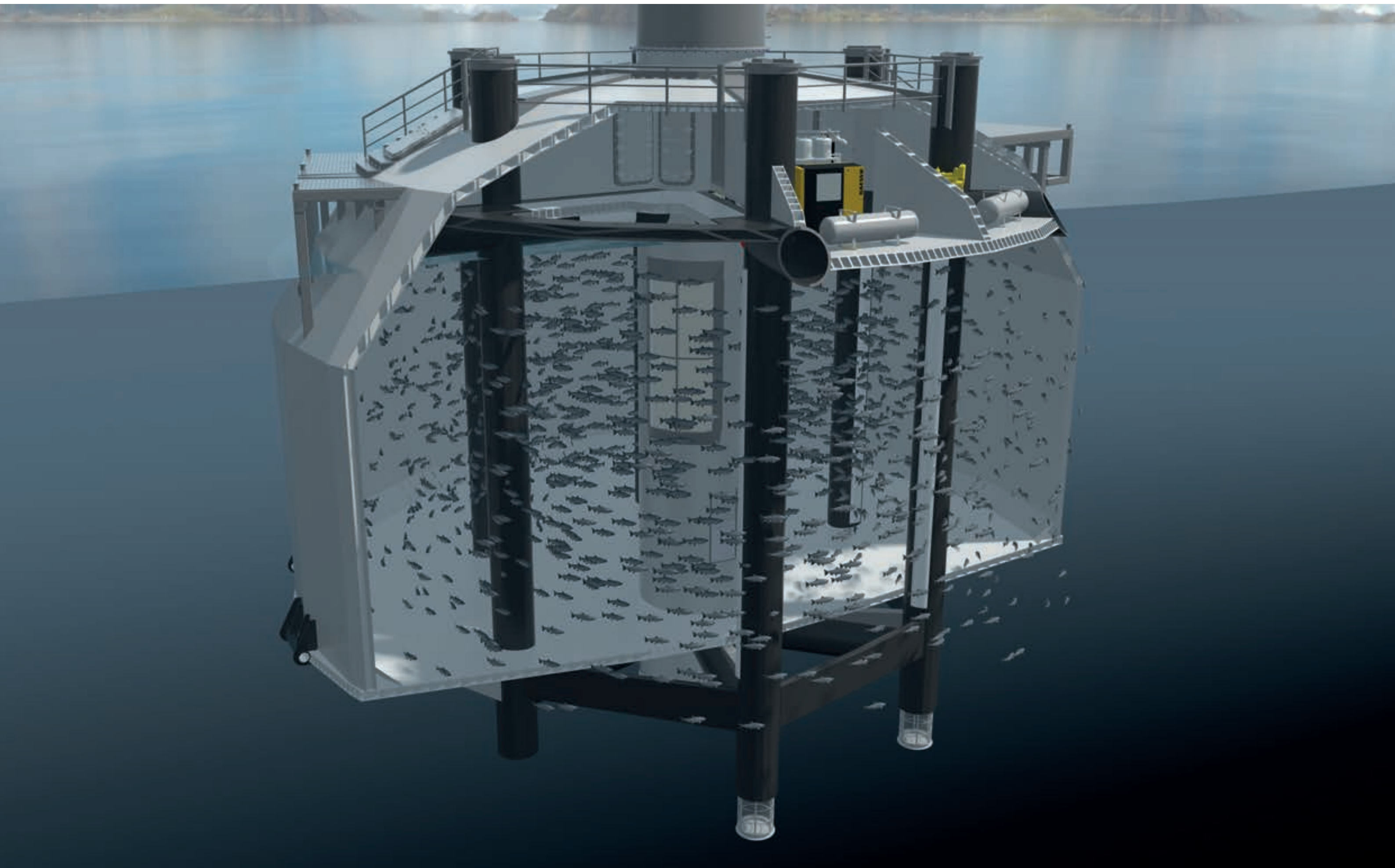
CtrlAQUA

Annual Report 2019
CtrlAQUA - Centre for Closed-Containment Aquaculture



sfi Centre for Research-based Innovation

The Research Council of Norway

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Frontpage picture:
FishGLOBE – an CtrlAQUA innovation now producing post-smolts in Lysefjorden.
Illustration: ©FishGLOBE

CONTENT

1 OVERALL PROGRESS AND SUMMARY FOR 2019

CtrlAQUA SFI was kicked off in spring 2015 as a Centre for Research-based Innovation. Our vision to make Closed-Containment aquaculture Systems (CCS) a reliable and economically viable technology is as relevant as it was from the start, if not more. The increasing demand for sustainable growth in aquaculture is seeking for new technologies and methods that will minimize what is preventing progress today. Together with Recirculating Aquaculture Systems (RAS) and semi-closed containments, other production methods such as off-shore and land-based production all the way to slaughter, in addition to the traditional way of production with flow through and with cages, will likely be important for further sustainable growth.

In 2019, CtrlAQUA went through a mid-way evaluation to ensure funding for the rest of the Centre lifetime. Fortunately, the evaluation went well, and we are allowed to continue as planned. This has been a long and positive process, and the mid-way evaluation was also a topic in the Annual report for 2018, with articles about success criteria such as internationalisation, recruitment and prospects. The evaluation will also be part of this Annual report, and we will publish articles with reference to the evaluation process and recommendations that we received from the review committee. In the first article we will describe, with the words of a user partner, how CtrlAQUA results are implemented in the routines at the farm and thus contribute to innovations for the industry. We will also present the three new focus areas; issues with hydrogen sulphide, nephrocalsinosis and early sexual maturations, that CtrlAQUA was able to implement into the Centre plan as a result from the mid-term evaluation. Further, in 2019 CtrlAQUA welcomed two new partners that will contribute even more to technological improvements. CreateView with their sensor for monitoring welfare and Atlantium with their UV technology are very relevant and both partners will be introduced in this Annual report. The focus on technology development is also illustrated with partner FishGlobe on the front page of this Annual report. FishGlobe officially opened their facility in August 2019 and has gone through a tremendous development the last years, with much input and follow up by CtrlAQUA. Lastly, we will present a doctorate candidate a little outside the norm, as John Davidson from Freshwater Institute, USA, decided to do his Dr. philos partly inside CtrlAQUA. John therefore contributes to one more doctor from CtrlAQUA.

It is impossible to summarize CtrlAQUA from year 2019 without focusing on the mid-way evaluation. Involvement with the consortium, providing the evaluation committee with all written materials that they needed and arranging the site-visit in March occupied much time for many CtrlAQUA members. Thanks to many participating consortium members, including students, the site-visit turned out to be very successful with many fruitful discussions.

Scientific highlights have been many, also in 2019. Two experiments with high degree of innovations have been conducted. In one project, different industry relevant disinfection protocols were studied with the aims to optimize the disinfection protocols of materials and equipment important in RAS facilities, and to evaluate the effects of disinfection on fish, water quality and biofilter. In another experiment the effects of light quality and quantity on performance, welfare and health of Atlantic salmon post-smolt were investigated. RAS water with high TSS and turbidity will absorb light differently compared to clear water and thus change the availability of light for the fish. The light quality and quantities

Mid-way evaluation of CtrlAQUA. Site-visit at Nofima in Sunndalsøra 8th March 2019. Photo: Bente Torstensen/Nofima

tested were defined in a pre-test where light was measured in commercial RAS tanks. Both experiments have been well utilized by several students.

Besides performing new experiments, we also provided input and data from our user partners in order to plan further experiments and getting an insight of where the future focus should be. Examples of activities are collection of fish samples from user partners to monitor health and early detection of possible new pathogens. Throughout the Centre time we aim to keep an update of optimal water quality requirements in RAS. In addition to CtrlAQUA data we use literature data for this update. Also, a survey among the user partners to define best practice for water quality monitoring was performed. Lastly, to follow up on the mid-way evaluation recommendation of technological improvements, we conducted two evaluation reviews of technologies for CO_2 removal in RAS and water treatment technologies.

CtrlAQUA results have been widely disseminated, and we are very happy to see that the external aquaculture society is interested in what we have achieved. Our students are excellent ambassadors for the Centre and many of them have presented their results at different meetings and conferences. Together, the CtrlAQUA team look forward to three more years with even more achievements.

March 2020
Åsa Maria Espmark
Centre Director CtrlAQUA SFI

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

The Norwegian government and salmon industry are aiming to increase the production in the years to come. However, this growth must be sustainable and not putting the environment and fish health and welfare at risk. The previous ambitions that were put forward in the report "Value created from productive oceans in 2050", has later been moderated and described in the report "Sea-map towards 2050", because the ability of growth will depend on many factors, including how sea lice and escapes are managed, amongst other challenges. Innovations in closed-containment aquaculture systems, where the salmon is separated from the outside environment by a closed barrier, can be important for further development of aquaculture. CtrlAQUA is a Centre for Research-based Innovation (SFI) that will work on such closed-containment systems. The main goal of CtrlAQAUA SFI is to:

"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

PhD student Sharada Navada is analyzing metals concentration in RAS nitrifying bioreactors at NTNU. Photo: Per Henning/NTNU *challenges limiting the envisioned growth in aquaculture".*

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

In the Centre we focus primarily on the most sensitive phases for the salmon in the production cycle, such as the first seawater phase, the so-called post-smolt stage (Figure 1.1). However, the research is also highly relevant for other strategies shown in the figure. The main innovation will be reliable and efficient production of robust post-smolts in closed and semi-closed systems on land and at sea. Thus, the industry can get a good realistic alternative or supplement to the current 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, reducing the risk of escape and diseases transmission to wild stocks, and optimizing tank/cage environment, amongst others. These innovations will be of value to the Norwegian society, as closed systems for strategic phases in salmon farming can contribute to the foreseen growth.

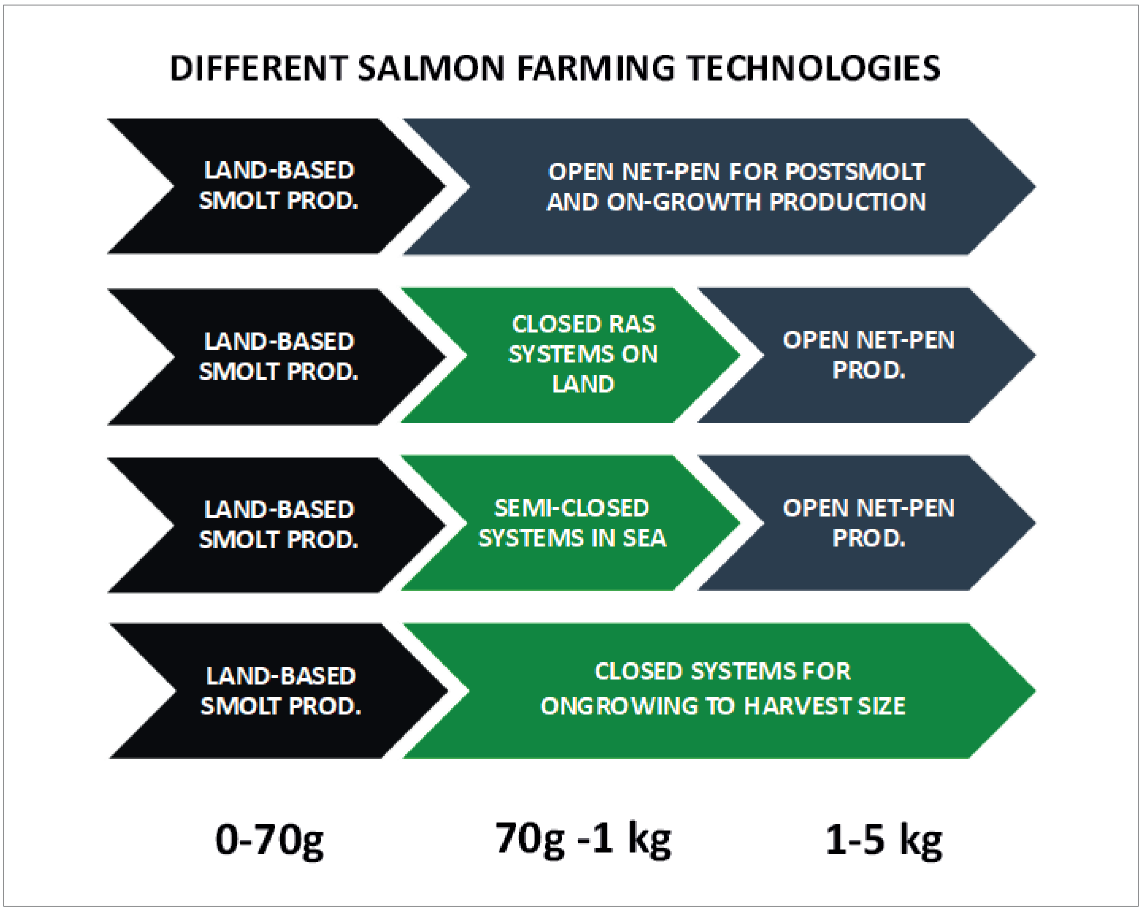


Figure 1.1 Different ways of producing Atlantic salmon including closed-containment aquaculture systems.

Rapid implementation of innovation

Article by Reidun Lilleholt Kraugerud

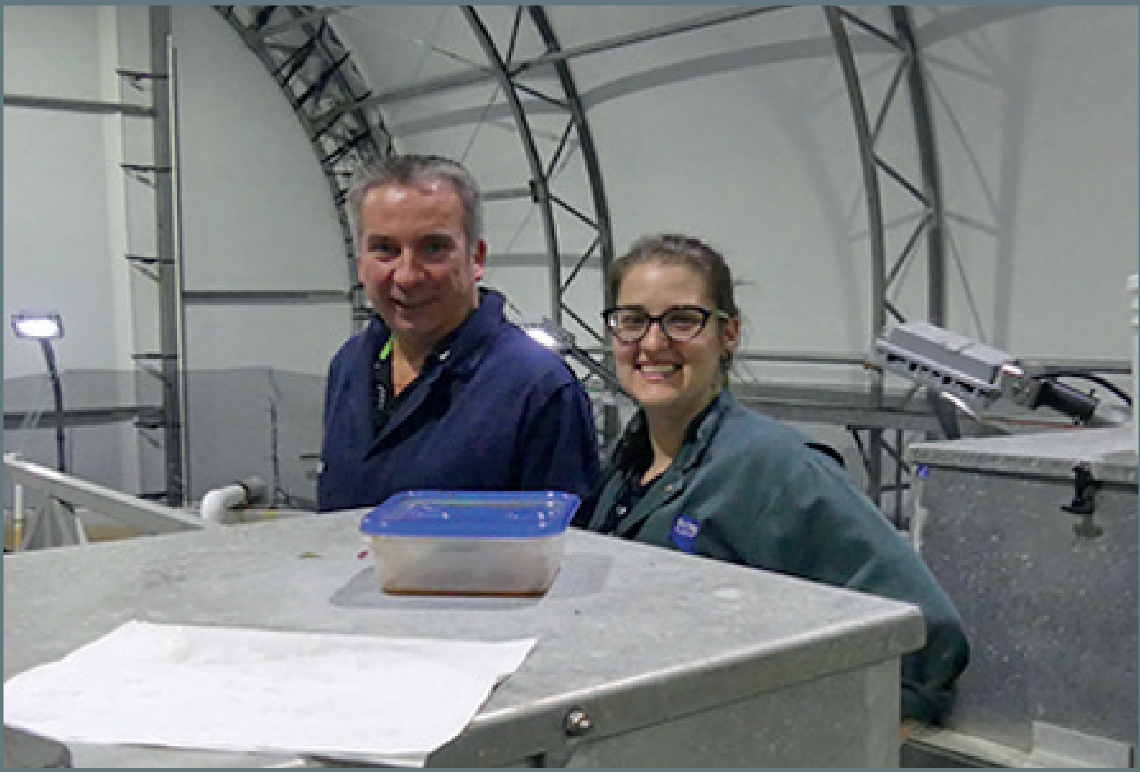
Even before the results of the CtrlAQUA project, BENCHMARK, appeared in any report, Grieg Seafood was implementing the knowledge at its RAS facilities in Canada.

”This knowledge from BENCHMARK concerns which light regimes and water qualities provide the best smolt output in recirculating facilities. The former chairman Frode Mathisen* of Grieg Seafood quickly took interest in this knowledge, which he enthusiastically conveyed to the partners during CtrlAQUA's annual meeting in May 2019.

"I am very interested in telling you about how we implemented this innovation in our production, because that is what CtrlAQUA is all about," Mathisen said.

*About Frode Mathisen

- On 22 September 2019, we received the tragic message that Frode had passed away.
- Frode was the manager of a freshwater facility in Campbell River, British Columbia, Canada, and the technical adviser for all of Grieg Seafood's freshwater facilities.
- He was the chairman of CtrlAQUA SFI from its inception in 2015 until his passing in 2019.
- This story with his quotes is based on audio recordings and was approved by his closest associates at Grieg Seafood.



Frode Mathisen with a colleague at the RAS facility in Canada, where testing of the BENCHMARK regime started. Photo: ©Grieg Seafood

He wanted to show how a rapid impact of innovations in one's own business could be achieved if one paid attention and that innovation in a SFI is most often knowledge, rather than something you can actually put your hands on.

Research

The experiments in BENCHMARK showed that smolt that has had 24 hours of light grew better in a recirculating system than fish that had received a winter signal (12 hours of light: 12 hours of darkness). In addition, the fish on 24 hours of light grew slightly better when they received a little salt water early, rather than being in pure fresh water. However, the research does not provide a clear answer to which light regime and water quality that are best in the long run.

Implementation

As the manager of a freshwater facility in Canada, Frode Mathisen wanted to deliver large, robust post-smolt to sea farming, and therefore chose to test out salmon production with 24 hours of light and salt water in a separate production batch in 2017, with some adaptations.

Grieg started testing 24 hours of light on fry in March. At a size of around five grams, they introduced 4-5 ppt (parts per thousand) of salt into the water, and the fish's growth increased dramatically. At a size of around 60 grams, they introduced 12 ppt of salt (pure salt water has about 30 ppt of salt). The fish still grew well, as expected.

And so it went on

At the end of 2019, Production Manager Arvid Pedersen at Adamselv in Finnmark could tell that they had a close dialog with Mathisen regarding the hypothesis, and that they tested this more or less in parallel with both Canada and CtrlAQUA.

"And it was very good that we could rely on empirical scientific data from CtrlAQUA when discussing this," says Pedersen.

Grieg Seafood has also produced some groups at its facility in Trosnavåg, Rogaland, with traditional light management and some with 24 hours of light right up until delivery in 2019. They monitor these groups closely during the sea phase, especially with regard to sexual maturity.

"There is no doubt that we achieve better growth at our facilities now. It appears as if this continues in the sea, but it is still a little early to draw any conclusion. We will continue with the same light strategy in 2020, and we will eventually see what is right based on the results from the sea phase," says Pedersen.

In Canada, Grieg practices the new regime with 24 hours of light at all of its RAS divisions there.

Will be remembered

As a very active partner in CtrlAQUA, Frode Mathisen was always looking for useful results like this. He is described by the partners in CtrlAQUA as someone who always sat in the front row paying attention, who was inclusive, who shared his experiences and who was interested in the major issues in the CtrlAQUA project and aquaculture in general. Frode Mathisen will be remembered as a dedicated chairman of CtrlAQUA and an active disseminator of research and the fish farmer's perspective.

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 on the research 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 inputs received from the partners during project annual meetings and thematic meetings. A Scientific Advisory Board (SAB) is appointed for CtrlAQUA, consisting of researchers and stakeholders with competences in the fields of research in the Centre. Important tasks of the SAB is to give advice during development of the annual plans and to evaluate the work in the Centre.

The annual plan consists of common projects and user-specific projects. Both types of projects contributes 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 can be termed an "Associated Project" to CtrlAQUA, and be entitled as such when applying for grants. The consortium behind this Associated Project*

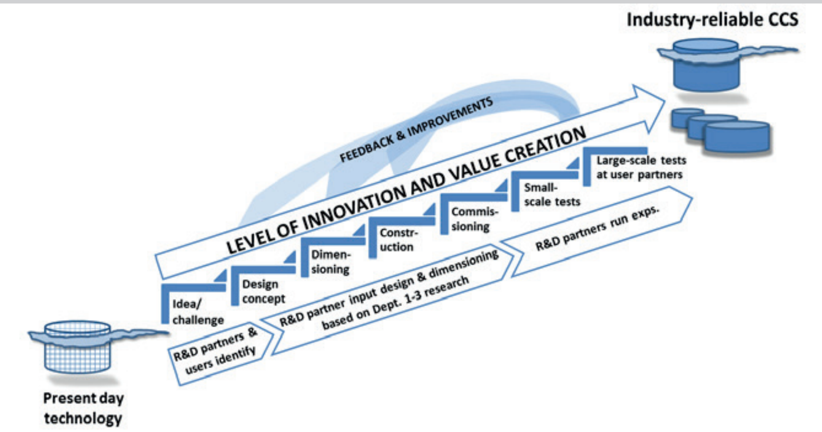


Figure 2.1. Innovation process in CtrlAQUA, from present day cage technology, to establishment of industry-reliable closed containment systems, either in-sea closed tanks or land-based RAS. Exps. = experiments.

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 the 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, nephrocalsinosis and early sexual maturation.

An inside view into the Atlantium UV system. Atlantium is a new partner in CtrlAQUA that will strengthen the research strategy of technological development. Photo: ©Atlantium

Spotlight on a deadly gas, disease and puberty

Article by Reidun Lilleholt Kraugerud

During the lifetime of a Centre for Research-Based Innovation (SFI), there is a high probability that new challenges emerge and must be resolved in order to achieve the goal. In the case of CtrlAQUA, the ambition is to make closed-containment systems for salmon up to one kilogram into off-the-shelf systems by 2023. After conducting the mid-way evaluation, the Centre has decided to tackle three new challenges, which we formally call "areas of focus". These three areas of focus are hydrogen sulfide gas (H_2S), the disease called nephrocalcinosis and early sexual maturation, all of which have received great attention in recent years, especially in RAS.

"In CtrlAQUA, work being done on the areas of focus is incorporated in projects we are already working on. Everything that takes place there will be applied and solution-oriented", says Centre Director Åsa Espmark.

The deadly gas H_2S

Hydrogen sulfide gas is a colorless and toxic gas that occurs in biofilm or sediment in water and has been suspected to be the cause for occasions with mass mortalities among farmed fish. The dangers that this gas poses are difficult to detect in advance, and it has become a significant problem in seawater-based recirculating aquaculture systems in recent years.

The key to understanding the dynamics behind H_2S formation is to understand the chemical reactions that occur in biofilm and sediment. In CtrlAQUA they will investigate how much sedimentation has to take place before H_2S is formed and identify risk factors in order to prevent H_2S formation.

"We also hope to find indicators in the fish, or sensors that measure low levels of the gas or H_2S precursors. One current problem is that the gas isn't detected early enough. When an outbreak eventually occurs, there is a risk of losing every single fish at the facility", says Espmark.

Risk factors for kidney stones

Nephrocalcinosis, or kidney stones as it is also called, is a chronic kidney disease that is a growing problem in salmon farming. Kidney stones in salmon can cause difficulties in regulating salt balance and transition to seawater, reduced growth and feed utilization, and increased mortality rates. It is reported as being a problem in post-smolt, large smolt and in salmon that are kept in land-based tanks for long periods of time. The fact that salmon are kept in land-based tanks for long periods of time has several positive effects, including on health, welfare, growth and the environment, and it makes the problem of kidney stones all the more important for the industry to solve.

"The aim is to find kidney stone risk factors in salmon that can explain the increase in the number of reported cases", says Nofima's Lill-Heidi Johansen, who leads the fish health research at CtrlAQUA.

Johansen hopes they will gain a better understanding of the physiological mechanisms behind the disease. In the long term, the researchers will also develop methods of early detection and come up with preventive measures to reduce its scale.

How to hinder early puberty

Early sexual maturation in farmed fish is a known welfare and financial problem that has increased in high intensity production of large smolt and post-smolt in RAS, particularly when temperature and growth is high.

Scientists at Norce and the University in Bergen are now intensifying the research on early sexual maturation of salmon in RAS-systems in CtrlAQUA. In picture: Valentina Tronci and member of the leader group Naouel Gharbi. Photo: Andreas R. Graven/Norce

"Generally speaking, the process of sexual maturation in males may start already when salmon reach 50 grams. When they reach the 4 to 500 gram phase, the process is increasing in intensity", says associate professor Tom Ole Nilsen at the University of Bergen and head of the production and welfare department at CtrlAQUA.

"Can the light be used differently as a preventive measure? Are there any temperature intervals we should avoid? We think it's a combination of several factors, but we don't know what triggers it all", says Nilsen.
The aim is to clarify how factors such as light, temperature and fish size can affect early puberty in post-smolt.

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 financial, partnership, and IPR issues, as well as ratifying annual research plans made by the leader group. In 2019, the Board met for two physical meetings. The Board from 2019 consisted of the following elected members:

- Frode Mathisen, Grieg SeaFood, Chairperson of the CtrlAQUA Board until 30th September
- Harald Takle, Cermaq, Board Member until 30th September and Chairperson of the CtrlAQUA Board from 1st October
- Siri Vike, Pharmaq Analytiq, Board Member
- Hans Kleivdal, Norce, Board Member
- Hilde Toften, Nofima, Board Member and representing the host institution
- Øyvind Oaland, Mowi, Board Member from 1st October
- Asgeir Knutsen, Krüger Kaldnes, Board Member

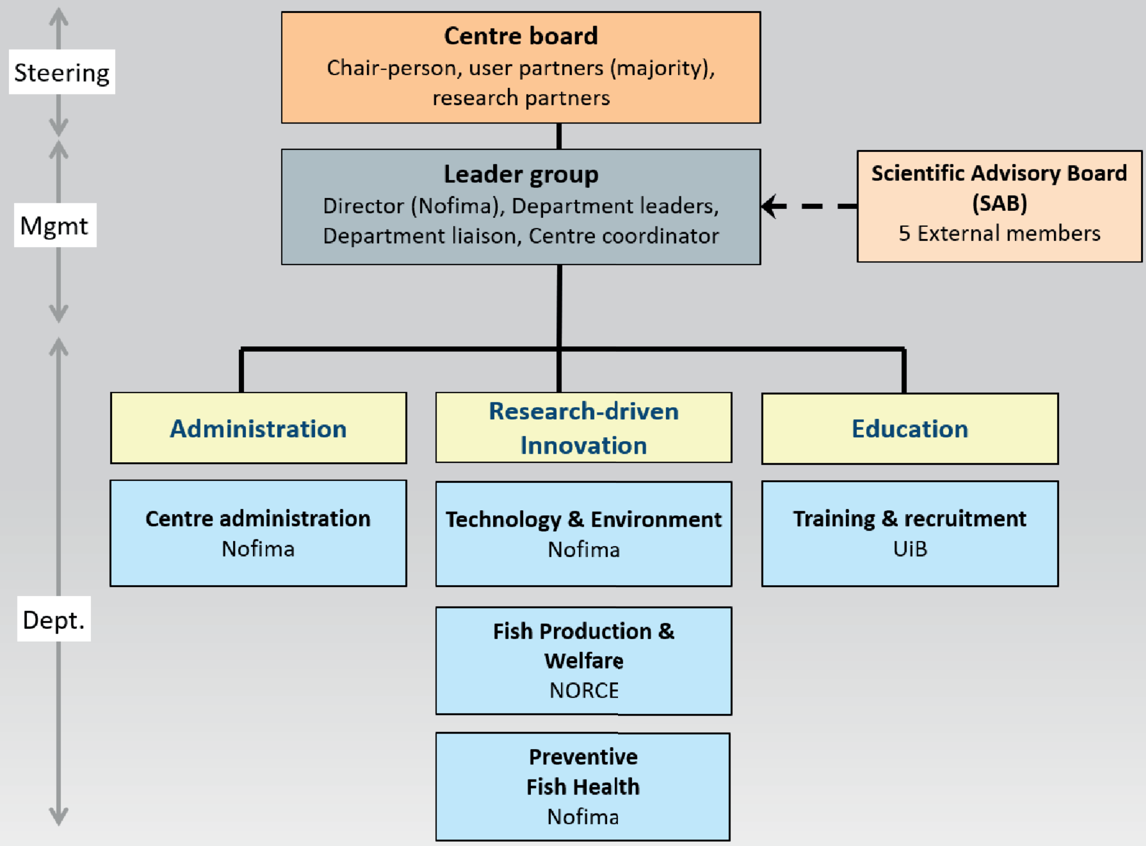


Figure 3.1. Organizational structure of CtrlAQUA.

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

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

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

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

In CtrlAQUA there has been a strong 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). In addition, 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.

Picture of the CtrlAQUA leader group: Sigurd Handeland, Åsa Espmark, Lill-Heidi Johansen, Sigurd Stefansson, Jelena Kolarevic, Tom Ole Nilsen. Not in picture: Naouel Gharbi.

THE CtrlAQUA BOARD 2019

Frode Mathisen
Grieg SeaFood, Chairperson of the CtrlAQUA Board until 30^{th} September

Harald Takle
Cermaq, Board Member until 30^{th} September and Chairperson of the CtrlAQUA Board from 1^{st} October

Siri Vike
Pharmaq Analytiq,
Board Member

Hans Kleivdal
Norce,
Board Member

Hilde Toften
Nofima,
Board Member and representing the host institution

Øyvind Oaland
Mowi,
Board Member
from 1^{st} October

Asgeir Knutsen
Krüger Kaldnes,
Board Member

PARTNERS

Per January 2020, CtrlAQUA has 21 partners, where seven are R&D partners and 14 are user partners.
CtrlAQUA was joined by new user partners Atlantium and CreateView in 2019.
User partner Vard Aqua Sunndal left the centre in July 2019.

R&D PARTNERS

Nofima

NORCE

UNIVERSITY OF BERGEN

NTNU
Norwegian University of Science and Technology

USN University of South-Eastern Norway

UNIVERSITY OF GOTHENBURG

THE CONSERVATION FUND

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 CTO/Head of Mowi's Global R&D and Technical Department, Øyvind Oaland and Group Manager Freshwater & Closed Production Technology, also in the global R&D Department, Trond Rosten. Sara Calabrese was employed in Mowi as an industry-PhD student linked to CtrlAQUA and defended her thesis in June 2017. In addition to the closed-containment system site at Molnes in Sunnhordaland, other Mowi RAS sites also provide input and are involved in various projects in CtrlAQUA. With headquarters in Bergen, Norway, Mowi employs approximately 15 000 people in 25 countries worldwide, and is listed on the Oslo Stock Exchange.

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

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

Grieg Seafood ASA is one of the world's leading salmon farming companies, specializing in Atlantic salmon. The company has a production target of 100 000 tonnes gutted weight in 2020. Grieg Seafood is present in Finnmark and Rogaland in Norway, British Columbia and Newfoundland in Canada and Shetland in the UK. The head office is in Bergen, Norway. Approximately 820 people work in the company. Grieg Seafood ASA was listed at the Oslo Stock Exchange in June 2007. Grieg Seafood focuses on responsible farming practices and sustainable growth. The company is represented in CtrlAQUA by Chief Operating Officer Knut Utheim. Grieg Seafood will contribute with their long experience in salmon aquaculture and RAS, as well as running large-scale trials.

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

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

NEKTON

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

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 sea 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.

KRÜGER KALDNES

Krüger Kaldnes AS offers world-class know how and technologies for water purification in the aquaculture industry and designs tailored solutions to meet the highest standards. Krüger Kaldnes is a fully owned subsidiary of Veolia Water Technologies-Nordic Region, and provides total solutions for wastewater treatment, water treatment, sludge treatment, rehabilitation and services to municipalities and Industries in Norway. The Kaldnes®RAS system, developed in 2008, is an example of this innovation leadership. The main focus is on high quality, bio secure fish production, and optimal logistic to create well-designed facilities, and provide complete range of support and services to customers. In CtrlAQUA, Krüger Kaldnes is represented by Business Development Manager Aquaculture Frédéric Gaumet. Krüger Kaldnes will contribute with own expertise, and prototype hardware.

FiiZK

FiiZK's primary focus is the supply of tarpaulins for aquaculture. The use of tarps has increased due to a dramatic increase in salmon lice infestations in fish farming facilities. FiiZK's products are individually tailor-made. Factors that our customer's needs, cage size, durability and design are important. In this way we can deliver a product that makes the job for the fish farmers as easy as possible. In CtrlAQUA FiiZK is represented by CEO Magnus Stendal, and the daughter company Botngaard System AS, that will contribute with knowledge and experience with closed containments.

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. The company offers analytical services and consultation to solve challenges faced by intensive fish production – in a preventive way by monitoring, diagnostics and interpretation of biological data. In 2008 PHARMAQ Analytiq opened a state-of-the-art real time RT-PCR laboratory for the detection of pathogens and in 2018 the laboratory was accredited by Norwegian Accreditation. Furthermore, histology and bacteriology extend the advisory and problemsolving capability which PHARMAQ Analytiq offers the aquaculture industry. In CtrlAQUA, PHARMAQ Analytiq is represented by Director Strategic Development Dr. Siri Vike, who is also a member of the CtrlAQUA Board and R&D Manager Dr. Stian Nylund. Both have an extensive research background in fish health. PHARMAQ Analytiq will contribute in development of tools for assessment of salmon post-smolt robustness, improved fish health, reduced stress and ensure a functional immune system.

CreateView is a technology company based in Molde. CreateView develops and sells welfare sensors that monitor lice and fish health status in fish farms to optimize fish welfare. 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 CView 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 vaccines and innovation for aquaculture and part of Zoetis, the world leader in animal health. The company provides environmentally sound, safe and efficacious health products to the global aquaculture industry through targeted research and the commitment of dedicated people. The vaccines are manufactured in a state-of-the-art production facility in Overhalla and Oslo, Norway. Administration and research and development activities are based in Oslo with subsidiaries in Norway, Chile, United Kingdom, Vietnam, Turkey, Spain, Panama and Hong Kong. PHARMAQ has approximately 200 employees. The company's products are marketed in Europe, North and South America, and Asia. In CtrlAQUA, PHARMAQ is represented by Technical Manager Nils Steine, Technical Manager Mari Solheim and Senior Scientist Elin Petterson and will contribute with expertise and vaccine development in Dept. Prev Fish Health.

Atlantium is one of the leading UV companies in the world providing water disinfection solutions to tier one companies in a variety of industries such as aquaculture. Atlantium's solutions are all based on its unique, propriety Hydro-Optic Technology (HOD) holding more than 60 registered patents. In the aquaculture industry, Atlantium is working with major industry players around the globe designing solutions for complete sustained microbial inactivation, safeguarding complete facilities from otherwise detrimental losses. The Atlantium HOD technology bases its method for delivering uniform UV doses to pathogenic microorganisms on Total Internal Reflection, a principle. The core of the HOD system is a disinfection chamber made of quartz and surrounded by an air block. The UV light's rays long path inside the chamber combined with optimally engineered flow of water in a controlled, defined pattern, creates a uniform UV dose distribution that reaches and inactivates microorganisms and is the key to attaining sustainable and reliable water bio-security.

Two new technology partners

Article by Reidun Lilleholt Kraugerud

CtrlAQUA has welcomed two new technology suppliers as partners. While the contribution from Atlantium from Israel is to work on treating intake water with UV, the contribution from the Norwegian CreateView is machine learning and artificial intelligence for improved fish welfare.

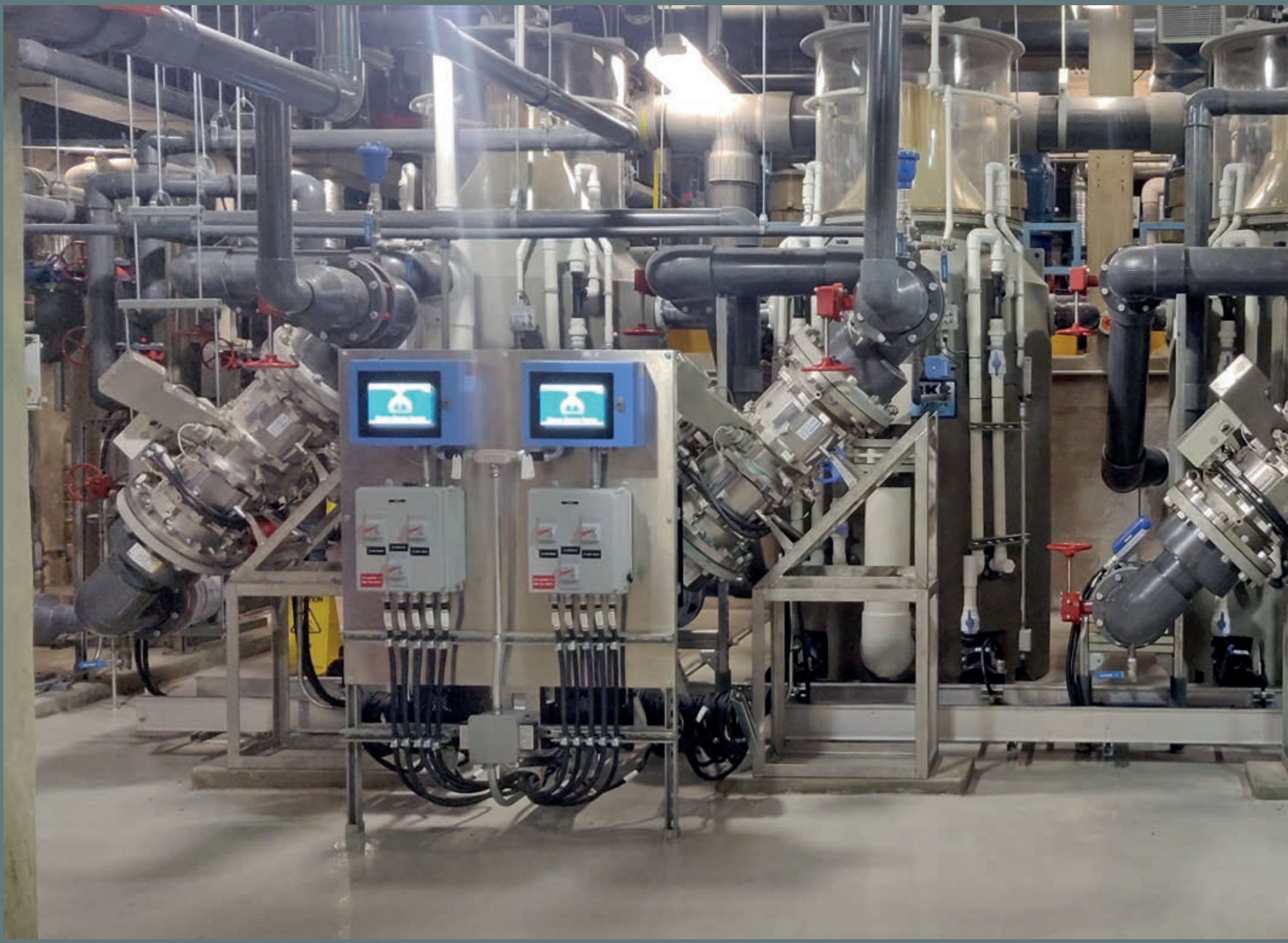
Atlantium

Getting Atlantium as a partner demonstrates a turning point in CtrlAQUA from the Centre's emphasis on documenting the technology's impact on fish, to further developing the technologies in closed systems.

Atlantium is a global provider of disinfection solutions, with proprietary UV disinfection technology. Atlantium has high activity in Norway. One goal of their participation in CtrlAQUA is disinfecting sea-water:

"Our immediate goal is to achieve at least a preliminary mapping of the sea-water microbiological challenges and the required UV doses for their inactivation" says Aran Lavi, Vice President of product in Atlantium, and in charge of their involvement in CtrlAQUA.

He thinks there is a great amount of misinformation and uncertainties relating to UV applications in aquaculture production today, though there has been tremendous development in the field of UV science, in terms of available technologies, their capabilities, and



how they can be applied in both land based and closed systems in sea.

"I hope that Atlantium can demonstrate together with our partners in CtrlAQUA that not only can UV be instrumental for the sustainable operation of such facilities, but also that through prodigious qualification, sizing and design, it can actually simplify intake water treatment and make it more straight forward efficient and cost-effective", says Lavi.

CreateView

CreateView is a Norwegian technology company that develops and sells welfare sensors that monitor fish health status in fish farms. Their sensors are based on machine learning, artificial intelligence and camera technology. With this technology they can monitor in real time without causing stress to the fish, and potentially detect sea lice, scale loss and skin damage on individual fish.

"We became a partner in CtrlAQUA SFI because we want to strengthen our expertise and adapt our products within closed farming concepts. Membership also strengthens our strategy in investing in this market area", says Even Bringsdal, CEO of CreateView.

Bringsdal hopes that their contribution will provide increased control and better fish welfare in closed systems.

Installation of the Atlantium UV systems in a RAS facility in N. America for Myxobolus Cerebralis and Myxosporean protection. Photo: ©Atlantium

Current Certus semi-closed containment system (8400 m³) located at Cermaqs site at Horsvågen, North Norway. Photo: Tor Evensen/Nofima

4 SCIENTIFIC ACTIVITIES AND RESULTS

DEPARTMENT OF TECHNOLOGY AND ENVIRONMENT

In 2019 Department of Technology and Environment continued work on sensing environment in the closed containment systems, assessing and modelling hydrodynamics of tanks and floating systems in the sea, and reviewing available technologies for carbon dioxide in RAS.

In-depth knowledge on dissolved organic matter (DOM) and its accumulation in closed containment systems is lacking. Substances in question from natural and anthropogenic origins enter into RAS with the intake water and are formed within the systems from degradation of feed pellets and fish excrements. This organic matter is involved in different processes that can affect the water quality of aquaculture system and with-it fish welfare. Presence of these substances in aquaculture can lead to: (1) aesthetic effects such as odour, taste and colour; (2) light attenuation; (3) pH buffering and (4) transport of water-soluble and insoluble species such as contaminants. Water quality management and ultrafiltration processes can also be affected by organic matter. In fact, accumulation of organic matter not only deteriorate the environment but also decreases water clarity giving a yellowish-brown coloration. The major components of DOM that cause coloration are humic substance, more specifically fulvic acids. Thus, the characterization of the bulk DOM along with the fulvic acid fraction of the coloured dissolved organic matter (CDOM) are of great interest.

During 2019 we have focused on non-targeted qualitative characterization of dissolved organic compounds in RAS where two different types of feed have been used, one standard feed for Atlantic salmon and one for RAS-feed. Our preliminary results show clear difference in characterized dissolved organic material in RAS when different feeds were used while keeping system conditions constant. In addition, the number of compounds also changes within the system. We are currently looking into anthropogenic substances and seven classes of compounds: lipids, proteins, amino sugars, carbohydrates, condensed hydrocarbons, lignin and tannin and their presence in the system when different feeds were used. Further extraction techniques for targeted characterization of fulvic acids in aquaculture have been developed in 2019. Main achievements have been the possibility to extract fulvic acids using just few liters of water, starting to analyze composition of fulvic acids using UPLC-q-TOF, and comparison of fulvic acids in authentic aquaculture water with IHSS fulvic acids standards.

We have worked on developing sensor system for simultaneous determination of trace metals (zinc, copper and iron) by use of electroanalytical sensor systems. Trace metals may pose a serious threat to farmed salmon not only because they are toxic above certain levels, but also because they can mimic essential metals and inhibit several biochemical and physiological functions in fish. An automatic trace metal system was installed and run during production of post-smolts when two different feeds were used. Preliminary results indicate difference in accumulation of zinc when two different feeds were used in RAS (Figure 4.1.).

One of the main objectives of Department of Technology and Environment is to investigate how water flow behave in small and large tanks and how to improve/optimize hydrodynamics by using computational fluid dynamics modeling (CFD) and simulation. The most vital aim of the calculations is to help the industry develop optimal farming tanks for post-smolt production with low energy footprint. Tank environment should both provide the fish with proper swimming conditions, while ensuring that the water flows spread oxygen and feed evenly and that necessary self-cleaning is achieved. In 2019 we have developed CFD model of 15 000 m^3 floating closed containment system in the sea with flexible walls (Photo: Certus S-CCS, page 24). This model predicted hydrodynamics in the system while optimizing positioning, placement and depth of inlets and number of outlets in the design. We created six CFD models in which the orientation of the inlet column nozzles was between 5 and 90°. Using the optimal combination of the inlet column nozzles (2 inlets with 90° and 2 inlets with 36,5° with the reference to the side wall) and reduced overall number of outlets improved uniformity of velocities, lowered vortices and reduced wall shear stresses.

In our CFD work we also concentrated on the large (850 m^3) octagonal dual-drain tanks with two inlets in land-based systems. In current setup, outlet flow ratio was fixed at 85% sidewall outlet and 15% central bottom outlet to provide optimal flow conditions for fish welfare and performance. In addition, two set-up cases of the inlet column nozzles angles (15° and 45° with reference to big side wall) were selected for both inlets columns to determine how to optimize rotational velocities and mixing patterns across the octagonal tank. The results showed that using inlet column nozzle angles of 15° for both inlets provided better overall hydrodynamic conditions in the tank. The comparison of empirical data and CFD analysis (2D color contour and 2D velocity mapping image) also showed good compatibility (Figure 4.2). The 2D velocity mapping show the secondary vortices that promote mixing action in the tank through tea-cup hydrodynamic effect.

The development of energy-efficient RAS for Atlantic salmon is one of the main goals of

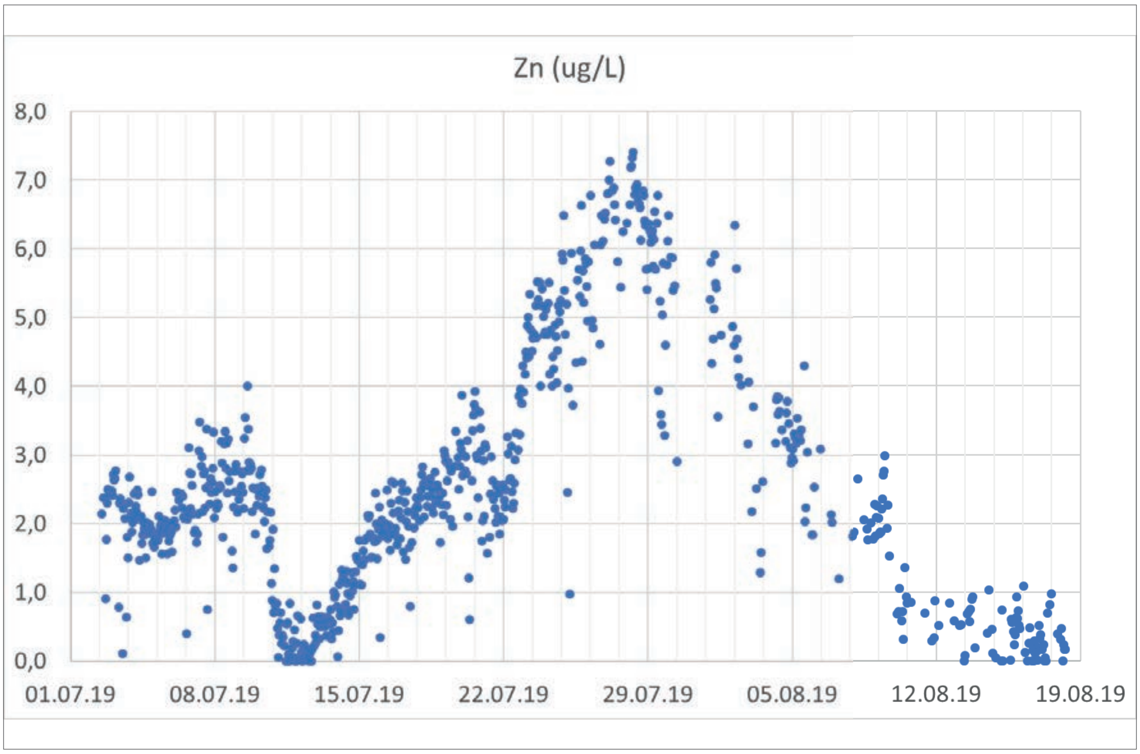


Figure 4.1. Online measurements of labile zinc (ATMS) in RAS where standard feed was replaced by RAS-feed on July 26th. Biomass reduction was performed on July 11th when system volume has been flushed in one day (Ingrid N. Haugen, 2019).

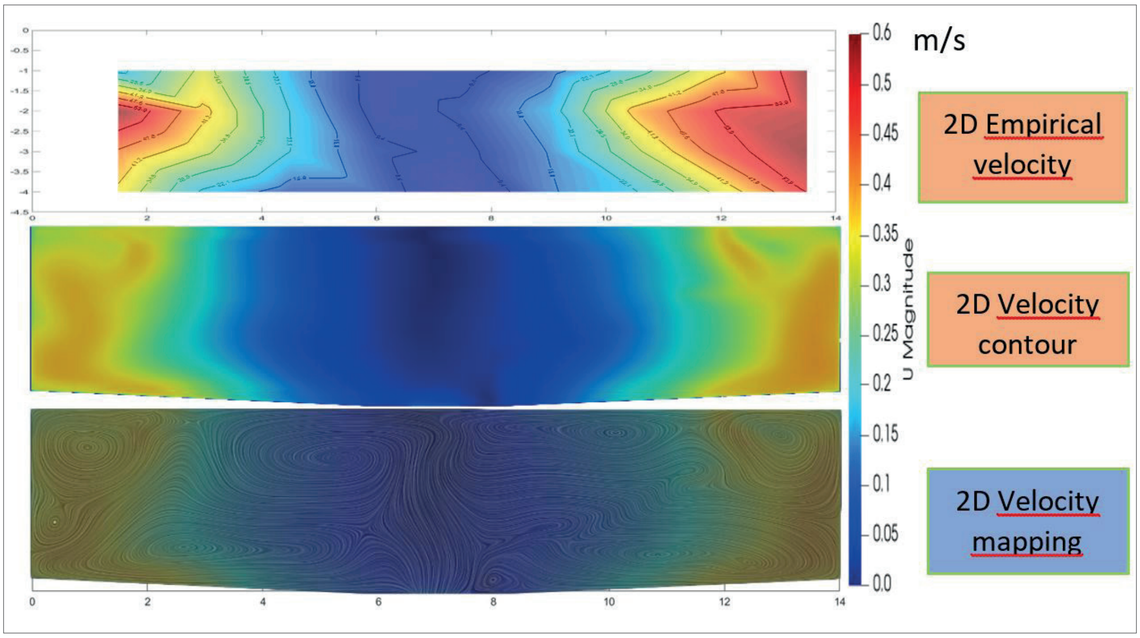


Figure 4.2. Comparison between empirical (A) and CFD analysis (B, C) of the 850 m³ dual drain octagonal tank with the inlet column nozzles angles of 15° (with the reference to the long wall). The outlet water flow rate ratio was fixed at 85% sidewall outlet and 15% central bottom outlet (Ingrid N. Haugen, 2019).

the Department for Technology and Environment in CtrlAQUA. Efficient CO_2 removal in brackish and seawater RAS which is less efficient compared to freshwater RAS is therefore in focus. In 2019 we have reviewed existing degassing technologies. The results show that the CO_2 removal technologies did not change significantly during the last decades. The two main strategies used in modern RAS facilities are tickling and submerged aeration system (Photo: Submerged aeration system). Both systems have their advantages and disadvantages. Which of the two technologies is more energy efficient will depend on the design and energy use of chosen components. Submerged aerator degassing units might require lower investment costs, however a trickling design with countercurrent air suction can have comparable running energy costs. In addition, a modular trickling system is more flexible and allows for improvement (media, flow, airflow, additional suction) compared to simple submerged systems.

Additional bypass degassing systems via air stones or airlifts in strategic location are also used in some RAS facilities. The use of fans, blowers and/or suction devises help to improve degassing performance considerably. However, current degassing units are still not actively using feedback control systems, like automatic fan shut down, or pH buffer management to reduce energy costs. This approach is something we will explore in our future work.

Submerged aeration system for degassing in RAS at Mowi facility in Nordheim. Photo: Kevin Stiller/Nofima

Carlo C. Lazado is evaluating the external welfare status of salmon reared in brackish-water RAS that routinely employs peracetic acid (PAA) as a water disinfectant. This is part of CtrlAQUA project DISINFECT that aims to evaluate the health and welfare impacts of water disinfection in RAS on smolts. At the back is João Osório, a student from the University of Lisbon who is doing his MSc thesis in the project. Photo: Kevin Stiller/Nofima

DEPARTMENT PREVENTIVE FISH HEALTH

Inventions to prevent, detect and control diseases in closed and semi-closed containment systems (CCS/S-CCS) are main objectives in Dept. Preventive Fish Health. This may be obtained by different measures, such as strengthening fish robustness and disease resistance, improving pathogen control and handling of disease outbreaks, securing stable conditions in the production systems to avoid potential risks to fish health and welfare, and by developing new or refined vaccines and vaccination protocols for pathogens representing a special threat in these systems.

In CtrlAQUA we explore the potential for controlling water flow and velocity for improved growth and health. We have recently performed lab trials and defined optimal water velocity levels that increase growth of post-smolts without negative impact on health. To test if similar effects can be found in large-scale tanks, we performed a trial at a commercial smolt RAS facility. Two tanks were set to the highest pump-output while two others were set to a lower output. Growth and welfare were monitored for three months without finding any differences between the groups. By hydrodynamics analysis we found that the overall differences in velocity turned out to be low between groups in the trial period. The experience is that large-scale tanks are not easily adaptable to higher velocities, and more work is needed to improve set-ups to be able to perform solid tests and implement them in the industry.

An important task in the Centre is to identify and characterize the most important known and emerging microparasites in CCS and S-CCS. This task runs throughout the whole Centre period. The hypothesis is that use of S-CCS will not affect the diversity, prevalence and load of parasites compared to open production systems at sea. In 2019 variation in prevalence, load and diversity of microparasites were tested in two S-CCS at different geographical locations (north and south), before and after sea transfer.
Control sites with open cages were included. No serious disease outbreaks were registered in any of the systems in 2019 and there were only minor differences in the dynamics of pathogens prevalence in open compared to S-CC systems. So far in CtrlAQUA we have evidence to support the hypothesis that S-CCS do not have more pathogens than open cages.

Although commercial vaccines are available, outbreaks of ulcerative disease in farmed Atlantic salmon is an impeding factor for sustainable growth within the industry. We need to understand how basic mechanisms in host-pathogen interactions and vaccine-associated protection of the skin can influence the development and outcome of skin infections. We have investigated the effects of intraperitoneal vaccination and enduring immune modulations and responses to infection in the skin of Atlantic salmon. We have found that vaccination results in protection to both *Moritella viscosa* induced mortality and skin ulceration but still, infection is established regardless of vaccination. Image analysis shows how *Moritella viscosa* initiate infection by colonizing the scale surface and cause scale degradation. Tissue responses to infection include influx of blood and immune cells between the outer surface of the scale and the outermost skin layer, epidermis, and thickening of the epidermis. Gene analysis suggests that vaccination affects various skin layers differently, but that skin do respond immunological to intraperitoneal vaccination. Furthermore, vaccinated and unvaccinated fish seem to respond to infection in different skin layers, and mediators of skin immunity are primed in the epidermis in vaccinated fish.

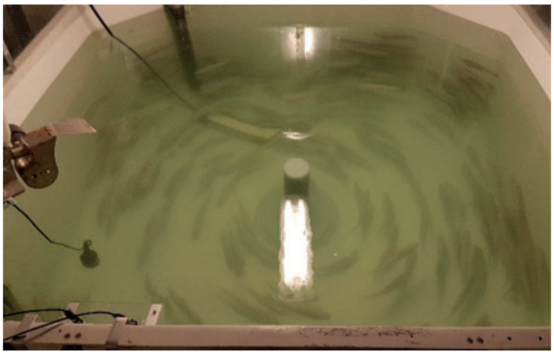
In CCS and S-CCS intake water treatment is used to create a barrier that prevents pathogens from entering the facilities. Unlike land-based RAS, the lack of water reuse and the resulting large flows in S-CCS (≥ 500 m^3/min) pose a significant challenge for finding safe and financially viable intake water treatment strategies. We have reviewed experimental data and literature for relevant filtration and disinfection technologies and conducted an informal survey with technology users and suppliers to discuss opportunities. Gaps in knowledge were identified and will be addressed in future research. A combination of microfiltration and UV treatment remains the most promising and cost-effective approach to treat intake water in S-CCS. Other novel technologies were also identified as potential applications in intake water treatment. Due to lower flow rates in RAS, membrane filtration could be an attractive option to prevent pathogens from entering CCS. Optimizing energy efficiency of treatment technologies and quantifying "acceptable risk" in operation are keys for developing a sustainable concept for intake water treatment in the future.

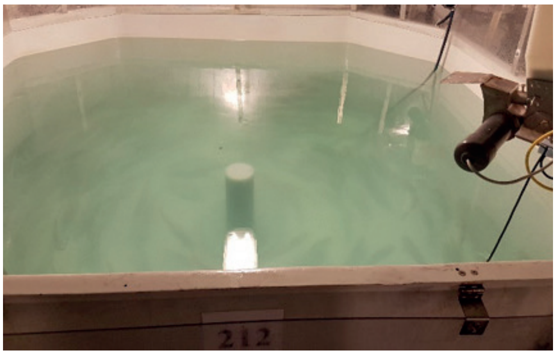
Functional and stable biofilters are essential in RAS to maintain good production conditions, however the biofilters are affected by changes in water salinity. In experiments we have shown that seawater priming can help salinity adaption in one commonly used biofilter, Moving Bed Bio Reactors (MBBRs). Brackish water MBBRs are more resilient to salinity increase than freshwater MBBRs, while start-up takes similar time. Thus, brackish water start-up may be a strategy for high salinity RAS. The salinity adaptation strategies are now used in the planning of new facilities that start up in 2020.

Based on user partner-surveys on disinfection strategies for biofilters in RAS 2018, we evaluated chemical disinfectants and pH manipulation in MBBRs (Photos: Disinfection of biofilters). All protocols effectively disinfected the biofilter, however, recovery time varied. For instance, systems disinfected with chlorine recovered faster than those disinfected with peracetic acid (PAA) and a quaternary compound. The results will contribute to greatly improve and shorten the disinfection processes in the industry.

The impacts of PAA and ozone application as routine water disinfection protocols on salmon smolts in brackish water were also evaluated. Fish were first exposed to periodic application of PAA without any negative effects. However, when fish were prompted with a secondary stressor (acute confinement test), the group treated with PAA tended to recover relatively slower, as shown by development of cortisol and glucose levels. Gene analysis revealed that the gills mounted

Disinfection of biofilters. Right: Addition of disinfectant into the reactor. Left: Routine water sampling to follow the activity and recovery of the biofilters after disinfection. Photo: Carlo C. Lazado/Nofima





Colour of the water in the tank during the ozone trial. Left: No ozonation. Right: With ozonation. Photo: Carlo C. Lazado/Nofima

stronger responses to PAA compared with two other mucosal tissues, skin and olfactory rosette. Furthermore, the impacts of continuous ozonation on the health and welfare were explored. Ozone concentration used (320-350 mV) was identified in a previous CtrlAQUA trial to be the upper safe limit for smolts in flow-through. No mortality was recorded during the whole trial and fish external welfare scores were superior in both systems (Photos: Colour of water ozone trial).

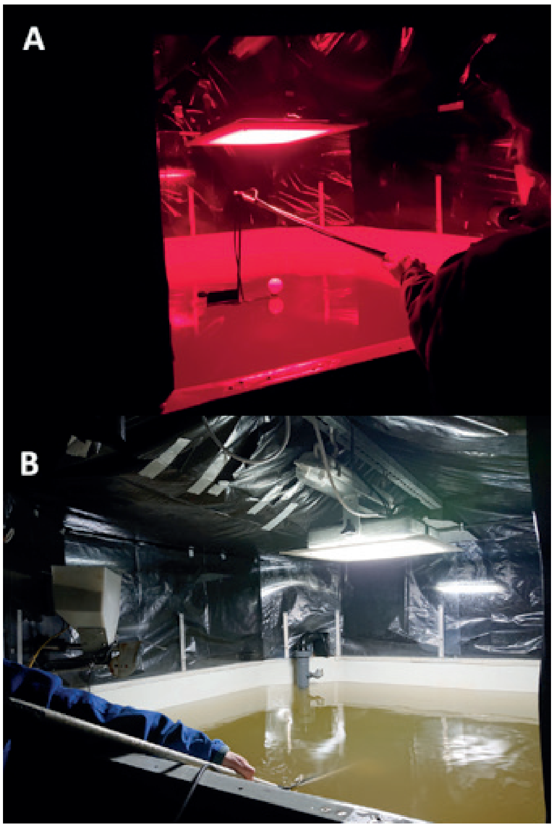
Ozone may also have other properties than water disinfectant. To study if water ozonation can reduce or remove waterborne sex hormones in RAS that may give early maturation, water samples from RAS with and without ozonation were analysed for concentrations of the sex hormones testosterone, 11-ketotestosterone (11-KT), estradiol (E2), and cortisol. Even though 11-KT and E2 were lower in ozonated RAS, maturation was still high in both test groups. Thus, other yet not identified environmental factors seem to have a strong impact on maturation.

DEPARTMENT OF FISH PRODUCTION AND WELFARE

The main objective of Department of Fish Production and Welfare is to provide knowledge and innovations to determine environmental and biological requirements of Atlantic salmon in CCS. During 2019, both experimental work and analysis in ongoing projects has focused on providing an improved scientific basis for recommendations on optimizing environmental requirements of salmon in CCS and S-CCS. To this end, work in Department of Fish Production and Welfare has focused on completing the work on robustness markers and environmental factors important for optimizing performance of post-smolts. In 2019 CtrlAQUA transferred identified robustness markers to CtrlAQUA partner Pharmaq Analytiq. Together, we have evaluated five selected biomarkers against environmental conditions (water quality, temperature, training, densities etc.) in controlled small-scale experiments. Two of these biomarkers have further been selected for large scale industry validation and commercialization. Future work on biomarkers will be continued in the associated project “PRESTIIS – Predicting Stress in Salmon" for which funding has successfully been obtained through the Research Council of Norway's FORNY program.

A priority within Department of Fish Production and Welfare is to optimize environmental rearing conditions for post-smolt in CCS. The majority of modern RAS for post-smolts are indoor facilities where fish are never exposed to natural light. This makes choice of artificial light extremely important as we know that light quality can modulate e.g. feeding behavior, growth, smoltification and reproduction. The development of narrow-wavelength LED light technology has opened up for new possibilities for light control. However, the use of different types of LED lights (spectral composition and intensity) and its effect on Atlantic salmon is not well known. At Nofima Centre for Recirculation in Sunndalsøra we have exposed Atlantic salmon post-smolt with starting weight of ca. 100 g to three different light qualities: White LED light, full spectra LED light and red LED light. In addition, we exposed post-smolts to two different average light intensities (high and low) (Photo: Light intensity measurements). Post-smolt were kept until 1 kg in RAS without disinfection, at salinity of 12 ppt, average temperature of 13°C and with 24h light photoperiod.

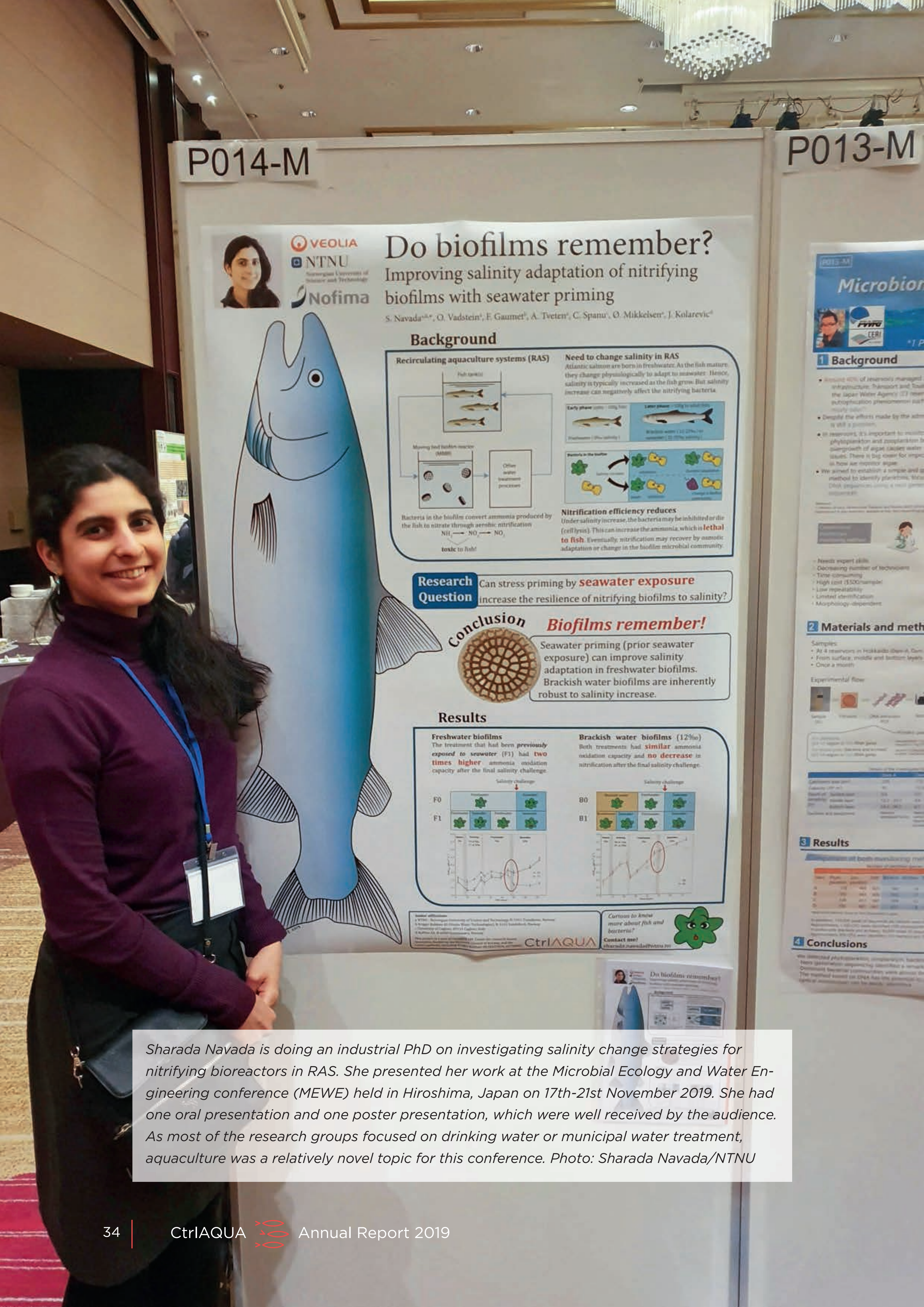
Our results show that RAS water can change light characteristics, both intensity and spectral composition. Intensity measurements have shown that only about 20% of the light intensity at the surface remains at the bottom of the tanks (~0.8 m). Contrary to typically clean sea water, blue light did not penetrate the water very well. The selective removal of blue light might be an effect of the accumulation of humic acids in RAS and calls for



Light intensity measurements in the tank with red LED light (A) and full spectra LED light (B) at Nofima Centre for Recirculation. Photo: Andre Meriac/Nofima a review of current lighting strategies not only in RAS, but also in indoor flow-through systems using water rich in humic acids. Post-smolts exposed to red LED light with low intensity were significantly smaller compared to other four treatments. When reaching 1 kg the difference between red LED light treatment and other treatments remained, while there was no significant difference in average individual weight between other treatments. Post-smolts exposed to higher light intensity were the largest at the end of the experiment. Our work with optimizing light conditions will continue in 2020 where we will look more into the effect of light on physiology and welfare of post-smolts.

Early puberty in males is an increasing challenge when producing large smolt and post-smolts, while females mature typically at a larger size. In addition, use of triploid fish has been launched as a strategy to avoid genetic introgression in wild fish from escapees. Hence, the use of photoperiod and ploidy on growth and early puberty development in all-female diploid and triploid post-smolt was investigated. The fish were exposed to either a standard square wave smoltification regime (i.e., 12 hours light, 12 hours dark, for six weeks beginning when mean fish size was 40 g), or continuous 24-hour photoperiod during early rearing, and then raised under continuous photoperiod for the remainder of the study, up to a mean harvest size between 4 and 6 kg. Early rearing was carried out in a flow-through system, followed by transfer at 100 g to a partial reuse system. At approximately 1,000 g, post-smolts were transferred to a single grow out RAS and were identified during subsequent sampling events. No significant differences in growth were noted between treatment groups at the early post-smolt stage. Still, a trend wherein both diploids and triploids that did not receive a winter signal displayed a higher weight than those that received the winter photoperiod, which is consistent with known effects of constant light on growth. No maturation was observed at post-smolt transfer. At the end of the study photoperiod did not result in growth differences between photoperiod groups, however, diploid fish demonstrated significantly greater growth than triploids. Significantly greater maturation was observed in the diploid cohorts, whereas significantly greater incidence of deformities was observed in triploids.

We have followed up previous investigations, documentation and comparison of growth, performance, welfare, mortality and lice infection in Atlantic salmon raised in large scale semi-closed system (S-CCS: Preline, Neptun and Certus). In addition, selected production data from six generations of salmon produced in Preline have been used to compare growth and performance in fish raised in S-CCS and in a reference open net pen. A benchmark study was carried out in two phases; 1. Post-smolts (from 150 to 600 g) in seawater (fish in S-CCS vs. reference group in open pen) and 2. On-growing salmon (from 600 to 5000 g) in open cages (fish previously reared in S-CCS vs. fish from reference group). Preliminary results show a significantly higher growth of the fish from Preline compared to the reference group in open pen. Further, fish from Preline also showed less sea lice in open net pen until harvest compared to reference. Finally, salmon raised in Preline showed significantly higher survival compared to the reference, especially during winter season, indicating increased robustness when exposed to open net pens. In line with the Preline findings, data from Certus show 14 % improved post smolt growth and minimal with sea lice when compared to reference fish in open pen. Moreover, fish from S-CCS showed lower cortisol and plasma ion levels at baseline, giving a stronger response to acute stress challenge than fish from reference, suggesting a lower and more adaptive stress response in the S-CCS than in the reference open pen. These results provide a foundation for a linear economic model that will be used to analyze the effect of implementing a new S-CCS post-smolt production strategy against a conventional open net pen production line.



Sharada Navada is doing an industrial PhD on investigating salinity change strategies for nitrifying bioreactors in RAS. She presented her work at the Microbial Ecology and Water Engineering conference (MEWE) held in Hiroshima, Japan on 17th-21st November 2019. She had one oral presentation and one poster presentation, which were well received by the audience. As most of the research groups focused on drinking water or municipal water treatment, aquaculture was a relatively novel topic for this conference. Photo: Sharada Navada/NTNU

5 INTERNATIONAL COLLABORATION IN 2019

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

CtrlAQUA researchers are invited as speakers at different international scientific meetings. In addition, we are often invited to host sessions at meetings. At the Nordic RAS and EAS meetings in Berlin in October 2019, CtrlAQUA contributed with seven presentations and one poster. In addition, we led the session "Sustainable systems for large scale production - closed, offshore or both". Nofima also hosted the first conference in "Mucosal Health in Aquaculture", 11th - 13th September 2019 in Oslo, Norway. During the conference CtrlAQUA contributed with seven presentations, and one session was chaired by the international CtrlAQUA partner Gothenburg University (UGOT). The conference was attended by 17 different nationalities.

There are two international R&D partners in CtrlAQUA, Gothenburg University (UGOT) and The Conservation Fund Freshwater Institute (FI), USA. Gothenburg University is represented in CtrlAQUA by Prof. Kristina Sundell and her research group. In 2019 UGOT has contributed to important knowledge regarding skin and gut as barrier organs. They have also introduced an associated project on effects of microplastics in RAS. The Conservation Fund Freshwater Institute (FI) has continued the trials on optimal photoperiod and feed ration for post-smolts reared in RAS in their facilities and done research on optimal use of ozone in fresh water. Furthermore, FI has been leading CtrlAQUA project HYDRO, on hydrodynamic measurements and development of flow models for large fish tanks in closed systems.

CtrlAQUA opened in 2015 for associated projects. Associated projects need external funding and can in addition to CtrlAQUA partners involve partners that are not regular CtrlAQUA partners. In 2019 we registered three associated projects that involves international partners: RFF TROUT is funded by Regional Research Fund (RFF) and is in collaboration with Sterling University. Late 2018, CtrlAQUA partner UGOT (Henrik Sundh) got funding for the project “Microplastics in the environment: An investigation into how they affect fish and potential risks for the aquaculture” from the Swedish Research Council. In 2019 Nofima (Carlo Lazado) got the project “Prevalence and consequences of hydrogen sulphide in land-based Atlantic salmon production” (H2Salar) accepted, funded by the The Research Council of Norway, where the primary objective is to create knowledge and advance our understanding of the risks and impacts of exogenous hydrogen sulphide (H_2S) to the physiology of Atlantic salmon in recirculating aquaculture. H2Salar includes international partners DTU, Atlantic Sapphire and Blue Unit.

Researchers in CtrlAQUA are often involved in new project proposals where international partners are included. One example is a series of EU projects where some of the CtrlAQUA-partners have helped establishing first AQUAEXCEL, then the ongoing AQUAEXCEL2020 and the newly funded AQUAEXCEL 3, where among others Nofima Centre for Recirculation in Aquaculture (NCRA) in Sunndalsøra is included as one of the Transnational Access Points. This means that researchers across Europe can do experiments in NCRA funded by AquaExcel2020 and to be continued in AQUAEXCEL 3.

PhD student Patrik Tang. Photo: Sigurd Stefansson/UiB

6 RECRUITMENT, EDUCATION AND TRAINING

CtrlAQUA aims to have 15 PhD students to be educated throughout the lifetime of the Centre. We are approaching this number and have now recruited 11 PhD students and one Dr. philos. candidate to key research topics of the Centre and its associated projects (see table in section 8). In June 2019, Bernat Morro (funded in part by the associated project “Trout”) successfully defended his thesis at University of Stirling, Scotland. 9 master students finished in 2019 as well.

During 2019, the student forum has had some activity, but this is a part of the Centre which should be more active. The students have chosen a structure where they get together in satellite meetings during the annual meetings (spring), and CtrlAQUA has approved a request from the students for support for a meeting during the autumn. Sharada Navada serves as their representative, and the leader group has from time to time asked Sharada for input to the leader group meetings. The involvement of Navada in leader group meetings should be made more structured, and the leader group will make sure that this is done in 2020. The students played an important role during the mid-term review at Sundalsøra, where they were interviewed by the panel. On some projects, such as OPTIMIZE, the students are collaborating on the journal article to make it multidisciplinary.

In addition to the PhD students, we are educating several Master students within CtrlAQUA at the University of Bergen, Göteborg University, NTNU and recently also universities in Portugal (see table in section 8). So far in the lifetime of the Centre we have recruited 34 Master students. 17 of these students have completed their theses and final exam, while the other 17 candidates are at various stages of selecting and carrying out their research in CtrlAQUA projects and preparing their theses. Several of the scientists in CtrlAQUA are acting as supervisors and taking active part in establishment, organization and teaching of courses, both at bachelor and master level.

Gender balance among the PhD candidates was commented on in the 2019 Annual report and we will not make further comments here, except that the addition of John Davidson as a Dr. philos. candidate has helped this balance somewhat. As stated last year, the distribution reflects the quality of the applicants for the positions, as recruitment is based entirely on scientific quality. Among the MSc students, the gender balance is still approximately 60/40 male/female students. Again, these numbers reflect the recruitment base of MSc candidates who apply to do their project within the Centre and its associated projects.

A doctoral degree outside the norm

Article by Reidun Lilleholt Kraugerud

An experienced researcher will earn his Doctoral degree based on long term and new in-depth industry research.

John Davidson works at the Freshwater Institute, located in West Virginia, USA. During more than twenty years as a researcher there, he has an established track record but has had limited means to earn a Doctor degree while maintaining a fulltime industry position and family life. He is now aiming for a Dr. philos, which is an independent doctoral program offered by the University of Bergen. Compared to an ordinary PhD program, the Dr. philos program excludes organized training and supervision.

"I've first-authored more than twenty peer-reviewed articles on RAS-related topics, but this program pushes me to go a step further and consider my contributions with deeper industry perspective" says Davidson.

The Dr. philos program has specific requirements to compile impactful research with a unified narrative and to orally present and defend the thesis in front of a group of peers, much like a standard PhD dissertation defense.

The subject

"We've established a research direction that blends past work that I've contributed to at Freshwater Institute with ongoing research that I'm collaborating on through CtrlAQUA", Davidson explains.

His thesis will reflect on the importance of research specific to salmonid aquaculture in Norway and the United States and how this body of work has supported the advancement and development of the salmonid RAS industry.

At Freshwater Institute, they are equipped to study all life-stages of fish, from egg to market-size. However, they have found a niche in studying the production of post-smolt to market-size salmonids in freshwater RAS, Davidson explains. Much of the research that will be discussed in his Dr. philos thesis will focus on optimizing the environment for post-smolt salmonids cultured from 0.1 - 2.0 kg.

Challenges

Particularly for post-smolt to market-size Atlantic salmon production, Davidson thinks there is certainly a lot more to learn about fish production in RAS for it to be a success. "Broadly, I believe that the economics of commercial RAS is not fully understood and remains to be determined by the growing number of new land-based facilities. Research efforts that help to reduce fish production costs in RAS will be essential to the economic success of this industry sector".

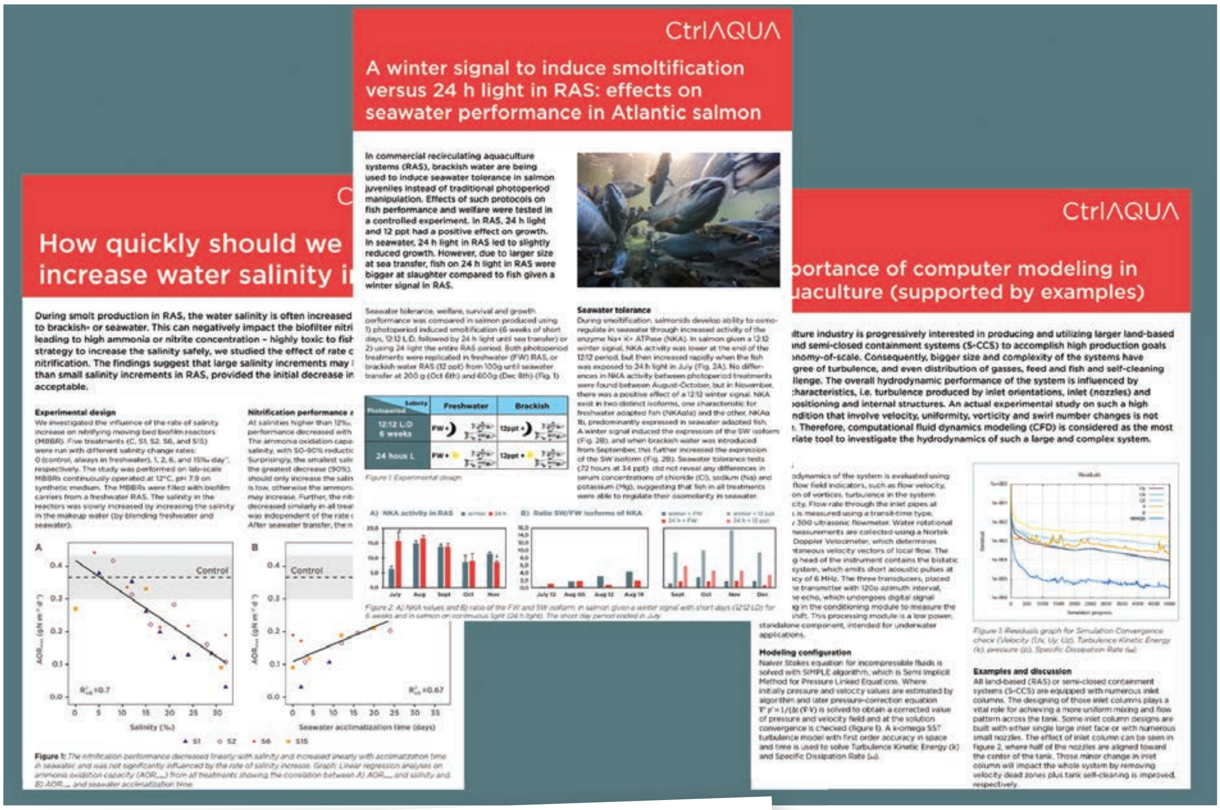
He mentions two examples of how economic benefits and improvements are being found through the Freshwater Institute and CtrlAQUA partnership:

"For example, we recently found that the use of ozone enhanced post-smolt Atlantic salmon growth in freshwater RAS, which could lead to reduced duration of the fish culture cycle and diminished production costs".

"We're also diligently working to define the environmental and biological conditions that lead to reduced maturation of RAS-produced Atlantic salmon, which would also improve economic feasibility", he says.

For CtrlAQUA, Davidson's Dr. philos means that this Centre for Research-Based Innovation is getting closer to reaching the education goal of 15 doctoral candidates in closed-containment aquaculture topics.

"The Dr. philos option is a perfect fit for me, professionally and personally. I'm grateful for this fantastic opportunity!" says John Davidson, experienced scientist and becoming Dr. philos. Photo: ©Freshwater Institute



Kjemi

Overvåking av vannkvalitet viktig for glad laks

av Ingrid Naterstad Haugen | 13. juni, 2019

Jeg holder på med en doktorgrad ved institutt for kjemi, hvor jeg er så heldig å ha blitt en del av et senter for forskningsdrevet innovasjon (SFI) kalt CtrlAQUA. CtrlAQUA jobber for å utvikle teknologi og løsninger for lukkede og delvis lukkede oppdrettsanlegg for laks

7 COMMUNICATION AND DISSEMINATION ACTIVITIES

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

At the annual meeting in May, being halfway in the Centre lifetime, the communication leader raised the question whether the communication plan is still valid and being followed. There was a discussion and the conclusion was "yes". However, industry, scien tists and NGOs agreed that it is necessary in addition to promote the work we do, and that we raise awareness in society about the obstacles for upscaling a large production to CCS and S-CCS.

When it comes to internal routines and systems for communication between the partners, the intranet is the most important tool. The intranet is the main communication channel within the Centre for the 108 participants now involved. The intranet has a document base, image base, message facilities, calendar and internal alerts of new findings or publications as agreed upon in the consortium agreement. Other systems for internal communication are regular meetings and providing instructions for presenting CtrlAQUA.

Image captions on opposite page:

- *In 2019 the first fact sheets were made.*
- *Centre Director Åsa Espmark (right) in interview with NRK radio about the future of aquaculture and environment in August. (Photo: Øyvind Fylling-Jensen/ Nofima)*
- *NTNU blog featuring CtrlAQUA student Ingrid Naterstad Haugen and her work in June.*

The main external communication channel is the website www.ctrlaqua.no, which is designed for presenting results, activities, publications and innovations as the Centre develops. In 2019 we made the first three fact sheets about available technology and new results, to make it easier for the industry to implement research. Activities have been spread in social media channels Facebook, Twitter and LinkedIn.

The interest from industry, the public and academia has been encouraging. This has resulted in 53 news articles in press and three in radio/podcast in 2019, many generated by the media itself. Students have made both a blog and a film about their work. Partners have been available for press to report on the progress of research and innovation in CCS and S-CCS in aquaculture.

In 2019 we have had high activity in disseminating progress and results at conferences, particularly towards our main target groups in industry and research.

Examples of dissemination activities in 2019 are:

- May: Student film about sensors was released.
- June: Student blog at NTNU.
- July: First out of three fact sheets in 2019 was released for distribution at Aqua Nor and Aquaculture Europe.
- August: Presentations at Aqua Nor generated media interest, in particular Centre Director in radio and podcast. An opinion article, where the Centre Director encouraged to remember fish health when applauding closed facilities, raised engagement.
- October: Session about RAS at Nordic RAS/Aquaculture Europe where Ctrl-AQUA was a key player.

8 ATTACHMENTS TO THE REPORT

Key R&D partners in 2019

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
Ida Rud	Nofima AS
Kevin Stiller	Nofima AS
Andre Meriac	Nofima AS
Khurram Shahzad	Nofina AS
Carlo Lazado	Nofima AS
Roy-Inge Hansen	Nofima AS
Sigurd Handeland	Norce
Tom Ole Nilsen	Norce
Pablo Balseiro	Norce
Naouel Gharbi	Norce
Simon Mackenzie	Norce
Alla Sapronova	Norce
Eirik Thorsnes	Norce
Sigurd Stefansson	Universitetet i Bergen
Are Nylund	Universitetet i Bergen
Øyvind Mikkelsen	NTNU
Frank Karlsen	USN
Snuttan Sundell	UGOT
Henrik Sundh	UGOT
Brian Vinci	Freswater Institute, USA
Chris Good	Freswater Institute, USA
John Davidson	Freswater Institute, USA
Chris Good	Freswater Institute, USA
John Davidson	Freswater Institute, USA
Steve Summerfelt (08.06.2018)	Freswater Institute, USA

Postdoctoral researchers in process

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

PhD-students/dr. philos

Sara Calabrese	2013 - 2017	UiB
Lene Sveen	2014 - 2018	UiB
Bernat Morro	2016 - 2019	UiB
Victoria Røyseth	2016 - 2019 (avbrutt)	UiB
Xiaoxue Zhang	2016 - 2020	NTNU
Patrik Tang	2017 - 2020	UiB
Sharada Navada	2017 - 2020	NTNU
Enrique Pino Martinez	2018 - 2021	UiB
Ingrid Naterstad Haugen	2018 - 2021	NTNU
Patricia Aguilaraguilar	2018 - 2021	NTNU
Tharmini Kalananthan	2018 - 2021	UiB
John Davidson	2019 - 2021	UiB
Even Mjølnerød	2020 - 2023	UiB

MSc students

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

BSc students

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

CtrlAQUA Dissemination and publications 2019:

Peer reviewed publications

Aslam, S.N., Navada, S., Bye, G.R., Mota, V.C., Terjesen, B.F., Mikkelsen, Ø. (2019). Effect of CO2 on elemental concentrations in recirculating aquaculture system tanks. Aquaculture. June 27th, 2019.

Benktander, J., Venkatakrishnan, V., Padra J.T., Sundh, H., Sundell, K., Murughan, A.V.M., Maynard, B., Lindén, S.K. (2019). Effects of size and geographical origin on Atlantic salmon, Salmo salar, mucin O-glycan repertoire. Molecular & Cellular Proteomics, June 1st, 2019.

Cabillon, N.A.R., Lazado, C.C. (2019). Mucosal barrier functions of fish under changing environmental conditions. Fishes. Volume 4, Issue 1.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S.T. (2019). Hydrodynamics of Atlantic salmon culture tank: Effect of inlet nozzle angle on the velocity field. Computers and Electronics in Agriculture, March 2019. Volume 158: 79-91.

Mota, V. C., Nilsen, T. O., Gerwins, J., Gallo, M., Kolarevic, J., Krasnov, A., Terjesen, B. F. (2019). Molecular and physiological responses to long-term carbon dioxide exposure in Atlantic salmon (Salmo salar). Aquaculture. November 8th, 2019.

Mota, V.C., Nilsen, T.O., Gerwins, J., Gallo, M., Ytteborg, E., Bæverfjord, G., Kolarevic, J., Summerfelt, S.T., Terjesen, B.F. (2019). The effects of carbon dioxide on growth performance, welfare, and health of Atlantic salmon post-smolt (Salmo salar) in recirculating aquaculture systems. Aquaculture, January 2019. Vol 498: 578-586.

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Padra, J.T., Murugan, A.V.M., Sundell, K., Sundh, H., Benktander, J., Linden, S.K. (2019). Fish pathogen binding to mucins from Atlantic salmon and Arctic char differs in avidity and specificity and is modulated by fluid velocity Bacterial pathogen binding to salmonid mucins. PLoS ONE 14(5): e0215583.

Sundh, H., Finne-fridell, F., Ellis, T., Taranger, G.L., Niklasson, L., Pettersen, E.F., Wergeland, H.I., Sundell, K., (2019). Reduced water quality associated with higher stocking density disturbs the intestinal barrier functions of Atlantic salmon (Salmo salar L.). Aquaculture, Volume 512, 15 October 15th, 2019.

Sveen, L.R., Timmerhaus, Krasnov, A., G., Takle, S.O, Handeland, S.O.O, Ytteborg, E. (2019). Wound healing in post-smolt Atlantic salmon (Salmo salar). Scientific Reports 9. Article number: 3565.

Venkatakrishnan, V., Padra, J.T., Sundh, H., Sundell, K., Jin, C., Langeland, M., Carlberg, H., Vidakovic, A., Lundh, T., Karlsson, N.G., Lindén, S.K. (2019). Exploring the Arctic charr intestinal glycome: Evidence for increased N-glycolylneuraminic acid levels and changed host-pathogen interactions in response to inflammation. Journal of Proteome Research, 2019, 18, 4, 1760-1773.

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Summerfelt, S.T., Terjesen, B.F., Gorle, J.M. (2019). Hydrodynamic Challenges in Huge Culture Tanks. RASTech conference in Washington, USA, May 13-14th, 2019. Abstract.

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Navada, S. (2019). Improving salinity adaptation in nitrifying bioreactors by seawater priming. AE2019, Berlin, October 8-10th, 2019.

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Navada, Sharada. Vadstein, Olav. Gaumet, Frederic. Tveten, Ann-Kristin. Spanu, Claudia. Mikkelsen, Øyvind. Kolarevic, Jelena. (2019). Improving salinity adaptation of nitrifying biofilms with seawater priming. 8th IWA Microbial Ecology & Water Engineering Specialist Conference (MEWE), Hiroshima, Japan, November 17-20th, 2019.

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Espmark, Å (2019). Closed and semi-closed containment aquaculture. Salmon Watch Ireland, Galway, October 19th, 2019.

Espmark, Å (2019). What should keep RAS farmers up at night? DNB Market, Oslo, October 21st, 2019.

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Karlsen C., et al (2019). Skin function and development in Atlantic salmon post-smolt after seawater transfer. Mucosal Health in Aquaculture 2019, Oslo, September 11-13th, 2019.

Karlsen C., et al (2019). Produksjon av robust smolt og overføring til sjø – hva kan det bety for lukkede anlegg? Fagseminar Nærings og Fiskeridepartementet, Oslo, October 29th, 2019.

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Floating semi-closed containment system Certus by FiiZK at Cermaq's facility at Horsvågen. Photo: Kjell Fredriksen

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Sundell, K.S. and Sundh, H. (2019). Functional Characterization of The Skin Barrier of Rainbow Trout and Healing of a Superficial Wound. MHA, Oslo 2019.

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Lerøy, H. (2019). Parr-smolt transformation in diploid and triploid Salmo salar and Salmo trutta hybrids. Master thesis, University of Bergen, Norway.

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Simopoulou N. (2019). Functional Characterization of The Skin Barrier of Atlantic Wolffish (Anarhichas Lupus) and Rainbow Trout (Oncorhynchus Mykiss). Master Thesis, University of Gothenburg.

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