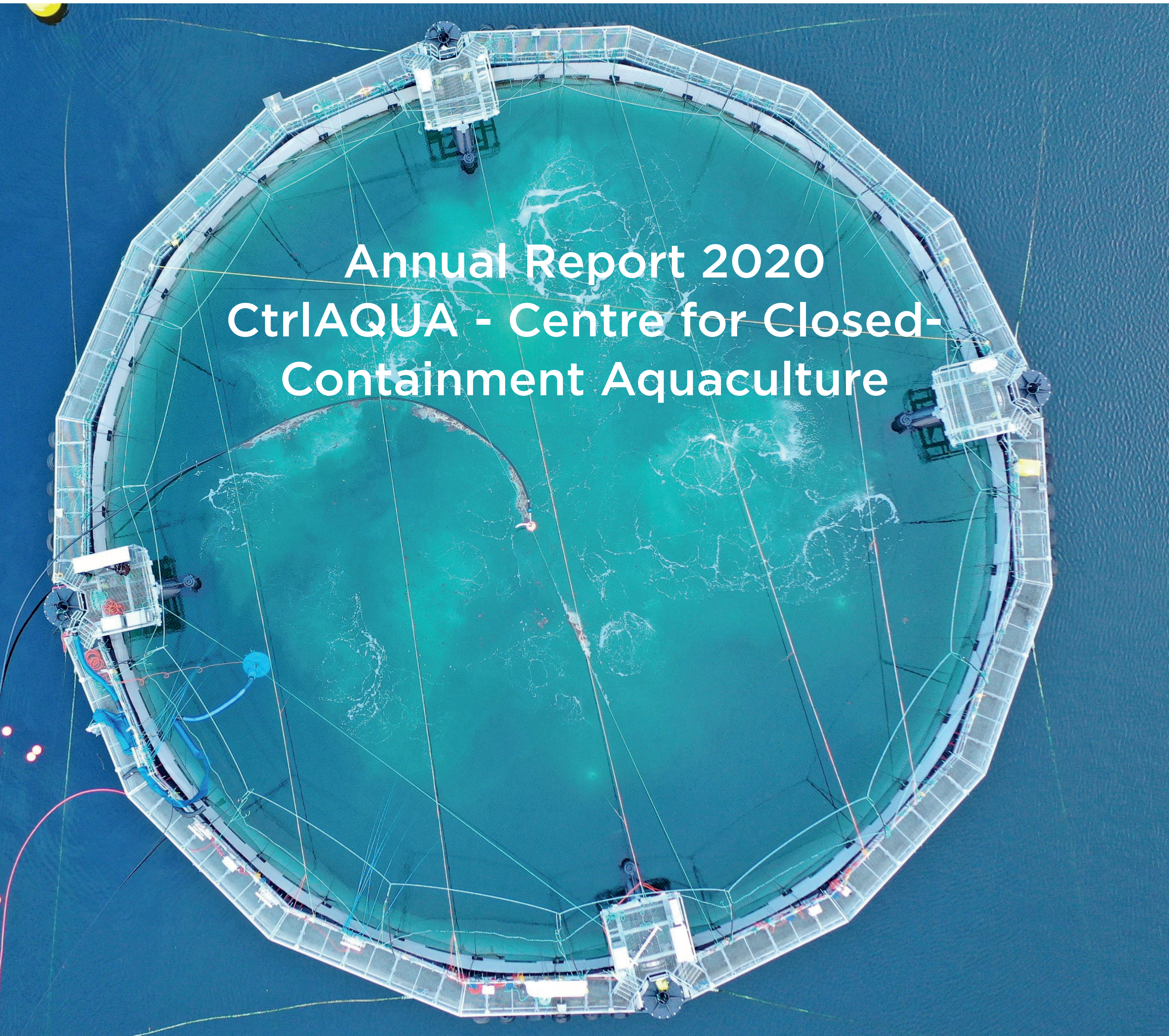
CtrlAQUA



Annual Report 2020
CtrlAQUA - Centre for Closed-Containment Aquaculture

sfi Centre for Research-based Innovation

The Research Council of Norway

Picture above:
The Annual Report 2019 front page was an illustration of FishGLOBE. Here is a real life photo from 2020, of FishGLOBE producing post-smolts in Lysefjorden. Photo: ©FishGLOBE.

Front page picture:
Direct overhead aerial of Cermaqs S-CCS facility in Canada. Photo: ©Sam Chen/Cermaq

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CONTENT

1 OVERALL PROGRESS AND SUMMARY FOR 2020

CtrlAQUA SFI was kicked off in the spring of 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 be commercially available. This last point is now the case for many of the systems used by centre partners, including for some of the partners using semi-closed systems.

Even though CtrlAQUA is in continuous progress with the innovations listed in the centre plan, there are still some bottlenecks left before we can say that the systems are fully developed to fulfil sustainability goals and for some systems, also full commercialization. In the annual report for 2020 we focus on these issues with two articles. One article is addressing the development of semi-closed systems, exemplified with Cermaq using the semi-closed system Certus. In the centre we have been able to follow fish in several semi-closed systems and we have shown that fish perform well and have good welfare both in the systems and after they are transferred to open net pens**.** However, the regulatory frameworks for the semi-closed systems are now preventing them from being fully economically sustainable. CtrlAQUA has the possibility to use the knowledge from the centre to guide the regulations in the direction of favouring the use of semi-closed systems. In the second article, Frederic Gaumet in Krüger Kaldnes is interviewed about their contribution in making the RAS systems more energy efficient, by e.g., increasing the CO_2 stripping capacity, but at the same time keeping the systems as cost effective as possible. The energy use in RAS is one factor that prevents the systems from being fully sustainable.

The year 2020 will for most people, including CtrlAQUA partners, be remembered for the Covid-19 pandemic. Naturally, this has also affected the progress in the centre. The restrictions of visiting the partner's facilities and closed research labs and infrastructure have caused delays in many projects. Also, students are delayed for the same reason. Therefore, some activities planned for 2020 have been moved to 2021. Finally, the planned annual meeting in Haugesund in May 2020 was replaced by a digital annual meeting. A very visible outcome was the alternative front page of the annual plan 2021 (Figure 1.1), that came in place instead of the group photo from the annual meeting that normally covers the annual plans.

Despite Covid-19, there are many interesting ongoing research activities in the centre that will be dealt with in this annual report. The centre administration has identified nine centre innovations that are implemented by the user partners. Examples of these are smolt protocols, light intensities in tanks, CFD modelling in tanks for optimal design, disinfection protocols, and exercise of fish with optimal velocity.

The introduction of H_2S activities and the lab methodology for analysing H_2S were among the new activities in the annual plan for 2020. Also, the use of UV for eliminating defined viruses and bacteria that may enter the semi-closed system have been in focus, and effective doses have been identified. An interesting effect of Covid-19 and the prevention of visiting Certus' semi-closed containment system for welfare scoring, has been the use of machine learning by CreateView. Photos of fish have been used to teach the camera to detect different skin issues and have provided much information on fish welfare.

Figure 1.1. Annual Plan 2021 front page

The CtrlAQUA partners have encouraged thematic meetings where project results are presented. In 2020, project leaders and scientists provided an update on the monitoring of microparasites entering semi-closed containment systems. The monitoring has been ongoing since 2015. In addition, a literature review and partner survey aiming to define causes of nephrocalcinosis was presented to the partners. Nephrocalcinosis has most likely a multifactorial cause, and the survey revealed that the condition can be detected in very small fish.

The centre has recruited many students, and by the end of 2020 we counted 11 PhD students and one Dr. philos candidate. So far, we have educated 36 MSc students. The students contribute to many of the centre results and dissemination activities. At the digital conference “Smolt production in the future” on 21st October 2020, nine CtrlAQUA presentations were held, where three were provided by our students.

We hope that you will enjoy the annual report 2020.

February 2021
Åsa Maria Espmark
Centre Director CtrlAQUA SFI

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

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 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 we manage sea lice and escapes. 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:

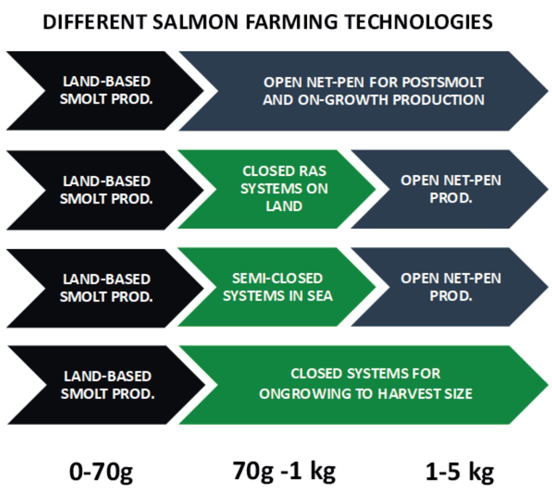


Figure 1.2. Different ways of producing Atlantic salmon: Closed-containment aquaculture systems.

"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 semi-closed containment systems (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 1.2). 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, since closed systems for strategic phases in salmon farming can contribute to the foreseen growth.

Some of the people working at Bremnes Seashore with Jarle Johansen (upper right) representing the future generation in fish farming. In photos: Upper left Thea Dolmen Heggdal, lower left Eldbjørg Strand, lower right Svein Olav Fjæra, Vidar Steinsbø and Øystein Staveland. Photos: Inger Lise Breivik/Bremnes Seashore.

Few lice, but major R&D efforts are still required regarding closed sea-based facilities

Article by Reidun Lilleholt Kraugerud

Cermaq has now started the third round of salmon production in closed-containment systems, without having to delouse.

Harald Takle, Cermaq.

In the neighbouring net pen, which has a traditional net system, they have had to delouse several times.

It is precisely the combination of a semi-closed containment system and an open net pen placed next to each other that makes Cermaq's semi-closed system, called Certus, a popular research object in CtrlAQUA. Nofima scientists and Cermaq have directly compared measurements from the two types of production, and obtained valuable information about the differences in growth, feed consumption, lice infestations and welfare. Harald Takle is Head of Marine Innovation and Development at the fish farming company called Cermaq, and he summarises the research results as follows:

"The most important sign of quality for Certus is that we have not seen any lice. The growth rate of the fish is also slightly better, even though Certus has a significantly higher density of fish. In addition, mortality rates are equally low in both facilities", says Takle.

He explains that the good growth rate in Certus is due to the absence of delousing, a slightly better average temperature, and a more stable water environment compared to an open net pen. In 2018, the first semi-closed containment system of 10,400 m^3 was established in Nordland, and a larger and improved version (15,000 m^3) was established in Canada in 2020. The technology provider and CtrlAQUA partner FiiZK has developed the containment system, with Cermaq as a very demanding client, according to Takle.

"We now have a promising technology that is in an early phase of development. If it is to be competitive in relation to RAS and open seabased net pens, we must continue to improve fish performance and reduce the level of cost", says Takle.

Bottleneck for increased production

He believes that the Norwegian aquaculture industry will experience a bottleneck in growth if initiatives regarding closed facilities at sea are not successful. "The most important thing about closed facilities at sea is to reduce the total strain caused by lice and increase the percentage of post-smolt in order to enable growth in exposed facilities and offshore. Exposed facilities require post-smolt to safeguard good fish welfare, at the same time as shortening the production cycle."

"As of now, the framework conditions for semi-closed facilities are not good enough. There is uncertainty regarding important regulatory factors, while we also lack sufficient documentation about the effects of semi-closed facilities. With only one closed containment system, it is difficult to get good quality documentation. Investment, therefore, carries a big risk. So for us, investment is currently on hold in Norway", says Takle.

Challenges that are crucial to solve

Cermaq summarises its foremost challenges with the words 'predictability' and 'cost-effectiveness': Cost-effective purification of intake water, sludge processing, oxygenation, as well as predictable framework conditions and the need for separate licensing schemes for closed facilities. He also calls for schemes that stimulate technology development and take into account the fact that closed facilities still have major R&D requirements in order for the technology to succeed.

In relation to these challenges, scientists at CtrlAQUA are working specifically on the purification of intake water. By purifying the intake water, the fish farmer can freely move the fish to other containment facilities without applying for an exemption. This is very important for a cost-effective production of post-smolt to exposed facilities and offshore production.

Nofima is working on the purification of intake water and has found that using UV can remove up to 99 percent of some of the most common microparasites.

Fantastic collaboration

During the development and testing of Certus, a number of companies and research institutes in the CtrlAQUA centre have contributed. Takle is eager to highlight why it is important to be part of this centre:

"It is a fantastic meeting place, melting pot and channel for exchanging information, where one can discuss current and future challenges and address them together. With all the partners who are part of a centre for research-based innovation, one gets a broad experience base from the industry combined with a pool of scientists, all of whom meet at topical and annual meetings at the centre. We take part in very good, open discussions", says Takle.

Certus, which means 'safe net pen' is also in place in Canada (pictured). Version 2 of Certus is based on the experience gained and research conducted on version 1, which is in operat.ion in Nordland, Norway. Photo: ©Sam Chen/Cermaq.

The fish are monitored by a camera from CreateView. "The monitoring has really been a gift during these Covid times. When scientists are unable to get to the net pens and see what is happening, we can still follow up on the trials via digital tools", says Takle. Photo: ©CreateView.

2 RESEARCH PLAN/STRATEGY

The Centre for research-based innovation in closed-containment aquaculture, CtrlAQUA, commenced operations in April 2015. The objectives of the Research Council of Norway (RCN) in running the SFI-program are fourfold: 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 the 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*

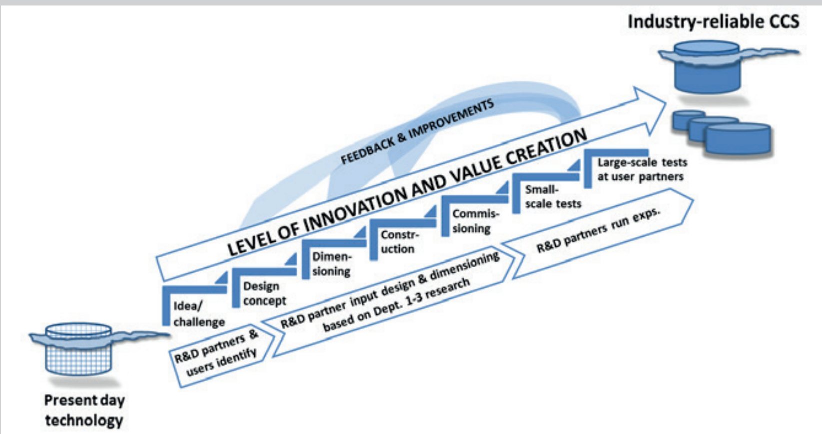


Figure 2.1. Innovation process in CtrlAQUA, from present day cage technology, to establishment of industry-reliable closed-containment systems, either in-sea closed tanks or land-based RAS. Exps. = experiments.

CreateView`s camera technology for monitoring fish welfare. Photo: ©CreateView.

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 midway 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 2020, the Board met for two digital meetings. The Board from 2020 consisted of the following elected members:

- Trond Rosten, Mowi, Chairperson of the CtrlAQUA Board from 17th June
- Harald Takle, Cermaq, Chairperson of the CtrlAQUA Board until 17th June, Board Member afterwards
- Hans Kleivdal, NORCE, Board Member
- Hilde Toften, Nofima, Board Member and representing the host institution
- Frederic Gaumet, Krüger Kaldnes, Board Member from 17th June
- Rolf Hetlelid-Olsen, PHARMAQ, Board Member from 17th June
- Siri Vike, PHARMAQ Analytiq, Board Member until 17th June
- Øyvind Oaland, Mowi, Board Member until 17th June
- Arne Henry Nilsen, Aquafarm Equipment, Board Member until 17th June

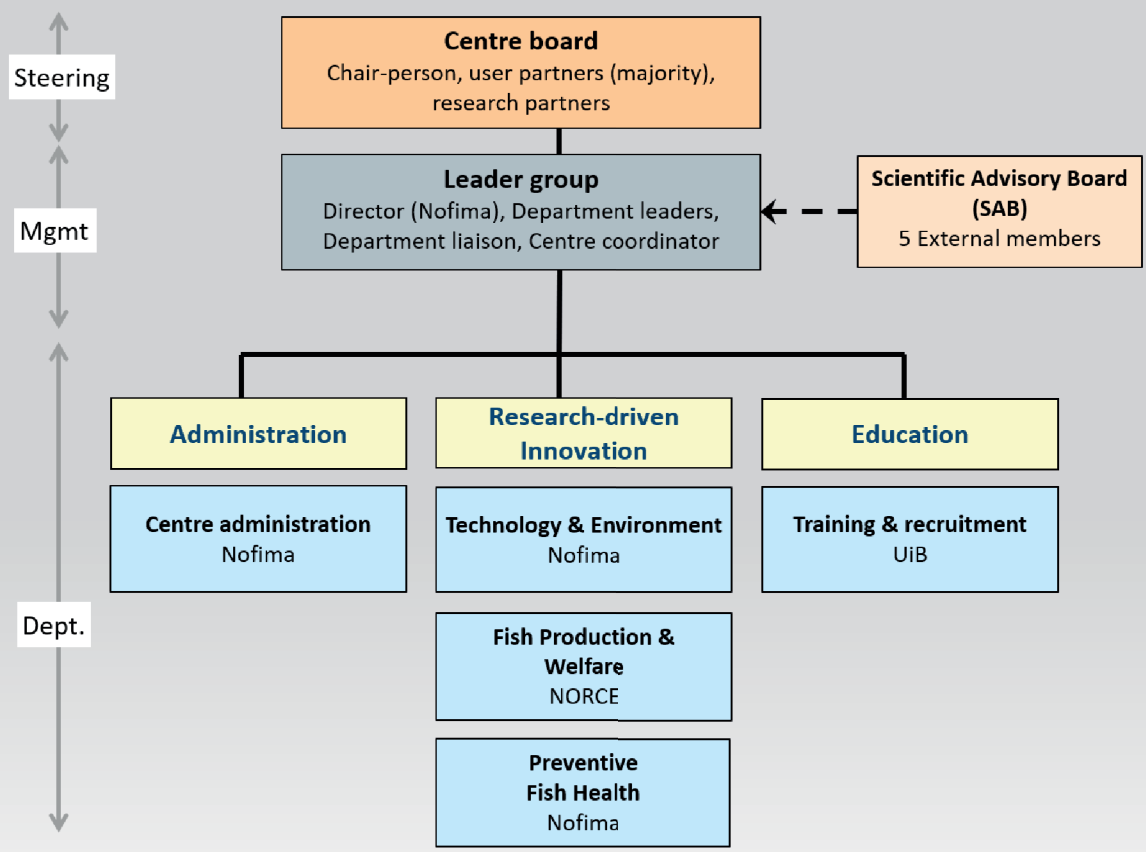


Figure 3.1. Organizational structure of CtrlAQUA.

The CtrlAQUA leader group at Teams meeting: Naouel Gharbi, Sigurd Stefansson, Kasper Thøring Juul-Dam, Tom-Ole Nilsen, Jelena Kolarevic, Åsa Espmark and Lill-Heidi Johansen.

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 management are managed in Dept. Training & Recruitment. The Dept. of Liaison ensures smooth collaboration between departments and identifies subprojects and user partners for projects.

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

In CtrlAQUA there has been a 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). 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 2020

Trond Rosten
MOWI
Chairperson of the CtrlAQUA Board from 17th June

Harald Takle
Cermaq
Chairperson of the CtrlAQUA Board until 17th June, Board Member afterwards

Hans Kleivdal
NORCE
Board Member

Hilde Toften
Nofima
Board Member and representing the host institution

Frederic Gaumet
Krüger Kaldnes
Board Member from 17th June

Rolf Hetlelid-Olsen
PHARMAQ
Board Member from 17th June

Siri Vike
PHARMAQ Analytiq
Board Member until 17th June

Øyvind Oaland
Mowi
Board Member until 17th June

PARTNERS

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

R&D PARTNERS

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

Cermaq is one of the world's leading fish farming companies, with operations in Norway, Chile and Canada, supplying Atlantic salmon, Coho and trout to the global market. Cermaq's vision is to be the preferred global supplier of sustainable salmon. Cermaq Norway produces Atlantic salmon with operations in Nordland (22 licenses) and in Finnmark (27 licenses) with processing plants in both regions. The four freshwater sites are all located in Nordland. Cermaq sets its operations in the context of the UN Sustainable Development goals, and Cermaq is a key driver for research and innovation as well as transparency and partnerships. Fundamental to this work is Cermaq Norway's preventative health strategy for fish. This means using the knowledge of the salmon's biology, physiology, and environment, to achieve the best fit between production, fish welfare and growth. In CtrlAQUA, Cermaq Norway is represented by Head of Seawater Innovation and Development, 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 about. The globe is built in polyethylene which is the preferred material to use at sea. The polyethylene is a thermoplastic which works well with waves and is wellsuited for fishfarming. The clue to hold the structure/form and make it strong and stiff, is to use the inlet and outlet pipes. To be able to use this material it holds to patents. The company was established in 2013, but the development of closed aquaculture technology has roots back to the late 80's. The company is located in Forsand, Norway. The vision of FishGLOBE is to develop new cost-effective solutions that makes it possible for the aquaculture industry to expand. The business concept is to offer a solution to the salmon farmers that make farming more profitable, more sustainable and with higher fish welfare. FishGLOBE entered CtrlAQUA in November 2015 and is represented by manager Arne Berge.

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

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

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

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

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

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 a 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.

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, optimisation, budgeting, analysis and digitisation of production management) and technical tarpaulins (lice skirts, treatment tarps, freshwater tarps, disinfections tarps).

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

CreateView is a technology company based in Molde. CreateView develops and sells welfare sensors that monitor lice, detects fish health status and measures biomass in fish farms to optimize production. The sensors are based on artificial intelligence, data acquisition and camera technology. This allows realtime 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 vaccines and innovation for aquaculture and part of Zoetis, the world leader in animal health. The company provides environmentally sound, safe and efficacious health products to the global aquaculture industry through targeted research and the commitment of dedicated people. The vaccines are manufactured in state-of-the-art production facilities in Overhalla and Oslo, Norway. Administration and research and development activities are based in Oslo with subsidiaries in Norway, Chile, United Kingdom, Vietnam and Spain. PHARMAQ has approximately 300 employees. The company's products are marketed in Europe, North and South America, and Asia. In CtrlAQUA, PHARMAQ is represented by Nils Steine, Mari Solheim, Øyvind Tønnesen, Rolf Hetlelid Olsen and Karine Lindmo Yttredal and will contribute with expertise and vaccine development in Department Preventive Fish Health.

Atlantium is a leading global water treatment company providing reliable water disinfection solutions for the aquaculture industry through the propriety Hydro-Optic™ disinfection (HOD) UV technology. Major industry players - producers, engineering firms and research institutes - around the world rely on Atlantium's proven HOD UV technology when designing solutions for complete sustained microbial inactivation, safeguarding facilities from otherwise detrimental diseases. Atlantium's HOD UV 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 UV technology employs a dedicated output sensor per lamp as well as an integrated UVT sensor for realtime accurate UV dose monitoring. The core of the HOD UV 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 UV system creates a uniform UV dose distribution that reaches and inactivates microorganisms and is the key to attaining sustainable and reliable water biosecurity.

Working for cutting energy use in a growing industry

Article by Reidun Lilleholt Kraugerud

With the pace of new land-based salmon facilities being build, one could get the impression that there are few challenges remaining with RAS technology. However, the increasing number and size of plants are incentives for solving sustainability challenges for the technology provider Krüger Kaldnes.

Frederic Gaumet, Krüger Kaldnes.

Recirculating aquaculture systems (RAS) has been around for decades.

"For salmon in Norway, it took off only 10-12 years ago, and now almost all new projects for smolts and post-smolts in Norway are RAS based", says Dr Frederic Gaumet, Business Development Manager in aquaculture for Krüger Kaldnes.

The development is driven towards bigger facilities, bigger tanks and bigger fish. With that, new challenges are constantly emerging. Krüger Kaldnes is an active partner that is involved in several research topics in CtrlAQUA, and that gave rise to a business PhD within biofilter technology in 2021. However, increased energy efficiency is a necessary step towards a fully sustainable industry, and in their partnership with CtrlAQUA, they address this issue:

"When we push the limits, the interface of RAS technology with environment is an inevitable topic. It is time to do something about energy savings for it to be truly sustainable", says Gaumet.

What can be done

Energy is the second largest cost in a RAS facility surpassed only by feed. Much energy is used on pumping water. In addition, energy is wasted when removing carbon dioxide (CO_2) from the used water, which is done in a carbon dioxide degassing unit. There has been little development with reducing energy use in these units through the decades of RAS, and it is now a goal of CtrlAQUA.

Today, CO_2 is removed by using gas exchange chambers where water is put into contact with large quantities of air, so CO_2 can transfer from the water to the air phase. This air is sent out of the building using electric fans. Here, Krüger Kaldnes see great opportunities to improve control over energy. Keywords are pH buffer management and fan automation.

Develops a carbonate toolbox

To get to the point where energy is saved, there is a need for a model - a toolbox - to manage the carbonate efficiently:

"Some of the systems are running in brackish water. When playing with salinity, you challenge the balance in the system, so everything needs to be controlled. To gain this control, we have been working closely with scientists in Nofima and discussing the need for estimating CO_2 development based on biomass, feed, pH and other factors" says Gaumet.

Nofima and Krüger Kaldnes are developing the toolbox. The scientists have already done the theoretical work on potential energy savings and carbonate modelling. Now, these

In the CtrlAQUA centre, Krüger Kaldnes is a very active partner that involves the employees in the research process. Photo: Krüger Kaldnes.

models will be validated in practice to make a digital carbonate toolbox to be used in energy management for salmon farmers with RAS.

Can save 20 percent energy

Gaumet think there is probably room for saving 15-20% of the energy used in a RAS facility in its entirety, by optimizing the use of energy sources, consumption and by recovering energy from water and air.

“We need to see the system as a whole loop, if we shall succeed in saving energy”, says Gaumet.

Need RAS competence in the industry

To operate and develop these systems further, the industry needs more trained people, as these are big and complex systems.

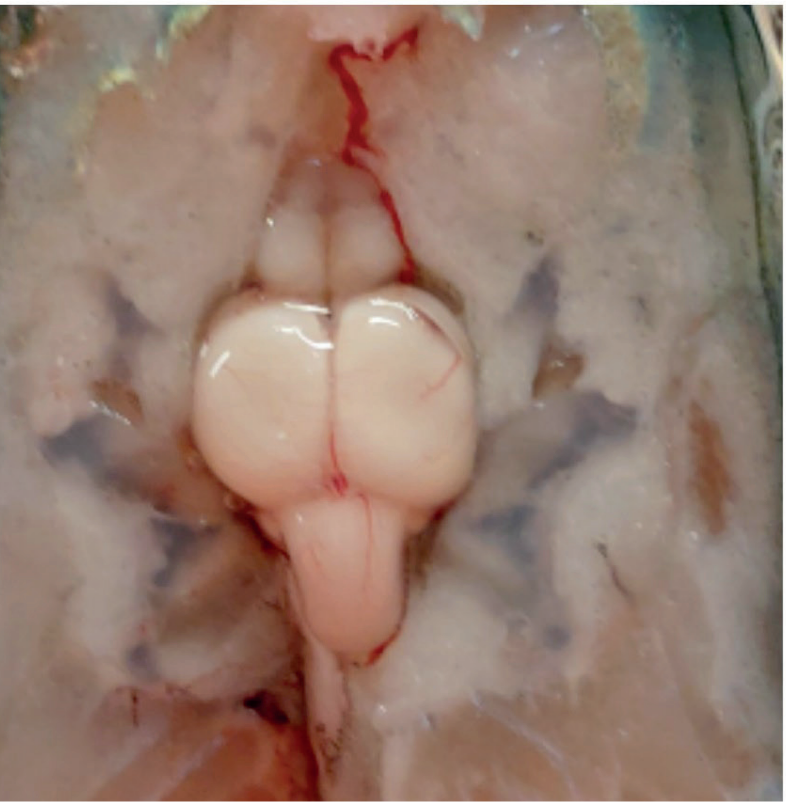
“That’s why we are so eager to use CtrlAQUA as an arena to increase the knowledge of our employees at all levels. We have the great advantage of participating in the discussions with the professionals in the CtrlAQUA consortium and combining the knowledge with the work we do. What makes this consortium very rich, is that there is very good representation of the leading companies in the industry, and research institutes that have RAS test facilities”, says Gaumet.

Gaumet states that they do not have a fixed product. It is a dynamic process where they keep learning how to optimize:

“We can really approach a lot of topics, and the results can be used directly by the industry”.

In the next facility that Krüger Kaldnes designs, Gaumet is certain that the latest knowledge from CtrlAQUA will be included and have an impact.

Read about the industry PhD from Krüger Kaldnes/ Nofima/NTNU: https://www.kyst.no/article/doktorgrad-viser-oppsiktsvekkende-resultater/



In the upper left and the bottom pictures Naouel Gharbi, Valentina Tronci and Marius Takvam from NORCE are sampling gills, brain, head, kidney and serum in order to analyze stress response and robustness in salmon. Photos: Naouel Gharbi/NORCE.
In the upper right corner, Pradeep Lal, also NORCE, is doing analysis in the lab. In 2020, he became the new R&D project leader in OPTIMIZE. Photo: Andreas R. Graven/NORCE.

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 CCS. Production of large smolt and post-smolts in closed rearing systems provide a high degree of control with environmental factors. To this end, the department's activities aim to promote optimal use of environmental factors to promote productivity and welfare while minimizing potential adverse effects under intensive post-smolt rearing conditions in RAS and semi-closed systems (S-CCS).

Light intensity and spectrum are influencing physiological aspects, such as growth, reproduction behaviour, smolt development and stress responses in fish. Changes in water quality can have profound effect on the transmission of light in RAS, especially in deep tanks. By measuring absorbance and calculating transmission in the RAS water (that was not ozonated) we extrapolated light intensities at different depths. With relatively clean water at the start of the experiment, only about 1.6% of the light from the surface would reach a depth of 3 meters. As visibility decreased during the experiment, transmission of light decreased by a factor of 16 to a mere 0.1% of surface light intensity at 3 meters depth. The most interesting finding was the selective absorption of blue light. Absorbance of blue light (~450 nm) was significantly higher than the absorption of green or red light ($p < 0.0001$) (Figure 4.1). Using the absorbance curves determined in our experiment, green and red light showed the best penetration in RAS water, with about 125 x more green (551 nm) and about 150 x more red (650 nm) light reaching a depth of 3 meters, compared to blue light (449 nm). We conclude that RAS water creates a steep light gradient in RAS tanks, limiting the efficacy of surface illumination alone in deep tanks. Furthermore, the lower transmission of blue light might hamper the use of light optimized for "ocean use", as they are heavy in the blue spectrum to maximize light penetration in clean water. To understand the consequences of these shifts under commercially relevant conditions, more research on changes in light quality and quantity in deep tanks is required.

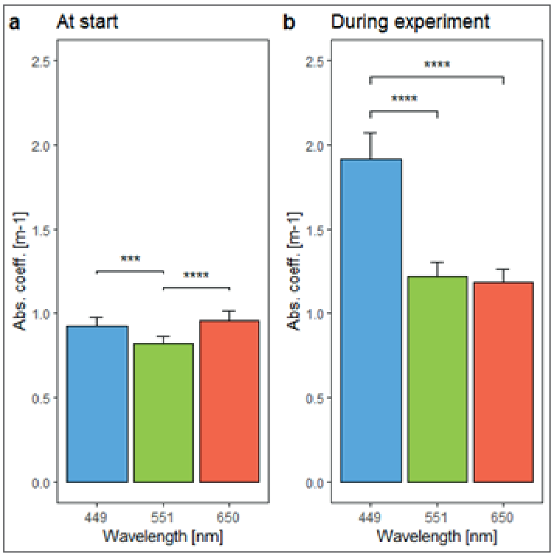


Figure 4.1. Differences in the absorbance of different wavelengths in RAS. Once feeding has started, the absorbance characteristics of the water changed, increasing the absorption of blue light and thereby reducing its transmission in the water of the tanks.

Benchmarking of production data from six generations salmon post-smolts performance in semi-closed systems and open reference cages demonstrate consistent higher specific growth rate (SGR), lower mortality and sea lice infestation during the post-smolt phase (size 100-800 grams) in S-CCS compared to the fish in reference cages. The good performance of post-smolt in S-CCS is reflected in lower baseline levels of the stress hormone cortisol and when subjected to an acute stress test, post-smolts in S-CCS elicit a higher cortisol response than fish in the open references cage, suggesting low chronic stress and more robust response to acute stressors of post-smolts in S-CSS. Notably, the increased performance and robustness of post-smolts in S-CCS appears to persist following transfer to grow out phase (0.8-5 kg) as judged by weight gain and sea lice infestation (Figure 4.2).

CtrlAQUA has increased its focus on systematically reviewing published literature and summarizing CtrlAQUA research results with the intent to better understand how environmental factors can be used to increase productivity and how correct application of environmental factors such as temperature, water velocity, salinity and photoperiod may contribute to mitigate adverse impacts of intensive production. Applications of sustained aerobic swimming is a promising approach to produce more robust fish. Swimming speeds are reported to give the best growth of salmonids in the range of 0.5-1.8 body lengths per second (bl^{s-1}). In cultured salmon juveniles and smolts the optimum sustained swimming speeds for increased growth, good welfare and disease resistance appears to be between 1-1.5 bl^{s-1}. Post-smolts in RAS display almost a linear correlation between weight gain and water velocity, and swimming speeds between 1-1.8 bl^{s-1} is considered beneficial but should not exceed 1.8 bl^{s-1} due to increased negative welfare effects such as gill, skin and fin damage. Differences in swimming capacity between individual fish is not uncommon and caution must be exercised when adjusting the swimming speed. For instance, the best swimming capacity of Atlantic salmon up to 500 grams coincides with water temperatures between 13 and 18 °C. Thus, sustained increase in swimming speed above 1.5 bl^{s-1} at the low and high end of this temperature range in S-CCS, particularly under full strength seawater, should be utilized with caution. Increased sustained swimming speed between 0.5-1.8 bl^{s-1} can stimulate appetite and feed intake without compromising growth rate, but also have negative effect on productivity through a progressively reduced feed conversion ratio (FCR) with increasing swimming speeds. One thus needs to ensure that the improved growth gained by applying higher swimming speeds do not lower the economic yield through increased FCR. Interestingly,

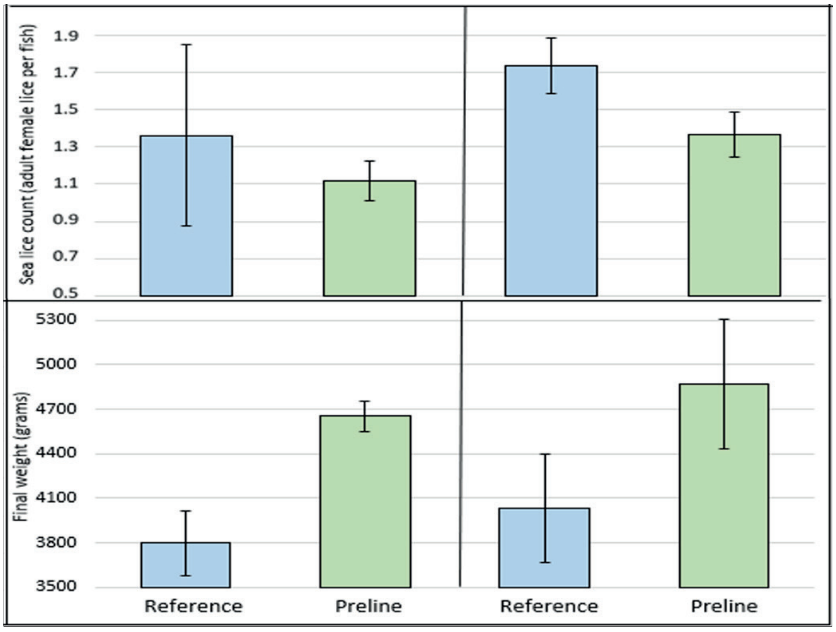


Figure 4.2. Smolts were stocked in Preline S-CCS during spring (left panels) and fall (right panels) and kept until 800 grams. Sea lice infestation (upper panels) and weight gain (lower panels) in post-smolts transferred from the Preline S-CCS to open sea cages (Tarald K. Øvrebø, Master thesis 2020).

one mitigating effect of increased swimming speeds is that Atlantic salmon exposed to swimming speeds above 1.5 bl^{s-1} display reduced proportion of precocious maturation compared to fish kept under 0.5 bl^{s-1}. If this holds true for post-smolt production in S-CCS and RAS, attentive use of sustained swimming speeds may prove helpful in reducing incidents with early post-smolt maturation in RAS.

Water temperature governs the salmon's physiology and rearing temperatures between 12 and 16 °C together with constant light (24 hours light) ensure sufficient post-smolt growth in RAS and S-CCS. However, intensive production regime in RAS often leads to unexpected adverse effects, one example is increased proportions of early puberty in males (Figure 4.3). Both literature surveys and own research suggest that large smolts and posts-smolts up to 500 grams reared above 13 °C will increase the risk of early maturation. When also reared under constant light, the combination of high temperature and light may result in up to 70% of the males maturing within a period of three months. This increase in the proportion appears when the males reach a size of 160 grams. Moreover, studies have shown that applying a 4-hour night and 20-hour light day length reduce the proportion of post-smolt maturation among males reared between 14-16 °C. To minimize the risk of early puberty development among male post-smolts under intensive rearing in RAS one may therefore consider keeping the temperature below 12,5 °C and apply a daylength of 20 hours light and 4 hours darkness. Especially when the post-smolts are getting close to 150 grams in size. Ensuring swimming speeds above 1.5 bl^{s-1} may also help reducing maturation.

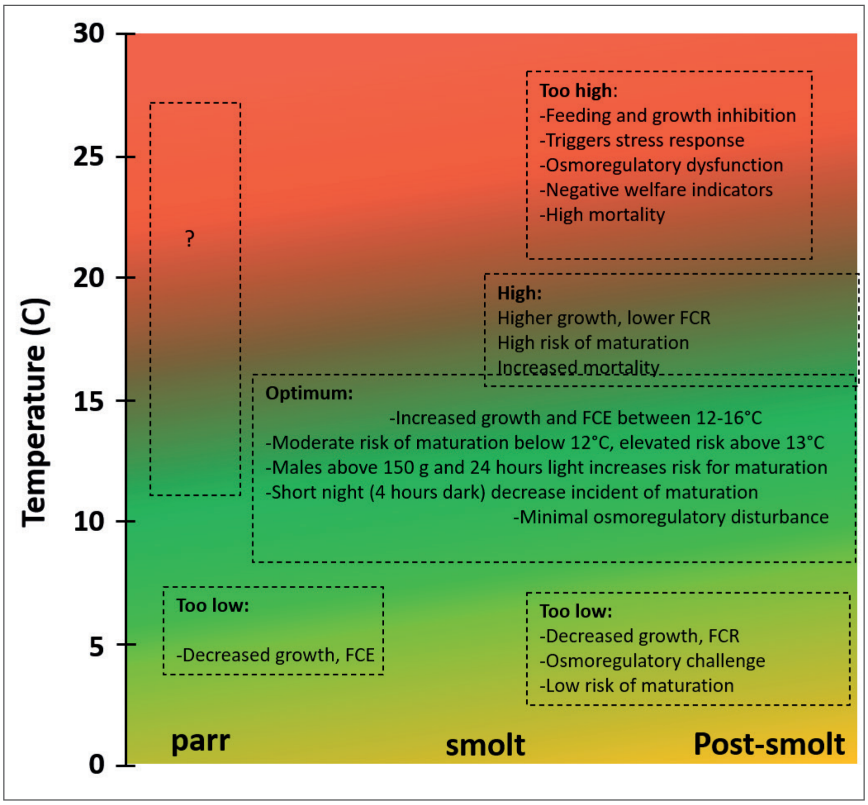
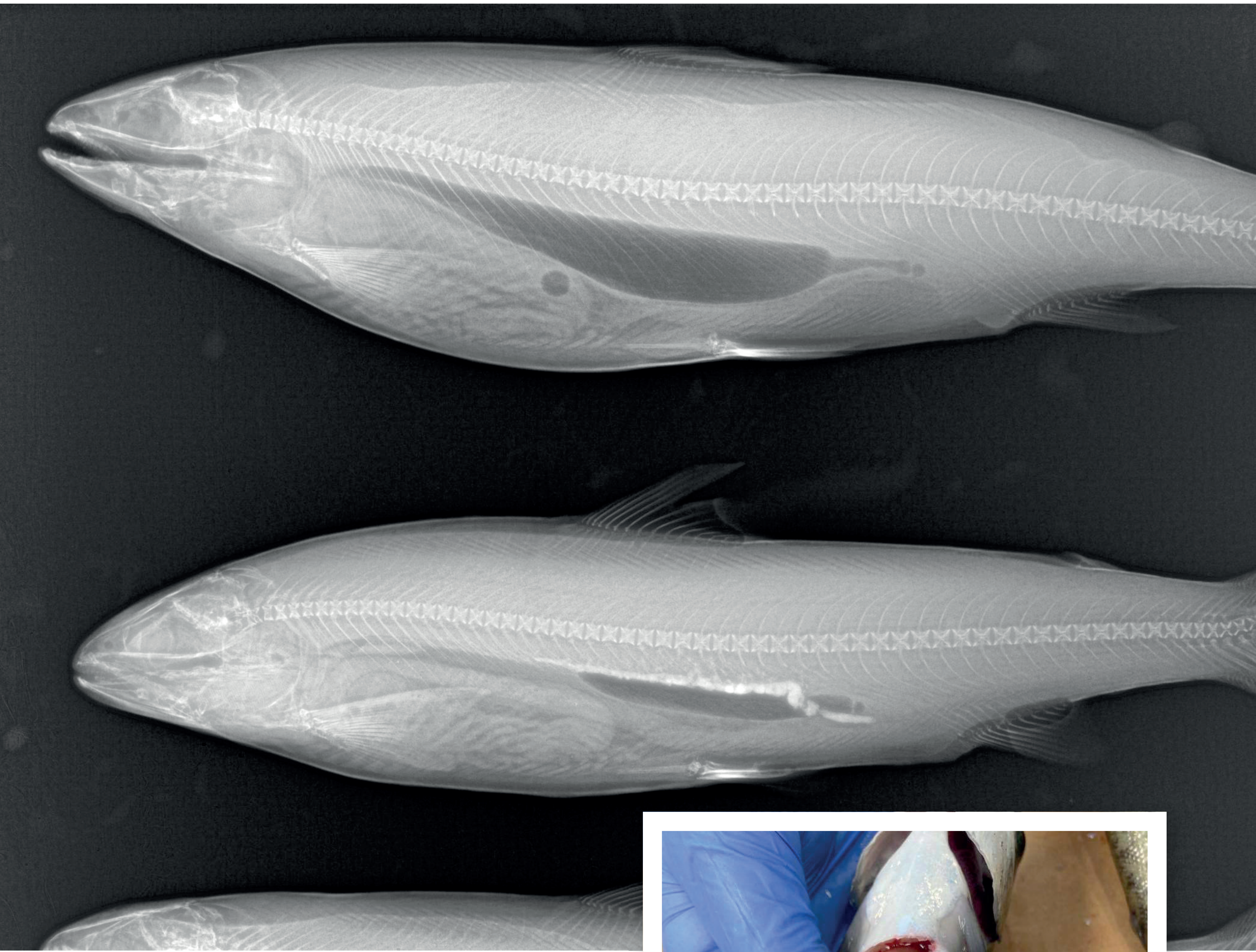


Figure 4.3. Overview of adverse effects of rearing juvenile parr, smolt and post-smolts under temperature condition only optimal for growth. Details on how environmental factors (temperature, photoperiod, swimming speed) can be adopted to mitigate and minimize risks of temperature on early puberty is described in the main text.



The upper fish is healthy while nephrocalcinosis can be seen in the center of the lower one. Photo: Svein Alexandersen/ Pharmaq Analytiq.

Nephrocalcinosis can be seen as the white lines on the left side of the fish: Photo: Inger Lise Breivik/Bremnes Seashore.

DEPARTMENT 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 (CCS/S-CCS). This may be obtained by different measures that are the focus of the department`s projects.

A major step towards successful production of Atlantic salmon in CCS and S-CCS will be a comprehensive study of the diversity, prevalence and load of microparasites (viruses, bacteria, protozoan parasites, and fungi) in comparison with existing knowledge from open production systems. Another important aspect is the different introduction routes of these microparasites into S-CCS. These may include vertical/transgenerational transmission (from brood fish), horizontal transmission through intake water, and accidental introduction due to human activity. Since the start of CtrlAQUA, surveillance of pathogens has been performed in several production rounds, in different types of S-CCS. Smolts (from smolt production site) and post-smolts (from S-CCS) have been sampled and screened for presence of several microparasites known to be associated with disease problems in marine production of Atlantic salmon. Results show that several microparasites seem to be introduced into the S-CCS via smolts from the smolt production sites. The risk of introducing marine microparasites into S-CCS also seems to be related to the depth of the intake water. Furthermore, slow water exchange could result in an increased infection pressure within the S-CCS. Future production should focus on high smolt quality (e.g., smolt free for microparasites) for further posts-molt production in S-CCS. The water intake to S-CCS should, if possible, be below the planktonic layer and preferably below 30 meters.

Feed is an important factor for sustainable growth of the industry. In addition, we need to understand better how different feed components may affect epithelial barriers which in turn will influence resilience and survival. In 2020 we successfully performed a trial with fish given full marine- vs plantbased diets. Dietary effects on the intestine and skin will be investigated for the impact upon barrier function and immune competence during the end of the freshwater stage and during the first timeperiod after seawater transfer. Analysis will be performed in 2021, and the experiment is also used for a Master thesis.

While it is well established that microplastics are present in the environment, also in CCS/S-CCS, less is known regarding biological effects of these particles on tissue functions. We therefore assessed the impact of 1 µm PS microplastic particles on Atlantic salmon intestinal barrier and transporting functions during an acute exposure (90 min). The results showed that intestinal barrier and transporting functions are not negatively affected during an acute exposure. Future studies will assess the impact of longterm (months) exposure to microplastics on intestinal functions.

Assessment and prediction of post-smolt performance is of further relevance to optimize production. Utilizing sensors with artificial intelligence could provide continuous monitoring and welfare status reports without handling the fish manually. Based on images generated from user partner CreateView, observable features were used in the purpose of categorizing images into a proposed classification scheme of wounds, that could further train the system. To further verify the technology, a controlled trial that tests the resolution of sensorbased welfare scoring is planned for 2021.

Biosecurity measures have crucial roles in maintaining an ideal rearing environment in RAS. Disinfection ensures that pathogens are prevented from entering and proliferating in a RAS-unit. However, in many disinfection strategies the extent of their effects on fish health and welfare is fragmentary, and their efficiency to prevent pathogen proliferation following an entry or outbreak remains poorly documented. In an ozone experiment that ended in 2020 we revealed that the earlier identified threshold for ozone in post-smolt brackish water flowthrough system is applicable to RAS as supported by a suite of health and welfare indicators that collectively indicated minimal physiological perturbations. Moreover, temporal rather than treatment impacts provide strong evidence that post-smolts could mount robust adaptive physiological responses to continuous ozonation over time. Two papers from the project were published in 2020, including a summary of the survey on disinfection strategies in Norway and North America conducted in 2018.

One of the aims in 2020 has been to gain insight into causal factors behind nephrocalcinosis (NC) and the physiological mechanisms associated with this condition that has increased in severity the last years. We have performed one literature review and one survey within the consortium to get information about possible causes of NC. Eight partners participated in the survey which was based on a questionnaire followed by an interview. The partners were asked about own experiences with NC, thoughts about the causes, their experience from one defined fish group with NC, and to compare a NC group with a NC free group. The partners were also asked about factors that were not considered as risk factors from the literature survey, to be able to pick up unforeseen issues. The questions were grouped as 1) questions about the fish history; 2) rearing conditions; 3) water quality; 4) general considerations. As expected, there were no clear conclusions about cases of NC, and it is likely caused by several factors. Some general results were that it is first seen in very small fish (< 15 grams), it has increased in severity the last years, it is more common in brackish water, it occurs both in RAS and FT and it may be related to mineral composition in feed

Nofima scientist Carlo Lazado evaluates the gill health after ozone exposure. Photo: Joe Urrutia/©Nofima.

and choice of buffer. Finally, NC is not solely a CO_2 problem, which has been the hypothesis. In the search in grey and white literature CO_2 had been raised as a cause, together with sudden changes in water quality parameters, imbalance in minerals, and the combination with high densities and low water exchange.

To gain a better understanding of the physiological perturbations associated with NC we have also addressed normal physiology, as remarkably little knowledge about changes in kidney functions in smolts and early post-smolt during transition from freshwater to seawater exists. A preparatory increase in kidney Na, K-ATPase (Nka) enzyme activity takes place as part of the smoltification process. This occurs significantly later than the classical increase in gill Nka and suggest that Nka activity in the kidney requires more time to reach peak activity levels (see figure 4.4). Thus, there may be a risk of osmoregulatory dysfunction in smolts or post-smolts if they are prematurely transferred to higher salinities, which in turn may apply to other key transporters and therefore contribute to precipitation of salts in the kidney. Such osmoregulatory dysfunction may in turn affect the prevalence of NC, particularly since water quality may vary with respect to ion composition and high salt content of feed in modern RAS. This work was part of a Master thesis at the University of Bergen.

Gill related problems has increased in farmed Atlantic salmon in recent years. One bacterium, *Candidatus Branchiomonas cysticola,* which causes epitheliocystis in Atlantic salmon, is present in both fresh- and seawater. At the moment there are no genotyping tools available for studies of transmissions routes. An attempt to identify and partially characterize the genome of this bacterium will be done using material for Next generation sequencing technology (Illumina) as part of a PhD work. Several different approaches have been used to isolate DNA from gills of salmon infected with *Cand. B. cisticola,* identification and verification of genes from the bacterium is ongoing and several genes have been identified as putative housekeeping genes. Selected genes in large contigs/scaffolds will be identified as belonging to *Cand. B. cysticola* using *in situ* hybridization, a method that uses a labelled complementary DNA, RNA or modified nucleic acids strand to localize a specific DNA or RNA sequence in a portion or section of tissue. In addition, we are attempting to extract DNA from cysts cut from gill sections using laser dissection in cooperation with a researcher at the medical hospital in Bergen.

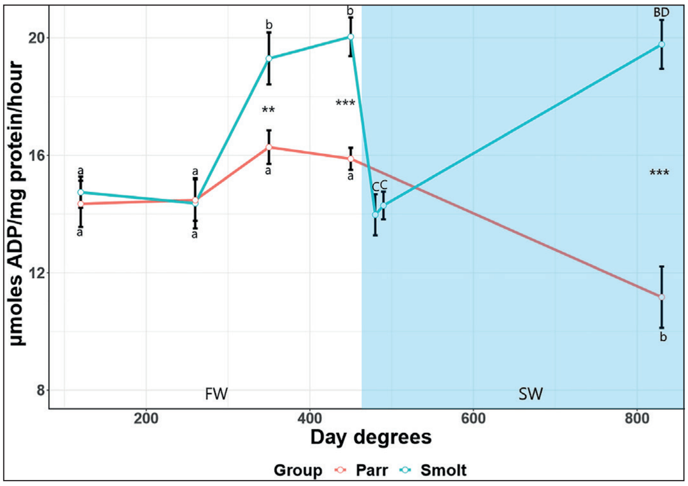


*Figure 4.4. Distal intestinal Na, K-ATPase (Nka) enzyme activity levels (µmoles ADP/mg protein/hour) of juvenile Atlantic salmon parr and smolts in freshwater (FW) and smolts after seawater (SW) transfer. Each data point = mean ± Standard Error of Mean (SEM), n=9-12. Small letters = significant differences between timepoints within the control group (parr) and experimental smolt group in FW (white area). Capital letters = differences within each group in SW (blue area). Significances following SW transfer is related to last timepoint in FW. * p<0,05; **p<0,01 and ***p<0,001 = significant differences between groups at each timepoint in both FW and SW. The control group remained in FW during the entire experiment.*

In 2020, we started working on a new activity on understanding and assessing the risks of hydrogen sulphide (H_2S) in RAS. Over the last years, a series of mass mortality events have been linked to H_2S, this being a problem especially for RAS operating with marine or brackish water. Subsequently, the uncertainty to causes and effects combined with the lack of systematic monitoring for H_2S affects the industry. The current hypothesis is that in the absence of nitrate, sulphate reducing bacteria will convert sulphate to H_2S when metabolizing residual organic matter in RAS. Although controlling nitrate levels in RAS seems a reasonable precaution to minimize the risk of H_2S events, it is not clear how the risk of residual organic matter and critical nitrate levels can be assessed.

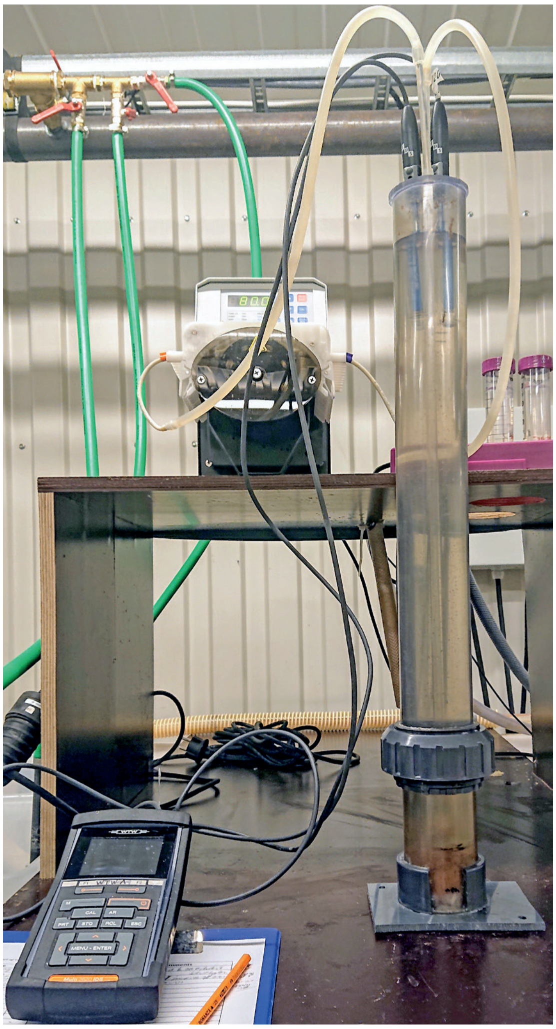


Figure 4.5. Testing a sediment reactor prototype. Photo: Andre Meriac/Nofima.

Our first step is the groundwork on the dynamics of H_2S generation in sediments or biofilms in brackish/marine RAS. The main goal is to devise guidelines for safe operation and the management of nitrate and organic matter in RAS and to identify risk factors and possible early warning markers for H_2S events. Pretrials on different setups for batch reactors and continuous sedimentchemostats (Figure 4.5) were started to investigate the stoichiometric relation of biodegradable organic matter and nitrate on reaction rates and the total potential for H_2S-generation in RAS. Based on our experience from 2020, the construction of a new set of sediment reactors has been started in December and will be used in experiments planned for 2021.

The work towards energy efficient RAS continued in 2020. The aim was to establish a universal unit that better describes the performance of a degassing unit. We used theoretical values of energy usage into the stripping efficiency adding the energy usage of used components (air blowers and pumps).

In the future close containment systems degassing units will most likely not run under full power at all times (overpowered degassing, black saturation curve in Figure 4.6, right). With that a significant amount of energy could be saved finding the most economic point in energy consumption (Effort in Figure 4.6) to possible degassing performance (Yield in Figure 4.6).

Good hydrodynamics in large RAS tanks is a very challenging task. It is necessary to optimize swimming speeds for the fish exercise, rapidly flush settleable solids for optimal self-cleaning, and to create homogeneous conditions with minimal gradients of dissolved O_2 and CO_2. In addition

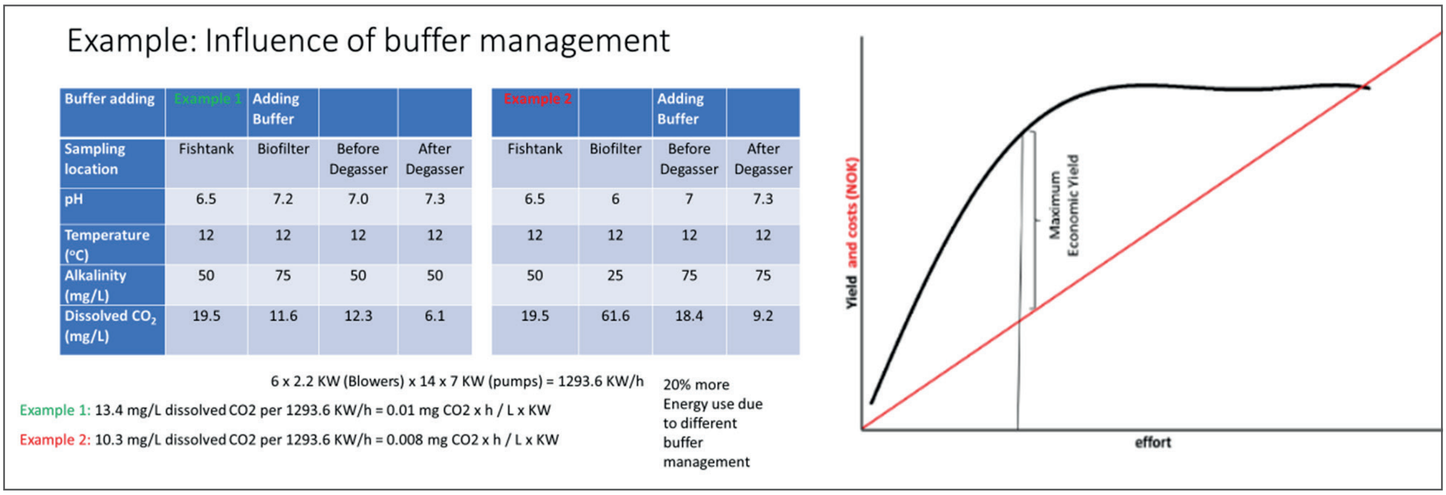


Figure 4.6. Simplified example of buffer management associated energy savings (left). The right picture shows a theoretical economical model to describe the most effective point of performance (yield) and energy use (effort) (Stiller K.T. 2020, unpublished).

to account for different tank geometry that can require different water flow injection and removal, it is also important to evaluate the effect that internal tank structures can have on tank hydrodynamics.

Our work so far shows that for small tanks (volume between 1-100 m^3), the best performance in circular tanks can be achieved by the setup with a single inlet column that will produce a triangular shaped current behaviour. The best performance in octagonal tanks of the same size can be achieved by the setup with a single inlet column, where the direction of the individual inlet column will be in the middle of the shorter wall.

For large tanks (volume between 100-1000 m^3), the best performance in circular tanks can be achieved by the setup with two inlet column nozzles positioned at different angle. This arrangement of nozzles provides better velocity profiling and mixing pattern in addition to self-cleaning of tanks.

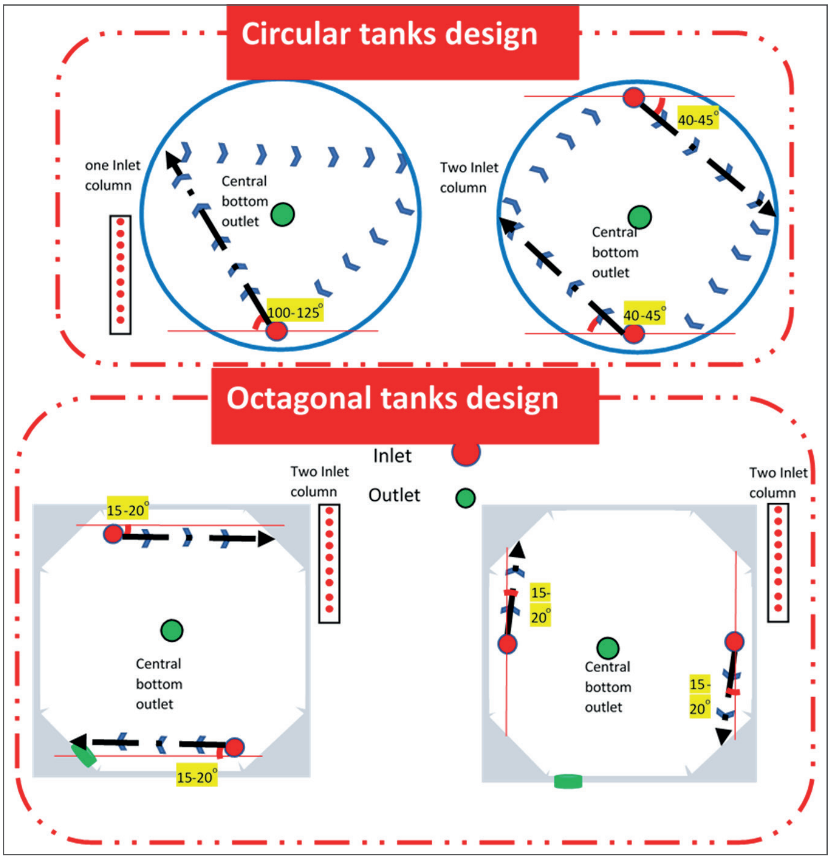


Figure 4.7. Recommended orientation of inlet column nozzles for circular tanks with one or two inlet pipes and octagonal tanks with two inlet pipes.

The best performance in octagonal tanks of the same size can be achieved by the setup with two inlet column nozzles at different angle; either the inlet column is located at the start of the long wall or the inlet column is placed between the long walls. Both designs, with their inlet placement and arrangement of nozzles develop better velocity profiling and mixing pattern across the large tanks with the addition of tank selfcleaning concept.

A key research line of the Department of technology and environment is semi-closed systems prototype development and testing. So far, all pilot S-CCS have been operating without treatment of intake water, however there is a need to evaluate the necessity and effect of such a treatment. Available intake water treatment solutions for these large flows (≥100 m^3/min) are scarce and require large investments. Among promising water treatment technologies, UV radiation has been more thoroughly tested namely on the necessary reduction equivalent UV doses to inactivate selected Atlantic salmon pathogens.

In 2020 we evaluated two different UV technologies, low-pressure (LP) and medium-pressure (MP) ultraviolet (UV) lamps, aiming to determine the minimum required UV dose to 99.9% inactivate specific Atlantic salmon pathogens: Infectious pancreatic necrosis virus (IPNV), ISAV, Moritella viscosa and Yersinia ruckeri. The results showed that the dose was pathogen specific and it differed between two tested technologies (Figure 4.8).

During 2020 we have developed and tested new membranes for CO_2 sensors, and continued the toxicity studies of such membranes towards biofilm formation. Focus has been on development of antifouling coating for sensors. We have fabricated polydimethysiloxane (PDMS)/ZnO-graphene oxide (GO) nanocomposite (PZGO) antifouling coatings. The coating was obtained directly by spin coating of PZGO/tetrahydrofuran suspension. Antifouling tests were performed using two marine microorganisms, the cyanobacterium

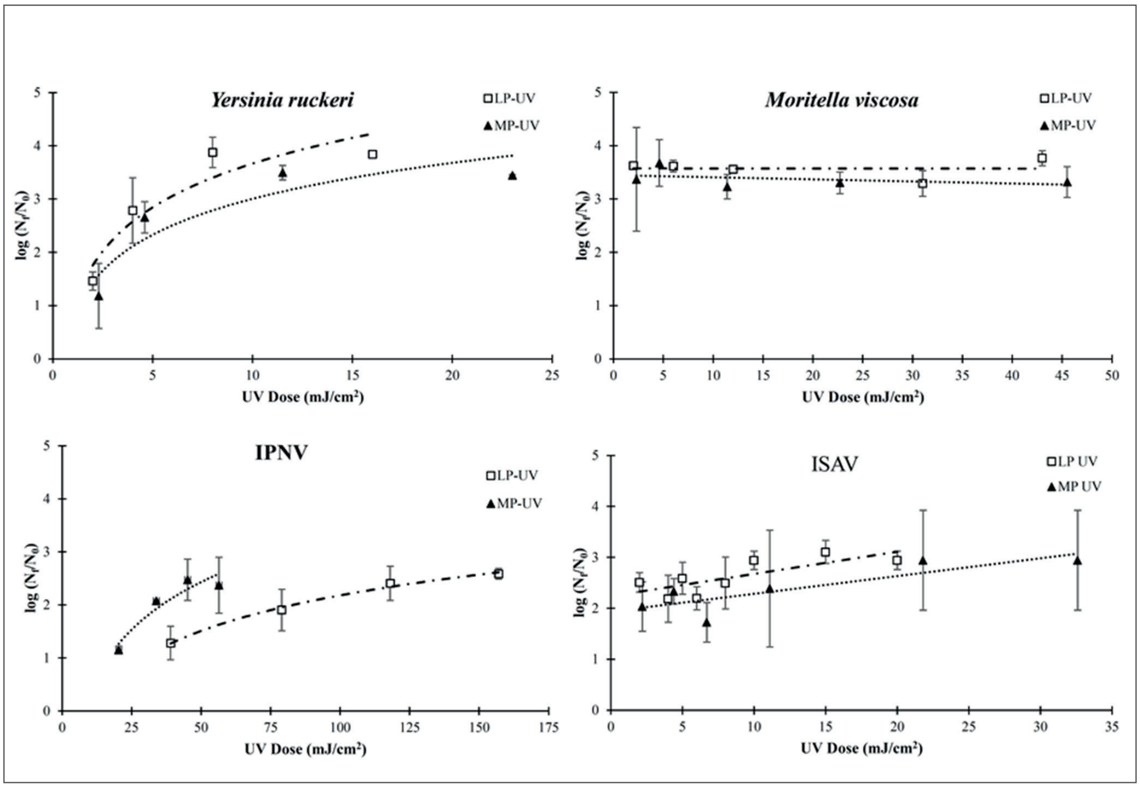


Figure 4.8. Dose response curve for inactivation of Yersinia, Moritella viscosa, IPNV and ISAV exposed to various doses of LP-UV and MP-UV irradiation.

Synechococcus sp. Strain PCC 7002 and the diatom Phaeodactylum tricornutum. The coatings were found to have promising antifouling properties. Antifouling property of the synthesized PZGO nanocomposite can be attributed to its high surface roughness and hydrophobicity due to excellent dispersion of ZnO-GO in PDMS matrix. Studies suggests a potential of PZGO nanocomposite for sensor's antifouling coating, which could contribute to improve sensor's durability relating to biofouling in the future. During 2020 the work on sensor system for zinc, copper and iron measurements with installation of sensor system in relevant water for monitoring over several weeks. Successfully online measurements were conducted during an experiment where feed was changed from commercial feed to a specialised RAS feed.

The activity on organic matter has during 2020 involved further development of analytical procedures and protocols for analysing and characterizing dissolved organic matter in CCS (S-CCS). A non-targeted approach using ultraperformance liquid chromatography coupled to a hybrid quadrupole-time of flight mass spectrometer was used to characterize compositional changes of low molecular weight (LMW) DOM in RAS, when operated under two different feed types. Over 1300 compounds were identified and the majority of those contained a CHON chemical group in their structure. Changes in the composition of LMW-DOM in RAS waters were observed when the standard feed was switched to RAS feed (Figure 4.9). The DOM with the use of standard feed, consisted mainly of lignin/CRAM-like, CHO and CHOS compounds, while the DOM that used RAS feed, was mainly composed by unsaturated hydrocarbons, CHNO and CHNOS compounds.

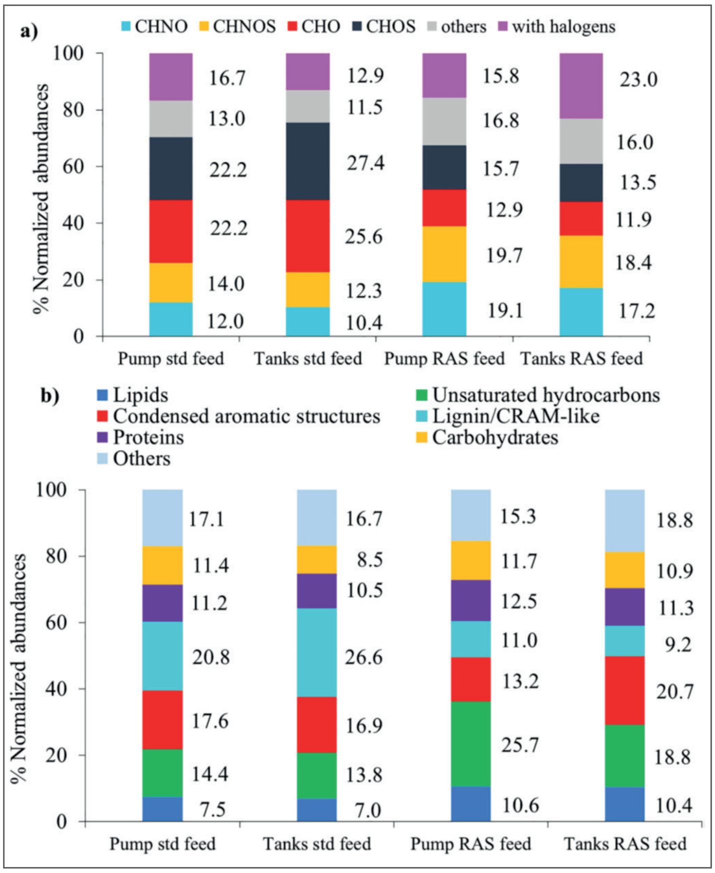


Figure 4.9. Comparison of the normalized abundances of LMW-DOM (in percentages) in the water after the water treatment processes (pump-sump) and in the tanks with standard feed at day 10 and with RAS feed at day 25: a) Groups: CHNO, CHNOS, CHO, CHOS, others, and with halogens; and b) Major biochemical classes (Aguilar-Alacon et al. 2020).

5 INTERNATIONAL COLLABORATION IN 2020

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

CtrlAQUA researchers are invited as speakers at different international scientific meetings, and we are often invited to host sessions at meetings. At the digital conference "Smolt production in the future", 21st October 2020, nine contributions from CtrlAQUA were given. Nofima is one of the organizers of this conference that is held every second year. This year the conference attracted around 300 international participants, and CtrlAQUA was heavily involved. Just before Covid-19 closed down most physical meetings, CtrlAQUA was invited to discuss land-based aquaculture in a panel debate organized by North Atlantic Seafood Forum. A total of 12 international leading industries were discussing future land-based aquaculture. After Covid-19 stopped all physical meetings, the European Aquaculture Society (EAS) launched several EAS talks. CtrlAQUA was one of the first presenting, and we were asked to give the talk "CtrlAQUA SFI, Contributions to Future Aquaculture".

Director of Research Chris Good collecting salmon tissues for analysis at the Conservation Fund Freshwater Institute in Shepherdstown, West Virginia, USA. Photo: Kata Sharrer/The Conservation Fund.

There are two international R&D partners in CtrlAQUA, Gothenburg University (UGOT) and The Conservation Fund Freshwater Institute (FI), USA. UGOT is represented in CtrlAQUA by Prof. Kristina Sundell and her research team. In 2020, UGOT contributed to important knowledge regarding skin and gut as barrier organs. They have also introduced an associated project on effects of microplastics in RAS. FI has continued the trials on optimal photoperiod and feed ration for posts-molts reared in RAS in their facilities and done research on optimal use of ozone in fresh water. They are also involved in ongoing work on optimal disinfection protocols. Furthermore, FI has participated in the CtrlAQUA project HYDRO, on hydrodynamic measurements and development of flow models for large fish tanks in closed systems.

In 2015 CtrlAQUA opened for associated projects. Associated projects need external funding and can in addition to CtrlAQUA partners involve partners that are not regular CtrlAQUA partners. We had four associated projects that involved international partners in 2020: 1) "Microplastics in the environment"

Master student Nefeli Simopoulou measures permeability in the skin at University of Gothenburg. Photo: SWEMARC, University of Gothenburg.

(lead by UGOT and funded by Swedish research council): an investigation into how microplastics affect fish and potential risks for the aquaculture industry; 2) "Post-smolt maturation" (lead by UiB, funded by RCN); 3) "Prevalence and consequences of hydrogen sulphide in land-based Atlantic salmon production" (lead by Nofima, funded by RCN): The primary objective is to create knowledge and advance the understanding of the risks and impacts of exogenous hydrogen sulphide (H_2S) to the physiology of Atlantic salmon in recirculating aquaculture; 4) "Water disinfection strategies to improve Atlantic salmon parr production in freshwater recirculating aquaculture systems" (Lead by Nofima, funded by RCN): The primary objective is to optimize existing disinfection protocols and develop new water disinfection strategies to control pathogens in Atlantic salmon freshwater RAS.

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 establish AQUAEXCEL, then secondly AquaExcel^{2020} and now the newly started AQUAEXCEL 3, where, amongst others, Nofima Centre for Recirculation in Aquaculture (NCRA) in Sunndalsøra is included as one of the Transnational Access Points (TNA). TNA means that researchers across Europe can do experiments in NCRA funded by AQUAEXCEL3, as also was the case in AQUAEXCEL and AquaExcel^{2020}.

PhD students from the Department of Chemistry at NTNU with Professor Øyvind Mikkelsen. From left to right - Xiaoxue Zhang, Sharada Navada, Øyvind Mikkelsen, Ingrid N. Haugen, Patricia A. Alarcon. Photo: Per Henning/NTNU.

Marius Takvam, to the left, finished his Master degree in July 2020 and started on the associated project Prestiis. Also in picuture: Valentina Tronci and Naouel Gharbi. Photo: ©NORCE.

Master student Tarald Kleppa Øvrebø graduated in 2020 from UiB with the thesis Growth performance and welfare of post-smolt (Salmo salar L.) reared in semi closed containment systems (S-CCS) – a comparative study. Photo: Frank Midtøy.

6 RECRUITMENT, EDUCATION AND TRAINING

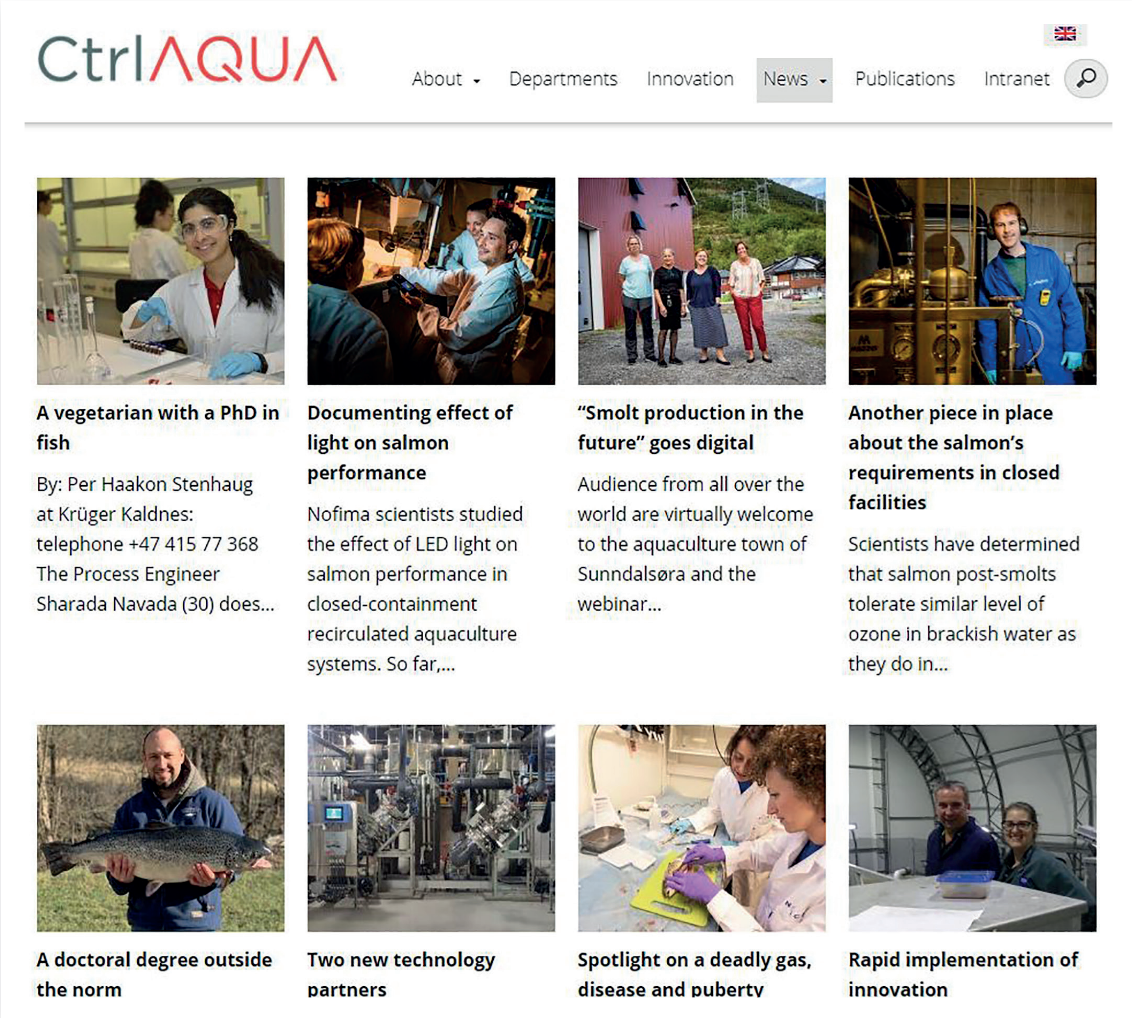
The aim of CtrlAQUA is to have 15 PhD students to be educated throughout the lifetime of the centre. We are approaching this number and have now recruited 11 PhD students and one dr. philos. candidate to key research topics of the center and its associated projects (see table in section 8). In 2020, one student was recruited at UiB within the project MICROPARASITES. This student, Even Mjølnerød, will most likely complete the thesis after the centre period has ended. A PhD position was awarded by UiB late in 2020 and is currently being announced. The successful candidate will begin work early in 2021, bringing the total of students to 13 (12 PhD and one dr. philos). In autumn 2020, Sharada Navada (Industrial-PhD with Krüger Kaldnes) handed in her thesis "Salinity acclimation strategies for nitrifying bioreactors in recirculating aquaculture systems" at NTNU. Trial lecture and public defense took place on February 18th 2021. Six master students finished in 2020 and a large group of students will finish in the first half of 2021.

2020 has been an unusual year for the students due to covid-19. Lockdown of universities have caused delay for many of our students, both master and PhD. The universities have granted an extension for the students who were affected by the lockdown, however, this means that there will be some delays in finishing both master and PhD theses. We do expect, however, that students who are currently working in the centre will finish within its lifetime.

In addition to the PhD students, we are educating several master students within CtrlAQUA at the University of Bergen, NTNU, UiT, NMBU, Göteborg University, and universities in Portugal (see table in section 8). So far in the lifetime of the centre we have recruited 36 master students. 25 have completed their theses and final exams, while the other 11 candidates are at various stages of carrying out their research in CtrlAQUA projects and preparing their theses. We will most likely continue to recruit new students who will finish within the lifetime of the centre. 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, four post-docs have also been recruited at various points. These scientists also form an important part of the centre's recruitment and training. The latest addition to the centre is Darragh Doyle, Göteborg University, who will carry out research until the end of the centre period.

With the addition of PhD student Even Mjølnerød the gender balance in CtrlAQUA is now 7 females and 5 males, and one more candidate will be recruited early in 2021 (see above). As stated in previous reports, the gender 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 now approximately 50/50. Again, these numbers reflect the recruitment base of MSc candidates who apply to do their degree within the centre and its associated projects.



At ctrlaqua.no there are several news about the latest research in the SFI.

Scan the QR-code to watch a film from 2020 about Nofima's RAS-facilities. These facilities are central for the CtrlAQUA research.

Centre Director Åsa Espmark (in the couch) was a panelist at Tekfisk direkte: «Når laksen lever i lukkede anlegg». Photo: ©Morgan Lillegård/Nofima.

7 COMMUNICATION AND DISSEMINATION ACTIVITIES

In CtrlAQUA, the overall goal with communication is to create interest around the activities of the centre, and to be a strategic contribution in attaining the goals of CtrlAQUA. The communication shall mirror the vision of the centre.

There has been a great interest from the industry and academia leading to 75 news articles in press in 2020. Though there is high interest from the industry and academia, there seem to have been less interest from the public audience for the development in closed-containment aquaculture, in comparison to the first years.

The Centre Director, partners and scientists have been available for the press to report on the progress of research and innovation in closed-containment aquaculture. It is worth highlighting the communication activities from professionals at The Freshwater Institute at several RAS-webinars initiated by US media, and the regular column that a Krüger Kaldnes employee has initiated and write at Tekfisk.

In 2020, the conference season for RAS never had the chance to begin before the pandemic changed all plans from March. Still, we have had high activity in disseminating progress and results at webinars, particularly towards our main target groups in industry and research. Social media platform LinkedIn has been particularly useful in spreading information and creating interest in what we are doing. News, webinars and podcasts are spread at LinkedIn, Twitter and Facebook from the host institute and partners.

Examples of dissemination activities in 2020 are:

- February: Three partners, FishGlobe, Aquafarm Equipment and Nofima in the panel of Tekfisk direkte: «Når laksen lever i lukkede anlegg»
- March: Åsa Espmark at EAS Talk with the talk "CtrlAQUA SFI: Contribution to future aquaculture" AND in panel debate at North Atlantic Seafood Forum
- October: Nofima released a film about research in RAS, where CtrlAQUA was central
- October: CtrlAQUA well promoted at the "Smolt production in the future conference" with several presentations

During 2020 the CtrlAQUA communication department has released nine news stories about the activities in the centre, well distributed in the media. All can be read at ctrlaqua.no.

Status of our internal and external communication platforms

The intranet is the most important channel for maintaining internal routines and systems for communication between the partners. It is the main communication channel within the centre with approximately 100 participants involved. The intranet has a document base, image base, message facilities, calendar and internal alerts of new findings or publications as agreed upon in the consortium agreement. Other systems for internal communication are regular meetings, mainly digital in 2020.

The main external communication channel is the website ctrlaqua.no, which is designed for presenting results, activities, publications, and innovations as the centre develops. Also, printed material such as fact sheets and roll-ups show externally what the centre is about.

8 ATTACHMENTS TO THE REPORT

Key R&D partners in 2020

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
Vasco Mota	Nofima AS
Sigurd Handeland	NORCE
Tom Ole Nilsen	NORCE
Pablo Balseiro	NORCE
Naouel Gharbi	NORCE
Simon Mackenzie	NORCE
Alla Sapronova	NORCE
Eirik Thorsnes	NORCE
Pradeep Lal	NORCE
Sigurd Stefansson	Universitetet i Bergen
Are Nylund	Universitetet i Bergen
Øyvind Mikkelsen	NTNU
Frank Karlsen	USN
Snuttan Sundell	UGOT, Sweden
Henrik Sundh	UGOT, Sweden
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 - 2022	NTNU
Nobotu Kaneko	2018 - 2019	UiB
Darragh Doyle	2020 - 2022	UGOT

PhD-students/dr. philos

Sara Calabrese	2013 - 2017	UiB
Lene Sveen	2014 - 2018	UiB
Bernat Morro	2016 - 2019	UiB
Victoria Røyseth	2016 - 2019 (avbrutt)	UiB
Xiaoxue Zhang	2016 - 2021	NTNU
Patrik Tang	2017 - 2021	UiB
Sharada Navada	2017 - 2021	NTNU
Enrique Pino Martinez	2018 - 2021	UiB
Ingrid Naterstad Haugen	2018 - 2022	NTNU
Patricia Aguilar Alarcon	2018 - 2022	NTNU
Tharmini Kalananthan	2018 - 2022	UiB
John Davidson	2019 - 2021	UiB
Even Mjølnerød	2020 - 2023	UiB

MSc students

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

BSc students

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

CtrlAQUA Dissemination and publications 2020:

Peer reviewed publications

Aguilar, P. A. (2020). Characterizing changes of dissolved organic matter composition with the use of distinct feeds in recirculating aquaculture systems via high-resolution mass spectrometry. Science of the Total Environment. Science of The Total Environment. Volume 749, 20 December 2020, 142326.

Benktander J., Padra J.T., Maynard B., Birchenough G., Botwright N.A., McCullogh R., Wynne J.W. Sharba S., Sundell K., Sundh H., Lindén S.K. (2020). Gill mucus and gill mucin O-glycosylation in healthy and amebic gill disease affected Atlantic salmon. Microorganisms 2020, 8, 1871.

Brijs J., Hjelmstedt P., Berg C., Johansen I., Sundh H., Roques J., Ekström A., Sandblom E., Sundell K., Olsson C., Axelsson M. and Gräns A. (2020). Prevalence and severity of cardiac abnormalities and arteriosclerosis in farmed rainbow trout (Oncorhynchus mykiss). Aquaculture. Volume 526, 15 September 2020, 735417.

Davidson, J., Summerfelt, S., Espmark Å.M., Mota, V. C., Marancik, D., Earley, R., Snead, A., Good, C. (2020). Effects of ozone on post-smolt Atlantic salmon (Salmo salar) performance, health, and maturation in freshwater recirculation aquaculture systems. Aquaculture. Volume 533, 25 February 2021, 736208.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S.T. (2020). Influence of inlet and outlet placement on the hydrodynamics of culture tanks for Atlantic salmon. International Journal of Mechanical Sciences. Volume 188, 15 December 2020, 105944.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S.T. (2020). Influence of inlet and outlet placement on the hydrodynamics of culture tanks for Atlantic salmon.

Valentina Tronci, Naouel Gharbi and Marius Takvam from NORCE analyzing samples in associated project Prestiis. Photo: Viviana Cetrangolo.

International Journal of Mechanical Sciences 188, 2020.

Lazado, C.C., Good, Christopher (2020). Survey findings of disinfection strategies at selected Norwegian and North American land-based RAS facilities: A comparative insight. Aquaculture. Volume 532, 15 February 2021, 736038.

Lazado, C.C., Voldvik, V., Breiland, M.W., Osório, J., Hansen, M. S., Krasnov, A. (2020). Chemical oxidative stressors alter the physiological state of the nasal olfactory mucosa of Atlantic salmon. Antioxidants. 9 (11), 1144.

Navada S., Vadstein, O., Gaumet, F., Tveten, A.K., Spanu, C., Mikkelsen, Ø., Kolarevic, J. (2020). Biofilms remember: Osmotic stress priming as a microbial management strategy for improving salinity acclimation in nitrifying biofilms. Water Research. Volume 176, 1 June 2020, 115732.

Navada, S., Sebastianpillai, M., Kolarevic, J., Olsen Fossmark R.,Tveten, A-K., Gaumet, F., Mikkelsen, Ø. Øyvind.,Vadstein, Olav. (2020). A salty start: Brackish water start-up as a microbial management strategy for nitrifying bioreactors with variable salinity. Science of the Total Environment. Volume 739, 15 October 2020, 139934.

P. Hjelmstedt, Henrik Sundh, J. Brijs, Andreas Ekström, Kristina Sundell, C. Berg, Erik Sandblom, J. Bowman, Daniel Morgenroth, A. Gräns. (2020). Effects of prophylactic antibiotic-treatment on post-surgical recovery following intraperitoneal bio-logger implantation in rainbow trout. Scientific Reports, 10, 27 March 2020.

Stiller, K. T., Kolarevic J., Lazado C., Gerwins J., Good C., Summerfelt . T., Mota V. C., Espmark, Å. M. (2020). The effects of ozone on Atlantic salmon post-smolt in brackish water — Establishing welfare indicators and thresholds. International Journal of Molecular Sciience 2020, 21(14), 5109.

Timmerhaus, G., Lazado, C. C., Cabillon, N. A. R., Megård Reiten, B. C., Johansen, L.-H. (2020). The optimum velocity for Atlantic salmon post-smolts in

Atlantium HOD systems for Paramoebae Perurans protection in Lumpfisk production. Photo: ©Atlantium.

Nofima's facility in Sunndalsøra. Photo: Peter Breivik/TINGH ©Nofima.

RAS is a compromise between muscle growth and fish welfare. Aquaculture. Volume 532, 15 February 2021, 736038.

Reports/abstracts/articles/media contributions

Navada, S. (2020). A salty start: Brackish start-up as a strategy for nitrifying bioreactors with variable salinity operation. Aquacultural Engineering Society, Newsletter August 2020.

Stiller, K. T.,Lazado C., Good C., Lilleholt Kraugerud, R. (2020). What's the optimum ozone level in RAS facilities?. The Fish Site 2020, 2020-09-01. https://thefishsite.com/articles/whats-the-optimum-ozone-level-in-ras-facilities?fbclid=IwAR0-bnX1Df7IlDyR6P8oG8ClAg9_km41SYH2JlB5r-gyasZTrJtMFiQPW4c.

Vinci, B. (2020). The Future of Land-Based Salmon. IntraFish Digital Events: The Future of Land-Based Salmon. https://www.youtube.com/watch?v=eZ_NZB2h2hw.

Prensentations (oral and poster)

Davidson J. (2020). Research on all female salmon production in RAS. Smoltproduction in the Future, webinar, 22nd of October 2020.

Espmark Å. (2020). Towards a sustainable interaction with our oceans and seas. Virtual MariMatch 2020 - International Maritime Event. 2 Sep 2020 - 4 Sep 2020.

Espmark Å. (2020). CtrlAQUA- hva er nytt?. Smoltproduction in the Future, webinar, 21st of October 2020.

Good C. (2020). Sexual maturation of Atlantic salmon in RAS. Smoltproduction in the Future, webinar, 24th of October 2020.

Good, C., Summerfelt, S.T., Vinci, B. (2020). Fish health in closed-containment aquaculture systems. Smoltproduction in the Future, webinar, 22nd of October 2020.

Karlsen C. (2020). Microbiota profiling – Interplay between microbes and Atlantic salmon. FHF Webinar: R&D on bacterial communities and microbiota in aquaculture – from lab to tank. 15th of October 2020.

Kleppa Øvrebø T. (2020). Production data analysis from Preline (Lerøy). Smoltproduction in the Future, webinar, 25th of October 2020.

Bremnes Seashore in Trovåg by night. Photo: Inger Lise Breivik/Bremnes Seashore.

Lazado C. (2020). Desinfection strategies in RAS. Smoltproduction in the Future, webinar, 23rd of October 2020.

Meriac, A. (2020). Intake water treatment in land-based aquaculture systems. MOWI workshop, Trondheim, 7th of January 2020.

Meriac, A. (2020). OPTIMIZE: Investigating light quality effects on post-smolt in RAS. Workshop for joint project, MOWI and Nofima, Sunndalsøra, 22nd of January 2020.

Navada S. (2020). Effect of salinity on biofilter nitrification. Smoltproduction in the Future, webinar, 27th of October 2020.

Nilsen, T.O., Mota, V. (2020). Hvilke CO2-nivå kan anbefales for oppdrett av laks i RAS? 15 min presentation at TEKSET 2020 seminar - er norsk settefisknæring så god som vi tror? Clarion Hotel & Congress, Trondheim, 11th-12th of February 2020.

Shahzad, K. (2020). Hydrodynamics in semi-closed aquaculture systems. Smoltproduction in the Future, webinar, 26th of October 2020.

Sundell, K. (2020). RAS a way for increased Swedish production of salmonid fish. Aquaculture from North to South webinar, 18th November 2020.

Sundt, H. (2020). Fish health and welfare in novel aquaculture environments. SASUF Meeting in Port Elisabeth, South Africa.

Timmerhaus, G. (2020). Summary of research on using water velocity to exercise fish at different life stages. CtrlAQUA deliverable.

Theses

Kleppa Øvrebø T. (2020). Growth performance and welfare of post-smolt (Salmo salar L.) reared in semi closed containment systems (S-CCS) – a comparative study. Master thesis, University of Bergen, Norway.

Sørstrand Haugen T. (2020). The effect of winter-signal photoperiod manipulations on smoltification of Atlantic salmon (Salmo salar) reared in commercial Recirculating Aquaculture Systems (RAS). Master thesis, University of Bergen, Norway.

Pharmaq Analytiq in the field. Photo: ©Pharmaq Analytiq.

Lab work at Pharmaq Analytiq in Bergen. Photo: ©Pharmaq Analytiq.

CtrlAQUA