CtrlAQUA

Annual Report 2018
CtrlAQUA - Centre for Closed-Containment Aquaculture

Photo: Aquafarm/Magne Langåker

Centre for Research-based Innovation

The Research Council of Norway

CONTENT

1 OVERALL PROGRESS AND SUMMARY FOR 2018

CtrlAQUA started up 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 growing demand for sustainable growth in aquaculture is seeking for new technologies and methods that will minimise what is preventing growth today. Together with RAS and semi-closed containments, other production forms such as offshore and land-based production all the way to slaughter, in addition to the traditional way of production with flow through and cages, will likely be important in the future.

For CtrlAQUA, 2018 was influenced by the mid-way evaluation from the Research Council of Norway (RCN) that took place in March 2019 in Sunndalsøra. With reference to this, the annual plan for 2018 put much priority into publications. In addition, all partners have participated through discussions about the centre progress and future during the annual meeting in Svolvær in May, and during a devoted mid-way evaluation meeting at Gardermoen in September 2018. All contributions and ideas have been reported to RCN by the centre management, Nofima as host institution and the partners themselves.

This Annual Report for CtrlAQUA 2018 will

CtrlAQUA gathered for the annual meeting in Svolvær in May 2018. Photo: Anders Finsland also be influenced by the mid-way evaluation in that in addition to the compulsory content, we are happy to present interviews that focus on internationalisation, recruitment and how we see the aquaculture future; issues that represent some of the success criteria for the Centres for Research-based Innovation.

Scientific highlights have been many, also in 2018. Work is continuously being done on the development and commercialization of markers that can objectively quantify fish robustness, immune competence and disease status, so that the fish is well-suited for life in the sea. Experiments in 2018 have shown that the fish immunity is lower in the transition between fresh to seawater (smolt to post-smolt), but with time in the sea, the fish resistance to external influences, measured as number of mucus cells, skin thickness and gene expression increases. In 2018, we also worked with optimal post-smolt protocols, i.e. how large should the fish be at sea transfer and what salinity and light conditions should they have been exposed to during fresh water phase in order to perform best and have the best health and welfare in the sea phase. We saw that photoperiod during RAS phase matters for the growth in the sea phase, but which salinity that is used during the RAS phase plays less role for later life. For the farmers it is also important to be aware of that the protocols that result in the best growth during freshwater phase do not necessarily provide the best growth until slaughter.

The fact that water quality is important for optimal health and welfare of the fish is no news. It is important to define limit values for water quality variables that are correct under the conditions in which the fish live. Since RAS water can become very turbid when the same water goes in the loop, many prefer to ozone the RAS water to make it clearer. In salt water, ozone forms substances (bromides) that may be toxic to the fish. Therefore, it is important to find how much ozone salmon tolerate. Experiments in CtrlAQUA have shown that Atlantic salmon is very sensitive to ozone compared to other farming species, so ozonation must be done with caution.

Optimal water velocity is important both for fish training and to ensure self-cleaning in the tanks. In CtrlAQUA, many scientific questions concern large production systems, and with increasing size, there might be challenges with heterogeneous distribution of water velocity and oxygen. Even distribution is also important in order for the fish to distribute and utilize the entire tank volume. To develop solutions to this issue, we work with advanced computer-based flow models. In 2018, we have continued to model tank hydraulics to describe how water and particles are distributed according to different tank design and design of water inlet. We see that different water inlet designs influence the way the water is distributed in the tanks. We have also shown that the fish grows exponentially with increasing water velocity, up to 2.5 body lengths per second. However, the behaviour of the fish suggests that the highest velocities should not be recommended, as the fish form groups where we assume that they try to hide from the highest velocities.

Another ongoing work is the effects of salinity on biofilters. This work is carried out by an industry PhD. During 2018, many interesting results for optimal maturation of the biofilter have been found, in regards of increasing salinity with time. A strategy to increase the salinity minimally does not appear to be profitable as this leads to an accumulation of total ammonium nitrogen (TAN).
In the center, monitoring semi-closed systems is one of more on-going activities. Many of these commercial systems lack both replicates and representative controls, both of which are important for obtaining robust research data. To compensate some for lacking controls, we have reference cages, which are open cages, but which cannot be directly compared with the semi-closed systems as they do not have the same abiotic conditions. To compensate for replicates, we have now managed to achieve six fish generations for one of the systems. This means that we can

Center Director Åsa Espmark, Nofima.

compare different generations, as well as see how the fish performs over time.

In the end of this small summary, we can also add that we are very happy to be able to present CtrlAQUA and the results at several occasions, and student progression and re-cruitment are progressing very well. CtrlAQUA received a lot of attention and contributed with 10 presentations during this year's conference "Fremtidens smoltproduks-jon", which was organised by Nofima at Sun-ndalsøra, October 2018.

March 2019
Åsa Maria Espmark
Centre Director CtrlAQUA SFI

Vision and objectives of CtrlAQUA – Centre for Closed Containment Aquaculture/Systems

Norwegian salmon industry and government has a goal to increase the production in the years to come. 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 degree of growth will depend on many factors , including how we manage sea lice and escapes, 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 challenges limiting the envisioned growth in aquaculture".

Valentina Tronci from NORCE with Patrik Tang. Photo: Terje Aamodt © Nofima

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 aquaculture/ systems. 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 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, markers for robust fish, minimizing environmental impact through water treatment, reduce the risk of escape, and diseases transmission to wild stocks, 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.

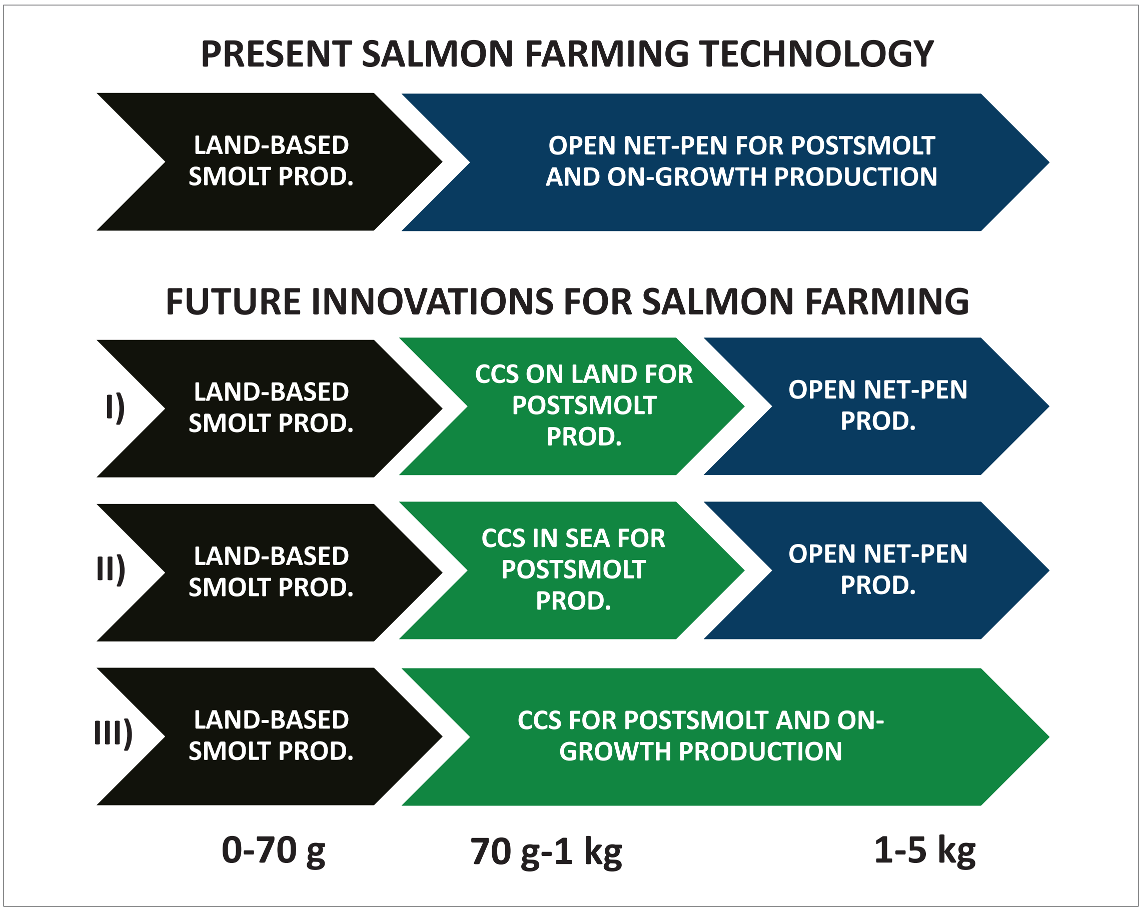

Figure 1.1. Present salmon farming technology, and future innovative strategies (I-III). CCS: Closed containment aquaculture/systems.

Are closed containment aquaculture/systems the only solution?

Article by Reidun Lilleholt Kraugerud

There is a growing interest in closed containment aquaculture (CCA). Many want to know more, and the questions are many: Why do we need CCA? What exactly is CCA? How widespread will they become?

”Closed containment aquaculture/systems come in several varieties. Whether a large proportion of farmed salmon will be produced in closed containment farms in the future depends on which salmon farming structures the government will facilitate, whether fish farmers will be able to carry out production activities within that framework, and whether the market is willing to pay for it. There are both advantages and disadvantages with such closed containment facilities, and personally, I believe many different types of technology will be used for salmon farming operations”, says Åsa Espmark from Nofima.

Espmark is the director of the CtrlAQUA SFI, which is a centre for research-driven innovation in closed containment farming systems. Here, 20 partners from the research, fish farming and supply industry sectors work together to make CCA solutions become an every-day shelf product by 2023.

“The reason why we are researching closed containment facilities is that the traditional method of open-net fish farming alone will not be sustainable in the future. The fish farming industry must find alternative ways to farm salmon. CCA will make it possible to farm salmon practically without salmon lice and escaped fish, as there will be a physical barrier between the fish and the sea so the lice cannot enter and fish cannot escape. We are now conducting research to find ways to make salmon thrive in such facilities”, says Espmark.

The solutions the CtrlAQUA researchers are working on are land-based facilities and semi-closed facilities at sea for production of salmon of up to 1 kg.

Why stop when the salmon reaches a weight of 1 kilogram?

”CtrlAQUA stops there as it is before the weight reaches one kilogram that we can do anything significant to strengthen the robustness, health and wellbeing of the fish. The rest is, to put it simply, basically a transport stage for the fish to grow bigger”, says Espmark.

Does the fact that not all salmon are kept in closed containment facilities until they are harvested have any negative environmental effects?

“I doubt that. As a salmon is approaching the target weight of five kilograms, it requires far more space than when it is small. With closed containment farming, the total Norwegian salmon production would require enormous land areas. It would also be very energy intensive and technologically challenging to operate an onshore fish farm with pumps and salt-water recycling, as salmon should preferably live in salt water as it matures”, says Espmark.

“I believe it will have a significant positive impact on the environment if we can reduce the amount of time the salmon spends in the sea by allowing it to spend more of its life in land-based facilities than it currently does”, she says.

Offshore fish farms as a complementary technology

Espmark is supported by Hans Bjelland of Sintef, who is Centre Director of the Exposed SFI. They are working with open-water fish pens in locations far from land, known as "exposed aquaculture". Like CtrlAQUA it is an SFI for exploring the opportunities for the future of aquaculture technology.

"The reasons for working with developing fish farming operations in exposed locations are that there is plenty of space; stable, good water conditions; and greater distance between each fish farming facility, which reduces the infection pressure. At the same time, ocean currents carry away fish faeces and uneaten feed."

"If we are able to let salmon grow big on land before it's transferred to sea, we can reduce the time spent at sea from the current 16-18 months down to 10 months, which means we can also avoid the two most severe winter months. Every third salmon that escapes does so during bad weather – and bad weather is more prevalent in winter", says Bjelland.

Salmon that is to be transported to offshore facilities far from land must be able to endure hours of strong currents and more waves than the salmon placed in net pens in more sheltered environments.

"In the Exposed SFI we are doing a great deal of research on swimming capacity and behaviour. The SFIs are complementing each other in this regard. Whereas researchers in CtrlAQUA are researching health and production efficiency in fish farming in order to produce smolt that can survive the transition to the sea, we also need even more robust smolt that can survive the transition to a more demanding open-sea environment", says Bjelland.

And finally –
Why is the centre called CtrlAQUA?

See page 10-11 for Facts about fish farming systems.

"CtrlAQUA stands for control in aquaculture production. Being able to control the production environment is key to sustainable farming and healthy salmon in closed containment facilities", says Espmark.

Åsa Espmark and Hans Bjelland from Sintef are each directors of separate SFIs researching the aquaculture technologies of the future. They met at a conference on the future of smolt production at Sundalsøra last October. Photo: Frode Nerland/Nofima.

Facts about fish farming systems

Traditional fish farming is when salmon fry are kept in land-based tanks (in practice a closed containment fish farm onshore) with water flowing through until the fish reaches the smolt stage and weighs around 80–100 grams, after which it is transferred to open net-pens in the sea. The salmon lives there until it reaches its harvesting weight of 4–5 kilograms. Fresh ocean water flows continuously through the net-pen, and the fish living inside are quite subjected to the forces of nature. One drawback to this is that waste and infections are freely exchanged with the surrounding environment. In addition, the walls of the net-pens can be damaged and fish escape. Benefits of such fish pens include the fact that they represent the cheapest method for farming salmon, and allow the fish to live as close to nature as possible. Such traditional farming is by far the predominant method used in Norway currently.

Photo: Helge Skodvin/Nofima

In closed containment facilities onshore it is possible to keep salmon until it reaches its harvesting weight of around 4–5 kilograms. However, at CtrlAQUA we do research on it until it reaches approx. one kilogram; known as the post-smolt stage. Such facilities are also called land-based facilities. They use water-recycling technologies to recycle up to 99.9% of the water used. These facilities require vast land areas and high expertise as well as significant economic investment and control with the technology, water quality, and health and well-being of the fish. We are able to capture more than 98% of the sludge generated in these facilities, but we have yet to find the best solution to dispose of or utilize it. Benefits of land-based closed containment facilities include the ability to completely avoid the issues of salmon lice and escaped fish, the ability to capture and potentially recycle nutrients contained in the sludge, and potentially the ability to produce more robust fish that is more capable of survival. One technical challenge researchers are facing is to supply the recirculation facilities (RAS) with seawater, which is what the fish naturally live in from the smolt stage onward. Further research needs to be done on this. Several large facilities for production of post-smolt (up to 1 kilogram) are currently being built in Norway, and in 2019 the first onshore fish farm will start farming salmon until it reaches its harvesting weight.

Photo: Magne Langåker/Nofima

In closed containment fish farms at sea, which we usually refer to as semi-closed due to the fact that they do not contain the waste created, and are thus not completely closed, it is possible to set out smolt and potentially keep them there until they reach a weight of one kilogram. In practice they currently work best as a stopover stage for salmon weighing between 250–500 grams. In research experiments carried out by CtrlAQUA they have succeeded in producing fish entirely free of salmon lice and without escapes, but a number of technical issues remain to be solved. The benefits of closed containment facilities at sea is that they utilise deep sea water from depths where lice cannot live, and they do not require the extensive water purification technology that land-based recirculation facilities do. A solid wall separates the sea environment from the fish on the inside of the facility, and prevents any interaction with the outside environment. Several varieties of prototypes for closed containment facilities at sea exist, but none of them are currently in commercial production.

Photo: Reidun Lillehølt Kraugerud/Nofima

Farming in **exposed facilities** far offshore is driven by the need for increased space and better production environments. Exposed localities provide more stable growth conditions and greater distribution of waste due to the fact that the sea is constantly in motion. In addition, exposed facilities can be located farther away from the wild salmon in the coastal areas, which can help reduce the negative environmental impact caused by salmon lice and fish escaping from the net-pens. However, this kind of facilities is also associated with challenging conditions for its operations, structures and equipment due to strong and alternating winds, currents and waves, in addition to the increased distance to the facilities. Farming in exposed localities requires new technical solutions combined with operational concepts for maintaining security and ensuring production reliability. Commercial salmon production is currently tried out in experimental net-pens such as Salmar's facilities outside Frøya (pictured above).
Research on these facilties is carried out in the Exposed SFI hosted by Sintef.

Photo: Salmar

2 RESEARCH PLAN/STRATEGY

The Centre for Research-Based Innovation in closed containment aquaculture/systems, CtrlAQUA, commenced operations in April 2015. The Research Council of Norway's objectives in running the SFI-program are four-fold:

- to stimulate innovation activities in strong industries in Norway,
- to promote collaboration between innovative industries and excellent research institutions,
- to develop industry-relevant research institutions that are leading in their field, and
- to educate new scientists and foster knowledge- and technology transfer. These goals, in addition to the specific goals of the centre, forms 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 plan is led by the leader group of CtrlAQUA, who uses several sources of information to develop the plan, 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 competencies in the fields of research in the centre. An important task of the SAB is to give advice during development of the annual plans.

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.

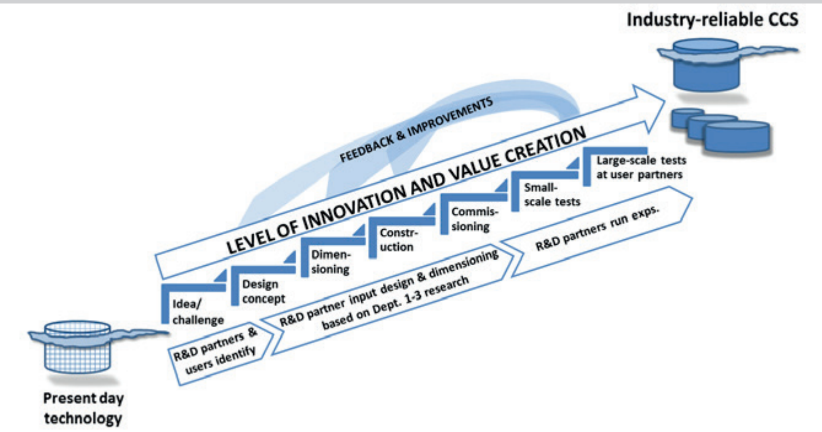

Figure 2.1. Innovation process in CtrlAQUA, from present day cage technology, to establishment of industry-reliable closed containment systems, either in-sea closed tanks or land-based RAS experiments.

Photo: Trond Rosten/Mowi

From 2015, we also included associated projects, defines 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 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.

3 ORGANIZATION

Organizational structure and cooperation between the center's partners

CtrlAQUA is organized (Fig. 3.1) with a Board that oversees that obligations are fulfilled, and decides on financial, partnership, and IPR issues, as well as ratifying annual research plans made by the leader group. In 2017, the Board met for two physical meetings. The Board from 2018 consists of the following elected members:

- Frode Mathisen, Grieg SeaFood, chairperson of the CtrlAQUA Board
- Harald Takle, Cermaq, Board Member
- Asgeir Knutsen, Krüger Kaldnes, Board Member
- Siri Vike, Pharmaq Analytiq, Board Member
- Hans Kleivdal, NORCE, Board Member
- Hilde Toften, Nofima, Board Member and representing the host institution

Each board member category (farming category, technology and biotechnology category, NORCE, Nofima) have 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 CtrlAQUA leader group: Sigurd Handeland, Åsa Espmark, Lill-Heidi Johansen, Sigurd Stefansson, Jelena Kolarevic and Tom Ole Nilsen.

The center 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 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), Center level (annual meetings), leader group (every third week), and thematic or project level (as required). In addition, the intranet has a news feed where center-participants have posted e.g. news, links to documents, research plans, results, pictures and videos. In addition to a formal news channel, the center intranet has also been used as a social media, thus contributing to build the CtrlAQUA team spirit.

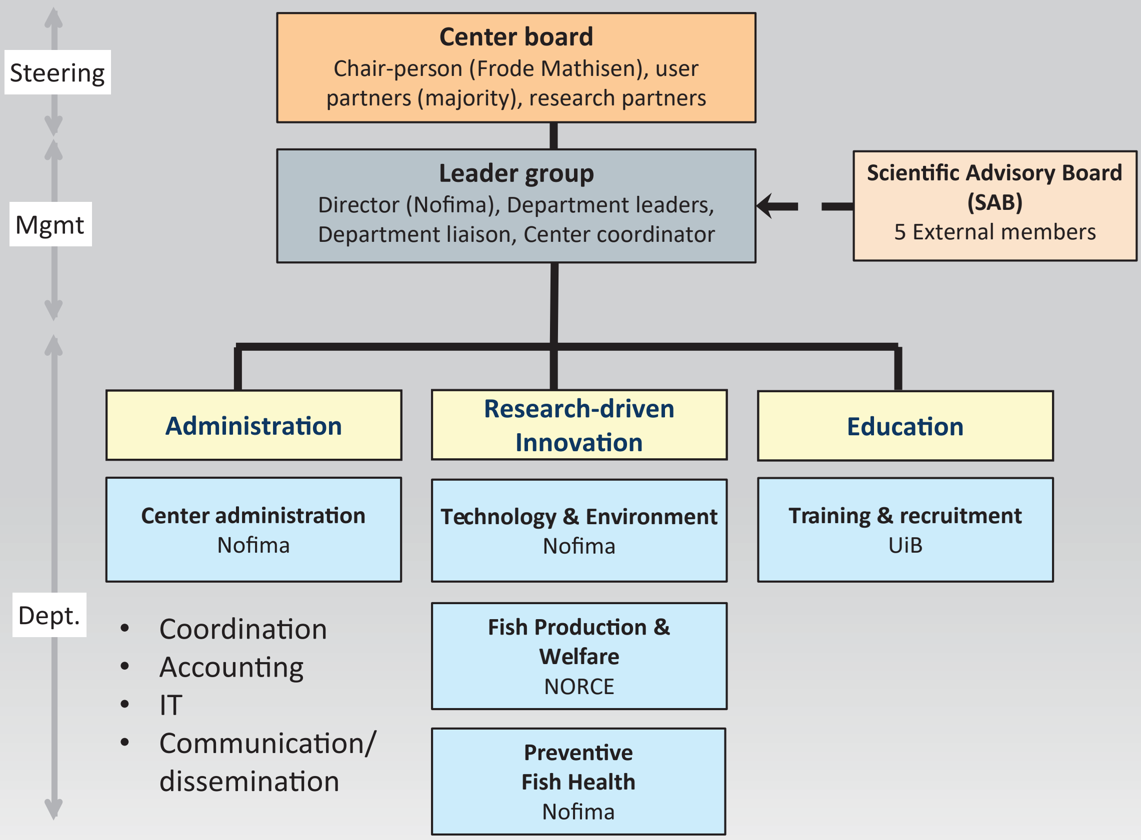

Figure 3.1. Organizational structure of CtrlAQUA.

THE CtrlAQUA BOARD as of May 2018

Frode Mathisen
Grieg SeaFood
Chairperson of the CtrlAQUA Board

Harald Takle
Cermaq Group
Board Member

Asgeir Knutsen
Krüger Kaldnes
Board Member

Replaced Knut Måløy,
Vard Aqua, in May 2018

Siri Vike
Pharmaq Analytiq
Board Member

Hans Kleivdal
Norce
Board Member

Replaced Tor Solberg,
Norce, in May 2018

Hilde Toften
Nofima
Board Member

Replaced Mari Moren,
Nofima, in May 2018

CtrlAQUA

PARTNERS

Per January, 2019, CtrlAQUA has 20 partners, where seven are R&D partners and 14 are user partners.
User partner Oslofjord Ressurspark left the centre October 2018.

R&D PARTNERS

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 offer analytical services and consultation to solve challenges faced by intensive fish production – in a preventive way by monitoring, diagnosis 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 2011 the laboratory was accredited by Norwegian Accreditation. Furthermore, histology and bacteriology extend the advisory and problem-solving capability which PHARMAQ Analytiq offers the aquaculture industry. In CtrlAQUA, PHARMAQ Analytiq is represented by General Manager 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 functional immune system.

Since the precursors of Marine Harvest started up in 1965, they have gone from a small entrepreneurial company to the world's largest aquaculture company. With 3.8 million daily meals, Marine Harvest in Norway is the largest food producer (in proteins) through the entire value chain from feed production to brood, eggs, fish, processing and distribution to sales. Most of the salmon from operations in Norway is exported to Europe, USA and Asia. Marine Harvest develops future solutions for farming and is a key driver for innovation, both in Norway and internationally. Business in Norway include being the largest aquaculture company in Norway with over 1600 employees and with operations along the Norwegian coast from Flekkefjord in Agder to Kvænangen in Troms. The company is part of the group Marine Harvest ASA, which operates in 24 countries and is listed on the Oslo Stock Exchange (OSE). The global headquarters are located in Bergen. In CtrlAQUA Marine Harvest is represented by Global Director R&D and Technical, Øyvind Oaland and Group Manager Freshwater & Closed Production Technology, Trond Rosten. Sara Calabrese was employed in Marine Harvest 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, Marine Harvest RAS sites, such as Steinsvik, also provide input and are involved in projects in CtrlAQUA.

LERØY

CERMAQ

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.

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.

BREMNES SEASHORE

Grieg Seafood®

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 Farming Manager Geir Magne Knutsen, and the company contributes financially and with farming expertise and large-scale facilities.

Grieg Seafood ASA is one of the world's leading fish farming companies, specializing in Atlantic salmon. They have an annual production capacity of more than 90.000 tons gutted weight. The Group is today present in Norway, British Columbia (Canada) and in Shetland (UK), employing approximately 700 people. Grieg Seafood ASA was listed at the Oslo Stock Exchange (OSEBX) in June 2007. The headquarters are located in Bergen, Norway. The business development of Grieg Seafood ASA focuses on profitable growth, sustainable use of resources and being the preferred supplier to selected customers. Grieg Seafood is represented in CtrlAQUA by Frode Mathisen, Director Freshwater Production. Frode Mathisen, who is also the chairperson of the Board of CtrlAQUA. Grieg Seafood will contribute with their long experience in salmon aquaculture and RAS, as well as running large-scale trials.

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. Krüger Kaldnes develops solutions for complete deliveries of land-based fish farms, as turn-key approach, in collaboration with selected building contractors. 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 and R&D Manager Aquaculture Andreas L. Brunstad. Krüger Kaldnes will contribute with own expertise, and prototype hardware.

FishGLOBE AS is a company that is selling closed floating fish cages. Prototypes have been tested and now the full-scale globe for postsmolt is ready for testing. The globe is built in polyethylene which is the preferred material to use at sea. The polyethylene is a thermoplastic which work well with waves and is well-suited for fish-farming. The clue to hold the structure/form and make it strong and stiff, is to use the inlet and outlet pipes. To be able to use this material it holds to patents. The company was established in 2013, but the development of closed aquaculture technology has roots back to the late 80's. The company is located in Forsand, Norway. The vision of FishGLOBE is to develop new cost-effective solutions that makes it possible for the aquaculture industry to expand. The business concept is to offer a solution to the salmon farmers that make farming more profitable, more sustainable and with higher fish welfare. FishGLOBE entered CtrlAQUA in November 2015 and is represented by manager Arne Berge.

Smølen Handelskompani AS is a holding company placed in Smøla County, Norway. The company owns Smøla Klekkeri og Settefiskanlegg AS and Sagafisk AS that together have a production capacity of 5.5 million salmon smolt per year. 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. Smøla Klekkeri og Settefiskanlegg is represented in CtrlAQUA by Managing Director Per Gunnar Kvenseth 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 louse, and reduces the release of organic nutrients and waste into the surrounding environment. For the past two years, we have worked closely with Marine Harvest to carry out a full-scale test of our semi-closed fish cage for post-smolt fish – and the results are very promising. Our fish-cage concept virtually eliminates 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 0.5 %. In CtrlAQUA, Aquafarm Equipment AS is represented by engineer CEO Atle Presthaug, and Business Developer Roger Thorsen, and contribute with their expertise in engineering of floating closed containment systems in sea.

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Vard Aqua Sunndal is a Norwegian equipment supplier that has worked to help customer profitability to increase in correlation with fish welfare for over 30 years. The company is, from November 2016, part of Vard Group. Through the integration with other entities in Vard Group, we have strengthened our offering and stepped up the commitment within aquaculture. Working closely with our customers, we develop vessels, fish farming technology and solutions to help build sustainable and efficient operations – inshore, offshore, at sea and on land. The products of Vard Aqua Sunndal focus on oxygen (adding, logging and adjusting), logging of environmental data, biomass measuring, tools for closed cage treatment, and feeding equipment for land- and sea. In CtrlAQUA, Vard Aqua Sunndal is represented by board member Knut Måløy (also member of the CtrlAQUA Board), and Christoffer Eriksson, and will contribute to Dept. Tech & Env. with equipment prototypes, and expertise.

O/R/P

Oslofjord Ressurspark (ORP) is a Norwegian commercial company delivering a point-of-care instrument and a disposable chip for automatic sample processing, sample refining and analysis of gene activity. ORP was established in 2013, and based its business on unique technology that is covered by own patents invented by the team of professor Frank Karlsen and licensed patented technology from PreTect AS. The strategy for ORP is to successfully sell and deliver products to customers in the international fish farming arena which will pave the way for other major markets in the oil, health, environment and agriculture fields. ORP is initially focusing on the supply of products on site for automatic and accurate detection of active fish genes and pathogenic micro-organisms in closed or open aquaculture facilities. In CtrlAQUA, ORP is represented by Business and Coordinator Manager Steve Hughes, and they will contribute with developing the pathogen sensor, together with CtrlAQUA partners (R&D, and user partners) for in-depth knowledge of relevant pathogens.

botngaard

Botngaard'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. Botngaard'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 Botngaard is represented by CEO Magnus Stendal, and the daughter company Botngaard System AS, that will contribute with knowledge and experience with closed containments.

PHARMAQ
part of zoetis

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 and Scientist Elin Petterson and will contribute with expertise and vaccine development in Dept. Prev Fish Health.


Photo: Terje Aamodt © Nofima

4 SCIENTIFIC ACTIVITIES AND RESULTS

DEPARTMENT FISH PRODUCTION AND WELFARE

The main objective of Department of Fish Production & Welfare is to provide knowledge and innovations to determine environmental and biological requirements of Atlantic salmon in CCS. In the previous two years a high number of experiments have been conducted. During 2018 the main focus has been on completing analysis and interpretation of result as to provide an improved scientific basis for recommendations on optimizing environmental requirements of salmon in CCS and S-CCS. To this end, continued testing and evaluation of newly identified robustness marker candidates has been conducted across environmental conditions such as water temperature, different levels of CO_2 exposure and water flow. The most promising markers includes differential expression of un-named marker nr 1, 2, 3 and 4 in fish exposed to either long term environmental stressors, or acute handling stress, suggesting specific markers should be used under specific environmental conditions. For instance, marker nr 3 display low baseline expression levels in post-smolts exposed to different flow rates, while handling induces marker nr 3 expression. In contrast, elevated baseline levels of marker nr 3 in water temperatures below 10 oC suggest that this specific marker may best be used when temperatures are above 10 oC. A shortlist of markers is now available and to be validated under large scale industry conditions.

A priority within Department of Fish production and Welfare is to optimize environmental rearing conditions for post-smolt in RAS/CCS. We found that post-smolts handle transfers across large temperature gradients (Δ8 oC) if temperature is the only environmental parameter that changes. However, it

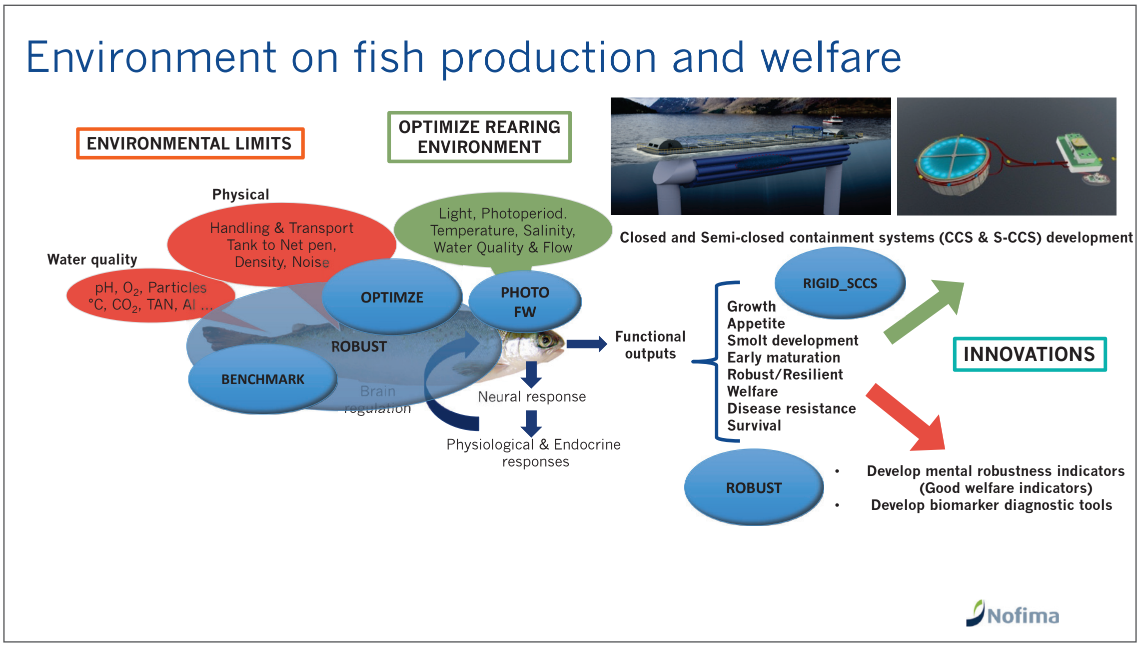


Figure 4.1. Schematic oveview of Department of Fish Production and Welfare main projects in 2018

is clear that rearing post-smolts at the high and low scale of these temperatures provide challenges at industry conditions. One should exercise caution when transferring fish between different temperatures, particularly in the low temperature range. Temperature is known to influence biological membranes and barrier functions. Fatty acid (FA) and phospholipid (PL) compositions of epithelial membranes are strictly regulated to maintain optimal protein conditions for osmoregulatory functions. However, these compositions are greatly influenced by environmental factors, such as temperature, that induce biochemical modifications at membrane level. Such modifications include changes to PL classes, constituent FAs and cholesterol levels to maintain appropriate membrane characteristics in fluidity and viscosity. Hence, in 2018 we have investigated more in detail how different temperatures may affect barrier structures and thus robustness of post-smolts. Preliminary lipid data from the temperatur transfer experiments indicate lipid compositional changes in response to temperature at both gill and skin sites. Typical homeoviscous adaptation in FA compositions was perceived to a larger degree in skin, whilst the gills showed to being more conserved towards FA compositional changes, perhaps indicating the high metabolic activity of gills and the importance of this organ in maintaining an appropriate functional environment for embedded proteins. Concerning PL classes, large compositional shifts occurred in Phosphatidylcholine (PC) and especially Phosphatidylethanolamine (PE), which decreased and increased, respectively, with increasing temperature. The increase in PE and the decreasing PC/PE ratio associated with high temperatures likely indicates increased requirement to stabilize ionic protein structures at these higher extremes. This indicates either more suboptimal membrane conditions at higher temperatures or/and greater functional demand upon the ionoregulatory systems. The fact that TAGs (triacylglycerol) were identified at gill site indicates the possible use of these energy rich substrates as an alternative fuel source to typical gill glycogen stores, via direct oxidation or gluconeogenesis. Further, the drop in TAG levels at high temperatures may indicate a higher functional and energetic demand in maintaining appropriate gill functions, as the use of glucose is often prioritized over the use of TAGs fish. One important further follow up is to confirm if specfic use different temperatures provide us with a mean to produce more robust fish thorugh effecting their barrier funtions.

Effects of photoperiod history in RAS was investigated using two photoperiod regimes: i) LD24:0 (i.e. 24 hours light, zero hours dark), and ii) LDN (simulated natural photoperiod, Bergen latitude) applied to Atlantic salmon post-smolts raised in freshwater systems at 13oC up to 500g in weight, and beyond. All fish were reared on LD24:0 from first feeding up to 40g, at which point the fish received a 6-week LD12:12 artificial winter while simultaneously being split into full feed ration (FR) and reduced (60%) feed ration (RR) groups. At 500g, the best growth performance was observed in the FR groups, and both ration and photoperiod were positively associated with increased growth performance. This pattern has continued as the salmon approached a mean weight of 1 kg. Although no signs of maturation were observed at 500g, by 1 kg maturation, assessed by gonadosomatic indices, was observed in all groups (as high as 70% of males undergoing maturation, in the FR LDN group) except the RR LDN cohort; by 2,000g, both male and female maturation was prevalent in all treatment groups. Hence, full grow out conditions in RAS represents high risk of maturation.

Benchmarking different post-smolt production protocols in terms of fish performance, health and welfare is important for optimizing production scenarioes for large smolts and post-smolts. We transferred post-smolt at 2 different sizes, 200 and 600 grams in addition to one 100g 'control' group. In RAS, these fish were either raised at photoperiods 12:12 or 24:00, and in either 12 ppt or fresh water, in a 2x2 factorial design. After transfer to sea, the fish were followed all the way until slaughter. While still in the RAS phase, the best growth was seen among the fish that were given the 24:00 and 12 ppt protocol. However, when the fish were transferred to sea, the fish that were given the 12:12 photoperiod had the best growth, while salinity during RAS did not seem to matter so much after sea transfer. All fish handled the sea transfer well as the accumulated mortality was less than 4%. Few signs of sexual maturation were seen. Fish size at slaughter was best for the control (100g) fish and the worst for the fish that were put to sea at 600g. The 200g sea transfer fish were in between. This experiment shows amongst others that it is important to consider the whole life cycle to find the optimal production protocol.

One major outcome from several generations of post-smolts production in S-CCS systems is that it appears as 400-500g post-smolts after 4-6 months S-CCS have fewer salmon lice infestation than fish directly transferred to open net pens, suggesting that post-smolt reared in S-CCS may have increased robustness against lice infestation. This could in part be due to the constant water flow, or 'training' effect, as post-smolts in S-CCS display elevated expression of the gene markers MEF2C and GATA4, indicating cardiomyocyte hypertrophy. In addition, higher frequency of small muscle fibres in S-CCS fish compared to fish in open net pens.This coincides with a clear trend of equal or higher growth rate and approximatley 10% higher food conversion ratio in S-CCS fish. Hence to date post-smolt kept in S-CCS seems to be healthy and robust.

Samling from PREVENTIVE-CARDIO experiment by Gerrit Timmerhaus. Photo by: Terje Aamodt © Nofima

DEPARTMENT PREVENTIVE FISH HEALTH

The main objective in Department Preventive Fish Health is to contribute to inventions to prevent, detect and control disease in closed and semi-closed containment aquaculture/ systems (CCS/S-CCS). This may be obtained by strengthening fish robustness and disease resistance with focus on barrier functions and cardiovascular capacity, strengthening pathogen control and handling of disease outbreaks in CCS and by developing new or refined vaccines and protocols for pathogens representing a special threat in CCS.

One of our main activities is to identify and characterize the most important known and emerging microparasites, followed by mapping of diversity, prevalence, load and transmission routes in CCS. Productions in two S-CCS in Western Norway have been followed in 2018, and in addition, another two productions are being monitored during 2018 – 2019, one of them being located in Northern Norway. A genotyping system, a tool to better characterize microparasites, has now been developed for Salmonid Gillpox virus (SGPV) (T. Kloster-Jensen, master thesis 2018) and the system will be used to track possible transmission routes for this virus. The bacterium Candidatus Branchiomonas cysticola is present in both fresh- and seawater, but today there are no genotyping tools available for studies of transmissions routes. A PhD

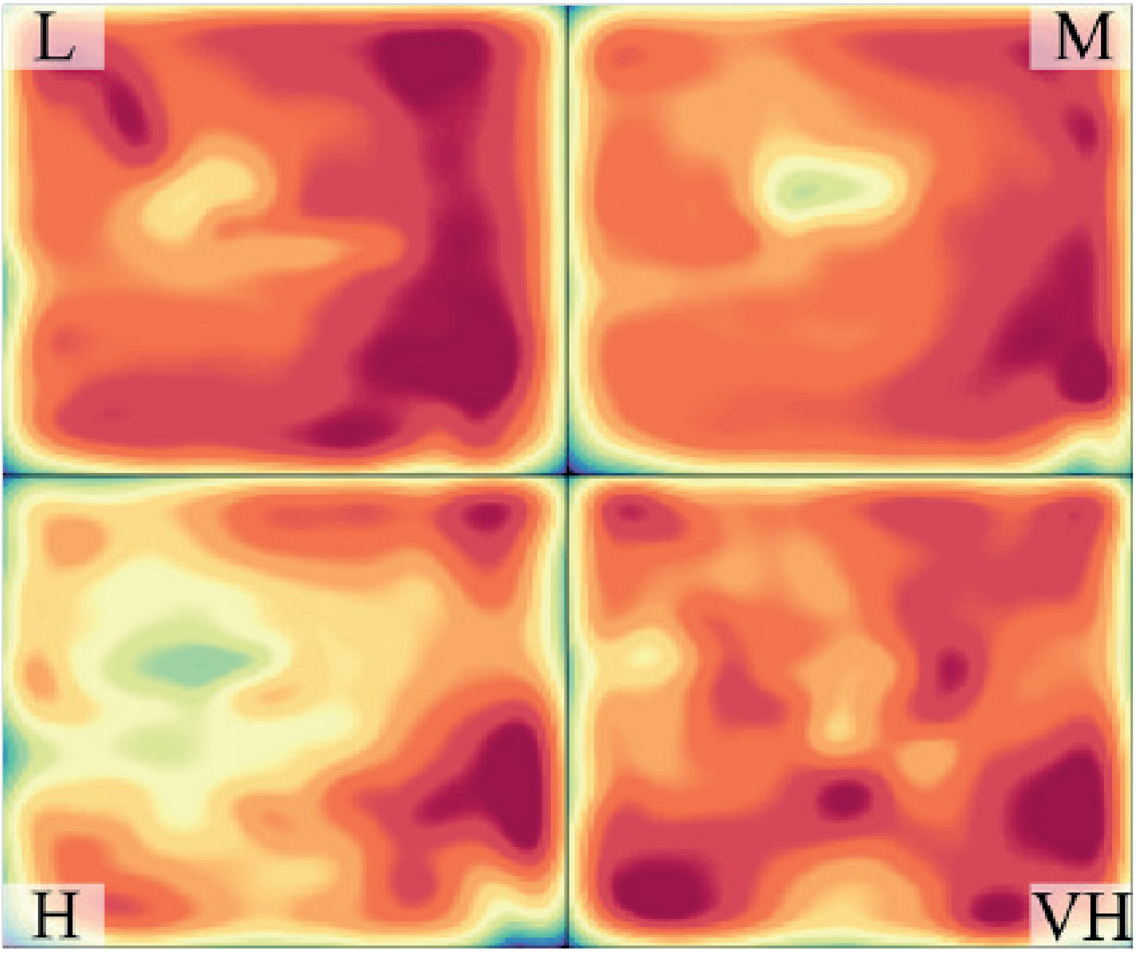


Figure 4.1. Project PREVENTIVE, CARDIO trial: Positioning of Atlantic salmon smolts in the tanks day 7 after setting the different water velocities: L= 0.5 BL/s (body length/second), M = 1.0 BL/s, H = 1.8 BL/s, VH = 2.5 BL/s. Dark red = areas with high densities of fish, light yellow = areas with low densities of fish.

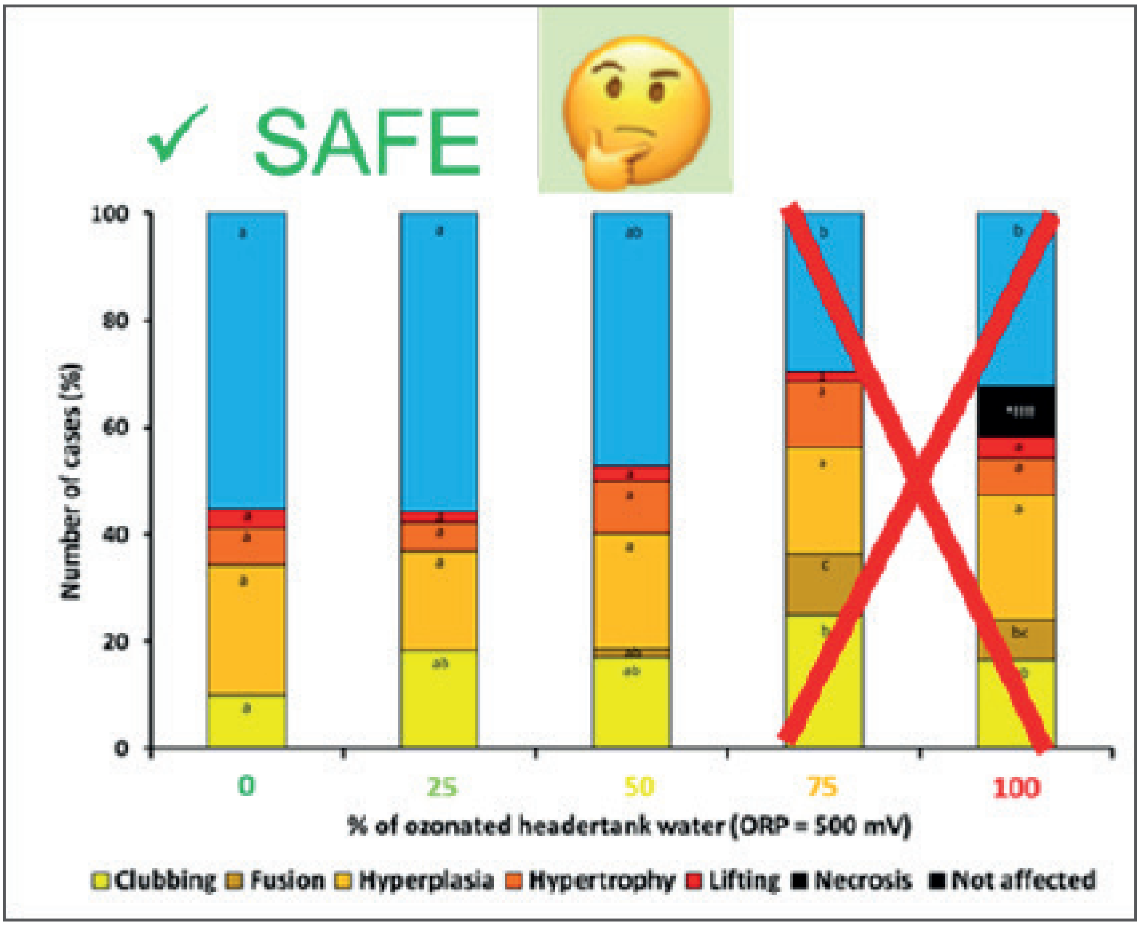


Figure 4.2. Project TREAT, activity EXPO: Ozonation of Atlantic salmon in brackish water – effects on gills related to ozon levels in the tanks.

project started on this bacterium in 2018. An emerging virus on lumpfish, Cyclopterus lumpus virus (CLuV) has been published.

In order to optimize health and welfare of post-smolts in CCS and beyond, we work to elucidate the anatomic barriers of Atlantic salmon and to understand production parameters that impact or enhance fish barrier functions. We have shown that the barrier functions, or the immune system, of smolts weakens in the period immediately after transfer to sea and that the fish use a few months were they gradually recover. During this period, they may be particularly susceptible to infectious diseases. Based on a S-CCS, we have characterized the bacterial community the salmon has in mucous surfaces and in the water column. As expected, some of the bacterial groups containing variants that may cause disease, such as Moritella, are associated with intake from a deeper water layer and are attached to particles rather than free-living in the water layer. These insights might provide new solutions to reduce pathogen loads in CCS.

The potential for controlling water flow and velocity in recirculating aquaculture systems (RAS) and CCS for improved growth and health is a key focus in CtrlAQUA. In a dedicated trial, we investigated the effects of low to very high water velocities on Atlantic salmon smolts in RAS to gain further insights into optimal rearing conditions. We evaluated growth, muscle development, schooling behavior, welfare scores and immunological- and stress responses of fish in four different velocity groups (0.5, 1.0, 1.8 and 2.5 body length (BL)/ second (s)) over three months. Findings included that fish in higher velocities form denser schools and certain fin damages were slightly more frequent. However, the overall external welfare scores remained favorable in all groups. Significant increased mean body weights correlated to the applied velocities, with the largest growth found in the 2.5 BL/s group, and this was linked to increased muscle growth. Plasma cortisol, used to validate stress level, was significantly elevated for the 2.5 BL/s group during the first week of the trial, however, these differences disappeared to the end of the trial. In conclusion, we found overall beneficial effects of elevated water velocities, but some results indicated possible negative effects for fish in the highest velocity group, indicating an optimum velocity between 1.8-2.5 BL/s for smolts in RAS.

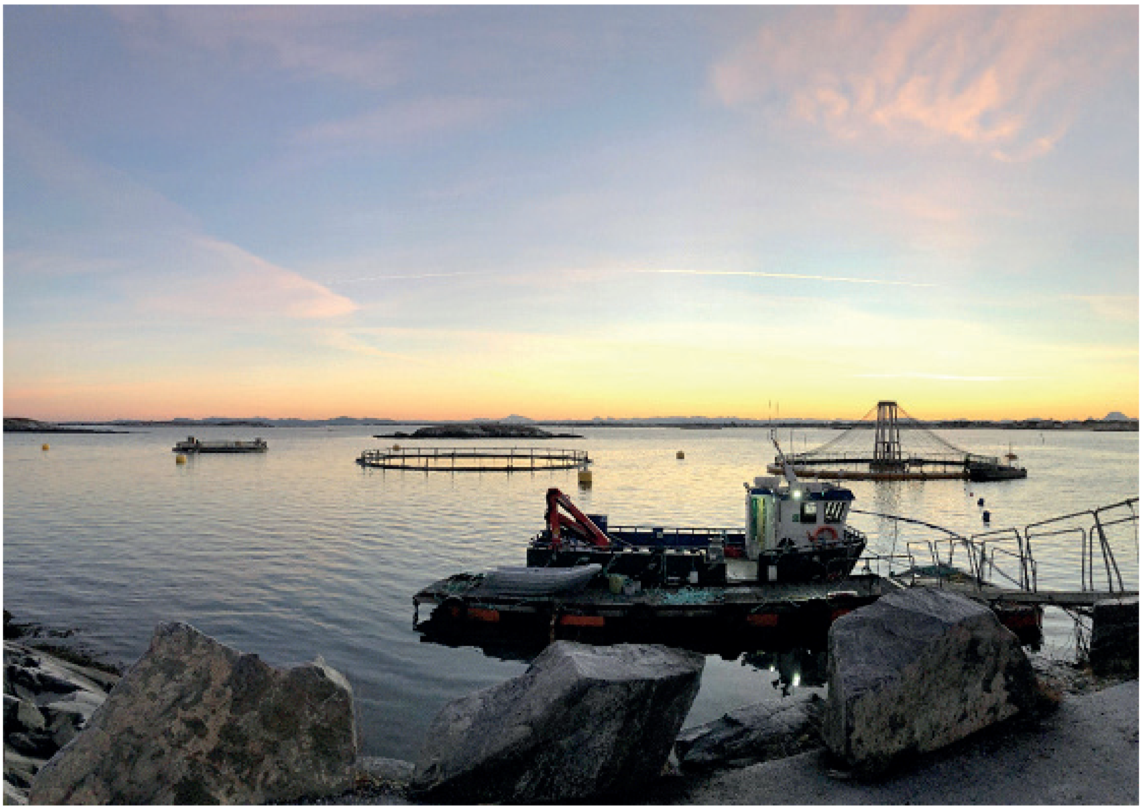
Rearing fish in a highly controlled environment requires that water quality is at an optimum and that a system is in place to prevent potential disease outbreaks. We are exploring the impacts of chemical-mediated strategies on system performance, water quality, biosecurity and fish health. We have documented the impacts of ozonation by-products, total residual oxidants (TRO`s), after ozonation of brackish water, on fish and welfare and. Results showed that the highest levels of TRO tested, significantly affected the gill health of salmon that eventually resulted in mortality. TRO levels of ca 300-350 millivolt represents a threshold for Atlantic salmon in brackish water RAS systems related to health and welfare. We have also mapped the current disinfection strategies used in RAS facilities in Norway. Two surveys aiming at profiling the current disinfection protocols, showed a number of similarities, but also dissimilarities between RAS facilities in Norway. Majority of the surveyed facilities have in-house disinfection protocols, however, the disinfection efficiency of the strategies is not verified experimentally. Peroxide-based disinfectants, (mainly peracetic acid) are the most commonly used chemical disinfectants, conforming to the approved disinfectants for aquaculture use by the Norwegian Food Safety Authority.

DEPARTMENT TECHNOLOGY AND ENVIRONMENT

Increased reliability of sensor data is one of the main objective in the Department of Technology and Environment . During 2018 we continued the reach activity on sensor protection systems to prevent biofilm formation and physical clogging of sensors. Main research was done on nanocomposites of polydimethylsiloxane modified with graphene oxide / zinc oxide, as well as a series of new graphene oxide compounds modified with silver nanoparticles. These nanocomposites were synthesized, characterized and coated successfully on sensor materials. The antifouling, wettability, morphology and composition of coating materials was characterized, and size and distribution pattern of silver nanoparticles was found to have significant impact on antifouling property. To avoid clogging a nylon filter and vibration system were studied with positive results. Ion selective electrodes are important for monitoring crucial ions like e.g. nitrate and ammonium in RAS water. However, drifting in sensor signal is a known issue for such ion selective electrodes. In connection to this, two methods; minimum least square regression (MLR) and Gan-Ruan-Mo (GRM) were studied for base line correction. Main results concluded that GRM worked better, as this method was found that the output from GRM was more reliable and demanded less adjustments subsequently. Finally, also a study on identifying organic compounds produced in aquaculture was initiated. This is an important stem in improving turbidity measurements in closed and semi-closed containment aquaculture/systems. During 2018 methods for efficient extraction has been studied, as well as a screening of compounds using novel non-target screening analysis. Of the solvents tested, Ethyl Acetate (EtAc) stood out as the most suitable solvent for liquid-liquid extraction of the culture water in RAS, followed by dichloromethane (DCM). In these initial studies the results from the non-target analysis tentatively identified 12 organic compounds in water samples collected at the RAS farming Atlantic salmon (Salmo salar) post-smolt. The compounds were assigned 8 different classes of chemical compounds which are Organophosphorus compound (OP), Carbohydrate, Amino acid, Ester, Alcohol, Steroid hormone, Ketone and unknowns respectively. Compounds assigned classes of Ketone and alcohol were found to be related to, and likely product-ions, of steroid hormones due to identical fragmentation pattern obtained from mass spectra analysis.

The results from the Department of Technology and Environment aim to better understand how to optimize fish culture tanks and vessels and were published in three peer-review journals in 2018. Engineers can now utilize the findings to create culture tank designs that improve fish health and welfare while maintaining an optimal water quality environment. When we performed the first ever high-fidelity study on the effect of the dual-drain on culture tank hydrodynamics, a good match between the computational and experimental results was achieved, which confirmed the validity of the computational fluid dynamics (CFD) model. The CFD analysis not only explored the hydrodynamics in the commercial culture tanks with Cornell-type dual-drain but also recommends the suitable flow-split between such outlet systems for operators. We published empirical data on rotational velocity and water quality in circular and octagonal tanks at two large commercial smolt production sites. In both cases, facility operators and culture tank designers were able to optimize flow inlet conditions to achieve appropriate tank rotational velocities despite a wide range of culture tank sizes, hydraulic retention times, and outlet structure locations. Additionally, estimates of the oxygen respiration rate appeared to double as the TSS concentration measured in the tank increases from 3.0 mg/L (0.3 kg O_2/kg feed) up to 10–12 mg/L (0.7 kg O_2/kg feed). Improving suspended solids control in such systems may thus dramatically reduce the oxygen consumption and CO_2 production. In addition to large tanks in RAS we also worked on the design of a floating closed containment fish farm (FishGLOBE) using computational fluid dynamics. CFD-assisted design improvement of a floating aquaculture system was performed and a cost-effective computational framework was developed for turbulence modelling. Two designs of pilot and post-smolt systems were investigated and the CFD model validated. This study has developed new inlet designs to improve the flow patterns by using CFD.

In the end, we have focused on algorithm development that would allow us to measure accurately size and total biomass of smolts and post-smolts up to 1kg. AkvaVision system for measurements of the biomass was calibrated to the desired size of Atlantic salmon and field trial was done in the semi-closed containment aquaculture/systems at Smøla During the trial, between 1200 and 3400 post-smolts with starting average weight of 251 g were measured on a daily bases. Farmer could at all times see the summary of measurements, weight distribution, and development of the biomass per hour, average weigh and picture of every measured fish. Information was available on the cloud-based solution developed by Vard Aqua. Measured daily growth was close to 2 g, as was expected. This trial indicated that AkvaVision system could be successfully used in semi-closed systems for real-time measurements of average weight and biomass of post-smolts smaller than 300g.



Gulklakken at Smøla where testing of AquaVision in the concrete tank was done.

During the conference «Smolt production in the future" at Sunndalsøra in October, which was heavily influenced by CtrlAQUA, 320 participants from 10 countries joined. Some visited the Nofima RAS facilities used in several CtrlQUA experiments. Photo: Frode Nerland © Nofima

5 INTERNATIONAL COLLABORATION IN 2018

Researchers and user partners in CtrlAQUA have an extensive international network of contacts. In our Scientific Advisory Board, who among other things provide input to the annual plans, there are several international members, including from the European Aquaculture Society, Danish Technical University, The University of Aberdeen, and University of Maryland.

CtrlAQUA researchers have in 2018 frequently been used as invited speakers at several international scientific meetings, such as the annually «Aquaculture Innovation Workshop», hosted by CtrlAQUA partner Conservation Fund Freshwater Institute (USA), and arranged in December 2018. In October 2018, Nofima hosted the conference "Future smolt production" in Sunndalsøra. This conference has become international with more than 10 participating countries in 2018. CtrlAQUA gave 10 presentations this year. CtrlAQUA results were also presented at the World Aquaculture Society's conference in Montpellier in August 2018, in addition to at several other conferences and work-shops.

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. UGOT has in 2018 contributed to important results on effects of stress on skin barrier functions in salmon held in closed containment aquaculture/systems. The Conservation Fund Freshwater Institute (FI) has continued the trials on optimal photoperiod and feed ration for postsmolts reared in RAS in their facilities, and done research on optimal use of ozone in fresh water. Furthermore, FI is 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 2018 we registered three associated projects that involves international partners: CO2RAS Associated is funded by the EU project AquaExcel2020 and will run at Wageningen University. RFF TROUT is funded by Reginal research fund (RFF) and is in collaboration with Sterling University. Late 2018, CtrlAQUA partner UGOT (Henrik Sundh) got funded the project "Microplastics in the environment: An investigation into how they affect fish and potential risks for the aquaculture" from the Swedish Research Counsel. The project was approved as associated since the Scientific Advisory Board expressed their wish for research on microplastic issues in the centre even if this is not within the centre description.

Researchers in CtrlAQUA are often involved in new project proposals where international partners are included. Specifically, research by some of the CtrlAQUA-partners has helped establish AquaExcel2020, 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. Furthermore, partners NORCE and the University of Bergen have been awarded a project called ExcelAqua Norway-Japan. This project is funded by the Research Council of Norway International Partnerships for Excellent Education and Research (INTPART), in aquaculture. ExcelAqua aims to develop a robust world-leading collaboration platform for outstanding research and education between the partners in aquaculture. CtrlAQUA participates here as one of the collaborative tools that will contribute to reaching the INTPART goals.

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

Research and industry well established in the international arena

Article by Reidun Lilleholt Kraugerud

Chris Good has seen US land-based salmon farming begin to take off during the four years since CtrlAQUA began, with massive facilities being built or in the planning stage.

Dr. Good is Director of Research at The Conservation Fund's Freshwater Institute in West Virginia, USA. The Freshwater Institute is international partner of CtrlAQUA along with the University of Gothenburg in Sweden, and is a pioneer in recirculating aquaculture systems (RAS) research in North America.

Close research collaboration

The Freshwater institute has a long history of collaboration with Nofima, beginning with the 5-year RCN funded Rasalmo project initiated in 2008. They were subsequently invited by Nofima researchers to join CtrlAQUA SFI.

"We were thrilled to be invited! This SFI is broad and extensive, with many well-known researchers in the field. We're meeting scientists now whom we've only met previously through publications", says Good.

The collaboration Dr. Good and his colleagues have with CtrlAQUA partners has been focused on experiments regarding photoperiod, water ozonation, and RAS disinfection, as well as RAS culture tank design and hydrodynamics.

"I expect after CtrlAQUA finishes in 2023 the links with our partners in the center will remain strong. We all have the same interests and research goals, and it's mutually beneficial to combine expertise to solve problems in an important and growing industry like RAS aquaculture. We definitely learn a lot from each other", says Dr. Good.

Industry growing in the U.S.

In Norway, fish farmers are weighing the benefits of raising fish in net pens against land-based farming. However, by growing salmon in the U.S., there's an environmental and economic benefit of cutting air freight. That makes the Americans, and the Norwegians who sees the opportunity across the Atlantic, eager to farm more.

CtrlAQUA coordinator, Åsa Espmark, is enthusiastic about the research collaboration across the Atlantic. Nevertheless, it is notable that although an SFI is supposed to stimulate international enterprises to establish in Norway, the market forces drag the other way:

"There is a so far a stronger pull for Norwegian enterprises to establish abroad rather than for international enterprises to establish in Norway. How an SFI can influence on process is limited, but this trend towards internationalisation represents a great opportunity for value creation among Norwegian aquaculture enterprises", says Espmark.

What impact will CtrlAQUA have on closed containment aquaculture?

Dr. Good believes that CtrlAQUA will have an enormous impact in the long term. With such a strong industry representation within CtrlAQUA, companies such as Mowi (former Marine Harvest), Grieg Seafood and Krüger Kaldnes can take back information from CtrlAQUA and apply it to their own objectives. Additionally, scientific publications from CtrlAQUA research will come out in an increasing pace for everybody to learn from.

"People are watching to see these technologies being proven in commercial settings. This still needs some proving, but we're well on our way. I believe one or two disasters could set things back temporarily, but I'm optimistic when it comes to producing salmon in closed containment aquaculture in the long run", says Good.

Doctoral candidate Ingrid Naterstad Haugen studying water quality in the recirculating aquaculture system (RAS) at Nofima, Sunndalsøra. Photo: Yuriy Marchenko/Nofima.

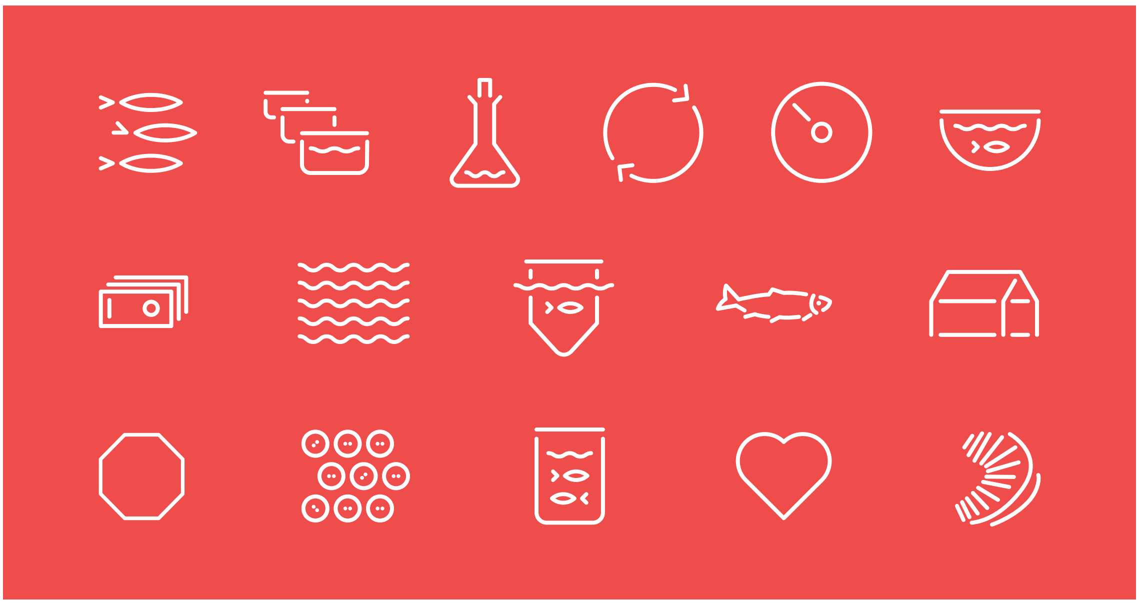
6 RECRUITMENT, EDUCATION AND TRAINING

Our target is 15 PhD students to be educated through the lifetime of CtrlAQUA. We are approaching this number and have now recruited 11 PhD students to key research topics of the center and its associated projects (see table in section 8). On November 30th, 2018, Lene Sveen (funded in part by the associated project SalmoFutura) successfully defended her thesis at the University of Bergen.

The student forum of the center was launched during the 2nd annual meeting in Bergen in May 2017. During 2018, 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. The students have appointed Sharada Navada as their representative, and the leader group regularly asks Sharada for input to the leader group meetings.

In addition to PhD students, within CtrlAQUA we educate a number of Master students, at the University of Bergen, Göteborg University and NTNU (see table in section 8). So far in the lifetime of the Centre we have recruited 24 Master students, of these 14 students have completed their theses and final exam. The other 10 candidates are at various stages of selecting and carrying out their research in CtrlAQUA projects. 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 deserves a specific comment. At present, we have eight female students (approximately 70 %) vs. three male students (approximately 30 %) among the 11 candidates currently associated with the Centre. This distribution reflects the quality of the applicants for the positions, as recruitment is based entirely on scientific quality. The leader group will monitor this distribution during the rest of the Centre's lifetime. Among the MSc students, the gender balance is 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.



Students in good company

Article by Reidun Lilleholt Kraugerud

Researcher education is an area in which CtrlAQUA can undoubtedly claim success, just half way through the centre's lifetime.

"From a purely quantitative perspective, we can claim success because we have already had eleven out of our fifteen doctoral candidates and twenty-two master's students at the centre," says Sigurd Stefansson, who heads the department for education and recruitment in CtrlAQUA and is a professor at the University of Bergen.

"The very best thing about this is that those who have been here say they greatly benefited from being students at the centre when it came to finding their first job in industry and research," says Stefansson.

A former CtrlAQUA master's student at NTNU can confirm this. Simen Haaland now works for Fredrikstad Seafoods, which is building the first facility in Norway for land-based salmon production up to slaughter:

"If my supervisor hadn't got me into the CtrlAQUA network, I would not have had the job I have today," says Haaland.

Sharada Navada is a doctoral candidate and head of the student forum in CtrlAQUA, which the students established in 2017.

"As a student, it is fruitful to work in this type of centre where we are all working towards the same goal – namely, to conduct research into closed farming systems in order to improve post-smolt production. The fact that we are part of this innovation in the industry inspires us to work harder," says Navada.

The students are split between the University of Bergen and NTNU, and have their forums and meeting places at their places of study and they all get together every year prior to CtrlAQUA's annual meeting, at which around 80 participants from research and industry meet to present results and discuss research into, and the development of, closed farming facilities.

Basic research and innovation

Professor Øyvind Mikkelsen, who is responsible for the students at NTNU, wants to ensure that even with the focus on applied research, a lot of basic research is involved.

"The students' tasks involve solving problems currently faced by the industry. But there are also clear aspects of basic research in this because, if you are going to publish something, it has to be new."

At NTNU, the students work on technology-related topics, which involves developing or improving sensor systems that can monitor water quality over time.

At the University of Bergen, the students work within physiology, fish health, nutrition and post-smolt maturation. Lene Sveen defended her doctoral thesis at the university in the autumn of 2018. This involved a good proportion of basic research into how wounds in salmon skin heal. It provided useful information for the farming industry about how stress affects the skin as an important barrier and the consequences for the immune response of salmon in facilities with differing fish densities.

Gender equality and industry PhDs

Sveen was one of many female doctoral candidates at the centre. While eight of the eleven doctoral candidates are women, nine of the twenty-two master's students are women.

"This is atypical compared with before, and we have not implemented any measures aimed at especially recruiting women. We select candidates on a purely academic basis. We are seeing something of the same trend on the courses we teach at master's level, where we also see a growing proportion of women. If we wanted to ensure there were more men at the centre, we currently have few means of achieving this," says Stefansson.

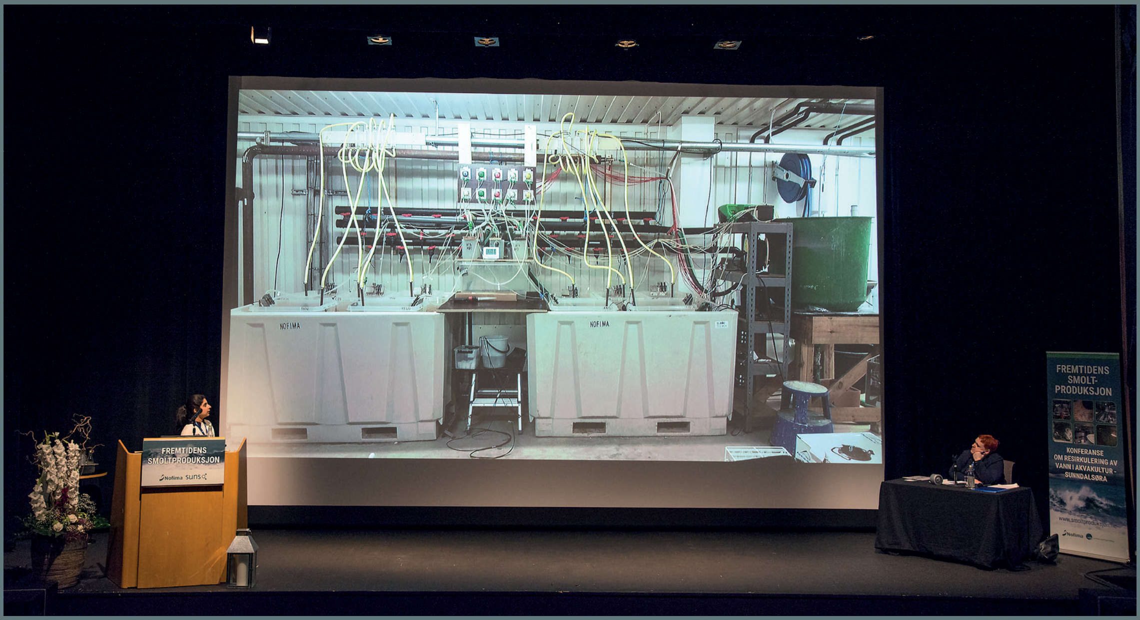
Want more industry PhDs

Meanwhile, what Stefansson would like to do something about is achieveing a somewhat higher proportion of industry PhDs at the centre. Today, two of the centre's eleven candidates were recruited via a company. Four doctoral positions remain to be defined and filled in the second part of the centre's life, and Stefansson is encouraging the industry partners to become proactive in order to have good candidates linked to their company. CtrlAQUA's management would be happy to help achieve this.

Sharada Navada is an industry PhD from Krüger Kaldnes and is thrilled about the scheme:

"An industry PhD is more challenging than a traditional PhD, as we need to balance the expectations of both the research community and the industry. However, it has its benefits as we get to learn how companies and research institutes can work hand in hand to create valuable projects with real world applications. Industry and research are a really good combination!" says Navada.

Lene Sveen defended her doctoral thesis at the University of Bergen on 30 November 2018. "My message would be that we need to keep preventive fish health in mind when we design closed systems. I think it will be exciting to see how the industry resolves this challenge." Photo: Elisabeth Ytteborg/Nofima.



Doctoral candidate Sharada Navada presented her research on biofilters at the conference «Smolt production in the future" at Sundalsøra in October. Photo: Frode Nerland/Nofima.

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Ledige stillinger i fiskeribladet
Ble overrasket over hvor interessant lakseskinn kan være
Lene Sveen har funnet ut at stress forsinker sårheling hos laksen.

7 COMMUNICATION AND DISSEMINATION ACTIVITIES

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

When it comes to internal routines and systems for communication between the partners, the intranet is the most important. The intranet is the main communication channel within the center for the 107 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.

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

The interest from industry, the public and academia has been considerable. This has resulted in 62 news articles in press in 2018, many generated by media itself. Research partners have actively made news stories covered in professional media, and all partners have been available for press to report on the progress of research and innovation in CCS in aquaculture.

In 2018 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 2018 are:

- February: Nhut Tran in CtrlAQUA was awarded best presentation at conference about electronics engineering in Vietnam.
- March: Many news hits on the research from the BENCHMARK project, that showed that large smolt not always performs best.
- May: Interviews with partner and student in annual report picked up by media.
- September: The magazine Aftenposten Innsikt 9/2018 portraited land based aquaculture over 17 pages, where Åsa Espmark was interviewed and CtrlAQUA PhD degree was referred to.
- October: NRK TV reported from the conference "Smolt production in the future" at Sunndalsøra, visiting Nofima's research facility and interviewing among others chair of the CtrlAQUA board, Frode Mathisen.
- November: News about the second PhD degree in CtrlAQUA was covered in several news sites.
- November: Several people in CtrlAQUA had presentations in the Aquaculture Innovation Workshop (AIW) in Vancouver, Canada, and were referred to in the media. CtrlAQUA partner Freshwater Institute and others arranged the conference.

8 ATTACHMENTS TO THE REPORT:

Key R&D partners in 2018

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
Grete Bæverfjord	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
Lars Ebbesson (30.09.2018)	NORCE
Sigurd Handeland	NORCE
Tom Ole Nilsen	NORCE
Pablo Balseiro	NORCE
Nahouel 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	HSN
Snuttan Sundell	UGOT
Henrik Sundh	UGOT
Brian Vinci	Freswater Institute, USA
Chris Good	Freswater Institute, USA
John Davidson	Freswater Institute, USA
Steve Summerfelt (08.06.2018)	Freswater Institute, USA

Postdoctoral researchers

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

PhD students

Sara Calabrese	2013 - 2017	MH
Lene Sveen	2015 - 2018	Nofima
Victoria Røyseth	2016 - 2021/22	UiB
Patrik Tang	2017 - 2020	UiB
Xiaoxue Zhang	2016 - 2020	NTNU
Patricia Aguilar Alarcon	2018 - 2021	NTNU
Enrique Pino Martinez	2018 - 2021	Uni/UiB
Ingrid Naterstad Haugen	2018 - 2021	NTNU
Tharmini Kalananthan	2018 - 2021	UiB
Sharada Navada	2017 - 2020	NTNU
Bernat Morro	2016 - 2019	UiB/Stirling

MSc students

Britt Sjöqvist	2015 - 2016	UGOT
Ida Heden	2015 - 2016	UGOT
Øyvind Moe	2016 - 2017	UiB
Ingrid Gamlem	2016 - 2017	UiB
Egor Gaidukov	2016 - 2017	UiB
Hilde Frotjold	2016 - 2017	UiB
Simen Haaland	2016 - 2017	NTNU
Kamilla J.Grindedal	2016 - 2018	NTNU
Thomas Kloster-Jensen	2017 - 2019	UiB
Gunnar Berg	2017 - 2019	UiB
Tarald Kleppa Øvrebø	2019 - 2020	UiB
Sjur Øyen	2019 - 2020	UiB
Hilde Lerøy	2019 - 2020	UiB
Ross Fisher Cairnduff	2019 - 2020	UiB
Marius Takvam	2019 - 2020	UiB
Tilde Sørstrand Haugen	2019 - 2020	UiB
Steinar Bårdsnes	2019 - 2020	UiB
Kristin Søiland	2017 - 2019	NTNU
Caroline Berge Hansen	2018 - 2020	NTNU
Silvia Keci	2018 - 2020	NTNU
Gisle Roel Bye	2016 - 2017	NTNU
Gulbrand Stålet Nilsen	2018 - 2020	NTNU

BSc students

Matilda Svensson	2016 - 2016	UGOT

Publications 2018 - 2019:

Peer reviewed publications

Aslama, S., Navada, S., Gisle, R. Byea, Mota, Vasco C, Terjesen, B.F.,Mikkelsen, Ø. (2018). Physio-chemical effects of different CO2 levels in recirculating aquaculture systems (RAS) for Atlantic salmon (Salmo salar L.) post-smolt Aquaculture journal

Balseiro P, Moe Ø, Gamlem I, Shimizu M, Sveier H, Nilsen TO, Kaneko N, Ebbesson L, Pedrosa C, Tronci V, Nylund A, Handeland SO (2018). Comparison between Atlantic salmon Salmo salar post-smolts reared in open sea cages and in the Preline raceway semi-closed containment aquaculture system. J Fish Biol. Sep. 93(3): 567-579.

Cabillon, Nikko Alvin R., Lazado, C.C. (2018). Mucosal barrier functions in fish under variable environmental conditions Fishes.

Good, C., Davidson, J., Terjesen, B.F., Takle, H., Kolarevic, J., Baeverfjord, G., Summerfelt. S. (2018). The effects of long-term 20 mg/L carbon dioxide exposure on the health and performance af Atlantic salmon Salmo salar post-smolts in water recirculation aquaculture systems. Aquacultural Engineering. 81:1-9.

Gorle J.M.R., Terjesen B.F., Mota V.C., Summerfelt S.T. (2018). Water velocity in commercial RAS culture tanks for Atlantic salmon smolt production. Aquacultural Engineering. 81: 89–100.

Gorle JMR, Terjesen BF, Holan AB, Berge A, Summerfelt ST. (2018). Qualifying the design of a floating closed-containment fish farm using computational fluid dynamics Biosystems Engineering. Vol 175, pp. 63-81, 2018.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S.T. (2018). Hydrodynamics of octagonal culture tanks with Cornell-type dual-drain system. Computers and Electronics in Agriculture. Vol 151, pp. 354-364, 2018.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S.T. (2018). Hydrodynamics of Atlantic salmon culture tank – Part 1: Effect of inlet nozzle angle on the tank's performance. Computers and Electronics in Agriculture.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S.T. (2018). Hydrodynamics of Atlantic salmon culture tank – Part 2: Effect of inlet and outlet placement on the tank's flow pattern. Computers and Electronics in Agriculture.

Gutiérrez, X.A., Kolarevic, J., Takle, H., Baeverfjord, G., Ytteborg, E., Terjesen, B.F. (2018). Protective effects of chloride during chronic sub-lethal nitrite exposure through the parr stage of Atlantic salmon Salmo salar. Aquaculture Research.

Holan, A.B., Vinci, B., Handeland, S., Kolarevic,J. (2018). Treatment of intake water to floating semi-closed containment aquaculture systems in sea.

Karlsen C., Rud I., Timmerhaus G., Krasnov A. (2018). Association between skin transcription, the skin mucus microbiome, and outcome after antibiotic treatment of Atlantic salmon with ulcerative disease.

Karlsen C., Ytteborg E., Timmerhaus G., Høst V., Handeland S., Jørgensen S. M., Krasnov A. (2018). Atlantic salmon skin barrier functions gradually enhance after seawater transfer. Scientific Report. 8:9510.

Lazado, C.C., Cabillon, N.A., Reiten, B.K., Johansen, L.H., Timmerhaus, G. (2018). Health and welfare of Atlantic salmon post-smolts exposed to elevated levels of water velocities.

Malthe H, Nilsen T.O, Oppdal F. (2018). Oxygen uptake and osmotic balance of Atlantic salmon in relation to exercise and salinity acclimation. Frontiers in Marine Science. 5:368. 1-11.

Mota, Vasco C. Nilsen, Tom Ole. Gerwins, Jascha. Gallo, Michele. Ytteborg, Elisabeth. Bæverfjord, Grete. Kolarevic, Jelena. Summerfelt, Steven T. Terjesen, Bendik Fyhn. (2018). The effects of carbon dioxide on growth performance, welfare, and health of Atlantic salmon post-smolt (Salmo salar) in recirculating aquaculture systems Aquaculture. Vol 498: 578-586.

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

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Ytteborg E., Krasnov A., Nilsen, T. O., Kolarevic, J. (2018). Performance of Atlantic salmon smolts in brackish and seawater: skin morphology and transcriptome.

Zhang, X., Mikkelsen, Ø. (2018). Graphene oxide/silver nanocomposites as antifouling coating on sensor housing. Journal of Chemistry Materials B.

Økland AL, Nylund A, Øvergård AC, Skoge RH, Kongshaug H (2018). Genomic characterization, phylogenetic position and in situ localization of a novel putative mononegavirus in Lepeophtheirus salmonis Archives of Virology.

Book/article in book/report/abstract

Berg, Gunnar (2018). Neuroendocrine factors involved in appetite control and feed intake in Atlantic salmon (Salmo salar) reared in Recirculating Aquaculture Systems (RAS) Master thesis, University of Bergen, Norway.

Cabillion, Nikko Alvin R. (2018). Plasticity of muscle growth and mucosal defences in Atlantic salmon (Salmo salar) subjected to different exercise intensities Master thesis, University of Highlands and Islands, UK.

Good, C., Summerfelt, S., May, T., Crouse, C., Ebbesson, L., Handeland, S., Stefansson, S., Nilsen, T., Terjesen, B., Mathisen, F. (2018). A 2X2 factorial study assessing photoperiod and feeding rate on the overall quality of Atlantic salmon Salmo salar post-smolts raised in land-based freshwater systems. Aquaculture America 2018 Book of Abstracts (Las Vegas, Nevada – February 19-22, 2018). p.177.

Grindedal, K.J. (2018). Water quality in closed-containment aquaculture systems (CCS) for Atlantic salmon post-smolt Non-target screening of organic substances using UPLC-MS/MS Master thesis, NTNU, Norway.

Karlsen C. (2018). Laksens immunforsvar svekkes etter utsett IntraFish 19.03.2018.

Karlsen, C. R., Ytteborg, E. (2019). Safer transfer to the sea. Creating value 2018.

Kloster-Jensen T.B. (2018). Genotyping of Salmonid Gill Poxvirus (SGPV) in farmed – and wild salmon (Salmo salar) in Norwegian waters. Master thesis, University of Bergen, Norway.

Nilsen, Tom Ole. Terjesen, B.F., Kolarevic, J., Ytteborg, E., Ebbesson, Lars O.E. Handeland, S.O. Mota, Vasco C (2018). Effects of high environmental CO2 levels on Atlantic salmon post-smolts Lessons from two high CO2 worlds – future oceans and intensive aquaculture., 10-12 April 2018. Ponta Delgada, São Miguel, Azores. Abstract.

Spanu, C. (2018). Analysis of water quality in recirculation systems (RAS) in salmon production Master thesis, NTNU (Erasmus), Norway.

Stiller, K.Y., Nilsen, T. O., Mota, V. C., Gerwins, J., Galo, M., Ytteborg, E., Baeverfjord, G., Kolarevic J., Summerfelt, S. and Terjesen, B. F (2018). The effect of carbon dioxide on fish growth performance in recirculating aquaculture systems. Lessons from two high CO2 worlds – future oceans and intensive aquaculture., 10-12 April 2018. Ponta Delgada, São Miguel, Azores. Abstract.

Summerfelt, S. (2018). Developments in closed-containment technologies for salmonids, part 2. Improved knowledge of closed-systems, innovations in aquafeeds. Global Aquaculture Advocate. 43164

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Thøring, S., Espmark, Å. (2018). CtrlAQUA - Annual Report 2017 - CtrlAQUA - Centre for Closed-Containment Aquaculture http://ctrlaqua.no/news/2018/04/06/annual-report-2017/.

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Presentations (oral and posters)

Aguilar, P. A. (2018). Characterisation, quantification and accumulation of dissolved humic and fulvic substances and particulate organic matter in Atlantic salmonid recirculating aquaculture systems (RAS NFR HAVBRUK PhD-samling, Asker 4th of September 2018, Norway

Davidson, J. (2018). Evaluating the Effects of Ozone on Steroid Hormones and Post-Smolt Atlantic Salmon Growth, Performance, and Maturation in Freshwater Recirculation Aquaculture Systems. Aquaculture innovation workshop, Dec 4-6, Miami, Florida.

Ebbesson, L. (2018). FHF and industry funding extension possibilities to follow fish in sea. LIGHT Workshop. CtrlAQUA workshop, Bergen, Norway 22. March 2018.

Ebbesson, L. (2018). Hvorfor er riktig lys viktig? – Lightqual. Kunnskapsoppdatering om optimal post-smolt produksjon. CtrlAQUA workshop, Bergen, Norway, 31st of January 2018.

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Eriksson, C. (2018). Biomas measurements with AkvaVision in closed containment systems. Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24th of October 2018, Sunndalsøra, Norway.

Espmark, Å. (2018). CtrlAQUA – Senter for lukkede anlegg i Akvakultur (2015 – 2023). Fagdag – Fiskeridirektoratet, Bergen, Norway. 12.04.2018.

Espmark, Å. (2018). CtrlAQUA – Senter for lukkede anlegg i Akvakultur. NCE Aquatech cluster, Sunndalsøra, Norway. 11.04.2018.

Espmark, Å. (2018). Økende kunnskap om lukkede anlegg for produksjon av Atlantisk laks Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway.

Espmark, Å. (2018). Fiskevelferd ved økt produksjon - utfordringer slik vi ser det TEKNA Havbrukskonferanse, 05. november 2018, Trondheim, Norway.

Espmark, Å. (2018). New Knowledge About Closed and Semi-Closed Containments Aquaculture innovation workshop, Dec 4-6, Miami, Florida.

Fossberg, J. (2018). Disinfection strategies in Lerøy.

TREAT Workshop, RAS, Treatment strategies in CCS/RAS: Impacts on system performance, water quality, biosecurity and fish health. CtrlAQUA workshop, Gardermoen, Norway, 16th of April 2018.

Good, C. (2018). Investigating the impact of RAS ozonation on waterborne steroid hormones and post-smolt maturation. TREAT Workshop, Treatment strategies in CCS/RAS: Impacts on system performance, water quality, biosecurity and fish health. CtrlAQUA workshop, Gardermoen, Norway, 16th of April 2018.

Good, C. (2018). Assessing Photoperiod Manipulation to Reduce Atlantic Salmon Maturation Aquaculture innovation workshop, Dec 4-6th, Miami, Florida.

Gorle, J., Terjesen, B.F., Summerfelt, S. (2018). Technology development in RAS: Focus on tank hydraulics Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway.

Handeland, S. (2018). Produksjon av postsmolt i semi-lukkede anlegg. Resultat fra en komparativ feltstudie. Fagdag – Fiskeridirektoratet, Bergen, Norway. 12.04.2018.

Handeland, S. (2018). Optimal salinitet i RAS (1). Kunnskapsoppdatering om optimal post-smolt produksjon, CtrlAQUA workshop. Bergen, Norway, 31 januar 2018.

Handeland, S. (2018). Postsmoltproduksjon i semi-lukkede anlegg Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway.

Haugen I.N and Mikkelsen. Ø. (2019). Continuous heavy metal monitoring in water for closed containment systems in aquaculture 2019, New Orleans 7-11th March.

Haugen, I. N. (2018). Monitoring and sensor development for metals and nitrate in aquaculture NFR HAVBRUK PhD-samling, Asker 4 september 2018.

Hjelle, E. (2018). Erfaring fra smoltifisering i RAS vist ved SmoltVision. Kunnskapsoppdatering om optimal post-smolt produksjon. CtrlAQUA workshop, Bergen, Norway, 31 January 2018.

Johansen, LH. (2018). Prevention, detection and control of diseases in closed containment systems – results from projects in CtrlAQUA SFI Aquaculture innovation workshop, Dec 4-6, Miami, Florida.

Karlsen, C.R., Ytteborg E., Timmerhaus G., Høst V., Handeland S., Jørgensen S. M., Krasnov A. (2018). Hudens utvikling og immunfunksjoner i postsmoltfasen Havbruk 2018, Oslo.

Karlsen, C.R. (2018). Effekt av håndtering og utvikling av barrierefunksjoner i postsmoltfasen. Kunnskapsoppdatering om optimal post-smolt produksjon. CtrlAQUA workshop, Bergen, Norway, 31 January 2018.

Karlsen, C.R. (2018). Påvirkning på laksens immunforsvar ved overføring til sjø. Europharma Lofotseminar, Lofoten, Norway, 13-15 June 2018.

Karlsen, C. (2018). Betydningen av god skinnhelse hos postsmolt Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway.

Kolarevic, J. (2018). Effects of seawater quality on treatment of intake water for use in closed-containment aquaculture systems. TREAT Workshop, Treatment strategies in CCS/RAS: Impacts on system performance, water quality, biosecurity and fish health. CtrlAQUA workshop, Gardermoen, Norway, 16th of April 2018.

Kolarevic, J. (2018). Experiments in semi-closed containment systems: case Smøla. Fagdag – Fiskeridirektoratet, Bergen, Norway. 12th of April 2018.

Kolarevic, J. (2018). General Discussion for Task INTAKE. TREAT Workshop, Treatment strategies in CCS/RAS: Impacts on system performance, water quality, biosecurity and fish health. CtrlAQUA workshop, Gardermoen, Norway, 16th of April 2018.

Kolarevic, J. (2018). Light Quality experiment RAS

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Kolarevic, J. (2018). The biological requirements for Atlantic salmon (postsmolt) production in RAS Patagonic RAS, Puerto Varas, Chile, 5th of April 2018.

Kolarevic, J. (2018). Light intensity: Survey of commercial RAS facilities Skretting seminar, Alta, Norway, 5th of April 2018.

Kolarevic, J. (2018). Hvordan dokumentere fiskevelferd i lukkede anlegg? Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway.

Kolarevic, J. (2018). Optimizing Light in Closed Containment Systems Aquaculture innovation workshop, Dec 4-6, Miami, Florida.

Lazado, C. (2018). DISINFECT: Perspectives and plans. TREAT Workshop, Treatment strategies in CCS/RAS: Impacts on system performance, water quality, biosecurity and fish health. CtrlAQUA workshop, Gardermoen, Norway, 16th April of 2018.

Lazado, C.C. (2018). Mucosal health in closed-containment aquaculture systems Invited speaker, Temasek Polytechnic, Singapore, July 4, 2018.

Lazado, C.C, Timmerhaus, G., Alvin Cabillon, N., Reiten, B-K., Johansen, L-H. (2018). Effects of low to very high water velocities on Atlantic salmon post-smolts: Part II: Welfare, mucosal health and stress responses 8th International Symposium on Aquatic Animal Health, 2-6 September, Charlottetown, Prince Edward Island, Canada.

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Mikkelsen, Ø. (2018). Hvordan kan vi forbedre påliteligheten av data fra sensorer for overvåking av vannkvalitet i CCS / S-CCS Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway

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Navada, S. (2018). Experiment 1 CtrlAQUA video presentation Sunndalsøra, January 1st 2018.

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Navada, S. (2018). Effekt av endring i salinitet ved nitrifikasjon i MBBR Fremtidens smoltproduksjon - Femte konferanse om resirkulering av vann i akvakultur, 23.-24. October 2018, Sunndalsøra, Norway.

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The host institute Nofima with it's CtrlAQUA management is based at Sunndalsøra in Norway. The long building in the middle/back of the picture is the Norwegian Centre for Recirculation in Aquaculture, which is a much used research facility in CtrlAQUA. Photo: Kjell Merok, Nofima.