CtrlAQUA

Annual Report 2016
CtrlAQUA - Centre for Closed-Containment Aquaculture

Photo: Terje Aamodt©Nofima

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

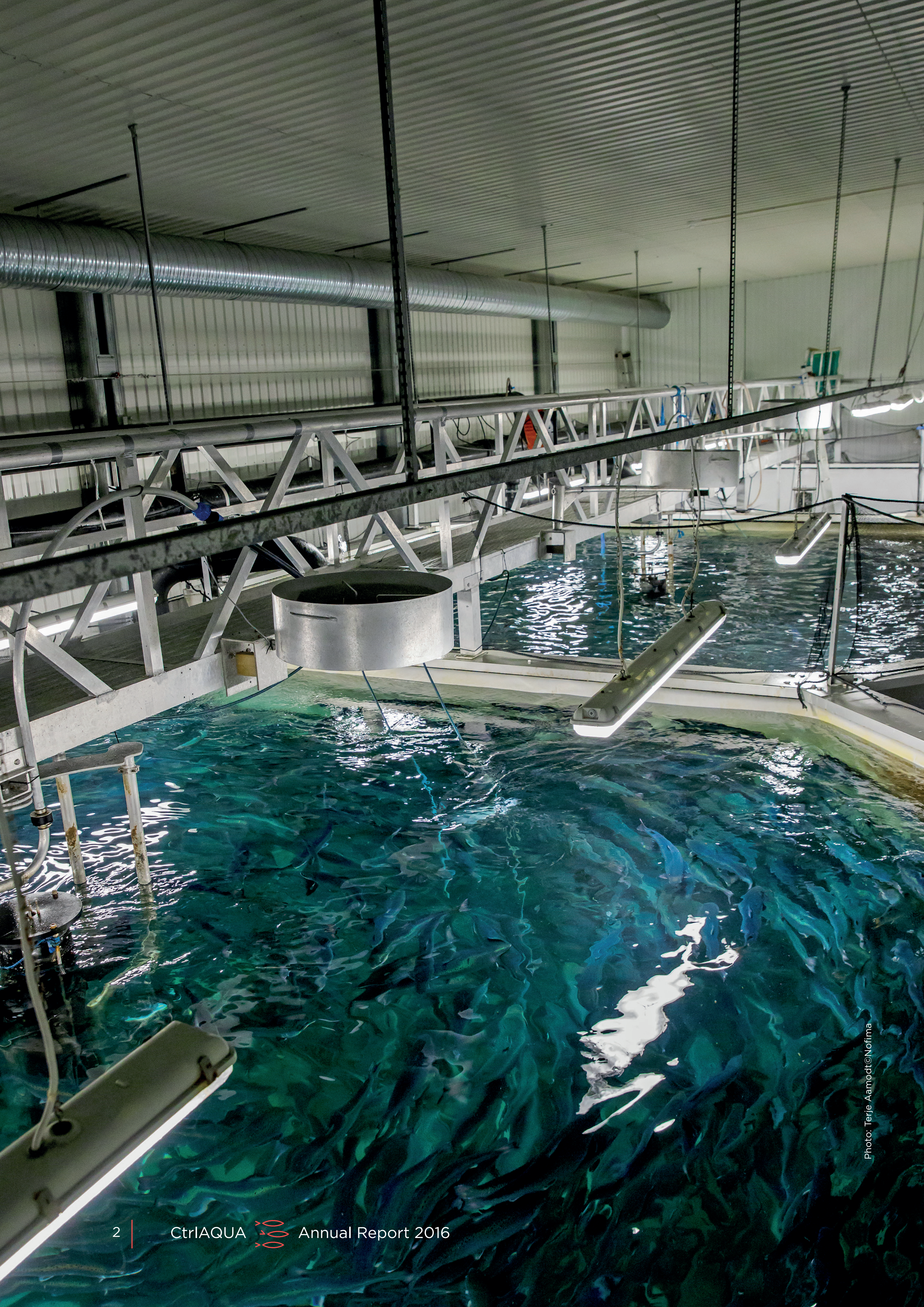


Photo: Terje Aamodt©Nofima

CONTENT

Photo: Terje Aamodt©Nofima

Centre Director Bendik Fyhn Terjesen, Nofima.

1 OVERALL PROGRESS AND SUMMARY FOR 2016

In CtrlAQUA our vision is to develop technological and biological innovations that will make closed-containment aquaculture systems (CCS) a reliable and economically viable technology. In 2016 we have demonstrated through several large-scale experiments that the use of closed-containment aquaculture systems can provide a solution to the problem of sea lice, one of the biggest challenges that prevent further growth of salmon farming. We find either no sea lice at all or very little lice on salmon reared in CCS. This is because closed systems are facilities for fish farming where the environment of the fish is separated from the ambient environment outside by an impermeable wall. This wall prevents the sea lice from gaining entry to the culture tank environment, and thus the lice cannot settle on the fish. In closed systems, the water is pumped into the tanks through pipes with just a few m^2 area. In traditional open systems, however, the water comes through the vast area of the net, which has several thousand m^2 of area. This makes it much harder to control that no sea lice enters into the cage.

During the year of 2016, we researched many different types of closed-containment aquaculture systems in CtrlAQUA. The studied systems are either land-based where the water is recirculated, called RAS. Here, we find that it is relatively easy to control the farming environment, in terms of water quality, temperature and other variables. We also research floating closed-containment aquaculture systems in the sea, called S-CCS for short, where control is also possible although not to the extent seen in RAS, due to the higher new water flow requirement. The prototypes that we have tested are of many different forms - either large bags or they are solid structures shaped like tanks or pipes. Common to them all is that they eliminate or reduce issues with sea lice.

In CtrlAQUA during 2016 we have been running a total of 18 projects, distributed across the three departments of technology, fish welfare and fish health, and supported by Dept. Training and Recruitment. We have worked in 2016 to strengthen the knowledge-base for reliable use of closed-containment systems. The results bode well for the goal that CCS should reach a level of reliability equal to an "off-the-shelf" product within the life-time of CtrlAQUA, meaning that it is a technology that is proven, predictable and gives the fish a good welfare and health.

We have found again that when salmon are kept in closed systems, in as various designs as bags, tanks, pipes or land-based RAS facilities, they still result in high survival of the fish, good growth rate, and no or very little sea lice. We also studied microparasites (e.g. virus and bacteria) in two different types of floating closed-containment systems in sea, over two consecutive production cycles and in a commercial-scale land-based RAS for posts-molts. When completed, this dataset will be a valuable tool for directing the later research efforts in the centre on how to avoid and control disease outbreaks in closed systems.

Although closed systems makes it possible to control the fish's environment almost exactly where *you* want it, there is a lack of research on exactly how the *fish* prefer it. Much of the previous research on fish environmental requirements have been done in open traditional cages, or in land-based flow-through systems and is therefore not always relevant to modern closed-containment systems. We have in 2016 conducted several experiments to determine optimal environmental conditions. For example, we performed experiments to find the maximum concentration of particles that salmon can handle when reared in RAS, and surprising results turned up. Some fish performance data (feed conversion, survival) and oxygen consumption wewre adversely affected by very high particle loads in the water but, surprisingly, gill scores and external welfare indicators indicated better fish health and welfare when exposed to high particle loads. Clearly more research and analyses must be devoted to this topic in the centre. We are also investigating limits for fish density and, after oxygen, limits for the often most decisive water quality factor for flow rates and pumping costs, namely CO_2 concentration in the RAS water.

When it comes to fish density (kg/m^3) in the culture tanks, this is a factor that has great impact on economics of closed systems, both in terms of investment and production costs. To reduce production costs in closed systems high fish density is advantageous, but this can only be done if it does not adversely affect welfare and health. We found that in land-based facilities the choice of technology and water quality significantly influence the tolerance of the fish to high density, before it starts to affect health and welfare. Our findings show that the skin of post-smolts from closed systems reflects both fish density and rearing technology, almost as a living sensor.
Another tissue, the brain, is also very useful to increase our knowledge: Earlier in the OPP project, we found that the maximal density of fish in floating closed-containment systems in the sea should be 75 kg per m^3 of tank water volume. We have now demonstrated that at this fish density certain genes in the brain, being important for learning and stress tolerance, is actually expressed at higher levels at 75 kg/m^3, than when the fish are held both at lower or higher densities.

In the center we also focus much on the technological aspects of closed systems. We suspected, and have indeed found that the large culture tanks now being used in CCS, of several thousand m^3 volume, can offer challenges in terms of hydrodynamics. This can be seen in models and measurements as whirlpools and dead-zones in the large tanks, which may cause problems for the fish and for the self-cleaning of feed remnants and faeces from the tanks. In order to develop solutions to these challenges we have created advanced computer-based flow models, such as being used for construction of new aircrafts and ships. This tool will be valuable for the continued research on large culture tanks, on land and floating in sea, in the centre in 2017. The R&D partners also experience much interest from external farming and aquaculture equipment suppliers who want information and projects on hydrodynamics in closed systems.

Another technology research field is sensors for water quality in closed systems. Correct information about the environment is essential to operate closed systems in a safe manner. However, the sensor technology is not sufficiently developed for intensive aquaculture systems. Over time sensors can return wrong values, with catastrophic consequences, sometimes within minutes, in closed systems where the fish is reared at high density and intensity. In CtrlAQUA we have developed promising compounds to be tested for surface treatment of sensors. These compounds can improve long-term reliability of real-time water quality measurements in closed systems.

In 2016 the centre really got up to speed. We have already published several papers in peer-reviewed journals, and are frequently invited as speakers or session chairs at meetings. Since the start of the centre we have organized two major research conferences on closed systems with several hundred participants. Many students are doing their thesis work connected to CtrlAQUA, and they are increasingly becoming a vital part of the centre. Several external commercial companies have expressed interest in joining the centre. The Board has established a system of associated projects, and six such projects have been funded partly as a result of the activities in the center. We believe that through the innovation-oriented research in the centre, CtrlAQUA have in 2016 contributed to increased knowledge on how to farm salmon in closed systems.

March 2016
Bendik Fyhn Terjesen
Centre Director CtrlAQUA SFI

Photo: Terje Aamodt©Nofima

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

In the report "Value created from productive oceans in 2050", aquaculture is expected to increase 5x in volume and 8x in value. The Norwegian authorities and salmon industry work towards this vision. But there are challenges that may hinder achievement of this goal, such as sea lice, diseases, escapes, and the loss of fish through production. 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"

From the opening of CtrlAQUA, May 2015. Per Brunsvik (Nofima), Bendik Fyhn Terjesen (Nofima), Elisabeth Aspaker (Minister of Fisheries), Øyvind Fylling-Jensen (Nofima) (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 (S-CCS). In CtrlAQUA the research deals with both approaches.

In the centre we focus primarily on the most sensitive phases for the salmon in the production cycle, such as the first seawater phase, the so-called post-smolt stage (Figure 1.1). However, the research is also highly relevant for other strategies shown in the figure. The main innovation will be reliable and efficient production of post-smolts in closed systems on land or 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 welfare and sustainability in closed-containment farms.

We do this through development of new and reliable sensors, minimizing environmental impact through recycling of nutrients and reduce the risk of escape, and diseases transmission to wild stocks. These innovations will be of value to the Norwegian society, since closed systems for strategic phases in salmon farming can help to make the vision of an eight-fold growth in value creation from aquaculture possible, and lead to increased number of jobs and production of healthy seafood.

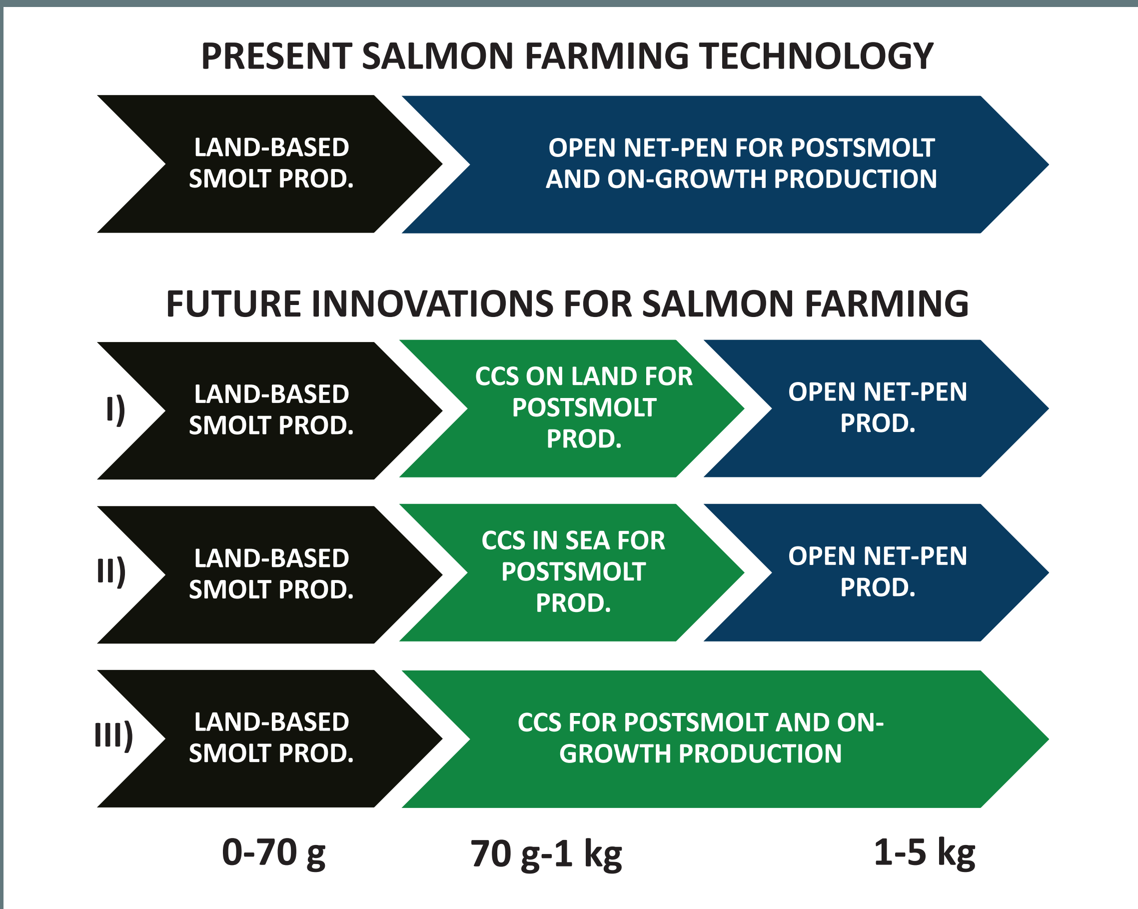


Figure 1.1. Present salmon farming technology, and future innovative strategies (I-III). CCS: Closed-containment aquaculture systems.

MEET THREE BUSINESS PEOPLE IN CtrlAQUA

They have different motivations for being in CtrlAQUA. But they all have an unshakeable belief that a closed facility will play a significant role in salmon farming of the future. All three are partners in CtrlAQUA and are involved in testing out the various technologies that are being researched.

The equipment manufacturer from Trøndelag

Magnus Stendal,
Botngaard Systems AS

Photo: Glen Musk©Nofima

The first company out as an SFI partner is Botngaard AS from Bjugn. They joined CtrlAQUA in 2016.

When they were established in 2009, they supplied delousing tarpaulins for fish farming facilities. Since 2010, they have taken the next step and developed a concept for semi-closed cages at sea. They achieved this in a network with other technology companies. But Botngaard needed a larger community, in part to access biological competence.

"Joining CtrlAQUA was an important part of our development strategy. We wanted to not only develop our own concept, but to also acquire sound knowledge on cage environments and fish health, which is a central focus of CtrlAQUA," comments Magnus Stendal, Managing Director in Botngaard Systems.

"For us it was important to get answers to questions such a what is good enough for the fish, and what is their tolerance in closed production," says Stendal.

CtrlAQUA contributes to Botngaard's innovation in two ways: By being a meeting place for people interested in closed fish farming production, and by having a project platform in which solutions could be tested in collaboration with partners from other disciplines.

"We are particularly interested in projects in the hydrodynamics of closed tanks and the treatment of intake water. We are also conducting a number of studies ourselves, and believe we can contribute greatly in CtrlAQUA. For example, we have experience with very large tanks (4000-7000 m^3), and testing of closed systems for large salmon," states Stendal.

Botngaard has tested closed systems with broodfish weighing around 12 kg which had lice when they were stocked. In the closed cages, lumpfish did the job of keeping the level of lice down, and that worked well.

"For us, it is essential to have a flexible technology platform with diverse applications. Also for the late phase, before harvest size. At the moment we do not have the technology to manage such large biomasses with such intensive feeding, but who knows where we will be in 10 years time?

Bontgaard has been directly involved in the CtrlAQUA project FLEXIBAG, which has been tested by Nekton Havbruk in Smøla. There, the postsmolt were contained in a closed system until they were 360 g, when they were transferred to open cages. Ten months later they were ready for slaughter. Traditional fish production in open cages normally requires 18 months in the sea.

"So I believe that, in a few years, we will see postsmolt in closed cages where they will grow up to a kilo in weight. The time in open cages will be reduced to 7-8 months," says Stendal.

Even though he is a supporter of closed systems, he nevertheless believes that in the future 85-90% of salmon growth will take place in open systems.

"We believe that halving the time in the sea using closed systems will generate great value for industry and for society. Less lice is one of the advantages of closed technology; less mortality is another. We believe this is definitely the right way to go, I am convinced of that. And it is possible," says an enthusiastic Stendal.

"Our contribution to developments is that every new closed system installed along the coast advances closed farming. We are therefore contributing to moving developments closer to the goal of making closed fish farming technology a shelf product.

The fish farmer at Bømlo

Geir Magne Knutsen, Bremnes

Photo Magne Langåker©Nofima

Bremnes Seashore is building recirculating aquaculture systems (RAS) for smolt on land. This is part of a long-term strategy based on a detailed assessment of the future production of salmon with little sea lice.

"We have tested many options but are now focussing on land-based production of large smolt. We have converted one of our hatcheries to enable production of fish up to 200 g on land. And now we are building two new halls to produce fish up to 500 g," says Geir Magne Knutsen.

Knutsen is Development Manager at Bremnes Seashore. He is convinced that large smolt on land is the right direction for Bremnes:

"From our own production, we see that fish stocked as 200 g in the spring tolerate more with less mortality, and achieve the slaughter weight more quickly, than smolt stocked at 100 g. And a shorter time in the sea means a lower risk of sea lice infection," says Knutsen.

Knutsen's observations in their facilities correlates well with the research done so far at CtrlAQUA. A high degree of control appears to be positive, both in regard to efficiency and the health of the fish. The development of closed facilities on land has taken off with the increasing problems with salmon sea lice, and because regulations now facilitate it. In 2016, permission was given to farm salmon all the way up to slaughter size in facilities on land.

"But we are moving into uncharted waters when we produce large salmon on land. So we wanted to join CtrlAQUA to be at the forefront of knowledge, and to collaborate with other researchers and fish farmers who have the same focus as us," states Knutsen.

What do you get out of the collaboration with CtrlAQUA?

"We make a number of choices that are partly influenced by the results from CtrlAQUA. Some are knowledge we already possess, but this knowledge has now been strengthened by the research. For example, selecting the tank size and light fittings has been influenced by the results from CtrlAQUA."

Knutsen also explains how they want to use the collaboration to bolster innovation in the company.

"Even though in a recirculating facility we have control of environmental factors such as temperature, lighting and feeding, the fish are to be released into the sea with naturally varying temperatures. We have knowledge gaps, for example on how to avoid early sexual maturation. By participating in CtrlAQUA, it is easier for us to conduct research on our facilities and to solve the challenges we are focussed on.

Originally, the idea was that Bremnes should contribute to CtrlAQUA with semi-closed facilities in the sea. But they decided against that and went for land-based. Knutsen has most faith in land-based for three reasons. He believes that it will be easier to control infection; that it will require less maintenance; and that it will be easier to meet increasingly stringent cleaning legislation.

"But not everyone agrees with me. Fortunately, because then several possible solutions will be tested. Whatever the results, I believe that by 2023, quite a large number of hatcheries will be built with the technology that we are now developing," says Knutsen.

And it doesn't stop there. Knutsen says that Bremnes will evaluate whether in the future it will expand to 1,000 g. So far, NOK 600 million have been invested in the production of up to 500 g.

"I will need to prove my case if I am to get acceptance to expand for the production of 1,000 g on land. But the gains to be realised by cutting down on the production time are so great that I believe it will pay," states Knutsen.

The technology founder in Vestfold

Bård Haug, ORP

Foto: Espen Winther/Norma

In office premises in Horten, in the development company ORP - Oslofjord Ressurspark, you will find Bård Haug. On his shelves he has two patents, and in his head he has ambitions.

The patents were the brainchild of his former colleague, Frank Karlsen, at the University College of Southeast Norway and deal with genetic analysis and particle separation. According to Haug, the patents open up for opportunities in medicine and early detection of cancer. But what does this have to do with closed fish farming facilities? For ORP, it's about market strategies.

"The instrument we are developing can be used to measure any and every biological activity. But we are a small start-up company and had to decide which industry we were to focus on," says Haug.

"In CtrlAQUA we saw a national, resource-strong group in an industry that needs improved disease control. I am a marine biologist with a history from fish farming, so this is familiar country for me," comments Haug. He also wants to contribute to sound management and production of fish in Norway.

"Our tool is nano- and microtechnology," says Haug.

In addition to patents and ambitions, ORP has the electronics company Mectro next door. They will put the technology into production. And they are well on their way with a prototype that will be ready in the spring of 2017.

ORP's primary contribution to development of closed facilities is the analytical instrument "PocLoc" which will measure the pre-stages of disease. With the technology they are sitting on for genetic analyses, they will be able to automatically measure whether a disease-triggering pathogen is present in a tank of fish, and the activity level, long before there are any visible biological consequences apparent on the fish. The knowledge on particle separation is used to collect enough data on sampling. This means that they can extract minute traces in a concentrated sample from a cubic metre of water. Post-doc Nhut Tran is working with this technology in a separate project in collaboration with Nofima.

Haug could not have wanted a better laboratory than that provided by closed containment aquaculture systems. These have full control of the water parameters. For Haug it is also important to work in clusters with people who have the same understanding as them. In CtrlAQUA, this common understanding is that control is important.

"Clusters are a type of collaboration that is essential if we are to succeed. We are dependent on the cluster in Horten and the cluster in CtrlAQUA.

"To illustrate how extremely important CtrlAQUA is for a small founder company like ours, we can look at turnover. About 12 % of turnover goes to our membership subscription to be in the centre. But we believe that as early as 2018 or 2019 we will have products on the shelves. Then things will be easier financially".

Discussions with partners in the centre have given Haug good ideas on the way forward for this small company from Horten. For example, salmon sea lice, poisonous algae and food safety monitoring on the salmon harvest process line.

"We will continue in fish farming and develop ORP further in this sector", says Haug.

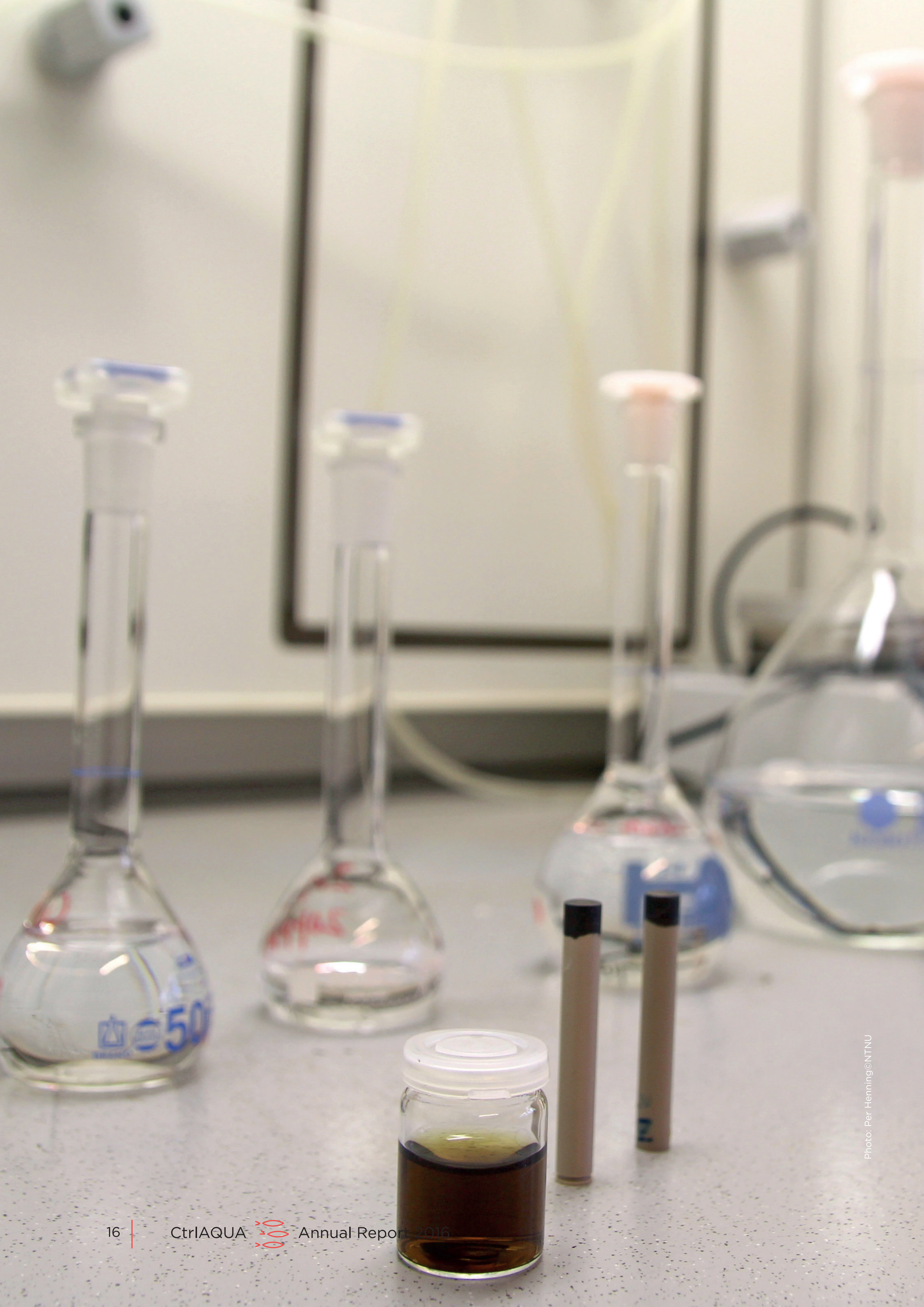


Photo: Per Henning©NTNU

2 RESEARCH PLAN/STRATEGY

CtrlAQUA commenced operations in April 2015. The Research Council of Norway's objectives in running the SFI-program are four-fold: 1) to stimulate innovation activities in strong industries in Norway, 2) to promote collaboration between innovative industries and excellent research institutions, 3) to develop industry-relevant research institutions that are leading in their field, and 4) to educate new scientists and foster knowledge- and technology transfer. These goals, in addition to the specific goals of the centre, forms the basis for the work in CtrlAQUA. Through close collaboration between user partners and the R&D institutions, the centre focus on new closed-containment system innovations, such as new RAS process units and methods for improved fish welfare and health, shown in Figure 3.1.

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 and annual 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 projects which are divided into common projects and user-specific projects. Both types of projects contributes towards the main goal of the centre. Common projects are defined as activities that benefit all partners in the centre, such as environmental requirements of salmonids in closed-systems or 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.

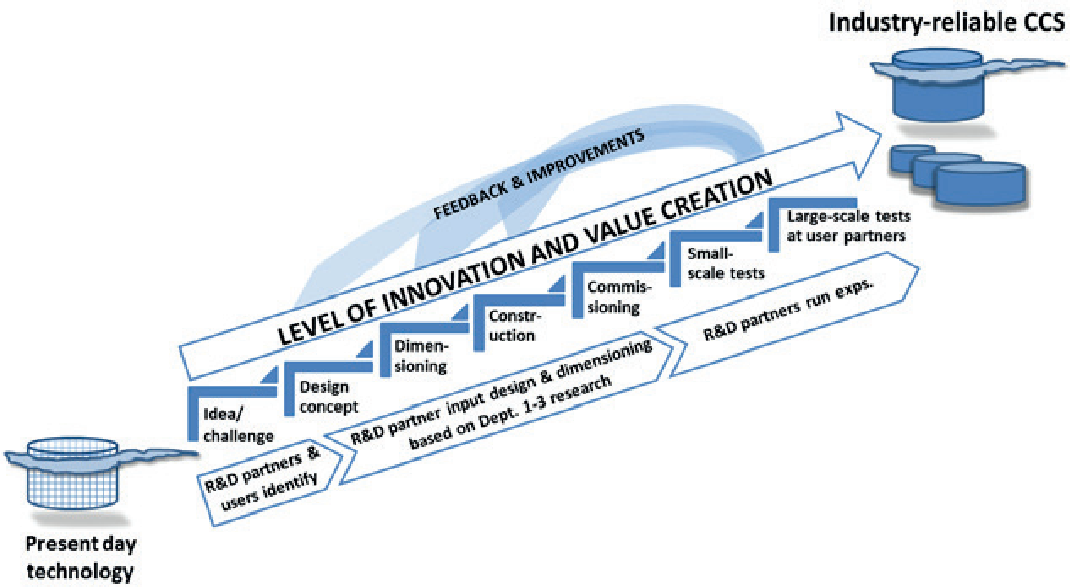


Figure 3.1. Innovation process in CtrlAQUA, from present day cage technology, to establishment of industry-reliable closed containment systems, either in-sea closed tanks or land-based RAS. Exps': experiments.

3 ORGANIZATION

Organizational structure, and cooperation between the center's partners

CtrlAQUA is organized (Fig. 3.2) 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. The Board consists of the following elected members (Fig 3.1):

- Frode Mathisen, Grieg SeaFood, chairperson of the CtrlAQUA Board
- Harald Sveier, Lerøy SeaFood Group, Board Member
- Knut Måløy, Storvik Aqua, Board Member
- Siri Vike, Pharmaq Analytiq, Board Member
- Tor Solberg, UNI Research, Board Member
- Mari Moren, Nofima, Board Member and representing the host institution

Figure 3.1. The CtrlAQUA board. Back left: Harald Sveier, Knut Måløy, Tor Solberg. Front left: Siri Vike, Frode Mathisen, Mari Moen (photo: Terje Aamodt©Nofima)

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

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 is managed in Dept. Training & Recruitment.

The leader group manages and leads CtrlAQUA, such as ensuring planning and running of experiments, recruitment of qualified personnel, and providing a good working environment.

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, as well as joint experiments, sampling and analytical work. Frequent meetings are organized at Board level (each six months), Center level (annual meetings), Dept. level (each month), leader group (every third week), and at 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 and pictures. 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.

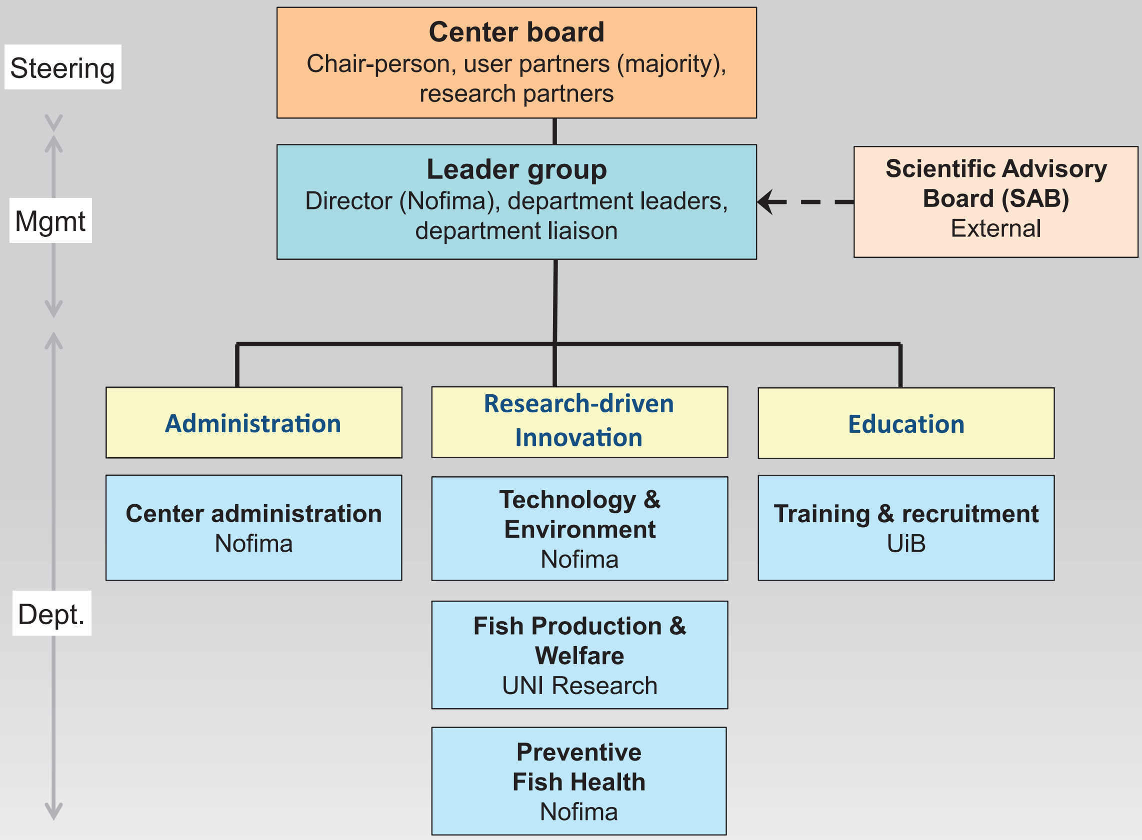


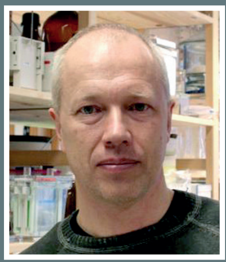
Figure 3.2. Organizational structure of CtrlAQUA.

The leader group

Dr. Bendik Fyhn Terjesen
(Nofima)
Center director, overall scientific and administrative leader and manager of Department Technology and Environment

Dr. Sven Martin Jørgensen
(Nofima)
Scientific manager of Department Preventive Fish Health

Dr. Lars Ebbesson
(UNI Research)
Scientific manager of Department Fish Production and Welfare



Dr. Sigurd Stefansson
(UiB)
Scientific manager of Department Training and Recruitment

Dr. Sigurd Handeland
(UNI Research)
Dept. liaison, ensuring collaboration between departments. Identify sub-projects and user partners for projects

Dr. Astrid Buran Holan
(Nofima)
Responsible for organizing meetings (invitations, logistics etc).

Dr. Åsa Maria Espmark
(Nofima)
Responsible for external and internal technical reporting

CtrlAQUA

PARTNERS

Per April 1, 2017, CtrlAQUA has 21 partners, where seven are R&D partners and 14 are user partners

There have been a few changes in the list of user partners in 2016:

- Botngaard AS was approved as a member of the consortium in 2016.
- University College of Southeast Norway (USN) was approved as a member in 2016

R&D PARTNERS

Nofima

uni Research

UNIVERSITY OF BERGEN

NTNU
Norwegian University of Science and Technology

HSN Høgskolen i Sørøst-Norge

UNIVERSITY OF GOTHENBURG

THE CONSERVATION FUND

Pharmaq Analytiq is a Norwegian biotechnology company. Havbruksinstituttet AS was founded in year 2000 to provide services in the industry. The services were counseling, biological quality assurance and production optimization. In 2008 the company opened its state-of-the-art real time RT-PCR laboratory for the detection of pathogens. The laboratory was accredited by Norwegian Accreditation in January 2011. Havbruksinstituttet AS was in 2012 bought by PHARMAQ Holding AS, and changed its name that year to PHARMAQ Analytiq. Analysis and advice on smoltification and infection monitoring is today the main aims of the company. They are specialized in analytical services and consulting to improve fish health and welfare in aquaculture. 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, who both have an extensive research background in fish health. PHARMAQ Analytiq will contribute in development of tools for assessment of salmon post-smolt robustness, and pathogen tests.

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) and New York (NYSE). The global headquarters are located in Bergen. In CtrlAQUA Marine Harvest is represented by Group Manager Technology Ragnar Joensen, and Fish Health Specialist Harald Takle and Industry-PhD student Sara Calabrese. In addition to the closed-containment system site at Molnes, Marine Harvest RAS sites such as Steinsvik is also provided to CtrlAQUA.

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, who is also a member of the CtrlAQUA board, will head Lerøy's work in developing closed-containment systems, and the testing-site Samnanger.

Cermaq Norway produces Atlantic salmon with operations in Nordland (22 licenses and two processing plants) and in Finnmark (27 licenses and one processing plant). The four freshwater sites are all located in Nordland. Cermaq's vision is to be a leading aquaculture company in Norway, through sustainable salmon farming. 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 R&D Manager Olai Einen. He has extensive background in research, R&D management, fish nutrition and product quality. Cermaq will also contribute with their fish health group, and closed system testing facilities.

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 are 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 Director Biological Performance and Planning 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

Krüger Kaldnes AS is an internationally oriented, Norwegian company that provides total solutions for wastewater treatment, water treatment, sludge treatment, rehabilitation and services to Municipalities and Industry in Norway. As part of Veolia Water, Krüger Kaldnes can offer a diverse range of world-leading technologies and products. The company is best known for Kaldnes®MBBR process, which is the market leader in the world and meets EU requirements for tertiary treatment. Known technologies in aquaculture is Kaldnes® Recirculating Aquaculture System (RAS), which includes particle separation with Hydrotech drum filters and biological treatment with Kaldnes® MBBR. In CtrlAQUA, Krüger Kaldnes is represented by VP Aquaculture Marius Hægh, and R&D Manager Yngve Ulgenes, who has 23 years of research background in SINTEF on water treatment technologies. Kaldnes will contribute with own expertise, and prototype hardware.

ORP Oslofjord RessursPark

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.

SMØLA KLEKKERI OG SETTEFISK A/S

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 was started up in 1984, and in 1999 it was invested in eel farming. The farm also has a cod license, but todays activities are hatching until feeding of trout and salmon. 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 AS

Aquafarm Equipment AS is the world's leading designer and producer of floating closed fish cage systems. The Neptun Cage has proven to give many advantages; no chemicals required for delousing, improved Feed Factor (FCR), reduced mortality, no escapes, controlled water flow and oxygen saturation, etc. The new generation of Neptun is now ready for sale. In CtrlAQUA, Aquafarm Equipment AS is represented by engineers CEO Atle Presthaug, and project manager Arne Henry Nilsen, and contribute with their expertise in engineering of floating closed-containment systems in sea.

FishGLOBE is a company that has developed, built and is testing a new solution for closed aquaculture. The solution is patented. The company was established in 2013, but the development of closed aquaculture technology has roots back to the late 80's. Then a closed solution was developed in concrete together with AS Betong. 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 Director Arne Berge.

PHARMAQ is the world's leading pharmaceutical company supplying the aquaculture industry 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 Manager Virus Technology Karine Lindmo Yttredal, and will contribute with expertise and vaccine development in Dept. Prev Fish Health.

Storvik Aqua is a Norwegian equipment supplier that has worked to help customer profitability to increase in correlation with fish welfare for over 30 years. The aim is to constantly develop, produce and deliver sustainable and eco-friendly solutions, designed to improve production for our customers. The products 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, Storvik Aqua is represented by chairman Knut Måløy (also member of the CtrlAQUA Board), and CEO Svein Arve Tronsgård, and will contribute to Dept. Tech & Env. with equipment prototypes, and expertise.

Botngaard's primary focus is the supply of tarpaulins for Aquaculture. The use of tarps have 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.

Photo: Reidun Lilleholt Kraugerud©Nofima

4 SCIENTIFIC ACTIVITIES AND RESULTS

DEPARTMENT FISH PRODUCTION AND WELFARE

The main objective of Department of Fish Production and Welfare is to provide knowledge and innovations to determine environmental and biological requirements of Atlantic salmon in Closed and Semi-Closed Containment Systems (CCS and S-CCS, respectively). To this end we have projects that 1) innovate new biological markers that will improve physiological and robustness assessment to reduce losses through improved adaptation to new or changing environments; 2) optimize environmental rearing conditions by identifying biological limits and optima in small to medium scale flow-through and Recirculation Aquaculture Systems (RAS); and 3) characterize the fish performance and welfare of salmon post-smolts in large-scale S-CCS and CCS. In summary for 2016, we investigated new ways to assess smolt and post-smolt quality and delivered new innovation tools for physiological assessment of smolt (ROBUST). Large experiments were also initiated that span into 2017 aimed towards benchmarking photoperiod and salinity in RAS systems (BENCHMARK). Further optimize rearing conditions to produce larger salmon (up to 1 kg in size) in freshwater in land-based post-smolt production systems to maximise smolt quality and robustness and reduce losses due to disease and early sexual maturation (PHOTO). The biological consequences of transferring post-smolt to different temperatures were also initiated (TRANSFER). A new round of evaluation of the large-scale Preline and Neptune systems continued and was initiated respectively in 2016. The results of these projects will be presented in different venues and here we will show some highlights from 2016.

A central theme in the Department of Fish Production and Welfare is to develop innovations to assess development and robustness. Smolt quality is critical for successful salmon aquaculture, and poor smolt quality may generate a wide range of problems; increased mortality in seawater (SW), increased vulnerability to diseases and poor growth. High quality smolts are also an important factor for successful and economically viable production of post-smolts in closed and semi-closed containment systems. Traditionally the aquaculture industry has documented seawater tolerance through standard seawater tests where survival and plasma ions are measured. In recent years gill enzyme Na^+, K^+ - ATPase (NKA) activity has become an important criterion for evaluation of smolt quality. A smolt with good seawater tolerance is characterized by elevated gill NKA enzyme activity. However, the demands of profitability has led to an increasing industrialization of today's aquaculture industry where intensification of production protocols means that established methods such as measurement of NKA enzyme activity do not always manage to capture sub-optimal quality smolt. Hence the salmon industry continuously seeks practical, cost and time efficient methods to predict smolt quality to ensure sustainable growth and survival in both open and closed production systems. In ROBUST, we have innovated 2 multiplex assays to assess ion-regulatory capacity. The first salmon assay is now licensed to Pharmaq Analytiq and the second Rainbow trout assay is moving on to field verification and subsequent licensing.

In addition to physiology, measures that can predict the competence of fish to adapt and be resilient to environmental changes will

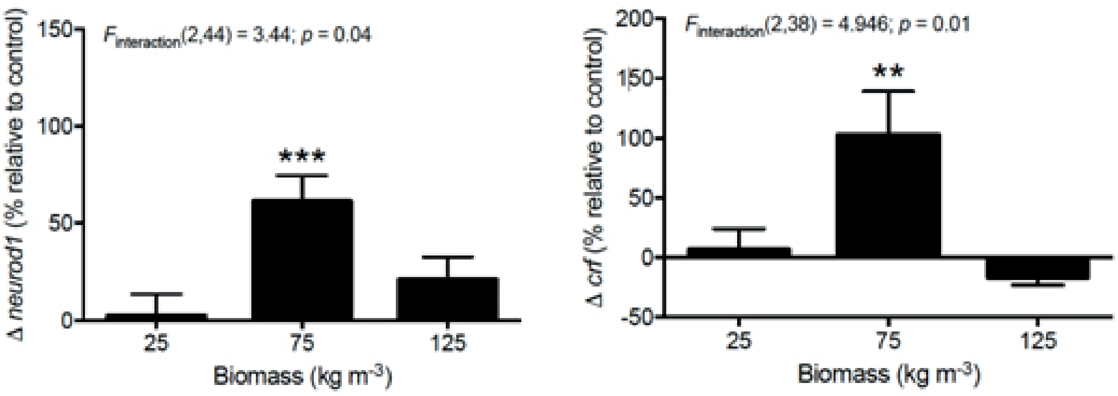


Figure 4.1: Upregulation of genes in the brain after an acute challenge reveal environmental situations that are optimum for salmon to adapt and be resilient to changing environments. (Calabrese et al., submitted)

improve survival. Within ROBUST, we show that how the brain responds to an acute challenge test can provide a refined evaluation of environmental requirements. Rearing density studies show that up to 75 kg/m^3 produce fish with good growth and welfare, in a protected and stable environment (Calabrese et al 2017), but what happens when fish are exposed to additional challenges as changing environments or handling? Our data suggests that also too low density may influence the resilience of postsmolts to challenges.

We have identified several markers that when combined with an acute challenge test consistently reveal pre-existing environmental conditions (favourable or chronic mild stress) in fish and predict the fish´s potential for resilience and adaptation to changes in their environment (Calabrese et al submitted, Figure 4.1). In 2017, we will be analysing material from many of the CtrlAQUA experiments collected previously and ongoing for their adaptive capacity for challenges and innovating new markers that will allow the industry to measure this in an easy and cost effective manner.

The increasing numbers of RAS for production of salmon smolts for transfer to seawater allows production at high temperatures. Furthermore, production of large smolts and post-smolt in RAS and Flow-through (FT) systems provides an even greater flexibility when producing season independent smolts and year-around transfer of post-smolts from CCS into open sea cages. The increased flexibility for season independent production and transfer of post-smolts results in challenges when transferring fish between greater temperature gradients as this may result in growth depression, increased stress and mortalities and poor animal welfare (Hevrøy et al., 2015; Olsvik et al., 2013; Jørgensen et al., 2014). In TRANSFER, part I, we have assessed effects of direct transfer of 250 grams post-smolts from 10°C to 13°C, 16°C and 18°C seawater. Post-smolts appear to handle direct transfer to all three temperatures surprisingly well as no mortalities were observed in any of the groups in the period after direct transfer, however potential additive challenge effects such as crowding and handling during transport or other operational events have not been assessed. This will be investigated in ROBUST in 2017. The skin properties - barrier function showed significant changes both with regard to acclimation temperature and transfer temperature (acclimation $p<0.01$; transfer $p<0.05$). There was an overall barrier strengthening effect in the fish acclimated to 16°C compared to 10 °C ($p<0.001$). A simula-ted acute acclimation temperature revealed an overall barrier disruptive effect, i.e. decreased TER, which was most apparent at 13 °C (Fig. 4.2). This suggests that transfer of

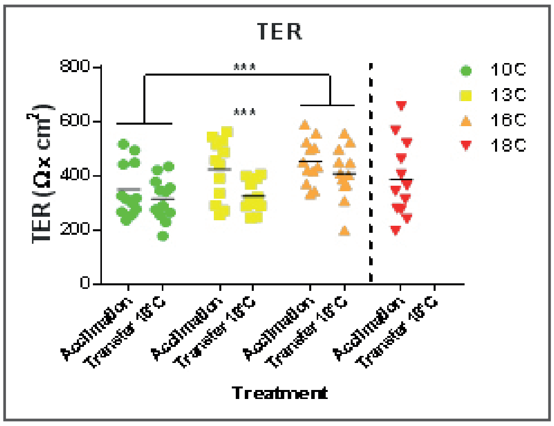


Figure 4.2: Skin from Atlantic salmon post-smolts acclimated at 10°C, 13°C, 16°C and 18°C for 52 days was mounted in Ussing chambers and exposed to 18°C and transepithelial electrical resistance (TER) as a measure of the paracellular permeability was recorded. Asterisks indicate significant differences between groups.

fish to higher temperature results in a disruption of normal barrier function which is most apparent at 13 °C. Further, fish transferred from 10 to 18 °C overcompensate this barrier disruption as suggested by the lower permeability observed in 16 °C fish.

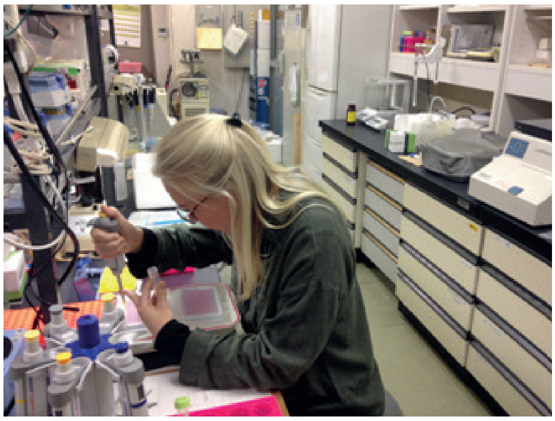


Figure 4.4. CtrlAQUA MSc student Ingrid Gamlem visiting Hokkaido University Japan Fall 2016 to analyse IGF-1 on PRELINE samples.

Evaluation of the large-scale Preline and Neptune systems continued and was initiated respectively in 2016. Postsmolts were transferred to the new Neptune tank in the Fall 2016.

The Preline 2 experiment in 2016 focused on Atlantic salmon post-smolts held in seawater under a constant water current in

Figure 4.3. Preline semi-closed aquaculture system at Sagen, Trengereid fjord, Norway and Neptune

Postsmolts were transferred to the new Neptune tank in the Fall 2016.

a semi-closed raceway system. The overall aim of this project in 2016 has been be to evaluate salmon quality and welfare in the Preline semi-closed containment raceway system, along with water quality, throughout the post-smolt stage of the production. The majority of the results from Preline 2 will be presented in 2017.

The aim of Ingrid Gamlem's MSc-project is to investigate whether post-smolt grow and perform equally well in the semi-closed system, PRELINE, as in open reference cages. She is looking to see if insulin-like growth factor 1 (IGF-I) can be used as one of the tools to evaluate and predict growth in Atlantic salmon post-smolts in ROBUST. In Japan she measured the concentration of IGF-1 in plasma samples using time-resolved fluoroimmunoassay (TR-FIA). The results show so far that the fish in the Preline system reached similar levels of IGF-1 compared to open cages. After standardising for length, results indicate that fish from the Preline system may have a better potential to grow during the on-growing phase in open net pens. More data is needed to confirm this hypothesis, and she is in the process of further analysis of samples in the lab in Bergen.

DEPARTMENT PREVENTIVE FISH HEALTH

Production of Atlantic salmon in closed-containment aquaculture systems (CCS) offers new fish health challenges. New pathogens and new impacts of known pathogens can be the result of increased use of CCS. A holistic approach on fish health and ways to prevent disease outbreaks are critical in CCS, with increased fish densities and short transmission distances. The major objective of this department is to develop new innovative tools to increase pathogen control, minimize disease risk and strengthen the health of salmon in CCS. This, in turn, can contribute to optimized production and reduced losses in CCS. Some of the results in PFH, achieved in 2016, are described below.

To obtain knowledge about pathogens in S-CCS/RAS we sample and analyze fish tissues from these production systems in the project MICROPARASITES, to monitor microparasites diversity, prevalence and load. We have also focused on methodology in 2016. We have developed novel assays for detection of new emerging microparasites in CCS, and studied how the biofilm on tank walls may influence sample analysis and interpretation. It was found that studies of biofilms in S-CCS and RAS facilities, using real-time RT PCR, will have to be optimized for each facility and possibly also for each sampling time point. This raises a serious question about the applicability of real-time screening of biofilms, and this concern must be taken into account when interpreting results.
In 2016, we studied microparasites in two different types of floating closed-containment systems in sea, over two consecutive production cycles and in one commercial-scale land-based RAS for postsmolts. At the production sites, salmon tissues (e.g. gills, kidney and heart) were collected from fish in RAS, at fresh water sites, in S-CCS and in traditional open cages that served as reference. This extensive material on prevalence and load of various pathogens in closed systems, as well as in reference open cages, is currently being evaluated in the centre. When completed this dataset will be a valuable tool for directing the efforts on how to avoid and control outbreaks in closed systems.

In the BARRIER project we work to understand the mechanisms that enhance fish robustness with regards to host-microbial relationships, and intrinsic and extrinsic barrier

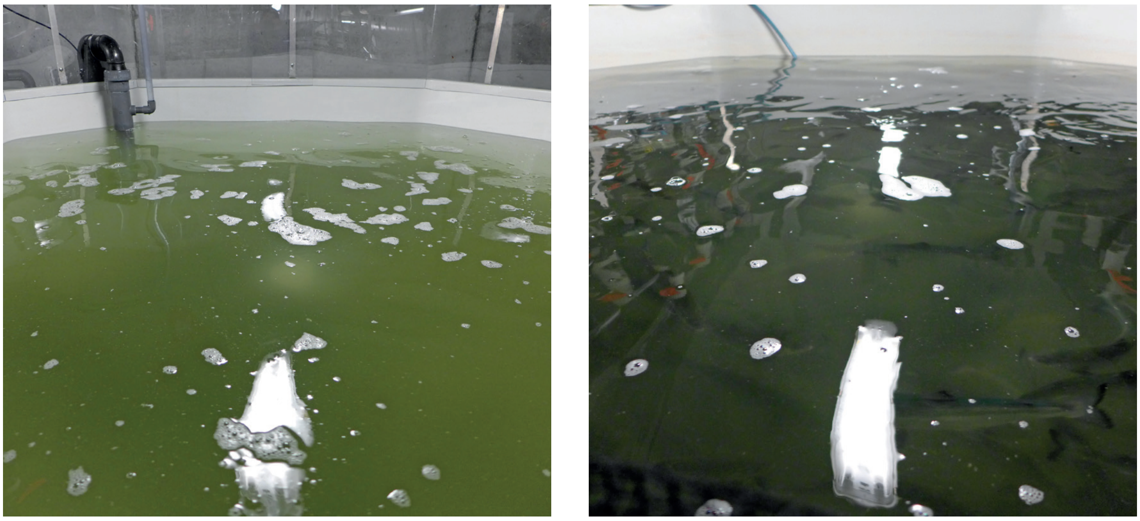


Fig. 4.5. Tanks with postsmolts kept at low density (left) or at high density (rightmost picture). In the BARRIER project and the associated project SalmoFutura, we investigate the effects of density on health and welfare parameters such as skin health (Photo: Jelena Kolarevic).

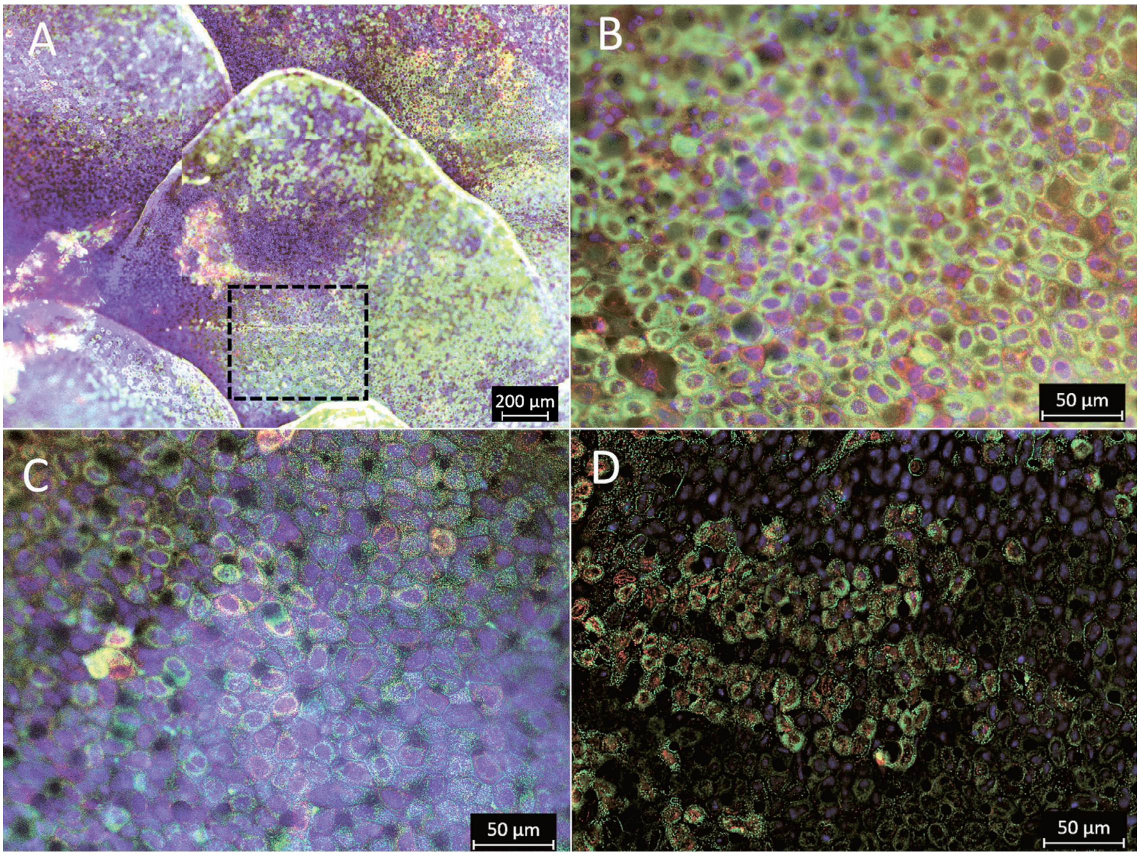


Fig. 4.6. Examples of how skin reacts to changes in the rearing environment of closed systems. The pictures show fluorescence staining of skin samples from an experiment on postsmolt salmon kept at different densities in flow-through tanks. Picture A, top left: Overview picture of whole-mount skin sample, dotted square show standardized analysis area. Note the overlapping scales and differences in fluorescence intensity in different areas of the tissue. Pictures B,C,D: Staining of skin from representative fish reared at either B) 25 kg/m^3, C) 50 kg/m^3 and D) 125 kg/m^3, respectively. Red fluorescence is ConA binding to lectins, green fluorescence is WGA binding to cell membrane and mucus cells and blue fluorescence is nuclear staining with DAPI. The experiment was part of OPP, an associated project to CtrlAQUA (Sveen et al., 2016. Impact of fish density and specific water flow on skin properties in Atlantic salmon (Salmo salar L.) post-smolts. Aquaculture 464, 629-637.)

functions. This will then enable us to develop innovations to secure strong mucosal tissue barriers of post-smolts in closed-containment aquaculture systems. Being in direct contact with the water, the fish skin has important roles in defense and protection against pathogens. In BARRIER we study skin as well as other mucosal tissues, also because they are important target tissues for evaluating welfare. To reduce production costs in closed systems, high fish density is advantageous, but only if this does not adversely affect welfare and health (Fig 4.5 and 4.6). Our findings show that the skin of post-smolts from closed systems reflects both fish density and rearing technology, almost as a living sensor. Both the cell numbers, morphology and gene expression in skin reflect the environment. In a newly published study on the effects of reduced water flow in closed tanks, we found also that while traditional indices such as growht rate or blood physiology offered little information about the effect of the treatments, skin gene expression clearly indicated when water flow was too low. These findings can be used to monitor fish and conditions and overall improve how we farm salmon in closed systems in the future.

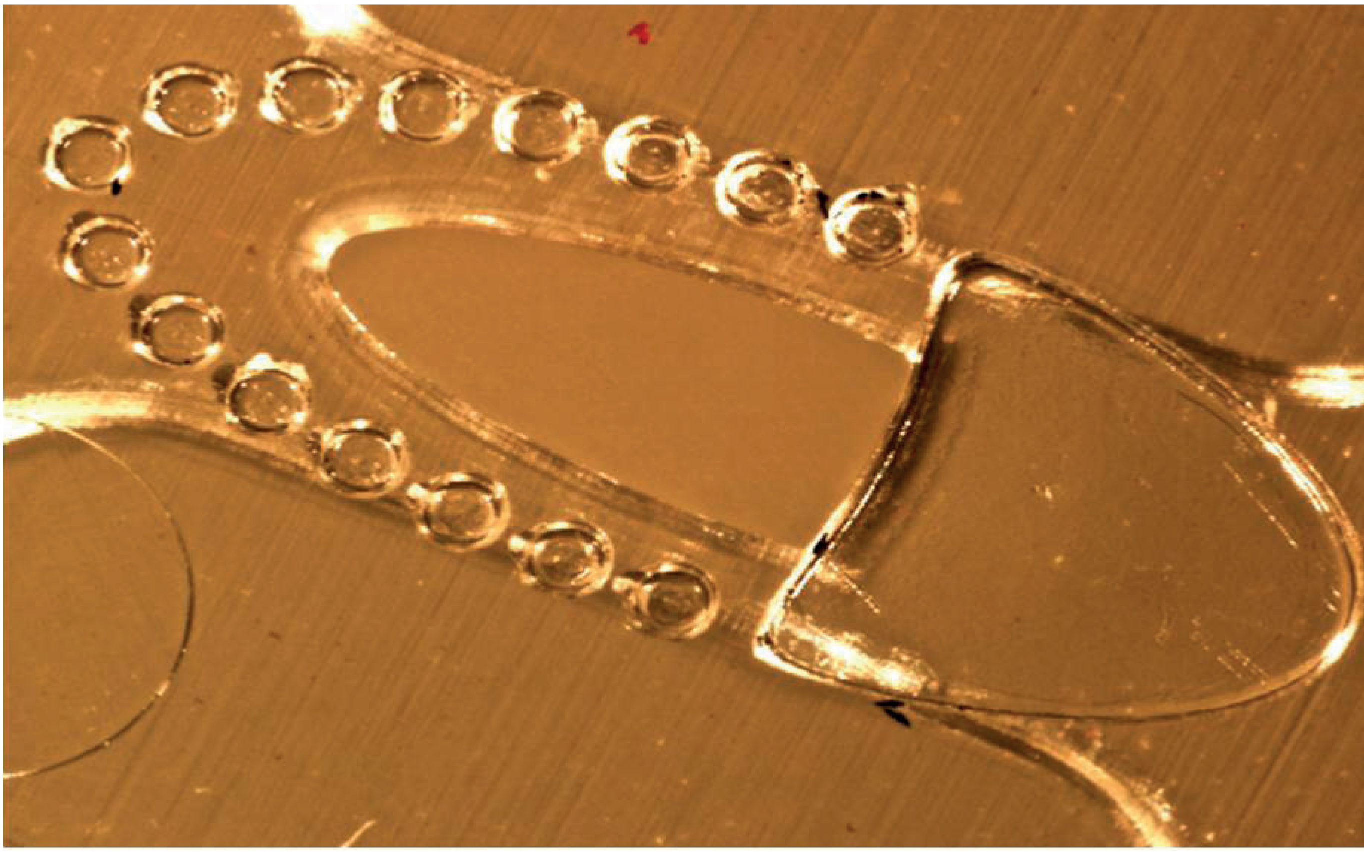


Fig. 4.7. Microscopic image of the continuous separation unit used for separation and concentration of particles, being developed in the post-doc project of Nhut Tran (Photo: Nhut Tran).

Pathogen surveillance is an important biosecurity practice in salmonid aquaculture; however the current analysis turnaround time is a bottleneck for efficient management practice to prevent and minimize risk of disease. A new Norwegian micro-refining technology by partner Oslofjord Ressurspark may help to concentrate, separate and sort unknown or low concentrations of pathogens long before they become a problem. In CtrlAQUA this work is being done in the POCNAD project, as well as in a separate post-doc project to Nhut Tran at Nofima. One of the challenges is to concentrate and separate viruses, bacteria, microparasites, particles or microanimals from large production volumes. This is difficult when the production water is seawater or very complex contaminated water. A continuous concentration and separation technology unit is currently being developed by using injection moulding. Different kinds of liquid or water consisting of various microorganisms are being tested at varying inlet and outlet pressure, including different concentrations of the microorganisms. The preliminary conclusion is that any microanimal may be concentrated from large volumes of sea-water into very small volumes of homogenized concentrated sample. This will significantly increase the sensitivity of any sensor used on this small volume.

DEPARTMENT TECHNOLOGY AND ENVIRONMENT

The goal of Dept. Technology & Environment is to facilitate innovation of CCS technology, water treatment processes, and sensors, to achieve a high level of production control. 2016 was a year with much activity and many experiments were initiated. Here we present some of the projects; other projects in Dept. Tech & Env have also achieved important results which will be presented at various venues during 2017.

Water quality (WQ) monitoring is an integrative part of closed-containment aquaculture system management. The SENSOR project focuses on sensor technologies and water quality in closed systems. A severe problem is the formation of biofilms and siltation on the sensor surfaces after some time use, which typically changes the sensor response and lead to incorrect readings. In CtrlAQUA we therefore develop promising sensor surface coatings. The challenge is to develop a compound layer which stops biofilm formation, but at the same time is porous enough for the compound to go through the protection layer and be measured by the sensor. We found that a compound called third-generation NH_2-terminated PAMAM-dendrimer grafted onto graphite oxide was promising. This coating material will be further studied during 2017, including optimizing the coating process, and study the performance of the coating in real CCS water.

In contrast to land-based facilities, there are no requirements for disinfection of inlet sea water to floating closed systems in sea (S-CCS). Except for coarse filters, water entering S-CCS does not undergo any treatment, leaving such system vulnerable to pathogens, sea lice and jellyfish. Such filtration must be able to handle huge flows (e.g. 100 m^3/min) but not result in large pressure head-loss and pumping costs. This technology is not currently available. The main focus of INTAKE is therefore to evaluate candidate technologies. We studied the influence of seawater quality on treatment efficiencies and WQ effects. Mechanical intake water filtration combined with various disinfection steps, such as ozone, ultraviolet (UV) or advanced oxidation processes (AOP) were tested. We found that UV and AOP reduced the amount of bacteria substantially. The reduction was in

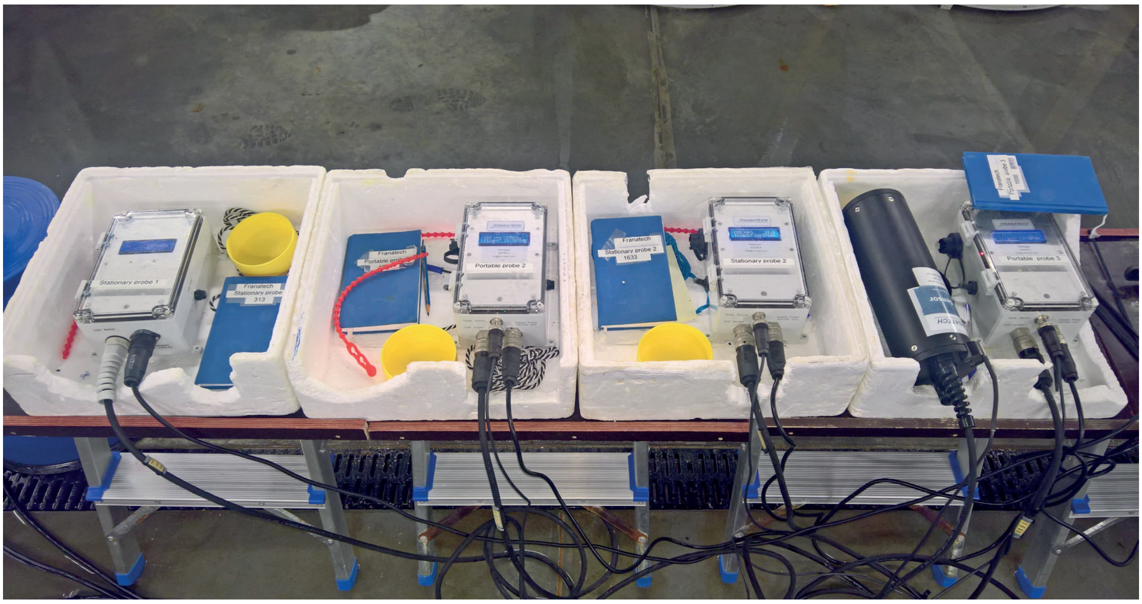


Fig. 4.8. Maintenance and control of sensors is an important and integrative part of rearing fish in closed-containment systems. Photo: Bendik Fyhn Terjesen

fact higher when operating under high particle (TSS) level of the intake water, and when including a filter (40µm or 300µm) prior to the disinfection. All the treatments showed a 99.9% reduction in bacterial numbers, or a 3-log10 removal, under high TSS in the intake water. A problematic effect of some technologies is formation of residual oxidants (TRO) which can be harmful to the fish. As expected, we found that TRO increased with use of ozone but, interestingly, the AOP treatment technology did not produce any detectable TRO. Work in INTAKE was also done on developing various ideas on how to install intake water treatment technology in S-CCS and in 2017 this activity will continue.

RAS generate small-sized particles <60 µm in size in the water. High levels of suspended particles can increase heterotrophic bacterial growth, reduce removal efficiency and deteriorate water quality. However, evidence on

Fig. 4.9. Picture of two similar 3.2 m3 tanks with postsmolt salmon, connected to a RAS without technology for filtration of fine particles (top picture) or a tank connected to RAS with such treatment technology. How do the fish react to these very different conditions? That is the main question being studied in the PARTICLE project. Photo: Astrid Buran Holan

Fig. 4.10. Measuring water velocity in large land-based tanks, in the HYDRO project

effects of RAS-particles on salmon postsmolt welfare, health and performance is lacking. In PARTICLE, a joint project with Dept. Fish Prod & Welfare, we found in 2016 that fish in high particulate water (> 27 mg /L TSS) have numerically lowest feed intake and growth rate. There was a significant negative relationship between survival and concentration of water suspended particles, and the feed conversion ratio increased significantly with high TSS in the water (i.e. worse feed utilization). Postsmolts in particle-rich water (> 14 mg/L) consumed more oxygen than fish in low particulate water (< 6 mg TSS/L). In contrast, the gills of fish in the low particulate water had, unexpectedly, more gill damage compared to gills in fish kept in high particulate water (> 14 mg TSS/L). Furthermore, the prevalence and severity of eye injuries was affected by treatment. The highest levels of injuries were observed among fish in the 1 mg TSS/L treatment and not in fish kept in water with high level of suspended solids. Hence, high particulate water in RAS affects tissues and functions differently. These exciting and relevant results will be further investigated during 2017, with the aim to present a more complete picture and overall conclusions.

Enormous culture tanks are often used in CCS, sometimes exceeding 3000 m³ on land, and 20000 m³ in S-CCS, due to economics of scale. However, there are many hydrodynamic challenges when using such large tanks. In particular, larger tanks make it harder to simultaneously achieve rapid solids removal and ideal swimming speeds for the fish, as well as avoiding non-homogeneous conditions and gradients of dissolved O_2 and CO_2. A survey was done in the HYDRO project to determine the geometry, operating parameters, and other key features of large culture tanks. We found that tanks built recently have been designed to operate at a much-reduced metabolic loading per unit of flow, a tendency that improves water quality throughout the culture tank, all else equal. We hypothesize that this trend is due to increased awareness of fish welfare and health, and has been made possible due to the ever-increasing application of water recirculating systems.

Another active part of HYDRO is studies on hydrodynamic properties of large tanks by Computational Fluid Dynamics (CFD) modelling approaches. We found that the large tanks are more turbulent than smaller units, which can be a problem since water velocity may be too high or too low in certain parts of the tanks, also creating dead zones that are not turned over sufficiently. We showed that by doing relatively small construction changes, these turbulent parts may be reduced. Much practical knowledge exists regarding tank design from previous research, but published computational models for these optimizations lack for large tanks for salmon. The work in HYDRO continues into 2017, with focus on how to improve uniformity of the flow patterns in large tanks (land-based and S-CCS) and obtaining more empirical data from field visits.

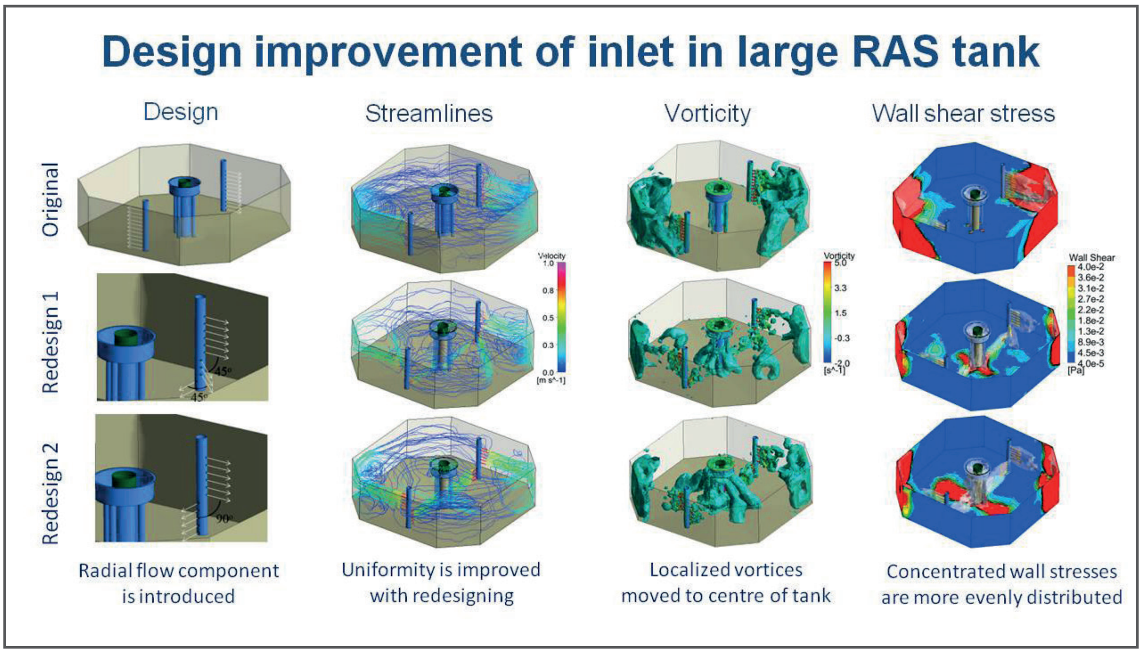


Fig. 4.11. Improvement in hydrodynamics of a 780 m³ large tank for postsmolts in RAS, by a Computational Fluid Dynamics (CFD) modelling approach. By changing the original design (top row) of the inlet nozzle angles, improved uniformity of velocities, lower vortices and less wall shear stresses can be achieved. Gorle et al., unpublished.

5 INTERNATIONAL COLLABORATION IN 2016

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.

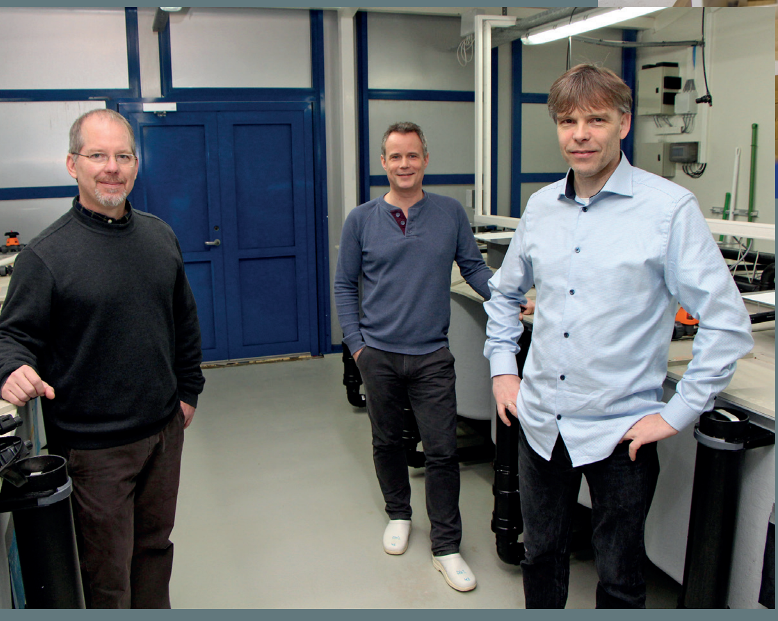
CtrlAQUA researchers have in 2016 frequently been used as session chairs or invited speakers at several international scientific meetings, such as the European Aquaculture Society's conference Aquaculture Europe in Edinburgh in September 2016. Furthermore, in the associated RCN project SalmoFutura, the R&D partners haves extensive collaboration with e.g. University of Nijmegen, Stirling University and Penn State University in the US.

There are two international R&D partners in CtrlAQUA, Gothenburg University (UGOT) and The Conservation Fund Freshwater Institute, USA. Gothenburg University is represented in CtrlAQUA by Prof. Kristina Sundell and her research group. UGOT has in 2016 contributed to important results, such as on the effects of stress and high fish density on skin permeability in salmon held in closed systems. The Conservation Fund Freshwater Institute (FI) has started trials on optimal photoperiod and feed ration for postsmolts reared in RAS in their facilities. Furthermore, FI by Director of Systems Research Steve Summerfelt, is also leading the efforts on hydrodynamic measurements and development of flow models for large fish tanks in closed systems.

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 UNI Research 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.

Good mood and knowledge exchange when CtrlAQUA partners meet. Here at annual meeting at Smøla in May. Photo: Reidun Lilleholt Kraugerud©Nofima

Nofima and Uni Research sampling fish that has been through a trial in the CO_2RAS project at Sunndalsøra.



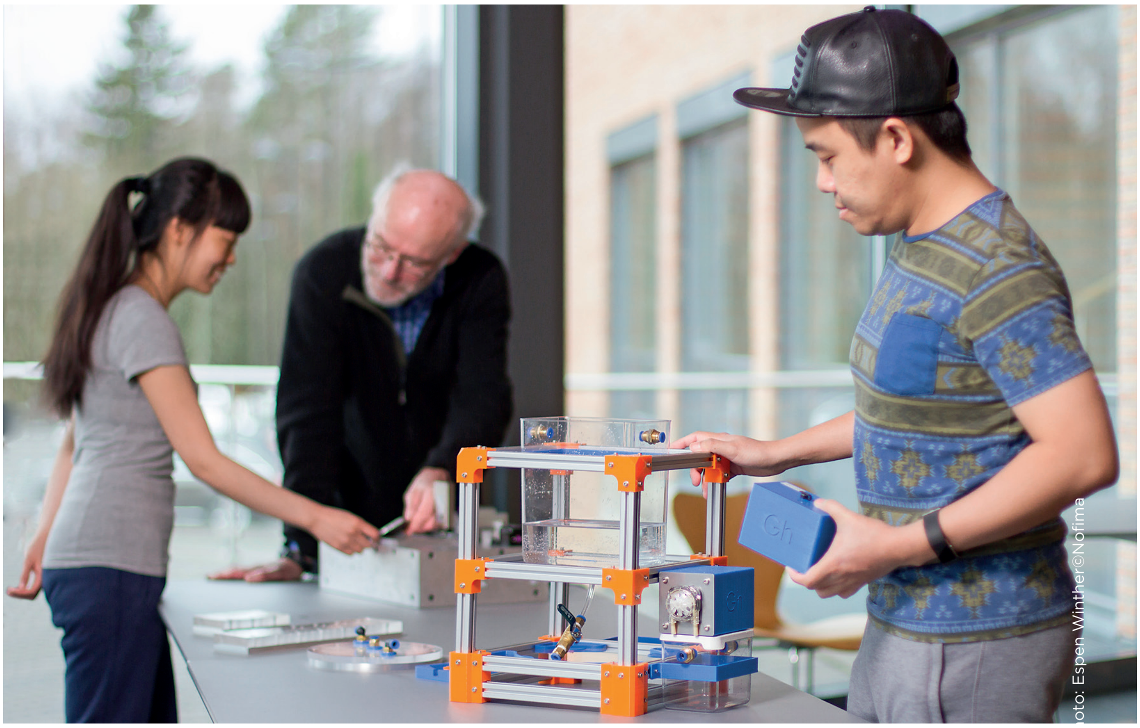
Scientists from Uni Research at the Industrial Laboratory in Bergen. Photo: Andreas Graven©Uni Research

6 RECRUITMENT, EDUCATION AND TRAINING

A total of 15 PhD students will be educated through the life-time of CtrlAQUA. The students are, and in the future will be, enrolled at the University of Bergen and NTNU. We have now recruited a total of seven PhD students to key research topics of the centre and its associated projects (see section 8), two PhD positions will be filled during the next few weeks, and two positions are in the process of being advertised.

During the site visit at NOFIMA, Sunndalsøra in October 2016 the Research Council brought up the need for a strategy to better integrate the students with the Centre and improve the communication and identity of the students within the Centre. We have responded to this request by creating a student forum which will be launched during the 2nd annual meeting in Bergen in May. In preparation for this process we have asked the students what they would like this forum to focus on, how best to organize the forum and how to keep communication going within the forum, ensuring a good flow of information. From the response we received we will propose a structure at the annual meeting, but to a large extent leave it up to the students to organize themselves. We would like the students to address the following topics: Organization, election of student representative, presentations of each student (especially those that do not have a talk during the meeting), photo shoot, Facebook page.

In addition to PhD fellows, CtrlAQUA seeks to educate a number of Master students, at the University of Bergen, Göteborg University and NTNU (see section 8). Two students at Göteborg University (Britt Sjöqvist og Ida Heden) have completed their theses, and several candidates are currently doing their theses in CtrlAQUA projects.



Bård Haug at ORP and two students developing technology for closed containment aquaculture.

Xiaoxue Zhang tries to keep the sensors free from bacteria in the fish farming system. Photo: Per Henning©NTNU

MEET FOUR CTRLAQUA STUDENTS

During its eight years as a center for research-based innovation, 15 young scientists have studied at CtrlAQUA for the title of PhD at the University of Bergen (UiB) and the Norwegian University of Science and Technology (NTNU).

What contribution have these young scientists made and what are their prospects for working in closed-containment technology? Meet four of our students.

"We need to chase high water quality"

Xiaoxue Zhang is a PhD student at NTNU Nanolab, working on the development of a material to apply to sensors in the water treatment systems.

Before her arrival at CtrlAQUA, closed-containment aquaculture was totally new to Zhang but, once she had started, she soon developed an enthusiasm for the work.

"At first, this was just a job that suited my competence. But, once I was involved, I saw how passionate the others at the center were about their work and it was contagious. I am now very enthusiastic about developing this material to improve the sensors," she says.

Zhang is approaching an invisible but crucial detail in today's closed-containment systems: the quality of the sensors:

"My thesis is about developing a material that can prevent the growth of biofilm on the sensors that measure water quality in the systems. If the sensors become coated with microbes, they are unable to make accurate measurements. And accurate measurements are essential in intense systems such as closed-containment systems, where we need to chase high water quality."

Zhang has already developed a prototype of the material and is now applying it to the sensors. Finally, she will study whether the material works effectively on the sensors in practice.

The main research contributions of NTNU to CtrlAQUA will be within sensor technology and sensor implementation.

University: NTNU
Student status: PhD 2016-2020
Supervisor: Øyvind Mikkelsen
CtrlAQUA project: SENSOR

"I was lucky enough to go to Japan for three weeks and work with experts in biological growth factors. It was an extremely rewarding experience," says Gamlem. Photo: Eivind Senneset Bergenhus, UiB.

She compares open cages to closed systems

One of the main issues with closed-containment systems is that they incur higher investment costs than traditional rearing technologies, which implies higher production intensity. It is important to research whether salmon post-smolts can perform equally well, or even better, in these closed systems compared with open cages. That's what Ingrid Gamlem's master's degree is about:

"My work focuses on whether post-smolt grow and perform equally well in the semi-closed system, PRELINE, as in open reference cages," says Gamlem.

Additionally, she is investigating if biological growth factors, such as the protein IGF-I, can be used as a tool to evaluate and predict growth in Atlantic salmon post-smolt. This is clear from laboratory studies, but has not been validated in large-scale systems.

"To make closed systems a reliable and economically viable technology, my contribution will be to clarify the production potential in a semi-closed system.

"These innovative systems have the potential to solve some of aquaculture's major challenges, whilst also being vital to the industry's ambitious future. I absolutely want to continue to work in this field if the opportunity comes my way," says Gamlem.

University:
University of Bergen – Institute of Biology
Student status: MSc 2015-2017
Supervisors:
Tom Ole Nilsen and Sigurd Handeland
CtrlAQUA project: PRELINE and Rigid S-CCS

"I want to contribute with knowledge of fish biology, so that we can adapt the technology to the fish rather than the other way around," says Sara Calabrese. Photo: Eivind Senneset Bergenhus, University of Bergen.

Motivated by sustainable aquaculture

Sara Calabrese has just handed in her thesis as the first in the CtrlAQUA portfolio of PhD students. Involved since 2013 in a precursor to CtrlAQUA, Calabrese feels that these are exciting times with a high degree of development.

Calabrese is employed by Marine Harvest and is doing her PhD degree in biology at the University of Bergen. Her reason for working in this field of research is that aquaculture will be the main fish supply sector in the increasing global demand for food.

"So we will produce a lot of seafood and we need to do it well. What motivates me the most is overcoming the main challenges for sustainability: sea lice, mortality and escapees. Closed-containment aquaculture addresses all of these issues," says Calabrese.

At CtrlAQUA, Calabrese is researching what farmed fish require to thrive and grow in closed-containment systems. Keywords are fish density, water quality, salinity and exercise. In particular, she is studying how these different rearing environments affect the robustness of fish and their ability to respond to additional challenges, such as transfer to sea.

"The great thing about doing an Industry PhD is that you are part of the research but also the implementation. Marine Harvest is already applying results included in my thesis to improve production, and that is exciting."

Calabrese is eager to pursue a career in closed-containment aquaculture:

"I definitely want to continue working in this field. It's just starting to take off and there are still so many questions that need to be investigated. It would be exciting to work either in academia or industry. I'm up for both!" says the eager student.

University: UiB, Institute of Biology
Student status: PhD 2013-2017
Supervisors:
Sigurd Handeland, Lars Ebbesson, Bendik Fyhn Terjesen, Tom Ole Nilsen and Sigurd Stefansson
CtrlAQUA project:
ROBUST, and OPP (associated project)

Sharada Navada recently started her PhD, studying biofilters at NTNU and Nofima. Photo: Per Henning©NTNU.

“Biological water treatment in fish farms can be optimized”

Sharada Navada is a process engineer from India who, after working a couple of years in the USA and a year in Drammen, has just started her doctoral work at the CtrlAQUA center. She is an employee of Krüger Kaldnes and currently resides in Trondheim where she is doing her PhD at NTNU and Nofima, thus creating a good synergy between industry and academia, like the CtrlAQUA center.

“I have always wanted to work in environmental engineering, and I really enjoy working on water quality.”

Her topic is optimizing moving bed biofilters, mostly in land-based aquaculture systems. Biofilters are central in a closed-containment system where dirty water from the fish tanks runs through a cleaning process, carried out by bacterial degradation. The biofilter is the biological part of the water treatment system, with a delicate balance maintaining the bacteria which degrade organics and convert ammonia to nitrates. Navada is looking at the dynamics of starting up the biofilter in different salinities and at how efficiently the bacteria convert ammonia to nitrates.

After completing her PhD in four years’ time, Navada says she will continue working for the recirculating aquaculture system supplier Krüger Kaldnes.

“I hope that during my four years as a PhD student, I will be able to build a good knowledge base, forge social connections in the scientific community and develop myself, so that I can contribute a lot more when I return to industry.”

Navada is very optimistic about closed-containment aquaculture:
“I believe that once we have improved the biofilters, we should also be able to reduce fresh water consumption quite substantially. That could have an economic impact by reducing the energy required for pumping and temperature regulation.”

University: NTNU - Department of Chemistry
Student status: PhD 2017-2020
Supervisors:
Øyvind Mikkelsen, Bendik Fyhn Terjesen, Frederic Gaumet, Bjørn Rydtun
CtrlAQUA project: EXPO

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 89 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 up and folder show externally what the center is about.
The interest from industry, the public and academia has been great. This has resulted in 50 news articles in press in 2016, 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 2016 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 2016 are:

- February 2016: Centre Director was invited speaker to the conference “Wild salmon in the North” in Alta, Norway. H.M.K Harald V opened the conference, and industry, academia, environmentalists and media were main audience.
- March 2016: Centre Director was invited speaker to the Zero Lice workshop at North Atlantic Seafood Forum, Bergen, Norway
- August 2016: Several people in CtrlAQUA had presentations in the Aquaculture Innovation Workshop (AIW) and 11th International Conference on Recirculating Aquaculture 2016 in West Virginia, USA. CtrlAQUA partner Freshwater Institute and others organized the conference.
- October 2016: The activity in CtrlAQUA was a main part of the program under “The Fourth Conference on Recirculating Aquaculture” at Sunndalsøra. 250 participants from industry, science, politics and media attended the conference, which focused on new innovations in smolt and post-smolt production.
- September 2016: Centre Director and RAS mentor prof. Harald Rosenthal chaired a session on Aquaculture Europe 2016 “Advances in recirculation and closed containment aquaculture systems” in Edinburgh, Scotland.

8 ATTACHMENTS TO THE REPORT:

Key R&D partners pr 01.12.2016

Name	Institution
Bendik Fyhn Terjesen	Nofima AS
Jelena Kolarevic	Nofima AS
Astrid Buran Holan	Nofima AS
Åsa Maria Espmark	Nofima AS
Sven Martin Jørgensen	Nofima AS
Trine Ytrestøyl	Nofima AS
Christian Karlsen	Nofima AS
Vasco Mota	Nofima AS
Jagan Gorle	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
Lars Ebbesson	UNI Research
Sigurd Handeland	UNI Research
Tom Ole Nilsen	UNI Research
Marco Vindas	UNI Research
Pablo Balseiro	UNI Research
Klaus Johanssen	UNI Research
Eirik Thorsnes	UNI Research
Carlotta Negri	UNI Research
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
Steve Summerfelt	Freswater Institute, USA

Postdoctoral researchers in process

Name	Period	Institution
Nhut Tran-Minh	2016 - 2017	Nofima
Shazia Aslam	2016 - 2018	NTNU

PhD students in process

Name	Period	Institution
Sara Calabrese	2013 - 2016	UiB
Victoria Røyseth	2016 - 2019	UiB
Dorien Dunnebier	2016 - 2020	NTNU
Sharada Navada	2017 - 2020	NTNU
Lene Sveen	2014 - 2017	UiB
Xiaoxue Zhang	2016 - 2020	NTNU
Bernat Morro	2017 - 2020	UiB

MSc students i process

Name	Period	Institution
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
Are Paulsen	2016 - 2017	UiB
Simen Haaland	2016 - 2017	NTNU
Kamilla J. Grindedal	2016 - 2017	NTNU
Gisle Roel Bye	2016 - 2017	NTNU

Publications 2015 - 2017:

Peer-reviewed publications:

Bakke, I., Åm, A.L., Kolarevic, J., Ytrestøyl, T., Vadstein, O., Attramadal, K.J.K., Terjesen, B.F. (In Press). Microbial community dynamics in semi-commercial RAS for production of Atlantic post-smolts at different salinities. Aquacultural Engineering.

Calabrese, S., Nilsen, T.O., Kolarevic, J., Ebbesson, L.O.E., Pedrosa, C., Fivelstad, S., Hosfeld, C., Stefansson, S.O., Terjesen, B.F., Takle, H., Martins, C.I.M., Sveier, H., Mathisen, F., Imsland, A.K., Handeland, S.O. (In Press). Stocking density limits for post-smolt Atlantic salmon *(Salmo salar L.)* emphasis on production performance and welfare. Aquaculture.

Davidson, J., May, T., Good, C., Waldrop, T., Kenney, B., Terjesen. B.F., Summerfelt, S.T. (2016). Production of market-size (4-5 kg) North American strain Atlantic salmon *Salmo salar* in a commercial scale, land-based recirculation aquaculture system using freshwater. Aquacultural Engineering 74, 1-16.

Døskeland, I, Imsland, A.K.J., Fjelldal, P.G, Stefansson, S.O., Roth, B., Eriksen, K.E., Mikalsen, B., Handeland, S. (2016). The effect of low temperatures and photoperiods on growth and vertebra morphometry in Atlantic salmon. Aquaculture International 24, 1421–1434

Pautsina, A., Cisar, P., Stys, D., Terjesen, B.F., Espmark, Å.M. (2015). Infrared reflection system for indoor 3D tracking of fish. Aquaculture Engineering 69, 7-17

Rud, I., Kolarevic, J., Holan, A.B., Berget, I., Calabrese, S., Terjesen, B.F. (In Press). Deep-sequencing of the microbiota in commercial-scale recirculating and semi-closed aquaculture systems for Atlantic salmon post-smolt production. Aquacultural Engineering

Summerfelt, S.T., Mathisen, F., Holan, A.B., Terjesen, B.F (2016). Survey of large circular and octagonal tanks operated at Norwegian commercial smolt and post-smolt sites. Aquacultural Engineering 74, 105 - 110.

Sveen, L.R., Timmerhaus, G., Torgersen, J.S., Ytteborg, E., Jørgensen, S.M., Handeland, S.O., Stefansson, S.O., Nilsen, T.O., Calabrese, S., Ebbesson, L.O., Terjesen, B.F., Takle, H. (2016). Impact of fish density and specific water flow on skin properties in Atlantic salmon *(Salmo salar L.)* post-smolts. Aquaculture 464, 629-637.

Book/article in book/report/abstract

Calabrese, S., Sævareid, B., Breck, O., Joensen, R. Nilsen,T.O., Kolarevic, J., Fivelstad, S., Takle, H., Hosfeld, C., Ebbesson, L.O.E., Stefansson, S., Terjesen, B.F., Handeland, S.O. (2015). Pilot study: Post-smolt Atlantic salmon production in semi-closed sea systems. In: Book of abstracts EAS Rotterdam 2015.

Calabrese, S., Sævareid, B., Breck, O., Joensen, R., Nilsen, T.O., Kolarevic, J., Fivelstad, S., Takle, H., Hosfeld, C., Ebbesson, L.O.E., Stefansson, S., Terjesen, B.F., Handeland, S.O. (2016). Semi-closed sea systems for postsmolt Atlantic salmon. The World Aquaculture Society meeting, Aquaculture 2016, Las Vegas, USA. February, 22nd-26th, 2016 (abstract ID 42049).

Ebbesson, L.O.E., Calabrese, S., Nilsen, T.O., Handeland, S.O., Gorissen, M., Flik, G., Braithwaite, V.A. (2016). Mental robustness indicators for adaptation potential and welfare assessment in fish aquaculture. In Aquaculture Europe 2016 Abstracts. Edinburgh, Scotland. September 21st -23rd 2016.

Good, C., Vinci, B., Summerfelt, S. (2017). Atlantic salmon production in land-based closed-containment systems. Swiss Fish Forum 2017. Lindau, Switzerland 17th February 2017.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S. (2016). Characterization of hydrodynamics in large tanks for Atlantic salmon postsmolts using CFD (computational fluid dynamics). In Aquaculture Europe 2016 Abstracts, pp 399-400, Edinburgh, Scotland. September 21st -23rd 2016.

Gorle, J.M.R., Terjesen, B.F., Summerfelt, S. (2016) Full-scale CFD modeling with experimental validation of large RAS tank hydrodynamics ICRA 2016, Roanoke West Virginia, USA 19 - 21. August 2016.

Holan AB, Gorle J, Terjesen BF (2016). Water velocities in FishGLOBE. Nofima report K-77/2016, pp 11.

Holan, A.B., Kolarevic, J., Fossmark, R., Bakke, I., Vadstein, O., Terjesen, B.F. (2015). Evaluation of membrane treatment effect on water quality in recirculating aquaculture systems (RAS) for Atlantic salmon post-smolts ***(Salmo salar).*** In: Book of abstracts 3d Workshop on Recirculating Aquaculture Systems. p. 52. 30th of September 1st October 2015, Molde, Norway.

Holan, A.B, Kolarevic, J., Jørgensen, S.M., Reiten, B.K.M., Nerland, F., Brunsvik, P., Rud, I., Karlsen, C.R., Terjesen, B.F. (2016). Particle tolerance of Atlantic salmon post-smolts reared in recirculating aquaculture systems. In Aquaculture Europe 2016 Abstracts, pp 435-436, Edinburgh, Scotland. September 21st -23rd 2016.

Holan A.B., Kolarevic, J., Terjesen, B.F. (2015). Evaluation of membrane treatment in recirculating aquaculture systems (RAS) for Atlantic salmon post-smolts ***(Salmo salar)***. In: Book of abstracts EAS Rotterdam 2015.

Holan, A.B., Kolarevic, J., Terjesen, B.F. (2016). Evaluation of membrane treatment effect on water quality in recirculating aquaculture systems (RAS) for Atlantic salmon post-smolts ***(Salmo salar)***. The World Aquaculture Society meeting, Aquaculture 2016, Las Vegas, USA. February, 22nd-26th, 2016 (abstract ID 42494).

Holan, A.B., Vinci, B., Handeland, S., Terjesen, B.F. (2016). Evaluation of available water treatment technologies for semi-closed aquaculture systems (in Norwegian). In Abstracts RCN Program conference Mariculture 2016, Bodø, Norway, April 18th – 20th 2016.

Jørgensen, S.M. (2015). CtrlAQUA – Improving safe and sustainable production. Kaldnes RAS Magazine: INSIDE Aquaculture, Special Edition, AQUA NOR 2015.

Kolarevic, J., Iversen, R., Martinsen, S., Kvenset, P.G., Terjesen, B.F. (2016). Production of Atlantic salmon postsmolts ***(Salmo salar)*** in flexibag semi-closed containment system, The World Aquaculture Society meeting, Aquaculture 2016, Las Vegas, USA. February, 22nd-26th, 2016 (abstract ID 42524).

Kolarevic, J., Sveen, L., Nilsen, T.O., Sundh, H., Aerts, J., Sundell, K., Ebbesson, L., Handeland, S., Jørgensen, S.M., Takle, H., Terjesen, B.F. (2016). Welfare and performance of Atlantic salmon post-smolts during exposure to mild chronic stress in closed-containment systems. In Aquaculture Europe 2016 Abstracts, pp 533-534, Edinburgh, Scotland. September 21st -23rd 2016.

Mota, V.C., Kolarevic, J., Terjesen, B.F. (2016). Ammonia and carbon dioxide modelling in a reuse system without a biofilter. In Aquaculture Europe 2016 Abstracts, pp 655, Edinburgh, Scotland. September 21st -23rd 2016.

Multiple authors (2016) Annual Report 2015 CtrlAQUA - Center for Closed-containment Aquaculture, eds. Terjesen BF, Espmark Å. pp 76. Nofima, Norway.

Sundh, H., Kolarevic, J., Nilsen, T.O., Jørgensen, S.M., Karlsen, C.R., Terjesen, B.F., Takle, H., Sundell, K. (2016). The impact of chronic stress on the barrier function of the skin in Atlantic salmon ***Salmo salar*** reared in closed containment systems. In Aquaculture Europe 2016 Abstracts, pp 992-993, Edinburgh, Scotland. September 21st -23rd 2016.

Summerfelt, S., Mathisen, F., Holan, A., Terjesen, B.F. (2016). Survey - Use of large circular tanks in Norwegian salmon smolt and post-smolt facilities. Aquaculture Innovations Workshop, August 19-21, Roanoke, Virginia, USA.

Sveen, L.R., Ytteborg, E., Timmerhaus, G., Stefansson, S., Jørgensen, S.M., Handeland, S., Nilsen, T.O., Takle, H., Terjesen, B.F. (2016). Effect of stress on wound healing and gene regulation in skin of posts-smolts ***(Salmo salar L.)*** in closed-containment aquaculture systems (in Norwegian). In Abstracts RCN Program conference Mariculture 2016, Bodø, Norway, April 18th – 20th 2016.

Sveier, H., Tangen, S., Handeland, S. (2015). Post smolt ***(Salmo salar L)*** production in floating raceway systems? In: Book of abstracts EAS Rotterdam 2015.

Terjesen, B.F. (2015). Nofima Centre for Recirculation in Aquaculture (NCRA), a research facility for the future salmon production methods. Aquaculture Europe Magazine pp. 33-43.

Terjesen, B.F. (2016). New results and plans in CtrlAQUA SFI – Centre for Closed-containment Aquaculture (in Norwegian). In Abstracts RCN Program conference Mariculture 2016, Bodø, Norway, April 18th – 20th 2016.

Terjesen, B.F., Abbink, W., Blom, E., Kamstra, A., Espmark, Å.M., Kolarevic, J., Nilsen, T.O., Ebbesson, L., Handeland, S., Sveen, L., Takle, H. 2015. Scaling of culture tanks and unit processes, relevant for Atlantic salmon post-smolt production in land based systems. In: Book of abstracts 3d Workshop on Recirculating Aquaculture Systems. p. 52. 30th of September 1st October 2015, Molde, Norway.

Zhang, X., Mikkelsen, Ø. (2016). Deposition of Silver Nanoparticles/Poly (amidoamine) Dendrimer/Graphene Oxide Nanohybrids on Sensor Surface for Anti-biofouling. Department of Chemistry, Norwegian University of Science and Technology. 13th International Conference on Nanotek and Expo (Dec 05-07, 2016 Phoenix, Arizona, USA)

Presentations (oral and posters):

Calabrese, S., Sævareid, B., Breck, O., Joensen, R., Nilsen, T.O., Kolarevic, J., Fivelstad, S., Takle, H., Hosfeld, C., Ebbesson, L.O.E., Stefansson, S., Terjesen, B.F., Handeland, S.O. (2015). Pilot study: postsmolt Atlantic salmon production in semi-closed sea systems. Aquaculture Europe, EAS, Rotterdam, The Netherlands, 20-23. October 2015.

Good, C., Summerfelt, S., May, T., Crouse, C., Ebbesen, L., Stefansson, S., Handeland, S., Jørgensen, S.M., Mathisen, F., Terjesen, B.F. (2016). Assessing photoperiod regimes for freshwater-reared post-smolts. Aquaculture Innovations Workshop, August 19-21, Roanoke, Virginia, USA.

Good, C., Vinci, B., Summerfelt, S. (2017). Atlantic salmon production in land-based closed-containment systems. Swiss Fish Forum 2017. Lindau, Switzerland 17th February 2017.

Gorle, J., Summerfelt, S.T., Mota, V.C., Marchenko, Y., Megård-Reiten, B.K., Terjesen, B.F. (2016). Hydrodynamic modeling of culture tanks in Norwegian salmon smolt and post-smolt facilities. Aquaculture Innovations Workshop, August 19-21, Roanoke, Virginia, USA.

Handeland, S., (2015). Produksjon av laks i lukkede anlegg. Får vi dette til? Hardangerfjordseminaret 2015.

Helland, S. (2016). Spennende satsing innen havbruk på Sundalsøra: SFI CtrlAQUA. Den lukkede fasen i lakseoppdrett. Marin Samhandlingsarene. Ålesund, 25. November 2015.

Holan, A. (2015). Utviklingen innenfor bruk av RAS i norsk akvakultur. Farmer Day, AquaCircle, DanAqua, Aalborg, Danmark 7. October 2015.

Holan, A.B., Kolarevic, J., Fossmark, R.O., Bakke, I., Vadstein, O., Terjesen, B.F. (2015). Evaluation of membrane treatment effect on water quality in RAS for Atlantic salmon post-smolts. NordicRAS Network, Molde Norway, 30. September - 1. October 2015.

Holan, A.B. Kolarevic, J., Terjesen, B.F. (2015). Evaluation of membrane treatment in RAS for Atlantic salmon post-smolts ***(Salmo salar).*** Aquaculture Europe, EAS, Rotterdam, The Netherlands, 20-23. October 2015.

Holan, A.B., Terjesen, B.F. (2015). CtrlAQUA Center for Closed Containment Aquaculture. Transatlantic Science week, The Norwegian Embassy in Washington DC, Ministry of Education and Research, Ministry of Trade, Industry and Fisheries, Research council of Norway. Boston, USA, 4-6. November 2015.

Holan, A.B., Reiten, B.K.M., Nerland, F, Brunsvik, P., Kolarevic, J., Rud, I., Karlsen, C. R., Jørgensen, S. M., Terjesen, B.F. (2016). Particle tolerance of Atlantic salmon post-smolts reared in recirculating aquaculture systems (RAS). Aquaculture Europe Edinburgh, 20-23 September, 2016

Holan, A.B., Reiten, B.K.M., Nerland, F., Brunsvik, P., Kolarevic, J., Rud, I., Karlsen, C. R., Jørgensen, S. M., Ytteborg, E., Terjesen, B.F. (2016), Toleranse til partikler hos postsmolt. Fremtidens smoltproduksjon - Fjerde konferanse om resirkulering av vann i akvakultur på Sunndalsøra. 25. – 26. oktober 2016.

Holan, A.B., Vinci, B., Handeland, S., and Terjesen, B.F. (2016). Evaluering av tilgjengelig vannbehandlingsteknologi for semi-lukkede anlegg – INTAKE. Programkonferansen Havbruk, Bodø, Norway, April 18-19, 2016.

Iversen, A., Hermansen, Ø., Terjesen, B.F., Andreassen, O. (2016). Competitiveness of new technologies in salmon farming. IIFET, International Institute of Fisheries Economics and Trade Conference 2016, Aberdeen, Scotland, 11th-15th of July 2016.

Kolarevic, J., Iversen, R., Martinsen, S., Kvenset, P.G., Terjesen, B.F. (2016). Production of Atlantic salmon post-smolts in flexibag semi-closed containment system, The World Aquaculture Society meeting, Aquaculture 2016, Las Vegas, USA. February, 22nd-26th, 2016.

Kolarevic, J., Reiten, B.K.M., Sveen, L., Nilsen, T.O., Aerts, J., Ebbesson, L.O.E., Handeland, S., Jørgensen, S.M., Takle, H., Terjesen, B.F. (2016). Welfare and performance of Atlantic salmon post-smolts during exposure to mild chronic stress in recirculation aquaculture system (RAS). In RCN Program conference Mariculture 2016, Bodø, Norway, April 18th – 20th 2016.

Nilsen, T.O., Sundh, H., Andersson, E., Stefansson, S.O., McCormick, S.D., Taranger, G.L., Schulz, R.W., Fjelldal, P.G., Ebbesson, L.O.E., Handeland, S.O., Sundell, K., (2016). Osmoregulatory changes in sexually maturing Atlantic salmon post-smolt and adults. 12th International Congress on the Biology of Fish, San Marcos, Texas, USA, June 12-16.

Nilsen, T.O., Sundh, H., Andersson, E., Sundell, K., Stefansson, S.O., McCormick, S.D., Taranger, G.L., Melo, M., Fjelldal, P.G., Ebbesson, L.O.E., Norberg, B. and Schulz, R.W., (2016). Effects of androgens on osmoregulatory mechanisms in Atlantic salmon ***(Salmo salar L.)***. 28th conference of European Comparative Endocrinologists, Leuven, Belgium, August 21-25th 2016.

Summerfelt, S.T. (2016). New Emerging Challenges and Solutions in RAS for Salmonids. 4th Conference on Recirculating Aquaculture – Smolt Production in the Future. October 25-26, Sunndalsøra, Norway.

Summerfelt, S., Mathisen, F., Gorle, J., Terjesen, B.F. (2016). Survey of large tanks operated at Norwegian commercial smolt and post-smolt sites (in Norwegian). In RCN Program conference Mariculture 2016, Bodø, Norway, April 18th – 20th 2016.

Summerfelt, S., Mathisen, F., Holan, A., Terjesen, B.F. (2016). Survey - Use of large circular tanks in Norwegian Salmon smolt and post-smolt facilities. Aquaculture Innovations Workshop, August 19-21, Roanoke, Virginia, USA.

Summerfelt, S., Mathisen, F., Holan, A., Gorle, J., Terjesen, B.F. (2016). Dimensioning and operation of large culture tanks in Norwegian smolt and post-smolt facilities. Havbruk 2016, April 18-20, Bodø, Norway.

Sveier, H., Tangen, S., Handeland, S. (2015). Postsmolt of Atlantic salmon ***(Salmo salar L.)*** production in floating raceway system? Expectations and preliminary results. Aquaculture Europe, EAS, Rotterdam, The Netherlands, 20-23. October 2015.

Terjesen, B.F., (2015). Presentasjon av CtrlAQUA, Forskningstorget, Oslo, september 2015

Terjesen, B.F. (2015). Is the future land-based? Invited speaker and panel participant. SpareBank1 and BEWI seminar on salmon aquaculture. Trondheim, Norway, August 20th, 2015.

Terjesen, B.F. (2015). How do we farm salmon in the future? Sunndalskonferansen, Sunndalsøra, 23rd June 2015.

Terjesen, B.F. (2015). Can the salmon industry grow with closed-containment systems? Nofima AquaNor seminar. Trondheim, 18th August 2015.

Terjesen, B.F. (2015). Post-smolt production in closed-containment systems: CtrlAQUA SFI and other relevant RCN projects. The Research Council of Norway AquaNor exhibition stand. Trondheim, 19th August 2015

Terjesen, B.F. (2016). SFI CtrlAQUA – closed and semi-closed plants. North Atlantic Seafood Forum, Zero Lice workshop, Bergen 1st March.

Terjesen, B.F. (2016). Research on Atlantic salmon postsmolt production in closed-containment systems. Invited speaker to the Salmonview Media seminar "Growing larger fish in RAS systems" at Aquaculture Europe 2016, Edinburgh, Scotland, September 22nd 2016.

Terjesen, B.F. (2016). CtrlAQUA research to optimize RAS for Atlantic salmon post-smolt production. Invited speaker to the Aquaculture Innovation Workshop 2016, Roanoke, Virginia, U.S. August 19th – 20th 2016.

Terjesen, B.F. (2016). Research on smolts and postsmolts in RAS. Invited speaker to the Veterinary Days 2016, Aquamedicine session. Hamar, Norway, 9th-11th of March, 2016.

Terjesen, B.F. (2016). Closed-containment aquaculture

systems, what solutions exist? Invited speaker to the conference Wild salmon in the North. Alta, Norway, February 12th, 2016.

Terjesen, B.F. (2016). Status closed containment systems on land and in sea – CtrlAQUA SFI as a tool against sea lice. Invited speaker to the workshop Non-medicinal tools for prevention and control of sea lice, organized by the The Norwegian Seafood Research Fund. Gardermoen, Norway, January 12th, 2016.

Terjesen, B.F. (2016). The path towards full control of the fish in RAS. Smolt Production in the Future - Fourth Conference on Recirculation of Water in Aquaculture. 25th – 26th October 2016, Sunndalsøra, Norway.

Terjesen, B.F. (2016). Water quality and fish welfare in closed-containment systems. Invited talk at Seminar on animal welfare for farmed fish. Nordic Council of Ministers, the Nordic Working Group for Microbiology & Animal Health and Welfare (NMDD) Bergen, Norway, 4th-5th October 2016.

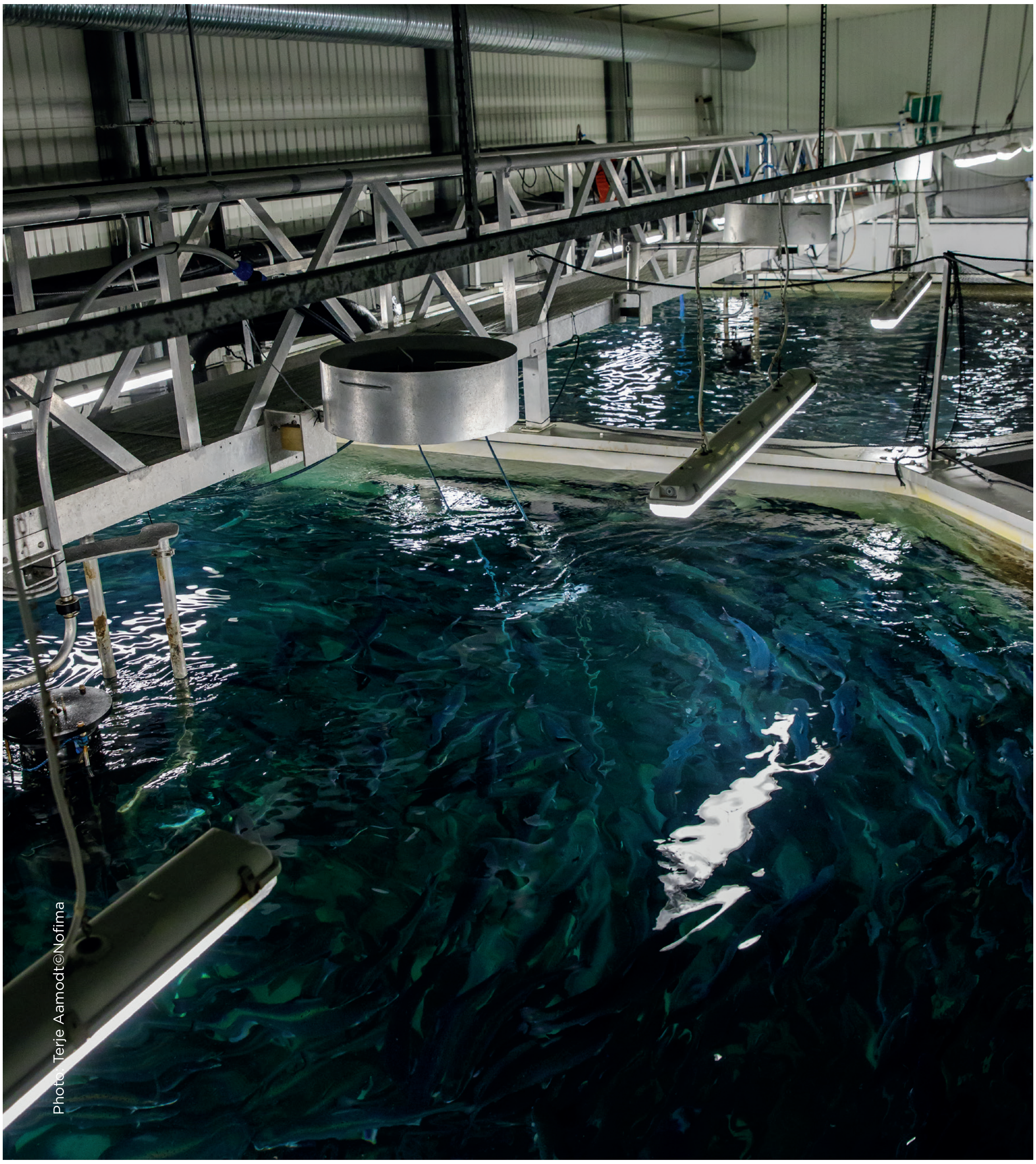


Photo: Terje Aamodt©Nofima