Annual Report 2012

CREATE

Centre for research-based innovation in aquaculture technology

Content

1. Summary

CREATE, the Centre for Research-based Innovation in Aquaculture Technology, conducts research to assist in the innovation of technology, products and solutions specifically to improve the grow-out phase of marine fish culture. A wide range of scientific disciplines are necessary to develop understanding of fish behaviour and needs, understand the biological process, fish farming processes, loads and motion of flexible fish farm constructions and to use this basic knowledge to develop fish farming technology and systems for the future. This design approach serves as the core research philosophy of CREATE. CREATE is a multi-disciplinary centre, with scientific disciplines covering fish ethology, fish feed nutrition, marine hydrodynamics, marine structures engineering, information and communication technology, marine biology and industrial design.

The centre have finished six year of work, and is presently running nine projects, ranging from fundamental research to acquire basic knowledge on biology for technology development to development of new technological solutions. The centre is presently engaged in seven PhD and three Post doc fellowships. In 2012 Dr. Mette Remmen defended her thesis on "The oxygen requirement of Atlantic salmon (Salmo salar L.) in the on-growing phase in sea cages" and Maike Oehme defended her thesis on "Feed utilization can be improved by optimizing physical pellet quality and feeding equipment in salmonid farming" early 2013.

CREATE researchers have so far published 64 articles in international, peer-reviewed scientific journals, such as *Aquaculture, Aquaculture Engineering, Aquaculture Environment Interactions* and *Ocean Engineering* and contributed numerous peer-reviewed book chapters. As well as a range of primary articles produced within the centre's projects, these contributions have included major reviews on the technological status of the modern fish farming industry, the environmental drivers of fish behaviour in sea-cages, and the causes of escapes and measures to prevent their escape.

Some of the main research achievements of CREATE to date are:

- Understanding of behaviour of salmon being submerged to different depths at different time periods. This is a breakthrough results, showing that salmon can be submerged for short periods of time, which will be important for further expansion of salmon farming into more exposed and offshore locations. For more information and results see chapter SMARTSUB - Smart submergence of sea cages to improve profitability, minimise environmental impact, and ensure welfare of salmon

- Basic understanding of characteristics of hydroids, like settlement preferences and results showing low effect of traditional in situ washing methods. Under development is a novel system for more effective bio-fouling control and removal, based on this knowledge. For more information and results see chapter CREATE biofouling and biocleaning

- Knowledge on tolerance limits of fluctuating hypoxia for salmon and water flow through and around fish cages with fish. These results are valuable for development of management protocols, feeding control, understanding of fish welfare and development of control and planning systems for fish farming. For more information and results see chapter Cage Environment

- Knowledge of the correlation between physical properties of feed, breakage in the feeding systems and its effect on biological response on fish. Showing that feed with good quality for the feed system is not necessary giving the best growth of the fish. For more information and results see chapter Pellet Quality - optimal conveying and biological response

- A new analysis tool for design of net cages based on nylon net. The demonstrator consists of a graphical user interface where users can specify the physical dimensions of a net cage, the physical properties of the net and ropes, and environmental loads like current and waves. The demonstrator supports environmental conditions through current simulations on the net structure as well as regular and irregular waves. For more information and results see chapter NetCageDesignTools

- Use of an innovative snorkel system, denying the salmon access to the depths with sea lice, but allowing the salmon to have access to air, reduced lice infestations by 66-86%. Lice infestation was reduced consistently over time and variable environmental conditions. Behaviour

of the fish was observed to be normal. For more information and results see chapter ReduceLice - Use of salmon behaviour to facilitate innovative surface-based de-licing technique (i) and to avoid sea lice infestation (ii).

- Novel model tests with live fish in a floating fish farm in waves and current have been performed to study how the fish influence the mooring loads. The latter effect is neglected in state-of-the-art computational tools used for the industry. The presence of current had an important effect and the mooring loads with fish were more than 10% larger than the mooring loads without fish. For more information and results see chapter Selected results from PhD and Post doc Work

2. Vision/objectives

Vision Understand, innovate and apply - creating technology for cultivation of the sea.

Objective The main objective of CREATE is to combine world-leading companies that supply aquaculture equipment and technology with prominent scientific research institutions into a centre with a common focus to innovate technology, products and solutions specifically to improve the grow-out phase of marine fish culture.

Secondary objectives

1. Understand fundamental biological preferences and behaviour of fish to set criteria for technology development
2. Develop improved management and operational protocols and systems based on the needs of the fish.
3. Develop equipment and systems to improve performance and safety of fish farming operations
4. Develop a framework for simulation, optimization and monitoring of all aspects of fish farming

3. Research plan/strategy

CREATE focuses research and development within three main research pillars:

Equipment and constructions The physical equipment used to farm fish.

Operation and handling The process of executing and carrying out operations necessary to farm fish.

Farming intelligence Control of the total process of farming by understanding the integrated use of equipment and the process of operations and combining this with knowledge of biological issues and the physical environment.

Within these three research pillars CREATE presently runs ten main projects, has eight PhD students and three post-doctoral researchers working within the centre. Figure 1**Error! Reference source not found.** below show the projects (orange), PhD (blue) and post-doctoral topics (light blue), and their relation to the three main research pillars of CREATE in 2012.

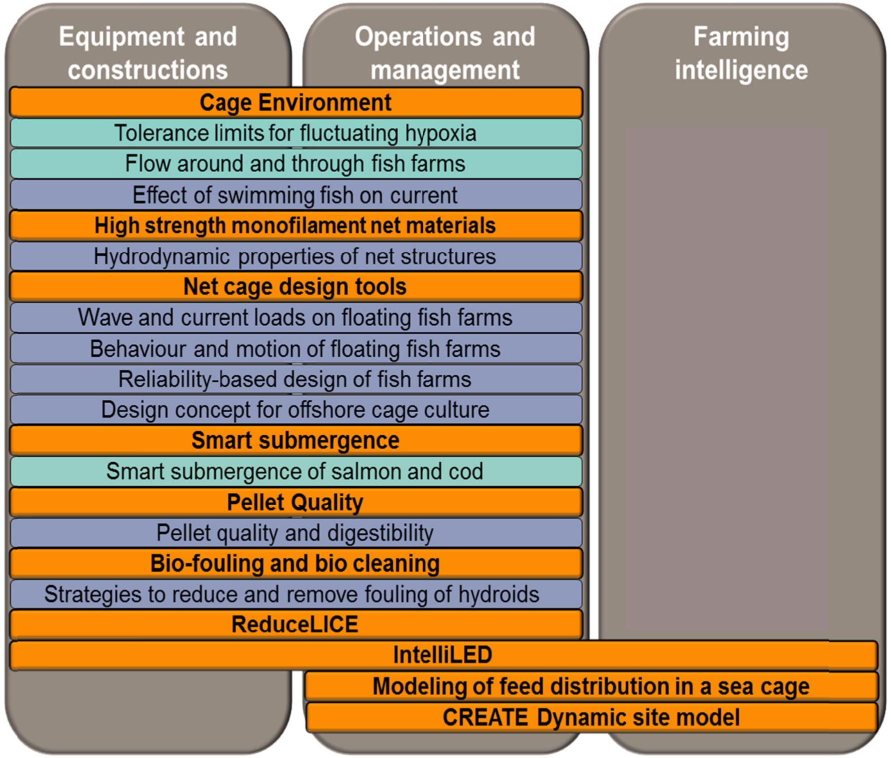


Figure 1 The projects (orange), PhD (blue) and post-doctoral topics (light blue), and their relation to the three main research pillars of CREATE

4. Organisation

4.1. Organisational structure

The centre is organized as an independent part of SINTEF Fisheries and Aquaculture, with its own Board, a Scientific Committee and a Centre director. CREATE have activities within three areas: Research Projects, Education and Innovation. Figure 2 show the organisation and relationships of the centre. The organisation and implementation of the centre is governed by a consortium agreement, describing the obligations and rights of the partners, as well as roles and responsibilities of the different parts of the organisation. CREATE is physically located at SINTEF Sealab,

SINTEF Fisheries and Aquaculture is the host institution for the centre, and the Centre Director is employed at SINTEF Fisheries and aquaculture.

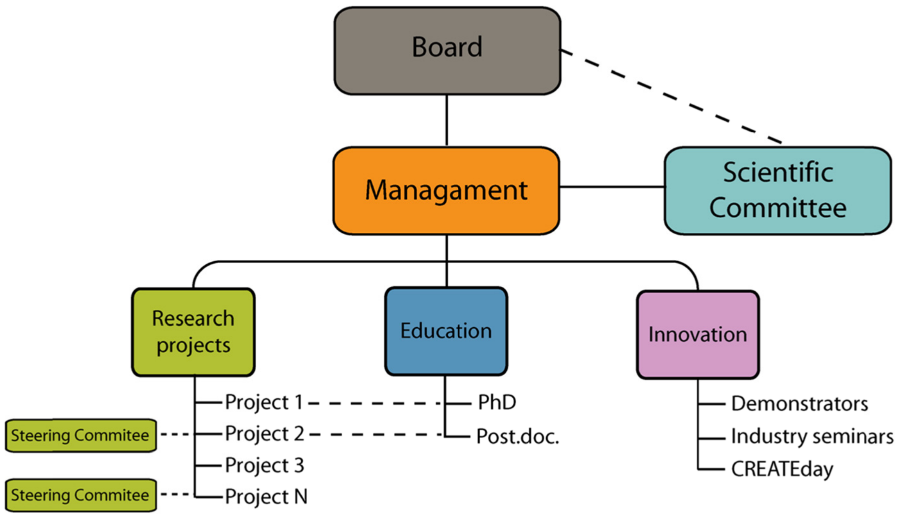


Figure 2 The organisation of CREATE, including projects and education

The Board of directors are has a majority of members from the industry partners and consists of in total six members, one member representing the Host Institution, one representing the research partners and four members representing the industry partners. The Board takes the decisions on organisation, budget, activities and working plan for CREATE. The development and content of the yearly working plans is carried out by the Scientific Committee. In 2012 the following people were members of the board:

Morten Malm (Chairman)	AKVA Group ASA
Karl A. Almås	SINTEF Fisheries and Aquaculture
Tore Kristiansen	Institute of Marine Research
Ove Veivåg	Egersund Net AS
Bjørn Karlsen	Erling Haug AS
Arnfinn Aunsmo	Salmar ASA

The Scientific Committee (SC) has members from all partners, research and users. The mandate of the Scientific Committee is to ensure development of new project ideas, new projects, and overall quality and scientific control of the research carried out in the centre. The Scientific Committee makes recommendations for the research plan and projects to the Board of directors. In 2012, the following people were members of the SC:

Kristine Brobakke	Erling Haug AS
Geirmund Vik	Egersund Net AS
Morten Malm	AKVA group ASA
Olav Breck	Marine Harvest Norway AS
Harald Sveier	Lerøy Seafood Group ASA
Eldar Bendiksen	Salmar ASA
Torbjørn Åsgard	NOFIMA AS
Pål Lader	SINTEF Fisheries and Aquaculture
Frode Oppedal	Institute of Marine Research
Mats Carlin	SINTEF ICT
Jo Arve Alfredsen	Department of Engineering Cybernetics, Norwegian University of Science and technology (NTNU)
Odd M. Faltinsen	Centre for Ships and Ocean Structures (CeSOS), Norwegian University of Science and technology (NTNU)

The projects are set up with a project leader and a Steering Committee (SteCo). The project leader has the responsibility for carrying out the project, while the Steering Committee has the responsibility to follow up on progress and objectives. Normally, the project leader is selected among the research partners and the leader of the Steering Committee is always from one of the user partners. The number of people in the Steering Committee depends on the size and type of the project, and ranges from two to seven. The Centre Director is a member of all Steering Committees.

Education Centre for Ships and Ocean Structures and NTNU Department of Engineering Cybernetics have the main educational responsibilities for PhD and MSc candidates. In addition, PhD and MSc candidates are educated at University of Bergen through collaboration with Institute of Marine Research and Norwegian University of Life Science through collaboration with NOFIMA Marin.

Innovation Once every year CREATEday is organized, which serves as a meeting place for innovation, presentation of results, exchange of ideas and creation of new projects.

4.2. Research facilities of the centre

CREATE has access to several research facilities through its research partners, including:

SINTEF Sealab is the host location of the centre. SINTEF Sealab houses laboratories with a sea-water system and tanks, designed especially for the marine research activities within SINTEF. The newly established SINTEF Sealab facilities for Simulations, Surveillance and Operations (Sealab SSO) is an important tool for studying remote operations, control and planning systems.

The SFH Flume Tank in Hirtshals, Denmark, is the second largest in the world and its size makes it possible to use large models with "full-scale" netting panels in tests. Experimental activities where steady currents are the main focus are carried out in the flume tank.

Aquaculture Engineering (ACE) provides industrial-scale testing facilities, including locations with and without fish and with different energy environments. ACE is ideal for testing of all kinds of fish farming equipment like cages, nets, monitors, feeding systems and also for operational systems and management procedures. ACE provides valuable quality controlled production data for bio-statistical analysis and development of control systems.

Institute for Marine Research, Cage Environment Laboratory, Matre. The Cage Environment Laboratory is a fjord-based full-scaled fish farm for studies related to fish behaviour and water flow dynamics and has a basic set-up of ten 12 x 12 x 15 m deep cages where behavioural and environmental screening can be carried out with high resolution in time and space in all cages.

NOFIMA Marin, Sundalsøra Research Station. The station comprises more than 600 research tanks in different shapes and sizes, ranging in size from a first feeding unit (diameter 20 cm) through to pools for broodstock (diameter 11 m). A large variety of sea and fresh water is available.

Marine Technology Centre. This is a unique laboratory infrastructure, comprising the world's largest ocean basin, towing tank, wave flumes and other marine technology related laboratories for hydrodynamics and structural mechanics studies.

AKVA group and Marine harvest is part owner together with Skretting in the Cage Aquaculture Centre, a research facility for feeding technology and feed.

Figure 3 Institute for Marine Research, Cage Environment Laboratory, Matre

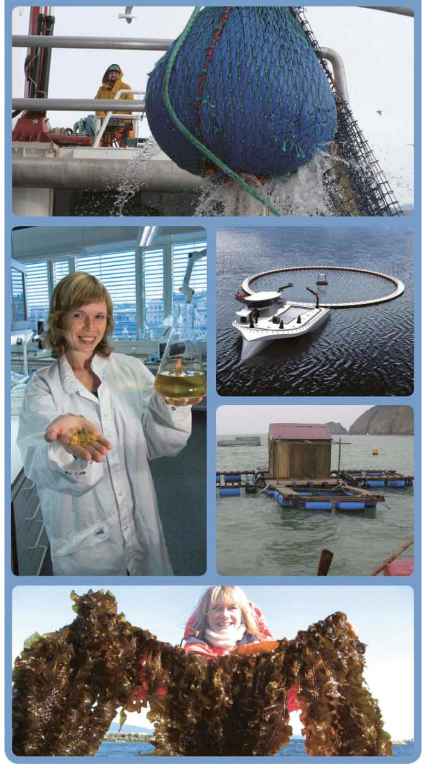
4.3. Partners

SINTEF Fisheries and Aquaculture (SFH) has knowledge and broad competence in the field of the utilization of renewable marine resources. The institute contributes to solutions along the whole value chain - from biological and marine production, aquaculture and fisheries to processing and distribution. SFH perform basic and applied research for commercial customers as well as governmental institutions and bodies, the Norwegian Research Council, the European Union, the United Nations (FAO), and others – more than 80% of revenue come from research contracts and among those, contract research for industry dominates.

AKVA group ASA is a leading supplier of technology to the world's fish farming industry. The technology supplied comprises products ranging from steel and plastic cage systems for fish farms to feeding- and information systems. The Company's headquarter is in Bryne, Norway. AKVA group also has offices in Trondheim, Brønnøysund, Averøy and Mo i Rana (all located in Norway) in addition to offices in Denmark, Scotland, Canada, Chile, Turkey and Thailand. AKVA group has organized its technology and product offering into two business areas, Farm Operations Technology, comprising centralized feed systems, sensors and camera systems, recirculation systems and process control-, planning and operations software, and Infrastructure Technology, comprising steel and plastic cages as well as certain other related products such as feed barges and floating rafts. AKVA group is targeting fish farming companies worldwide with main focus on the present main salmon farming countries, Norway and Chile, as well as other salmon producing countries and the Mediterranean region.

SINTEF Fisheries and Aquaculture - facts

- Vision: Technology for a better society
- Perform basic and applied research for commercial customers as well as governmental institutions and bodies
- Contributes to solutions along the whole value chain



AKVA GROUP - facts

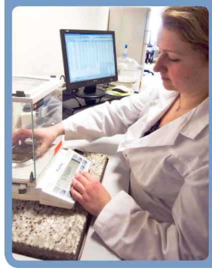
- The leading aquaculture technology supplier
- Only supplier with global presence
- Offices in 12 countries and staff of around 600
- The largest supplier to the aquaculture industry
- High growth company
- Profitable
- Industry consolidator

BioMar AS - facts

- Novel feed solutions for global aquaculture
- Healthy and sustainable growth
- Research-based innovation
- Interaction feed technology and biology
- Strong focus on fish nutrition and health

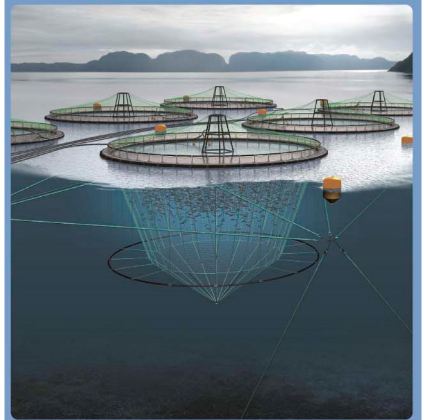







EGERSUND NET - facts

- Leading supplier for the fish farming industry
- Nets and bird nets
- Antifouling
- Service Equipment
- Quality products and experienced staff
- Profitable




BioMar AS The BioMar group is one of the leading suppliers of high performance fish feed to the aquaculture industry. Our main business areas are feed for salmon and trout in Norway, the United Kingdom, and Chile, and feed for trout, eel, sea-bass, and sea-bream in Continental Europe.

Roughly one out of four farmed fish produced in Europe and Chile are fed with BioMar fish feed.
Worldwide the BioMar Group supplies feed to around 60 countries and to more than 25 different fish species.

BioMar fish feed types cover the full life cycle of the fish including larvae feed, fry feed, smolt feed, grower feed, and brood stock feed.

Egersund Net AS has since the early 1970's, been one of the leading producer and supplier of nets for the fish farming industry in Europe, with modern production plants in Norway and Lithuania. Product development has always been a very important activity in Egersund Net. Their goal is to be a front leader of any technical development in manufacturing nets and netting, and also in design and testing of new models. Research and development in collaboration with customers and partners, like Create, makes the company able to continue its work for a better product, better quality and a better result for the fish farmers.

Erling Haug AS is located in offices in Trondheim, Kristiansund, Harstad, Ålesund, Florø and Puerto Montt, Chile. Our business areas range from the offshore industry, land based industry, retailers, the maritime industry and the aquaculture industry. Erling Haug provide the aquaculture industry with products related to complete mooring systems, components for mooring systems, lifting equipment and life saving equipment as well as several other product groups.

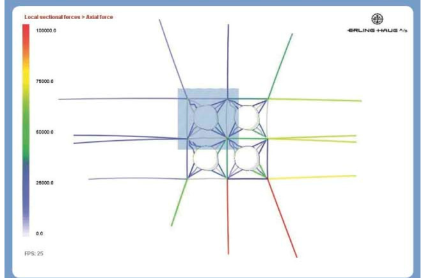
Erling Haug AS is part of the Axel Johnson Group. Customers range from private consumers to international companies, and products range from groceries to high-tech products. Foresight, entrepreneurship and creativity have been the watchwords of their past and will be the lights of the future. The group has around 15000 employees. Innovation has been part of the Erling Haug AS philosophy from the beginning. Key components in mooring systems are self-made based on experience and research.

Lerøy Seafood Group ASA is the 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. The Group's task is to satisfy the customer's requirements for cost-effective and continuous supplies of a wide range of high-quality seafood products. Lerøy Seafood Group`s vision is to be the leading and most profitable global supplier of quality seafood.

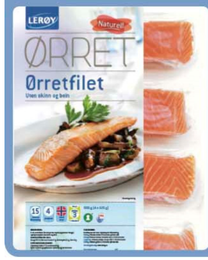
ERLING HAUG - facts

- Quality mooring components
- Dynamic analysis of mooring systems
- Flexible engineered mooring solutions
- Provides lifting- and HSE products, lice-skirts and LED marking buoys



Lerøy - facts

- Distribution, sale and marketing of seafood
- Production of salmon, trout and other species
- Product development



Marin Harvest - facts

- Farmed salmon
- Porcessed seafood
- Operates in the whole value chain

Salmar - facts

- Interactions between biology, environment and technology
- Focuses on a sustainable salmon industry
- In-house processing

Marine Harvest ASA is the world's leading seafood company offering farmed salmon and processed seafood to customers in more than 70 markets worldwide. The company is present in all major salmon farming regions in the world and the biggest producer of farmed salmon with one fifth of the global production. In addition to fresh and frozen salmon, Marine Harvest offers a wide range of value added products such as coated seafood, ready-to-eat meals, delicious finger food and smoked seafood. Though salmon is the main farmed product, the company also farms trout and white halibut.

Marine Harvest has salmon farming and processing activities in Norway, Chile, Scotland, Canada, Ireland and the Faroes. Value adding processing activities take place in the US, France, Belgium, the Netherlands, Poland and Chile. In addition Marine Harvest has several sales offices worldwide.

Salmar ASA is one of the world's largest and most efficient producers of farmed salmon. SalMar's vision is to be the most cost effective supplier of salmon and salmon products while maintaining high standards with respect to biology, ethical production and quality. With international competition increasing all the time, low production costs are a vital competitive parameter to achieve strong margins and a good return on equity. Salmar owns 67 licenses for marine production of Atlantic salmon in Norway and owns 50% of Norskott Havbruk AS, which owns 100% of Scottish Sea Farms Ltd, Great Britain's second-largest salmon farmer with production capacity in excess of 30,000 tonnes gutted weight.

The company wishes to continue investing in biological development to enable further industrialisation. SalMar also aims to increase the level of salmon processing undertaken so that a larger proportion of the value added is retained within the company. Increased local processing will also have environmental benefits through a reduction in exports of whole fish, the head and bones of which are largely discarded by the consumer. Moving forward creating and developing secure, interesting and profitable workplaces will remain an important objective for SalMar. The further development of SalMar's company culture and the SalMar Standards will be achieved through a continuation of the SalMar School.

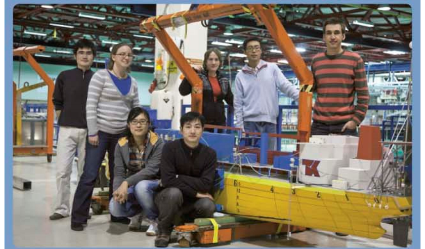
Centre for Ships and ocean Structures (CeSOS) at the Norwegian University of Science and Technology, integrate theoretical and experimental research in marine hydrodynamics, structural mechanics and automatic control. Research at CeSOS aims to develop fundamental knowledge about how ships and other structures behave in the ocean environment, using analytical, numerical and experimental studies. This knowledge is vital, both now and in the future, for the design of safe, cost effective and environmentally friendly structures as well as in the planning and execution of marine operations.

The scientific and engineering research carried out in the Centre takes account of future needs, and extends current knowledge in relevant disciplines. The emphasis is on hydrodynamics, structural mechanics and automatic control, and in the synergy between them. In each of the past years, the research projects of CeSOS have proved valuable basis for the innovative design of structures, risers and automatic control systems.

Department of Engineering Cybernetics (DEC), Norwegian University of Science and Technology (NTNU) is responsible for the Master of Science and doctoral education in engineering cybernetics at NTNU. DEC is also the dominant national contributor to both theoretical and applied research in engineering cybernetics. The Department currently employs an academic staff of 23 professors and a techn./adm. staff of 13. In a typical year approximately 80 MSc's and 5-10 PhDs graduate from the DEC, with specializations in control systems engineering and industrialcomputer systems. The students apply their specialized knowledge to a multitude of application areas. In keeping with the department's tradition of performing research in areas of national importance, researchers at DEC have been targeting a wide variety of scientific and technological challenges present in the fisheries and aquaculture sector over the last 35 years. Based on this activity, DEC offers educational specialization and research opportunities for its candidates on the application of cybernetic principles and technology to the fisheries and aquaculture industry (fisheries and aquaculture cybernetics).

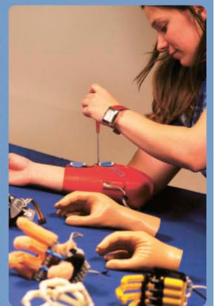
CeSOS - facts

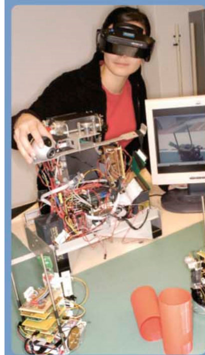
- Centre of Exellence initiated by RCN in 2003
- Internationally recognised research on ships and ocean structures
- Higly interdisciplinary approach
- About 100 affiliated PhD candidates and researchers
- More than 100 scientific publications per year



Department of Engineering Cybernetics - NTNU - facts

- Engineering Cybernetics is the science of control and communications in dynamic systems.
- One of Europe's most renowned research groups in the cybernetics field.
- 27 permanennt employees and about 40 PhD students ad temporary academic staff.
- Graduates 75 MSc and 10 PhD each year.
- Cybernetics is a science with a very wide range of applications.





The Institute of Marine Research (IMR) is with a staff of almost 700, Norway's largest centre of marine science. The main task is to provide advice to Norwegian authorities on aquaculture and the ecosystems of the Barents Sea, the Norwegian Sea, the North Sea and the Norwegian coastal zone. For this reason, about fifty percent of the activities are financed by the Ministry of Fisheries and Coastal Affairs. IMR's headquarters is in Bergen, but important activities are also carried out at departments in Tromsø, at the research stations in Matre, Austevoll and Flødevigen and on board IMR's research vessels, which are at sea for a total of 1600 days a year. IMR is also heavily engaged in development aid activities through the Centre for Development Cooperation in Fisheries.

IMR has high competence in the fields of aquaculture, fish behaviour, and fish physiology, including modelling and fisheries acoustics. The team has access to facilities at Matre and Austevoll Aquaculture Research Stations, including all life stages of Atlantic salmon and cod. This includes freshwater and seawater tank facilities with extensive control of water quality, photoperiod and waste feed, as well as a cage-environment laboratory with high temporal and spatial screening of environmental parameter and behaviour.

NOFIMA AS is an industry focused research corporation which aims to increase the competiveness of the food industry, including aquaculture, catch based fishing and the agriculture sector. The corporation is organized into four business areas: Marin, Food, Ingredients and Market. NOFIMA has its head office in Tromsø with research centres at Ås, Stavanger, Bergen, Sunndalsøra and Averøy.

Nofima Marin (www.nofima.no) engage in R & D, innovation and knowledge transfer for the national and international fisheries and aquaculture industry. The primary professional areas cover breeding and genetics, feed and nutrition, fish health, sustainable and effective production as well as capture, slaughtering and primary processing.

INSTITUTE OF MARINE RESEARCH - facts

- Owner: Ministry of Fisheries and Coastal Affairs
- Norway's largest marine research institute
- Marine biology and population dynamics
- Physical and biological oceanography
- Experimental biology and population genetics
- Welfare friendly and sustainable aquaculture
- Research and advice for sustainable use of oceanic and coastal environments and resources





NOFIMA MARIN - facts

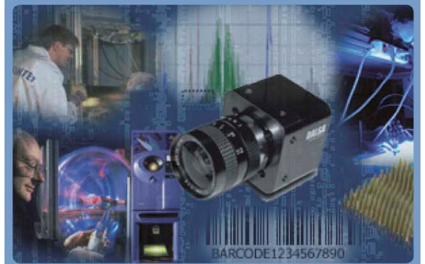
- R&D, innovation and knowledge transfer for fisheries and aquaculture
- Breeding and genetics
- Feed and nutrition
- Fish health
- Efficient and sustainable production
- Seafood processing and product development
- Marine bioprospecting

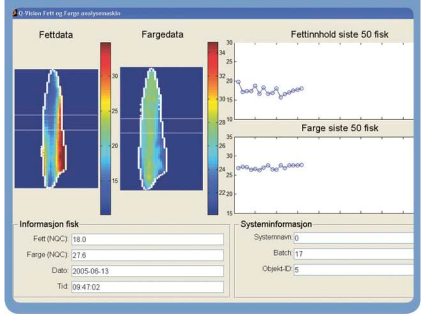




SINTEF ICT - facts

Information and Communication Technology (ICT) provides research-based expertise, services and products ranging from microtechnology, communication and software technology, computational software, information systems and security and safety. Work ranges from simple technical analysis to complete systems





SINTEF Information and Communication Technology (SINTEF ICT) provides contract research-based expertise, services and products within the fields of micro technology, sensor and instrumentation systems, communication and software technology, computational software, information systems and security and safety. Contracts for industry and the public sector generate more than 90% of our income, while 7% comes in the form of basic grants from the Research Council of Norway.

4.4. Cooperation between the centre's partners

The core activity within CREATE is the research projects, and the project related activities are the main source for cooperation and interaction between the partners in CREATE. All the research projects are set up with multiple partners involved, including always both research and user partners. This is essential for successful research and results within the frame of a centre for research-bases innovation. Further, all the projects are set up with a Steering Committee, in which all the industry partners involved in the project is members. This has resulted in good communication and collaboration between the industry and research partners and a mean to ensure industry related results from the research projects. The director of CREATE is member of all Steering Committees.

The projects have regular meetings with all participants, arrange workshops on specific targets and develop demonstrators to show industrial applications. Workshops are held both at the location of CREATE and the offices of the industrial partners.

Every year the centre arranges the CREATEday, where the focus is on dissemination of results, development of new ideas and innovation. Approximately 35-40 people attend CREATEday every year, with representatives from all partners. Specific workshops have also been arranged at the premises of the industrial partners to focus on topics relevant for the user partners. Regular meetings of the Scientific Committee are also held to develop new project ideas, assess project plans and discuss results.

In the last three year of the centre period, CREATE focuses on creating industry relevant results and that the competence and results achieved by the research are effectively transferred to and utilised by the partners. This is mainly taken care of directly within each project through direct involvement of user partners. For those projects where the user partners, due to the content of the projects, are not greatly involved, dissemination of their results occurs through the Steering Committees of each project, regular workshops and at the yearly CREATEday. Cooperation is further assured through the organisation and governance of the centre within the Board and the Scientific Committee.

5. Scientific activities and results

5.1. CREATE biofouling and biocleaning

Researchers: Lars Gansel, Nina Bloecher, Johanne Arff, Eirik Svendsen (SINTEF Fisheries and Aquaculture)

Industry partners: AKVA group, Egersund Net, SalMar

Background

Biofouling on aquaculture nets is a major challenge for the aquaculture industry. Biofouling adds weight to nets and equipment and it changes hydrodynamic properties of fish cage systems. Approaches to battle biofouling include prevention in form of anti-fouling coatings, and removal by underwater or land-based net cleaning, net drying or changing or biological controls. Underwater high pressure cleaning of nets is common in the Norwegian Salmon culture industry and it has a good immediate washing effect. However, some organisms are not completely removed and it was demonstrated that hydroids can quickly re-grow polyps when these are cut off. Underwater high pressure cleaning can lead to increased release of larvae from hydroids, which might rapidly settle on newly cleaned nets. New washing methods that kill or inactivate remaining fragments of fouling organisms on nets and larvae of fouling organisms during the washing process might, in addition to a good immediate washing effect, slow down the development of macro-fouling after washing events.

Biofouling is not necessarily homogeneously distributed on nets and there may be large variations of biofouling accumulation at a location throughout and in between years. Many fouling organisms have planktonic life stages and larvae can often decide if to settle on an available surface. Knowledge about connections between physical and chemical water parameters, composition of plankton, including planktonic stages of fouling organisms, and the development of a fouling community on suitable substrates can help understand biofouling processes and it might allow a forecast of fouling development on nets by monitoring environmental conditions and plankton.

Several techniques are used to evaluate the amount and composition biofouling on substrates, but not all are well suited for the use on nets. Given good image quality, image analysis allows for a fast and reliable calculation of net solidity and net aperture occlusion, which can be used as a measure for the amount of biofouling on nets.

Methods

Semi-automated image analysis for the quantification of fouling: Requirements and solutions to obtain high quality images. An algorithm for the calculation of net solidity and net aperture occlusion from images of nets and fouling was developed previously. The technique gives good results for images with high contrast between foreground (net and fouling) and background (net openings). Ambient light conditions change with depth and, close to the surface, with time, thus creating inconsistencies in the image quality of underwater images. Nets and coatings can be differently colored and different lighting might be necessary to gain a high contrast throughout images. Camera and light source often have to be at the same side of a net for practical reasons and a number of light settings were tested using an adjustable camera and lighting rig to find optimal settings as well as limitations for white and black lightly fouled nets.

Effect of heat treatment on hydroids. A conceptual model of a washing rig including a high pressure disc washer and a hot water applicator was tested as a means to deliver heat to previously washed nets to prevent re-growth of hydroids from hydroid remains after high pressure washing. A total of 32 net panels on 8 frames were deployed at a fish farm site. 8 nets served as control (fouling pressure between washing events). These nets were removed and replaced with new nets during the washing events. 12 nets were washed with high pressure and 12 nets were washed with high pressure followed by hot water treatment. The washing was repeated 3 times between August and November 2012 and the washing success and re-growth between washing events was measured based on images of the fouled nets.

Connections between water parameters/plankton composition and fouling on nets. To investigate the species composition and amount of biofouling between net types and locations along a fish cage and whether differences can be correlated (and explained) with other parameters, uncoated and silicon coated net panels were deployed in three locations close to and within a stocked fish cage (see Figure 4). Samples were taken weekly for Plankton, dissolved nutrients, particles (for C/N analysis), images were taken for monitoring biofouling growth and species determination and the water temperature was logged. Additionally, 10 samplings were carried out for all above parameters within a 24 hour period to gain information about temporal variability

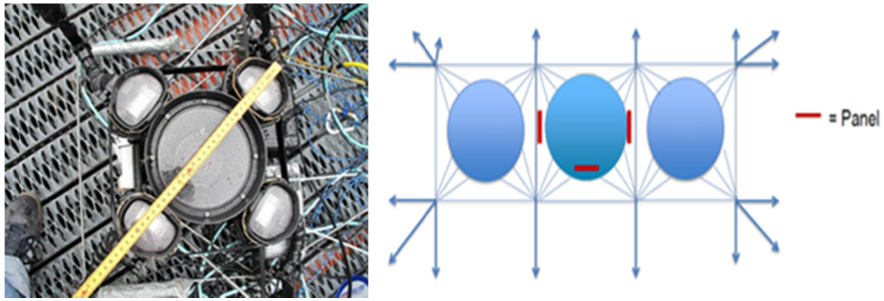


Figure 4 Part of the camera and lighting rig. Strobes are on flexible arms and the distance of the camera to the nets was adjustable (left) and sketch of the placement of net panels. Locations 1, 2 and 3 are at the right, lower and left panel, respectively (right)

Results

Semi-automated image analysis for the quantification of fouling: Requirements and solutions to obtain high quality images. Good image quality for an image analysis resulting in the calculation of net solidity is defined by a high contrast between net and fouling and background. Strong lighting gives good images for light nets and fouling, even though it might lead to loss of structure within net strands (see Figure 4). Strobes can be used to reach a light intensity high enough to compensate for even high levels of ambient light. Even very strong lighting might not result in sufficient contrast, as background and nets are relatively dark (see Figure 5) Fouling on dark nets improves the image quality, as it appears much lighter than the net and background when sufficiently illuminated. For very dark nets with little fouling lighting the background by moving strong light sources directly against the net to the sides of the camera, but with the light aimed through the net, gave good results. The results enable a more robust and more accurate evaluation of biofouling on nets through better protocols for taking underwater images. All results are transferable to other areas where underwater images and videos are of interest.

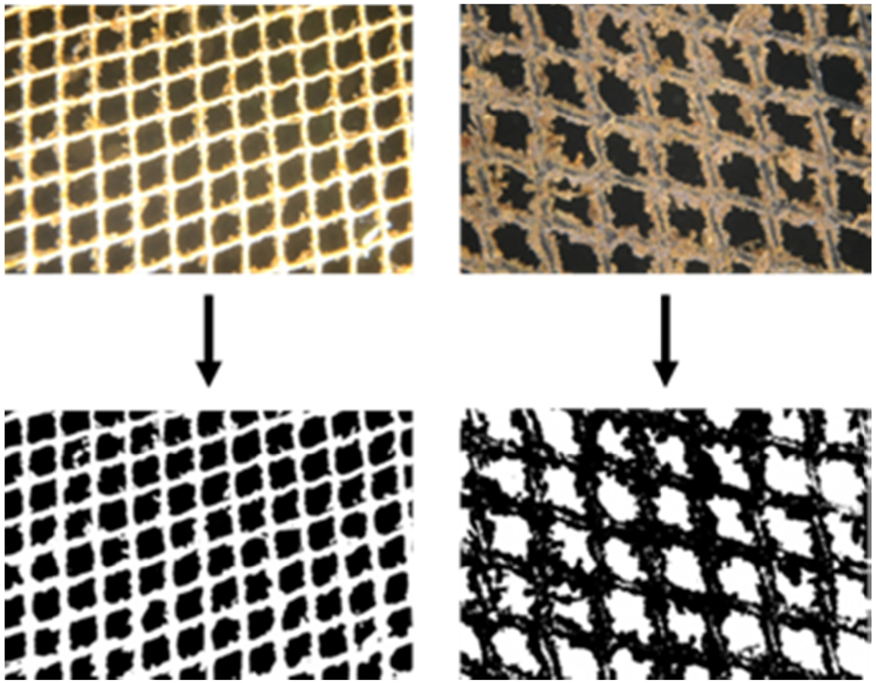


Figure 5 Image transformation for a white net (left side) and a black net (right side)

Effect of heat treatment on hydroids. The temperature of water leaving the hot water applicator directly at its outlets was about 75 C. Strong heat dissipation led to temperatures on the net being within the range of 55 C to 58 C, which was slightly below the temperature that was shown to be effective against adult hydroids. There were no significant differences in amount of biofouling on nets washed with different methods 4-5 weeks after washing events. The temperature of water reaching fouling organisms might not have been high enough to inhibit re-growth from hydroid fragments remaining on nets after washing events and the time interval between washing and evaluation of fouling after washing events might have been long enough for new fouling to mask an effect of the heat treatment on re-growth of hydroids. The test setup for future experiments is adjusted based on the experience from these tests: a temperature at the net of over 60 C will be ensured and the immediate effect of heat treatment in the field will be investigated on the survival of hydroid fragments remaining on nets after high pressure washing and on the settlement success of larvae after heat treatment. A method for heat application capable of inhibiting re-growth from damaged fragments of hydroids and settlement of larvae being released during the washing process can potentially prolong the time period between washing events and suppress rapid re-colonization of cleaned nets with larvae from fouling organisms originating from within the fish farm.

Connections between water parameters/plankton composition and fouling on nets. Net panels were submerged for 6 weeks in August and September, which, according to a previous study at a Salmon farm in Mid-Norway, falls within the peak period for fouling growth on aquaculture nets. However, there was almost no fouling on the net panels throughout the entire test period (see also Figure 6). This underlines the strong variability of fouling growth in space and time. An analysis of water samples over a period of several weeks and over a diurnal cycle is of interest by itself, as it gives an insight into some dynamics in the nutrient availability and the occurrence and composition of plankton. Concentrations of Nitrate/Nitrite and phosphate in the water coloumn were relatively stable over a 24 hour period with no consistent differences between sampling locations. Other studies report much higher, but also much lower nitrate/nitrite concentrations in Norwegian waters. Nitrate and Nitrite concentrations close to fish cages might therefore be more dependent on the ambient concentrations than on fish farm output. Ammonia concentrations peaked at positions 1 and 3 (panels left and right of the cage in Figure 2) at around midnight and slowly decreased to levels measured during daytime over a few hours (see Figure 6). Excretion from fish has a large impact on ammonia concentrations and there is a distinct diurnal pattern of Ammonia release into the surrounding water, which is likely to be influenced by the feeding regime.

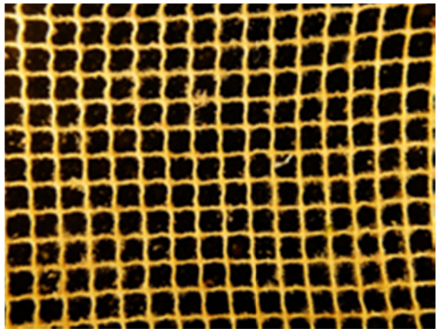


Figure 6 Maximum amount of fouling within the test period

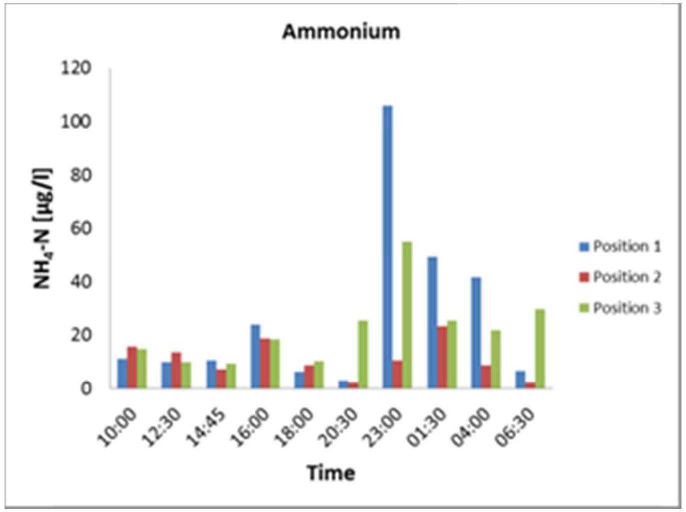


Figure 7 Diurnal cycle of ammonia concentrations at three locations of a salmon fish cage

CREATE publications related to bio fouling and cleaning

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Guenther J, Wright AD, Burns K, de Nys R (2009) Chemical antifouling defences of tropical sea stars: Effects of the natural products hexadecanoic acid, cholesterol, lathosterol and sitosterol. Marine Ecology Progress Series 385: 137-149

Guenther J, Misimi E, Sunde LM (2010) The development of biofouling, particularly the hydroid Ectopleura larynx, on commercial salmon cage nets in Mid-Noway Aquaculture 300: 120-127

Guenther J, Misimi E, Sunde LM (2010) Spatial and temporal effects of the underwater washing of salmon cage nets on the net aperture occlusion due to biofouling. Aquaculture 300:120-127

Guenther J, Fitridge I, Misimi E (2011) Potential antifouling strategies for marine finfish aquaculture: the effects of physical and chemical treatments on the settlement and survival of the hydroid Ectopleura larynx. Biofouling: The Journal of Bioadhesion and Biofilm Research 27:9, 1033-1042, doi:10.1080/08927014.2011.627092

Carl C, Guenther J, Sunde LM (2011) Larval release and attachment modes of the hydroid Ectopleura larynx on aquaculture nets in Norway. Aquacult Res 42:1056-1060

Fitridge I, Dempster T, Guenther J, de Nys R (2012) The impact and control of biofouling in marine aquaculture: a review. Biofouling: The Journal of Bioadhesion and Biofilm Research

Bloecher, N., de Nys, R., Poole, A. J., Guenther, J. (2013) The fouling hydroid Ectopleura larynx: a lack of effect of next generation antifouling technologies. Biofouling: The Journal of Bioadhesion and Biofilm Research 29:3, 237-246

5.2. Cage Environment

Researchers: Frode Oppedal, Mette Remen, Rolf Erik Olsen, Thomas Torgersen, Jannicke Vigen, Jason Bailey and Jan Aure (Institute of Marine Research)
Lars Gansel, Pascal Klebert and Pål Lader (SINTEF Fisheries and Aquaculture)

Industry partners: Marine Harvest, Lerøy Seafood Group, Salmar, Egersund Net, Erling Haug, AKVAgroup

Background

Oxygen is the main limiting factor for fish metabolism, and sufficient supply is critical for optimal growth and welfare of salmon in intensive aquaculture. Observations within commercial sea cages show fluctuating oxygen levels, which may drop to alarmingly low levels (30–70% O2). To improve cage systems and adjacent legislation, it was necessary to understand how oxygen levels fluctuate based on flow conditions in and around stocked fish farms (i) and how low oxygen levels may affect growth, feed conversion and the physiology of the fish (ii). Correspondingly, the main objectives were developed to improve oxygen management in net cages in order to increase fish welfare and maximise production efficiencies.

Methods

Studies of water flow dynamics were studied in flow-through tanks and in cages. The influence of fish and their movement on water flow was studied in cages. Models for water flow were developed and taken further via other projects. Experimental trials investigating hypoxia and fish physiology/production performance were performed in the Tank Environmental Lab of IMR at Matre. Protocols for better oxygen management have been developed, scientific publications have been produced and a PhD has been completed.

Results

Flow around and through fish cages. A review paper (Klebert et al., 2013) presents the status of flow hydrodynamics within and around sea-cages, providing a framework for understanding the spatial and temporal variability of key environmental parameters in these environments. The paper focuses on contemporary experiments investigating drag forces on net panels, model-scale cages, the biological effects of fish, biofouling and fish movements (example Figure 8). The accumulated experimental results are sorted out following a gradually increasing scale, from the cruciform as a basic element of a net, to a net cage with solidity and velocity as the main parameters, while the effect of fish and fouling are discussed only at the full-scale level. The compilation is important to understand issues related to the design and mechanics of net cages, and taking into account fish behaviour in relation to future engineering development within the field of hydrodynamics in aquaculture cage farming. Improved knowledge on water movement through aquaculture cages is critical for the future development of efficient and sustainable aquaculture, including a shift towards exploiting more exposed locations.

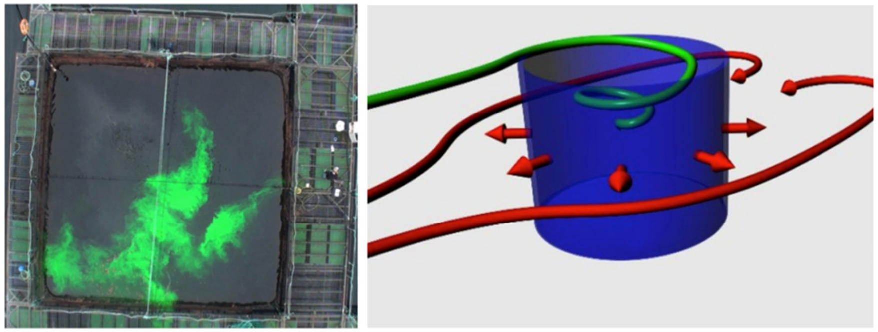

Figure 8 Left photo: Example of water flow in a cage with fish measured by a camera positioned 25 m above a 12 m × 12 m cage. Green dye is released at the right side of the cage and follows the main current pattern (red arrow) before the fish-made current pulls much of the dye into the cage centre and downwards. Right figure: Illustration showing water being forced around the fish cage (long red arrows), pushed out by the fish movement at their main swimming depth (short red arrows) and water being pulled down the centre of the cage (green line).

Hypoxia limitations and practical guidelines. For the typical autumn temperature of 16 °C, the dissolved oxygen (DO) threshold for optimal feeding of Atlantic salmon post-smolts is ~70% O2. Feed intake, and presumably the digestion rate, decreased with increasing hypoxia severity, reaching low levels as DO approached the hypoxia tolerance threshold of 47% O2. Below this DO threshold, fish were no longer able to maintain their oxygen uptake rate and resorted to anaerobic ATP production to cover their energy demand. Further, a general stress response was induced at DO equivalent to 51-54% O2, and a few fish died during the first day of hypoxic periods (40 and 50% O2). The limited ability to maintain basic functions and the stress and compromised survival at DO below the hypoxia tolerance threshold, demonstrate that this is a limit for acceptable drops in oxygen in Atlantic salmon sea cages, both in regards to production performance and welfare.

Post-smolt Atlantic salmon exhibit low swimming speeds and relatively low growth rates. As such, this DO threshold increases exponentially with temperature, from 29 to 55% O2 at temperatures ranging from 6–18 °C (Figure 9). This threshold should be increased by approximately 40% (i.e. 41–77% O2) in order to serve as practical guideline for salmon farming, due to the higher level of activity (feed intake, swimming speed etc.) that can be expected from fish in sea cages.

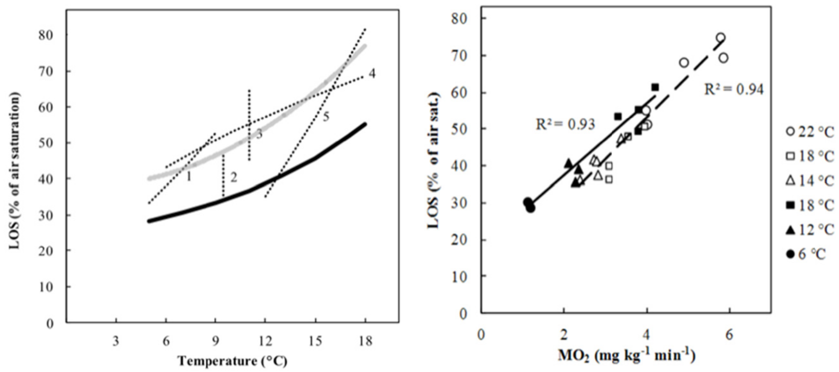

Figure 9 Left panel: The limiting oxygen saturation (LOS, % of air saturation) of fed Atlantic salmon post-smolts at temperatures ranging from 6-18 °C obtained in the present study (black line), compared to LOS estimated from MO2 measured in other studies of Atlantic salmon smolts/ post-smolts fed to satiation and swimming at various speed (broken lines). The hypothesized grey line represents a practical guideline of LOS for the salmon farming industry. Right panel: Linear relationship between oxygen consumption rate (MO2) and LOS (limiting oxygen saturation) for post-smolts < 1 kg providing background to predict LOS for fish with different oxygen demands. The points represent replicate fish groups kept at different temperatures.

The reduced feed intake of post-smolts in hypoxic periods was to a large extent compensated for by increased feeding in normoxic periods. This compensation developed after the initial stress response was down-regulated (< 1 week). However, feeding in normoxia did not fully alleviate the negative effects when hypoxia occurred for 2 h every 6 h. As growth reflects feed intake, it was concluded that such a frequency and duration of hypoxia reduces the growth and welfare of Atlantic salmon, and that the degree of any negative effects depends on the severity of hypoxia. The relatively large capacity for normoxic compensation does however suggest that negative effects of moderate hypoxia (DO>hypoxia tolerance threshold) may be fully alleviated if the hypoxic periods are of shorter duration and/or frequency. The hypoxia sensitivity of Atlantic salmon was not considerably reduced as a result of acclimation to cyclic hypoxia, as indicated by the persisting anaerobiosis and inhibited feed intake during the hypoxic periods.

The main conclusions from the PhD thesis were that reductions in DO below the hypoxia tolerance threshold is unacceptable, both with regard to production performance and welfare, while negative effects of DO concentrations ranging between this threshold and the threshold for maintained feeding, depend on hypoxia severity, frequency and duration. Acclimation to hypoxia did not reduce hypoxia sensitivity, while habituation to hypoxic stress was linked to an increased compensatory feeding in normoxic periods. Hypoxia occurring for ~2 h in tidal cycles (~every 6 h) was not fully compensated for, in spite of stress habituation and normoxic feeding.

CREATE publications related to cage environment and fish welfare

Oppedal F, Dempster T, Stian L (2011) Environmental drivers of Atlantic salmon behaviour in sea-cages: a review. Aquaculture, Volume 311, Issues 1-4

Oppedal F, Vågseth T, Dempster T, Juell J-E, Johansson (2011) Fluctuating sea-cage environments modify the effects of stocking densities on the production and welfare of Atlantic salmon (Salmo salar L.). Aquaculture Volume 315: 361–36

Gansel L.C., McClimans T.A. and Myrhaug D. (2012) Flow Around the Free Bottom of Fish Cages in a Uniform Flow With and Without Fouling. J. Offshore Mech. Arct. Eng., Vol. 134, Iss. 1.

Gansel L.C., McClimans T.A. and Myrhaug D. (2012) The Effects of Fish Cages on Ambient Currents. J. Offshore Mech. Arct. Eng., Vol. 134, Iss. 1.

Gansel L.C., McClimans T.A. and Myrhaug D. (2012) Average Flow Inside and Around Fish Cages With and Without Fouling in a Uniform Flow J. Offshore Mech. Arct. Eng. 134

Gansel, L., Rackebrandt, S., Oppedal, F., McClimans, T.A., (2012) Flow fields inside stocked fish cages and the near environment. Journal of Offshore Mechanics and Arctic Engineering

Remen M, Oppedal F, Torgersen T, Imsland A, Olsen RE (2012) Effects of cyclic environmental hypoxia on physiology and feed intake of post-smolt Atlantic salmon: Initial response and acclimation. Aquaculture 326-329, 148-155.

Klebert P, Gansel L, Lader P , Oppedal F, (2013) Flow hydrodynamics through nets and floating cages: a review. Ocean Engineering 58, 260-274.

Remen M., Aas T.S., Vågseth T., Torgersen T., Olsen R.E., Imsland A., Oppedal F. (2013) Feed intake, feed utilization, metabolism and growth of Atlantic salmon (Salmo salar L.) post-smolts during long-term cyclic hypoxia and subsequent compensatory growth. Aquaculture Research

5.3. Pellet Quality - optimal conveying and biological response

Researchers: Torbjørn Åsgård, Maike Oehme (PhD student), Mette Sørensen, Trine Ytrestøyl, Bjarne Hatlen and Turid Synnøve Aas (Nofima)

Industry partners: BioMar, Lerøy Seafood Group, Marine Harvest, SalMar

Background

The large units in salmon farming require effective storage and transport, and, to minimize pellet breakage, pellets with high physical quality is demanded. However, as shown previously in this project, pellet quality may affect feed intake and feed utilization in fish. In the latter experiment, soaking feed increased feed intake.

It was hypothesized that the variation in feed intake when feeding feeds of different physical quality may, at least in part, be due to differences in gastrointestinal passage rate. In the present trial therefore, fish was fed either a dry (as is) or a soaked diet, and fish was sampled at given times after feeding to investigate the passage rate.

Methods

Atlantic salmon of 1kg bodyweight was fasted until the gut was empty, and then fed one meal of either a dry feed (10 mm) or the same feed soaked in sea water for 2 h prior to feeding. The dry feed and the soaking procedure was the same as used in a previous trial. The fish was euthanized at 2, 6, 12, 18, 24 and 48 h after feeding, and the gut removed. The content was collected and divided in content from 1) stomach 2) pylorus and mid intestine and 3) hind gut. Material from three fish was pooled, and three pooled samples were collected at each time for both treatments (triplicate). The samples were weighed and analyzed chemically.

Results

There was unexpectedly large individual variation in gastrointestinal passage rate among the salmon. Two hours after feeding, significantly more of the feed (% of ingested dry matter) had moved from stomach to pylorus and mid intestine in salmon fed soaked feed compared to those fed dry feed (Figure 10). This shows that the gastric evacuation rate was increased when the feed was soaked. Several of the measurements indicated (non-significantly) that the soaked feed had a higher passage rate through the gastrointestinal tract than the dry feed. This information is valuable for optimizing feeding, and will be investigated further in a new trial.

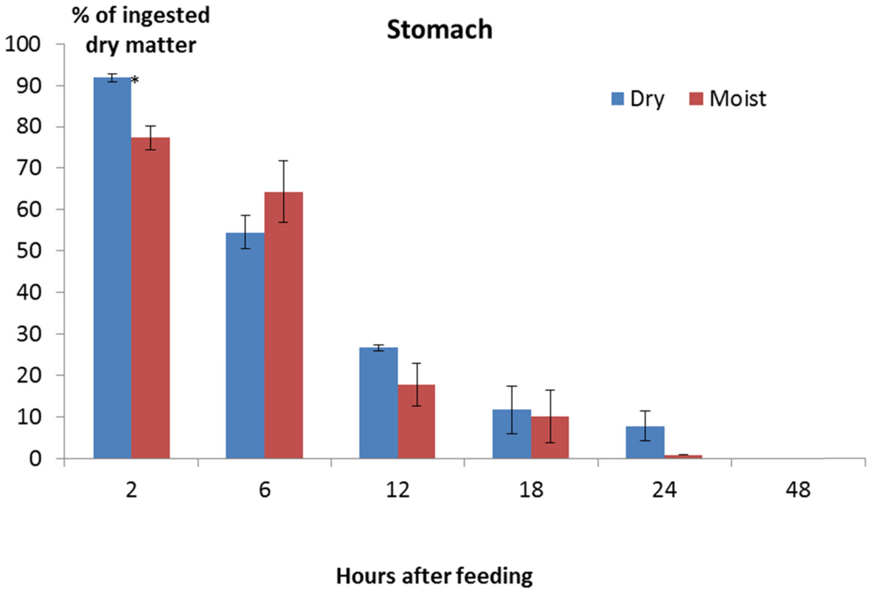

Figure 10 Content of dry matter (given as % of ingested dry matter) in stomach, pylorus and mid intestine and hind gut in Atlantic salmon 2, 6, 12, 18, 24 and 48 h after feeding a single meal of dry or soaked feed. Data are given as mean±SEM. Asterisk (*) indicates significant differences between the two treatments ($P<0.05$).

PhD thesis

Maike Oehme has been a PhD student on this project from 2010-2012, and submitted her thesis entitled 'Feed utilization can be improved by optimizing physical pellet quality and feeding equipment in salmonid farming' in December 2012.

CREATE publications related to pellet quality

Aas TS, Oehme M, Sørensen M, He G, Åsgård T(2011) Analysis of pellet degradation of extruded high energy fish feeds with different physical quality in a pneumatic feeding system. Aquacultural Engineering, Volume 44, Issue 1, January 2011, Pages 25-34

Aas TS, Terjesen BF, Sigholt T, Hillestad M, Holm J, Refstie S, Baeverfjord G, Rørvik K-A, Sørensen M, Oehme M, Åsgård T (2011) Nutritional value of feeds with different physical qualities fed to rainbow trout (Oncorhynchus mykiss) at stable or variable environmental conditions. Aquaculture Nutrition

Aas,T.S., Terjesen,B.F., Sigholt,T., Hillestad,M., Holm,J., Refstie,S., Baeverfjord,G., Rørvik,K.-A., Sørensen,M., Oehme,M., & Åsgård,T. (2011) Nutritional responses in rainbow trout (Oncorhynchus mykiss) fed diets with different physical qualities at stable or variable environmental conditions. Aquacult.Nutr. 17, 657-670.

Oehme M, Aas TS, Sørensen M, Lygrene I, Åsgård T (2012) Feed pellet distribution in a sea cage using pneumatic feeding system with rotor spreader. Aquaculture Engineering

5.4. NetCageDesignTools

Researchers: Finn Olav Bjørnson, Martin Føre, Brad Schofield, Per Runtop, Per Christian Endresen (SINTEF Fisheries and Aquaculture)

Industry partners: Egersund Net

Background

Existing commercial software is not suitable for designing net cages. The main reason is that they are in general focusing on verification of forces in the entire farm, including mooring and cages. This leads to long simulation times, limited number of design options and often very coarse and simplified net models. Egersund Net desired a numerical tool for easy and quick design of new net cages. The numerical tool should also give results that can be used when certifying the net cages.

Methods

The main method used for the project has been a scrum inspired agile method. The project group has had regular meetings every two weeks where we have looked at a list of requirements for the software and prioritized what is feasible to implement during the next two week period. To ensure feedback from the customer we have had several meetings with Egersund Net where we presented the software so far and gathered feedback on wanted functionality and future priorities. In 2013 the first beta version was released and presented to Egersund Net and within 2013 the first release version will be available.

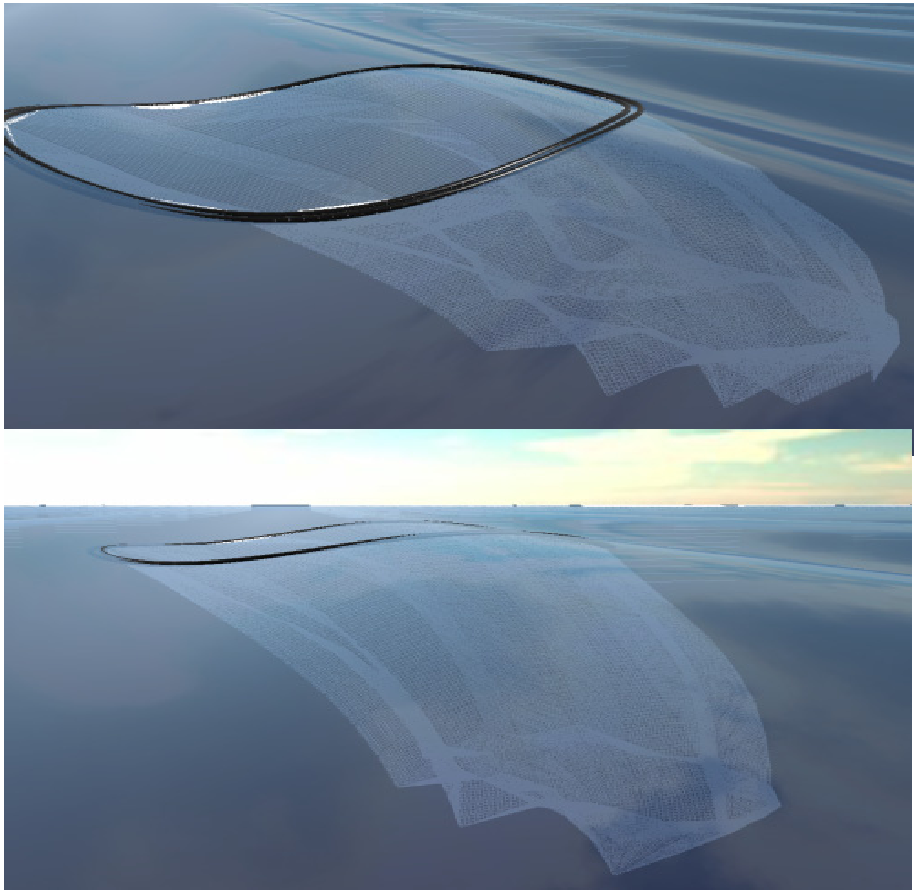

Figure 11 Screenshot of a deformed circular net cage with flexible floating collar in waves and current (left) and a deformed circular net cage with flexible floating collar in waves and current (right)

Results and Discussion

The demonstrator consists of a graphical user interface where users can specify the physical dimensions of a net cage, the physical properties of the net and ropes, and environmental loads like current and waves. The software takes this input and translates it to an input xml file for the fhSim Core 1.0, which then takes over and runs a simulation on the specified net structure. Both circular and rectangular nets can be modeled; with different geometries. Supportropes can be added vertically and horizontally. For circular cages the floating collar can be either rigid or flexible. The weight system can be either individual weights connected to the crossropes or a sinkertube, the weights can be calculated automatically or given manually. The demonstrator supports environmental conditions through current simulations on the net structure as well as regular and irregular waves.

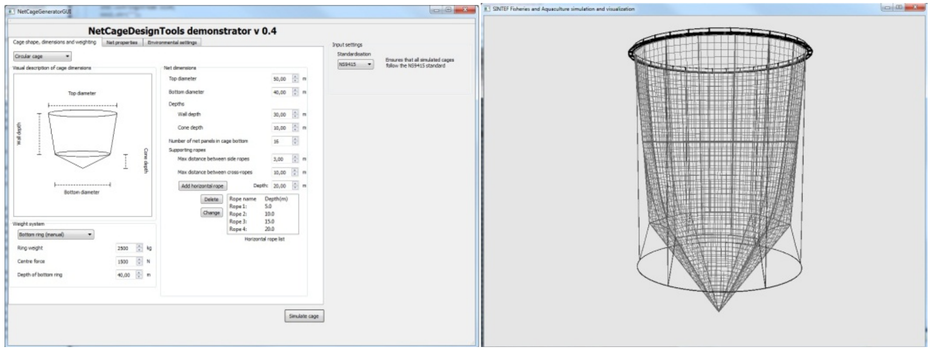

Figure 12 Screenshot of the first tab in the NetCageDesignTools demonstrator GUI. This tab is used to specify cage shape and dimensions, as well as which weighting method should be used in the simulation (Left). Screenshot of an undeformed circular net cage with rigid floating collar (right).

CREATE publications related to net cage design and loads on fish farms

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Lader PF, Jensen A, Sveen JK, Fredheim A, Enerhaug B, Fredriksson D (2007) Experimental investigation of wave forces on net structures. Applied Ocean Research 29(3): 112-127 1

Lader PL, Dempster T, Fredheim A, Jensen Ø (2008) Current induced net deformations in full-scale sea-cages for Atlantic salmon (Salmo salar). Aquacultural Engineering 38: 52-65

Moe H, Fredheim A, Hopperstad OS (2010) Structural analysis of aquaculture net cages in current. Journal of Fluids and Structures (in press)

Klebert P, Gansel L, Lader P , Oppedal F, (2013) Flow hydrodynamics through nets and floating cages: a review. Ocean Engineering 58, 260-274.

Kristiansen T, Faltinsen OM (2012) Modelling of current loads on aquaculture net cages Journal of Fluids and Structures Volume 34, October 2012, Pages 218–235

5.5. SMARTSUB - Smart submergence of sea cages to improve profitability, minimise environmental impact, and ensure welfare of salmon

Researchers: Tore S Kristiansen (leader), Øyvind Korsøen (post doc), Jan Erik Fosseidengen, Frode Oppdal, Ørjan Karlsen (Institute of Marine Research)
Tim Dempster, Samantha Bui (SINTEF Fisheries and Aquaculture and Melbourne University).

Industry partners: Egersund Net, Lerøy Seafood Group, Marine Harvest, Salmar, Akvagroup

Background

Is it possible to maintain neutral buoyancy in submerged farmed salmon? The submersion of salmon farms aims to permit increased production by creating opportunities to occupy alternative aquaculture sites, in addition to avoiding unsuitable surface conditions. After several attempts to hold salmon submerged at 3-10 m depth, for 3-6 week periods, this method has proven difficult to execute due to the salmon's swimbladder anatomy; salmon need to re-fill the swimbladder with air at the surface in order to stay neutrally buoyant and not sink. Sinking can, for shorter periods, be compensated by faster swimming and more structured schooling formation, but for longer periods this will lead to tilted swimming during night time, slower growth and consequently poorer welfare.

Methods

In a small submerged pilot-cage (5 x 5 x 7 m), we observed how 15 salmon learned to refill the swim bladder in an air-filled dome, hence maintaining their neutral buoyancy. To investigate how a large group of salmon would behave and utilise an "artificial surface", we introduced air to 5000 salmon submerged to 10 m depth in two different ways; 1) in a small air-filled dome and 2) from ascending air-bubbles.

Four commercial-scale cages (approx. 2000 m3) were used; two submerged and two control treatments were used. A 1 × 1 m clear plastic dome, containing ~120 L of air, was attached beneath the roof netting in the submersible cages (Figure 13). The salmon was submerged for 49 days from March 15 to May 02, 2012. Nine days after the completion of these treatments, one cage was submerged and an air-hose with 20 holes (Ø = 2 mm) was lowered to the bottom of the cage to release air bubbles. Four days after submergence, air was supplied daily between 15:00 and 22:00, and fish monitored by the echosounder system for 7 days.

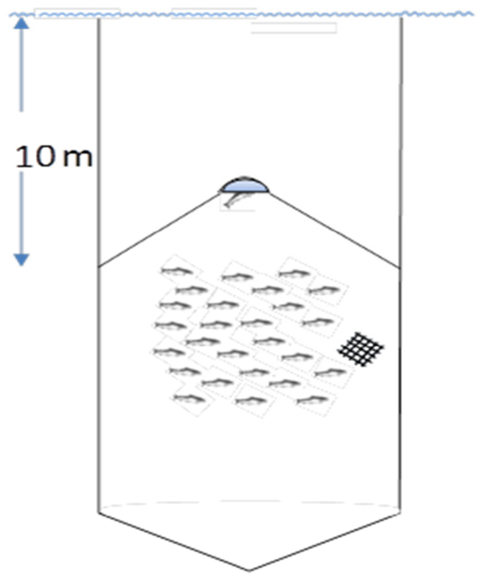


Figure 13 The principle of the air-dome in a submerged cage, with a school of salmon.

Results

As seen in previous experiments, the swimming speed for submerged salmon increased 1.6 times compared to that of the salmon in control cages. Additionally, the submerged fish maintained a structured school and paid little attention to the small air-dome. After around 28 days, random re-fill events were observed in one of the submerged cages, and a group of 200-300 salmon could be seen near the dome, separated from the deeper main school. This small group of fish seemed to be neutrally buoyant, as they swam slowly or glided with their head slightly downwards. This fact is supported from the echosounder signals, as the decline of average swim bladder gas stopped at the same time as the refill behaviour started (Figure 14). The appetite for the submerged fish seemed to fall during the experiment, and at the end the average growth rates was lower for the submerged fish compared to the control fish. Nevertheless, one of the submerged groups grew almost at similar rate as the lowest control group (SGR at 0.39 and 0.44 % BW day-1, respectively). During feeding, the schooling structure could be observed as a tall cylinder in the submerged groups, contrasting to the more normal donut-shaped school in the control cages. Further evidence for poor air-dome utilisation was the high rate of snout wounds in the submerged compared to control individuals.

The other method tested was to offer salmon air in a submerged cage by introducing air-bubbles at the bottom of a cage, to determine whether salmon were able to re-fill their swim bladder from bubbles ascending in the water column. The fish were not scared by the bubbles, as they swam unaffected through the “wall” of bubbles, however re-filling of the swim bladder was not evident in the echosounder signals. After re-surfacing the submerged cages, intense surface activity was observed, which strongly indicate that the fish lost air from their swim bladders during the 7 days of submergence.

Overall, the results show that most fish did not utilise the air-dome to re-fill their swim bladders during submergence. It is possible that the surface area of the air-dome was too small at 0.7% (1 m2) of the total surface area in the cage. In addition, the roof was angled at 40° and the air-dome was placed in the centre, the combination of which might have made it less available for the schooling fish. Therefore, the design of submersible cages must be developed to provide easy access to the artificial surface. We believe farming of salmon can be achieved in submersible cages if a large artificial area (one large or several small) is placed in a flat roof to ease access for the schooling fish. The feed should also be introduced in the air-dome to attract and teach the fish to find the available air.

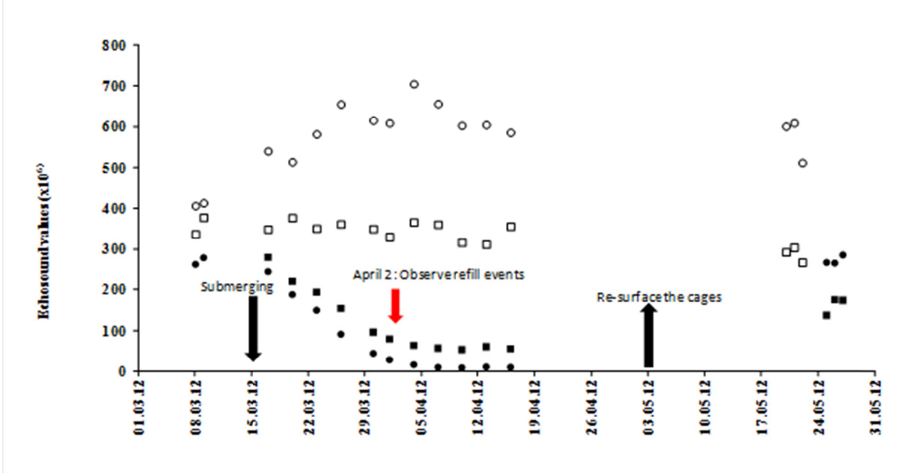


Figure 14 Echosounder values for salmon before, during, and after 49 days of submergence. ○ and □ are average values for fish in the control cages, while ● and ■ indicate fish in the submerged cages. Data were lost during the last three weeks of the experimental period, and during the test with air-bubbling.

Figure 15 Air-dome and salmon in a submerged cage.

CREATE publications related smart submergence and fish behaviour

Dempster T, Juell JE, Fosseidengen JE, Fredheim A, Lader P (2008) Behaviour and growth of Atlantic salmon (Salmo salar) subjected to short-term submergence in commercial scale sea-cages. Aquaculture 276: 103-111

Dempster T, Korsoen Ø, Oppedal F, Folkedal O, Juell JE (2009) Submergence of Atlantic salmon (Salmo salar) in commercial scale sea-cages: a potential short-term solution to poor surface conditions. Aquaculture 288: 254-263

Korsøen Ø, Dempster T, Fjelldal PG, Oppedal F, Kristiansen TS (2009) Long-term culture of Atlantic salmon (Salmo salar L.) in submerged cages during winter affects behaviour, growth and condition. Aquaculture 296: 373-381

Korsøen Ø, Dempster T, Fosseidengen JE, Fernö A, Kristiansen T (2010) Behavioural responses to pressure changes in cultured Atlantic cod (Gadus morhua): defining practical limits for submerging and lifting sea-cages Aquaculture 308: 106–115

Dempster T, Kristiansen T, Korsøen Ø, Fosseidengen J-E, Oppedal, F (2011) Technical note: Modifying Atlantic salmon (Salmo salar) jumping behavior to facilitate innovation of parasitic sea lice control techniques Journal of Animal Science 89:4281-4285

Korsøen Ø, Dempster T, Oppedal F, Kristiansen T (2012) Individual variation in swimming depth and growth in Atlantic salmon (Salmo salar L.) subjected to submergence in sea-cages Aquaculture 334-337. 142-151

Korsøen Ø, Fosseidengen J E,Kristiansen T S, Oppedal F,Bui S, Dempster, T. (2012) Atlantic salmon (Salmo salar L.) in a submerged sea-cage adapt rapidly to re-fill their swim bladders in an underwater air filled dome. Aquaculture Engineering, 5, 1-6

Skulstad, O.F., Karlsen, Ø., Fosseidengen, J.E., Kristiansen, T., Taranger, G.L. and Oppedal, F. (2012) Vertical distribution and sexual maturation in cage-farming of Atlantic cod (Gadus morhua L.) exposed to natural or continuous light. Aquaculture Research, 1-15.

Føre, M., Dempster, T., Alfredsen, J.A., Oppedal, F. (2013) Modelling of Atlantic salmon (Salmo salar L.) behaviour in sea-cages: Using artificial light to control swimming depth. Aquaculture 388-391, 137-146

Bui, S., Oppedal, F., Korsøen, Ø.J., Sonny, D., Dempster, T., (2013) Modifying Atlantic salmon (Salmo salar L.) behaviour to facilitate parasite control techniques: applying light or feed during submergence increases surface behaviours. Aquaculture Environment Interactions 3, 125-133

Korsøen, Ø., Fosseidengen, J.E., Kristiansen, T.S., Oppedal, F., Bui, S., Dempster, T., (2012) Atlantic salmon (Salmo salar L.) in a submerged sea-cage adapt rapidly to re-fill their swim bladders in an underwater air filled dome. Aquacultural Engineering 51, 1-6.

Bui, S., Oppedal, F., Korsøen, Ø.J.,, Dempster, T. (2013) Group behavioural responses of Atlantic salmon (Salmo salar L.) to light and infrasound stimuli. PLoS One

5.6. CREATE Site Sedimentation Model – SSM

Researchers: Gunnar Senneset and Ole Jacob Broch (SINTEF Fisheries and Aquaculture)
Ragnhild Lundmark Daae and Raymond Nepstad (SINTEF)

Industry partners: Lerøy Seafood Group, SalMar

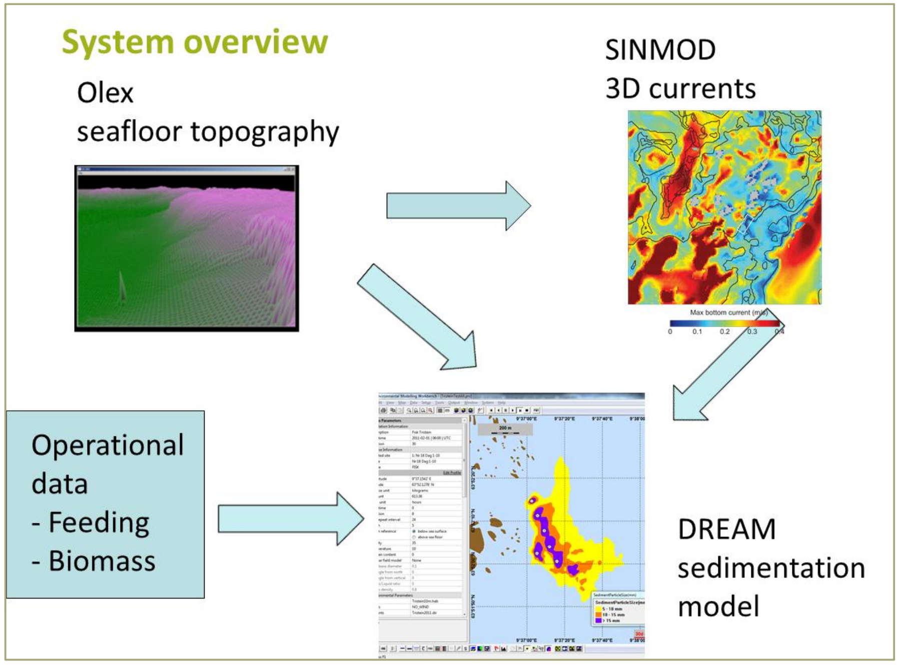
Background

The potential accumulation of sedimentation from aquaculture production sites can be an important criterion for selection of new sites. Modeling tools for estimating sedimentation can have significant benefits, not only for site selection, but also for determining optimal site configuration (e.g. number and location of cages). Detailed analysis can also give estimates of the maximal advisable production at a new site, with regard to avoiding an extended fallowing period between production cycles.

Integration of numerical models from various disciplines has been a focus in CREATE, and this project make use of a sedimentation model (DREAM) and an oceanographic model (SINMOD). The activity in 2012 has been a pre-project to test the integration and make simple comparisons between model results and in-situ environmental inspections. The ACE (AquaCulture Engineering) site Tristeinen has been used for the test.

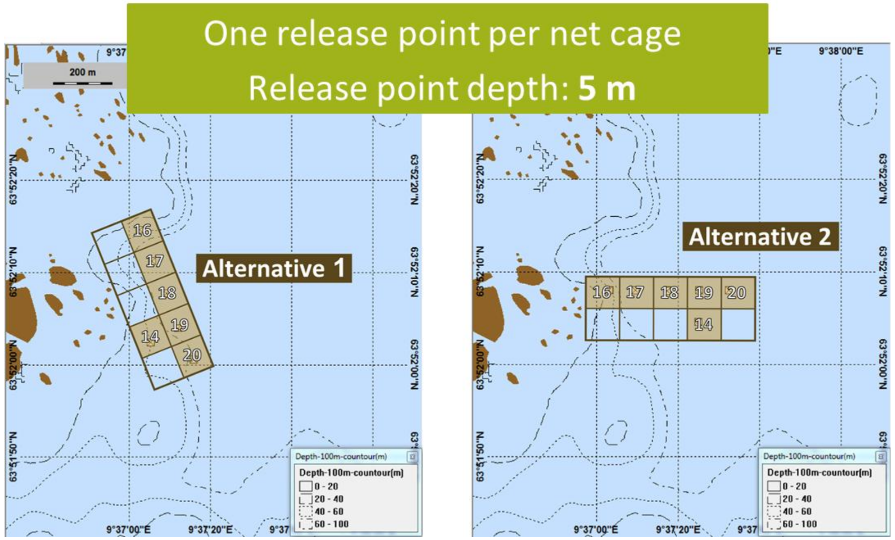
Methods

The DREAM model has been developed by SINTEF, initially for evaluating sedimentation from oil drilling operations. Different configurations and input parameters are required for use in the aquaculture domain, for example multiple outlet points (one per cage is used in the pre-project). Another example is the variation of the feces particle size distribution over time due to fish growth and different feeds used during the production cycle. The SINMOD model delivers detailed 3D current fields over time, in this case using a 32 meter grid to obtain enough details. Accurate seafloor topographical data (Olex) from the site surrounding area were used as input. The main system components are shown in the figure below.

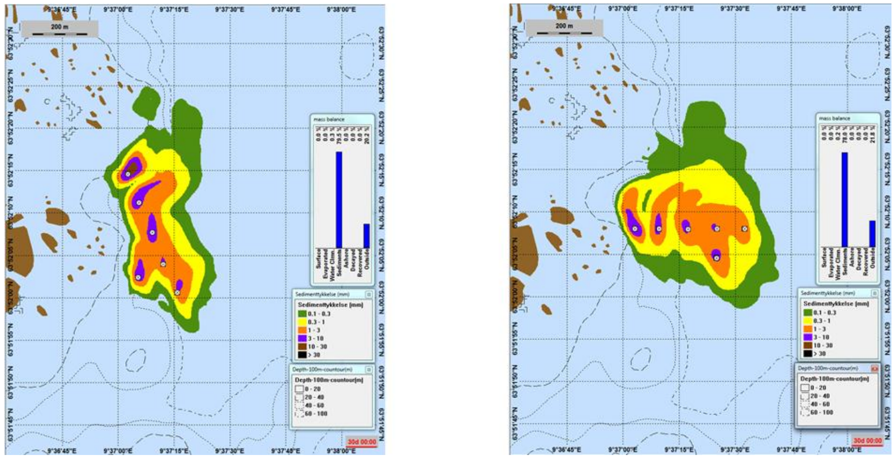


Results

The test case setup is shown in the figure below. Alternative 1 is the current site configuration, while alternative 2 has been discussed by site operatives as a possible improvement with respect to sedimentation build-up at the site.



A 30 day period at peak production (close to maximum biomass during the production cycle) was used for the test. The results in terms of sediment thickness distributions for the two alternatives are shown in the figure below.



For alternative 1, the results were compared with results from the environmental inspections performed at peak production. Exact comparisons are difficult, but the results are so positive that the project continues in 2013-2014. Important activities will be testing at several new sites and sensitivity analysis for input parameters. The project goal is an operative system for use by industry and service providers.

5.7. IntelliLED - Intelligent use of L.E.D. lights to prevent sexual maturation and reduce sea lice infestation

Researcher: Frode Oppedal, Thomas Torgersen, Ole Folkedal, Lars Stien, Tom Hansen, Per Gunnar Fjelldal (Institute of Marine Research)

Industry partners: AKVAgroup, Marine Harvest, Lerøy Seafood Group, Salmar

Background

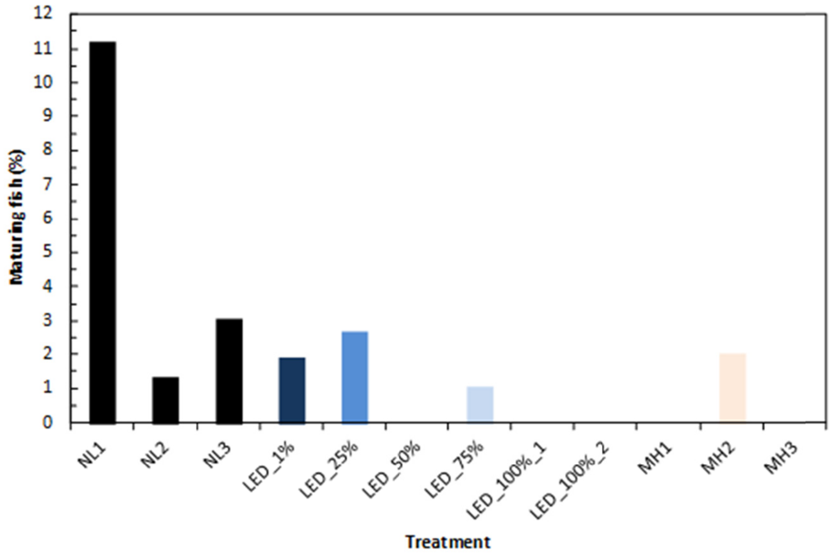
Artificial lights are routinely used as a management tool in Atlantic salmon farming to produce constant photoperiods that reduce or prevent incidence of sexual maturation. Such sexual maturation would else lead to loss of production efficiency for the farmer and reduced welfare of the fish due to reduced osmo-regulatory capacity and often mortalities. Earlier research has shown that in spring-transferred (from freshwater to seawater) salmon, onset of light from January the first winter in the sea reduces the incidence of sexual maturation from levels of 5-50% to 0-5% and comparable effects are seen using lights during the second sea-winter. In autumn-transferred fish equivalent reductions are seen using lights during the first sea-winter, while no trial has addressed effects of lights during the second sea winter. It has further been hypothesised that related changes in growth was dependent on the light intensity and unpublished results from Scotland indicate comparable effects of light intensity on reduced incidence of sexual maturation. Up until today metal halide lamps has been the major light source, while use of modern and more energy saving L.E.D. (Light Emitting Diode) may prove beneficial. L.E.D. light sources may also be dimmed in comparison to direct on/ off characteristics of metal halide lamps and may be used in more intelligent manners in future aquaculture. The first goal of the project was to develop the use of high efficient L.E.D. light in preventing sexual maturation in sea cages.

Salmon aquaculture lack sustainability due to the increased lice infestation pressure on wild stocks of salmonids. During common topical delousing, welfare of farmed salmon is depressed, the environment is polluted by treatment chemicals, fish production performance is reduced and lice treatments are generally considered a critical production point. Keeping the salmon away from the surface layer will potentially reduce lice infestation. Submerged light sources attract salmon and may be used to manipulate the swimming depth and densities. However, use of artificial light in the autumn may increase unwanted incidence of sexual maturation. The second goal of the project is to reduce the impact of salmon aquaculture on the environment and wild fish through reduced lice infestation rates. This is to be reached by development of low intensity submerged L.E.D. lights during the autumn in two steps: (i) Test what light quality is needed to attract the salmon to deeper waters and (ii) test if this light quality increase the incidence of sexual maturation or may be used as generally intended.

Methods

Within the Cage Environmental Lab at IMR-Matre Atlantic salmon were divided among 13 cages of approximately 2000 m3 were exposed to experimental light conditions from January to June 2012. Treatments included artificial light of both metal halide and different intensities of L.E.D. compared to natural conditions and effect of incidence of sexual maturation and growth during the second sea-winter of autumn-transferred Atlantic salmon were investigated.

At the Cage Environmental Lab of IMR- Austevoll three replicate cages of 5 500 salmon were exposed to 7 different colours of L.E.D. lights combined with 3 to 6 intensities per colour. Measurements of swimming depth and densities were used to describe attraction and avoidance to the light qualities. The trial commenced in November 2012 and lasted until May 2013.



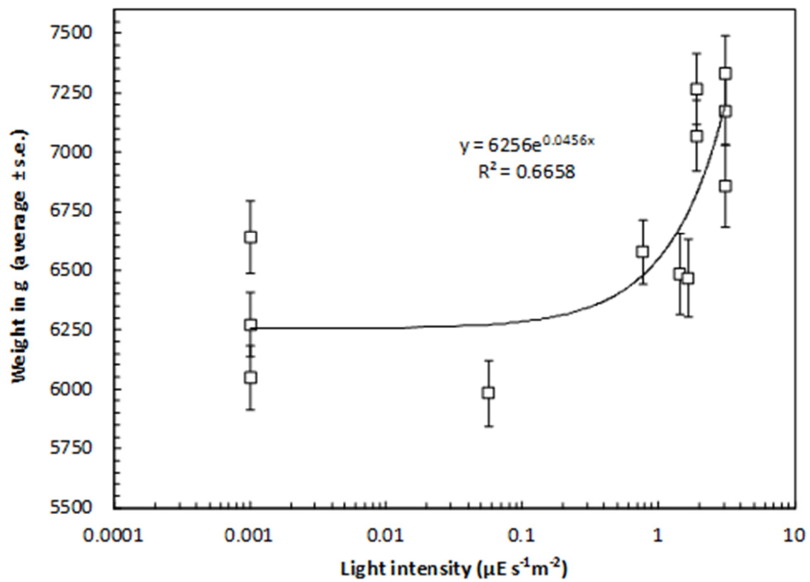


Figure 16 Incidence of sexual maturation in 2-seawinter Atlantic salmon exposed to continuous additional artificial light from January to June during their second sea winter. No differences are seen between replicate cages of Metal Halide (MH) or L.E.D. lights of different intensities (LED_% intensity), while one of the replicate cages on natural conditions (NL) displayed significant numbers of maturing fish.

A general increase in appetite and growth was seen dependent upon intensity of the light used. These findings are in accordance with earlier indications. A positive relation between light intensity and harvest weight was measured (Figure 17).

Figure 17 Average weight of Atlantic salmon given different intensities of artificial light or natural conditions (0.001 µE s-1 m-2) from January to June. The curve describes a positive relationship between light intensity and harvest weight. No significant differences were seen between Metal Halide and L.E.D. lights of similar intensities.

In conclusion, L.E.D. light sources may be used as a tool to reduce unwanted sexual maturation and increase growth within sea cage farming of Atlantic salmon.

The test of attraction towards different light qualities is promising and results will be presented in 2013. Light clearly attracts the salmon to swim deeper and potentially reduce the infestation of sea lice.

5.8. Modelling and optimization of feed distribution in sea cages

Researcher: Jo Arve Alfredsen, Kristoffer Rist Skøien (NTNU)
Turid Synnøve Ås, Torbjørn Åsgård (NOFIMA)
Morten Omholt Alver, Torfinn Solvang-Garten,
Martin Føre (SINTEF Fisheries and Aquaculture)

Industry partners: Egersund Group, Lerøy Seafood Group, Marine Harvest, Salmar

Background

Feed makes up a large fraction of the total costs in Atlantic salmon (Salmo salar L.) cage culture. With feed loss from commercial farming sites at 5-7%, minimizing the amount of wasted feed is important both for economic reasons and to reduce the environmental impact of salmon farming. To achieve this, a better understanding of the dynamic processes involved in the feeding process is needed. For this purpose, the dynamics of the feeding process are studied through further development of a model published by Alver et al. (2004), where the feed concentration is calculated in a 3D grid. The model takes into account the physical properties of the feed, the geometry of the cage, the properties of the feed spreader, environmental factors such as wind and current, as well as the feeding behavior of the fish.

Methods

Feed spreader patterns have been parameterized based on data from Oehme et al. (2012). The data was fitted to skewed normal distributions in the forwards and backwards directions, and a 360 degrees distribution was computed based on interpolation between the two measured directions.

The original pellet distribution model has been further developed into a 3D model, by using a 3D version of the transport equation. Some further modifications were needed to make the model work in three dimensions. Handling of 3D cage geometry was added, such as calculation of feed wastage when feed moves outside of the designated cage volume.

Validation of the model will be done in several steps: 1) Validation of physical pellet spreading properties with no fish present. 2) Validation with fish present in small sea cages. 3) Validation in full scale cages. The first of these steps is ongoing, while step 2 and 3 are planned autumn 2013/winter 2014. In all validation steps instrumentation is required to provide actual measurements of the rate of pellets passing through a given cage volume as a function of time. A pellet sensor based on underwater machine vision technology has been developed to serve this requirement.

Machine vision pellet detection systems have been developed and investigated previously, but for the purpose of high-resolution model validation current solutions seem inadequate. A high accuracy detection system with respect to spatial and temporal distribution of pellets in the water column during a feeding bout is required. As opposed to many commercial systems, which measure pellet loss beneath the feeding depth, this sensor must be able to measure the pellet flux at any location within the cage.

Results

Figure 18 shows examples of comparisons between the measured spreading patterns in two directions for three air speeds and two different feed types, and the modeled spreading patterns.

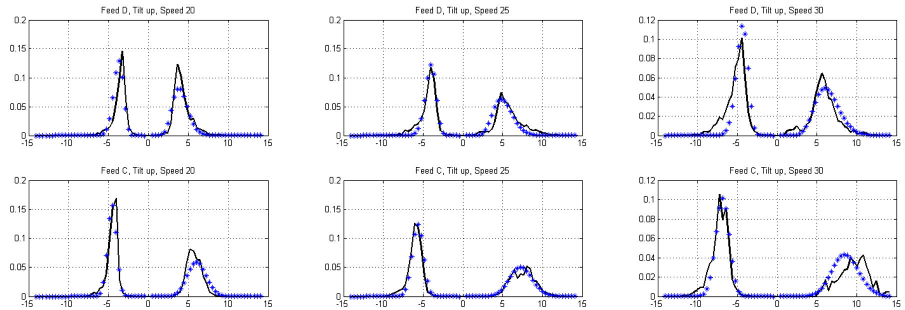


Figure 18 Examples of comparison between modeled and measured feed spreader patterns

Figure 19 shows example output from the modeled feed spreader pattern, as well as an example of a 3D feed distribution produced by the pellet distribution model. The output was produced by running a simulated case matching the validation scenario used in Alver et al. (2004).

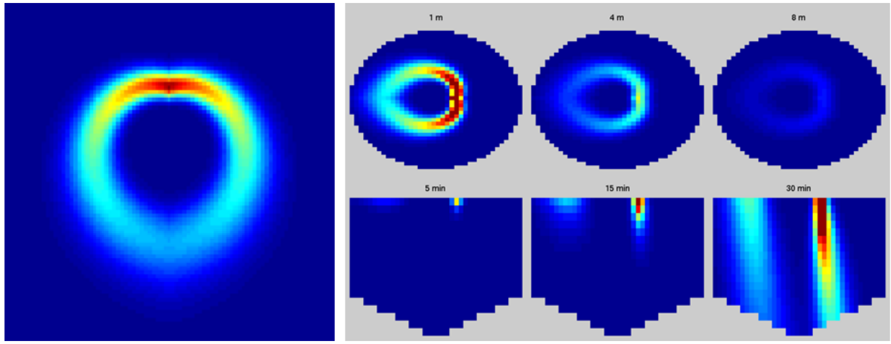


Figure 19 Left panel: example of modelled surface distribution of feed. Right panel: example of 3D distribution of feed, seen from above and from the side. The side plots show the pellet distribution at different times during a short, intensive, feeding period.

A prototype machine vision pellet detection system has been designed and implemented (Figure 20). The pellet sensor itself consists of a high definition digital camera, positioned horizontally, and pointed against a uniformly backlit opaque surface. Tests have shown that the backlighting approach yields a high-contrast image of passing pellets while avoiding the adverse effects of ambient light variations and an unpredictable image background. A funnel allows for defining the extent of the horizontal area covered by the pellet sensor, and guides the pellets into the machine vision detection system. All objects in the camera's field of view are detected using blob-analysis and their motion is individually tracked using a Kalman filter. The image analysis algorithm enables filtering on a range of variables, such as pellet sinking speed, projected area and convexity. This makes it possible for the detection system to separate pellets from foreign objects, as well as detecting overlapping pellets. Figure 21 shows an example of the output of the pellet detection algorithm.

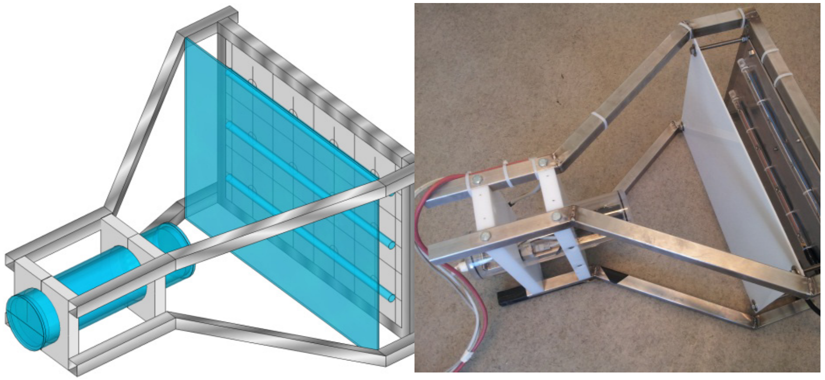


Figure 20 Mechanical outline (left) and realization (right) of the prototype pellet sensor unit. The camera is situated in a waterproof housing, pointed towards an opaque, uniformly backlit surface. This configuration yields high-contrast images of passing pellets, which are transmitted through an Ethernet link to a PC for image processing and analysis.

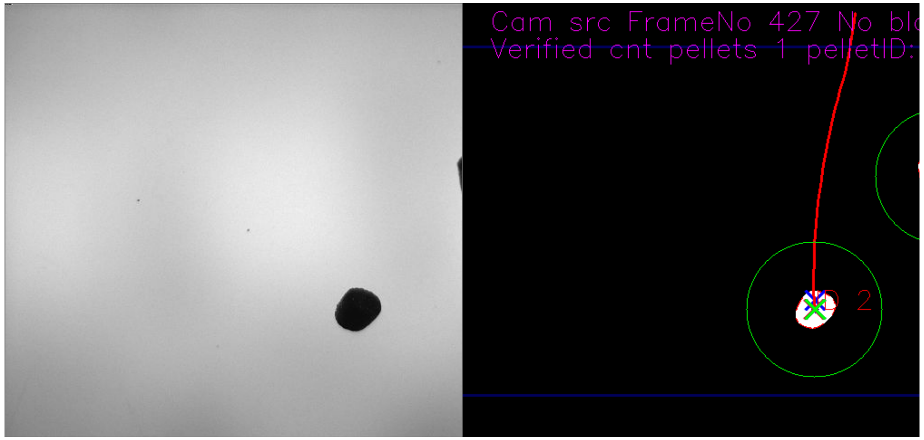


Figure 21 Pellet detection using image analysis. Raw image (left) and analyzed image (right).

5.9. ReduceLice - Use of salmon behaviour to facilitate innovative surface-based de-licing technique (i) and to avoid sea lice infestation (ii).

Researcher: Frode Oppedal, Thomas Torgersen, Øyvind Korsøen, Lars Stien (Institute of Marine Research)
Tim Dempster, Samantha Bui (University of Melbourne)
Østen Jensen, Pål Lader (SINTEF Fisheries and Aquaculture)

Industry partners: Egersund Group, Lerøy Seafood Group, Marine Harvest, Salmar

Background

There is a lack of sustainability in salmon aquaculture due to increased lice infestation pressure on wild stocks, as well as negative environmental impacts in the release of treatment chemical after topical de-lousing or from orally-treated fish. Welfare of farmed fish may also be depressed during common topical delousing.

An innovative method of de-lousing in a surface oil layer has been described but with variable results due to low surface activity of salmon. However, recent knowledge within CREATE have led to the development of techniques to increase surface activity, by temporarily removing surface access. Combining the past and present results will provide a fruitful future method to efficiently treat salmon for lice, with minimum impacts on fish and environment.

Alternative to treating the fish for the parasite, prophylactic management to reduce infestations would be beneficial. The infestative stage of the salmon lice is free-swimming, predominantly occupying surface waters. It has been indicated that keeping the fish away from the surface layer will potentially reduce lice infestation. Egersund Group has developed within CREATE a net roof solution to hold the fish away from surface layers while still providing surface access for the fish to re-fill the swim bladder, through a tube-like chimney structure called a ‘snorkel’ (Figure 22). This innovative technology needs to be fitted to biological limits and optimal technological designs.

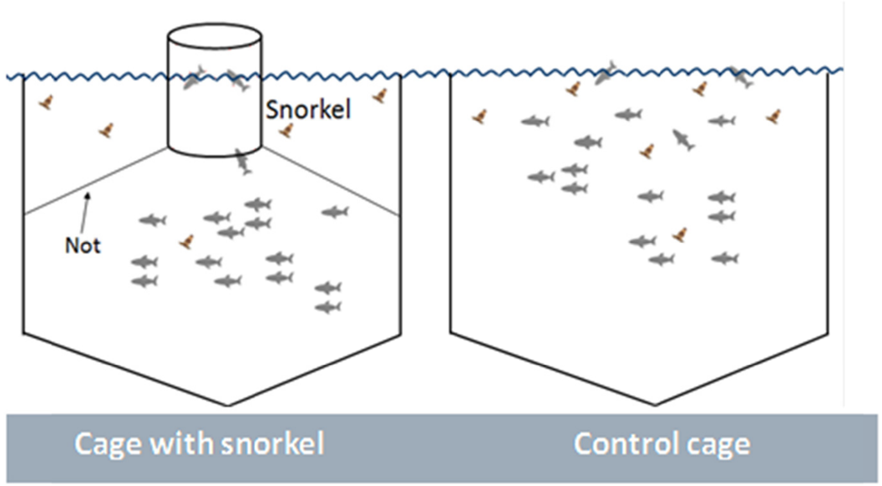


Figure 22 Principle of the snorkel cage. We created a mismatch between the swimming depth of the salmon and the surface-related infestative sea lice larvae in order to reduce the level of parasites on the fish.

Methods

The IMR Tank Environmental lab was used for testing drugs in oil. The IMR Cage Environmental Lab was used for testing of jumping behaviour using oil floated on the surface, and of snorkel designs in relation to salmon behaviour, lice infestations, and production performance. SINTEF Fisheries and Aquaculture are using mathematical models to calculate forces in different designs, and will follow up by testing of down-scaled models in flume tank facilities in Hirtshals.

Results

Killing of sea lice dipping fish through oil layer containing treatment drug. Combinations of oil thicknesses and concentrations of cypermethrin (a commonly used lice treatment drug) were tested by dipping anaesthetized fish through the layer (Figure 23, photo). The de-licing effects were less than 40% (Figure 23) and consequently, there is a need to develop a more efficient drug before we proceed with further testing of the method at a larger scale.

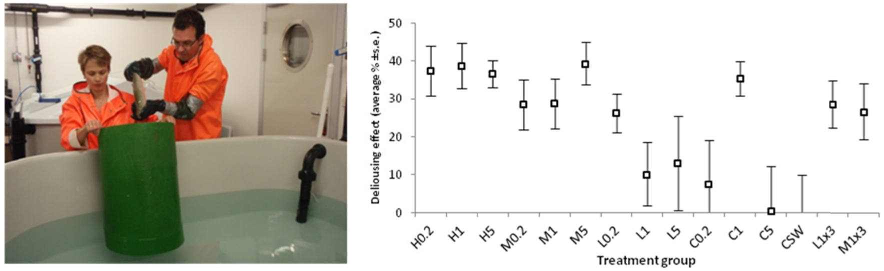


Figure 23 Photo showing the method of dipping anaesthetized fish through surface floating oil layer within the green pipe containing de-licing drug. Figure displaying de-licing effects in treatment groups of high (H), medium (M) or low (L) concentrations of cypermethrin given layer thicknesses of 0.2, 1 or 5 mm compared to controls (C) and number of dipping times (treatment × number).

Test of fish avoidance of oil layer at cage surface. Salmon groups (N=200-300) were submerged using a cage roof for two days. Immediate jumping behaviour (Figure 24) after re-instating surface access was observed in five replicates with normal surface conditions, and compared to a treatment group where an oil layer (using rapeseed oil) of 1 mm thickness was added. No significant differences in jumping were observed between the control and oil group.

Figure 24 Photo displaying fish jumping though oil layer in a cage.

In conclusion, no avoidance of the surface during re-filling of their swim bladder was observed when an oil layer was present.

Snorkels reduced lice infestations by ¾. In pilot set-ups, we tested if salmon held in modified cages were using the snorkels to re-fill swim bladders or overused them so that the oxygen conditions were degraded to detrimental levels (Photos in Figure 25). As such, we conducted a full-scale trial at the research sea farm at the Institute of Marine Research, Austevoll, Norway, during summer 2012. We used 18 000 salmon of 89 g divided between triplicate cages with surface access (control), and cages equipped with a snorkel-like chimney attached to a net roof positioned at 3 m depth. For every third week from May 29 to August 21, a random sample of 20 fish per cage were anaesthetized and number of lice and stage registered.

The mismatch of the fishes' swimming depth from the copepodids' resulted in reduced lice infestations by 66-86%. Lice infestation was reduced consistently over time and variable environmental conditions. Behaviour of the fish was observed to be normal. However, a potential drawback of this technique was a growth reduction of 33%, likely caused by under-feeding due to the biofouling on the net roof.

Thus, we are presently performing a follow-up trial (funded by FHF) at IMR-Matre monitoring the growth performance, together with description of the groups' behaviour, in both control and treatment cages. Fine-tuning and development of this preventive technique towards larger industrial use will advance the salmon farming industry towards increased sustainability. This is the first, but not last, ecology-based prophylactics practice to mitigate parasitic problems within aquaculture.

Figure 25 Pilot and full-scale design of snorkels used to prevent sea lice infestations by 66 to 86% compared to normal cages.

5.10. Selected results from PhD and Post doc Work

Fouling of hydroids on net cages (Parts of the PhD thesis of Nina Bloecher)

Within CREATE two experiments were conducted. The focus of Experiment I was to gain background knowledge on the occurrence and dynamics of biofouling on net cages of a commercial salmon farm during one year. Experiment II analysed why hydroids are so abundant on salmon cage nets and if their presence may be facilitated by nutrients released from the fish farm.

Experiment I

In a 1-year field study at a commercial salmon farm in Central Norway the effects of immersion period (1, 3, 6 and 12 months), sampling time, mesh size (13 and 25 mm half-mesh) and variation among three individual cages on the biomass, species richness and community composition of biofouling on net panels were investigated.

On 432 net panels a total number of 90 species and multi-species categories were identified. The five most frequent sessile macrofoulers were the amphipod Jassa falcata, the blue mussel Mytilus edulis, the hydroid Ectopleura larynx and the algae Polysiphonia stricta and Saccharina latissima. M. edulis and E. larynx, along with the mussel Hiatella arctica, contributed most to the biomass. Immersion period and sampling time had a strong effect on the biomass accumulation, the species richness and the community composition. The variation between cages and, to a lesser extent, the differences in mesh size only influenced the community composition for 1-, 3- and 6-month samples. After 12 months of immersion, the biofouling community had reached a climax state where neither mesh size nor variation between cages had an effect.

The results of this study may contribute to the optimisation of current antifouling treatments of aquaculture nets and provide background knowledge for farm operation and management with regard to monitoring and cleaning procedures.

Experiment II
To identify the main diet of E. larynx growing at a fish farm, the hydroid and its possible food sources, plankton, caprellids, particulate organic matter (POM), fish faeces and fish feed, were sampled at a commercial Atlantic salmon farm. In addition, hydroids were sampled from a reference station without direct fish farm influence. In a stable isotope analysis the stable carbon (δ13C) and stable nitrogen (δ15N) values of all samples were compared.

Cage and upstream POM, caprellids, fish food and fish faeces appeared too depleted in both δ13C and largely also in δ15N (fish feed δ15N value being just within the range of a possible food source) relative to farm E. larynx to be anything other than minor possible contributors to the hydroid diet. Plankton, however, was indicated as the likely primary dietary source for the farm hydroids with a depletion of δ13C and δ15N values by 0.6‰ and 2.2‰ on average, respectively.

The results from the SI analysis show that the diet of E. larynx growing on cage nets consists mainly of plankton while fish farm derived nutrients do not play a major role. This indicates that the availability of settlement space in combination with plankton presence in the environment may be the main reason for the high hydroid abundances found on fish cages.

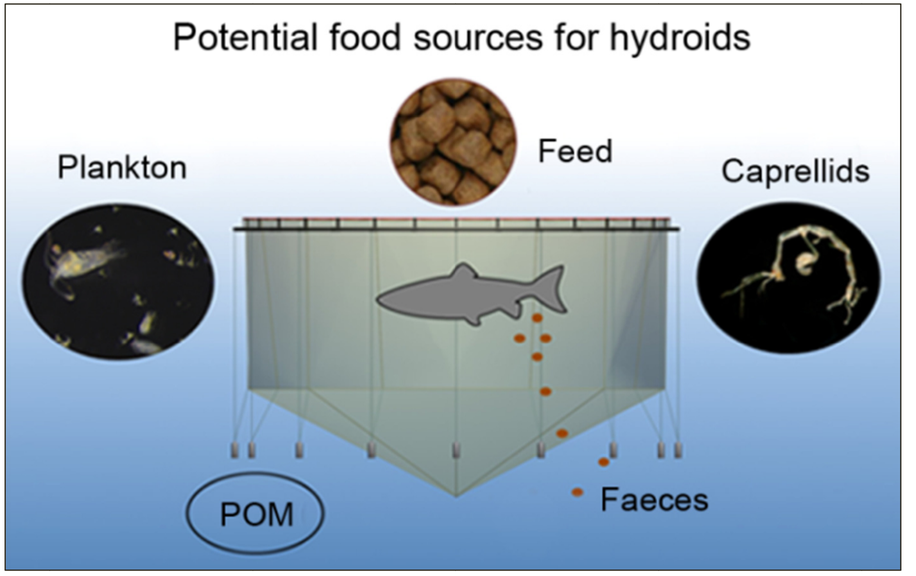


Figure 26 Overview of potential food sources of the hydroid E. larynx, compared with stable isotope analysis

Wave and current loads on fish farms (Parts of the Post doc work of Dr Trygve Kristiansen)

An analytical potential-flow model for the linear wave loads and hydrodynamic coefficients on an elastic circular floater has been developed and verified by comparing with a state-of-the-art boundary element method. It is demonstrated that strong 3D flow effects occur which implies that commonly used strip theory formulations are not correct.

Since the computational time makes state-of-the-art CFD methods unrealistic, simplified hydrodynamic models that account for the net deformation and elastic deformations of floater in waves and current have been developed. The numerical model is validated by comparing with experimental mooring loads at model scale for realistic wave and current conditions and solidity ratios for the net. Figure 27 illustrates indirectly the experimental set up by showing a snapshot from the numerical simulations. Systematic parametric studies have been performed to identify the effects influencing most strongly the numerically predicted mooring loads. The bottom weight matters for mean loads. The tension in the elastic floater is quite important. The wave model (linear, second order, Wheeler stretching) influences the mean loads and load amplitudes. The drag on the floater, and hence local overtopping, is important in long steep waves.

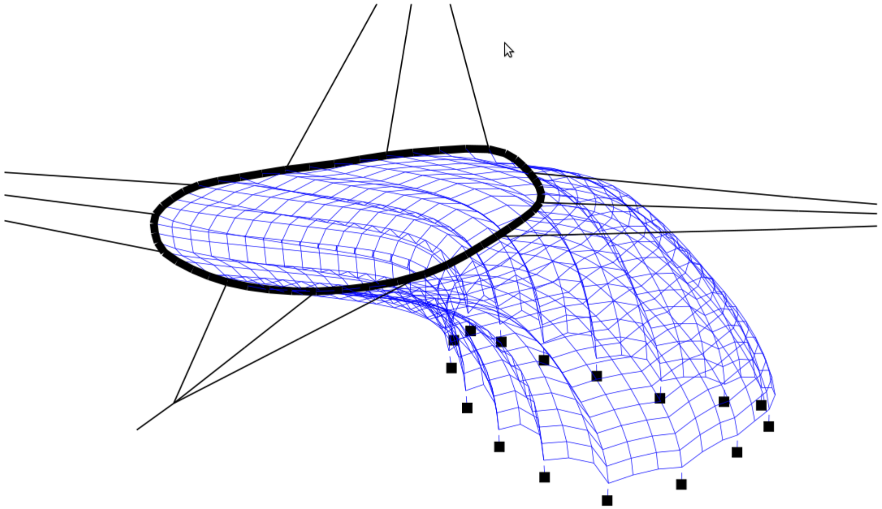


Figure 27 Snapshot of numerical simulations in waves and current showing the floater, mooring system, bottom weights and the equivalent net used in the numerical model.

Effect of fish on flow and loads on fish farms

Novel model tests with either rigid fish models or living fish in a floating fish farm in waves and current have been performed. The objective was to find out how the fish influence the mooring loads. The latter effect is neglected in state-of-the-art computational tools used for the industry. Nine equivalent rigid fish models with total volume of 2.5% of the fish cage volume were used to study the influence of the “fish” on the mooring loads.

Figure 28 Left illustrates the experimental model in calm water. Current was simulated by towing the model with the rigid fish models fixed relative to the floater. The numerical model considered the displacement effect of the fish models on the inflow to the net. Both the numerical and experimental results showed that the mooring loads due to the fish models were less than 3% of the mooring loads without fish models.
More than 800 small salmons of length 16cm occupying about 2.5% of the fish cage volume were used in the living-fish experiments. The presence of current had an important effect and the mooring loads with fish were more than 10% larger than the mooring loads without fish. Figure 28 Right illustrates the fish configuration relative to the net in a current velocity corresponding to 0.8m/s in full scale. The fact that the salmons are close to the downstream part of the net is believed to be an influencing factor.

Figure 28 Left: Model tests with 9 rigid fish models in a fish cage. Right: Bird-eye view of model tests of a fish cage with 800 small salmons in current velocity 0.16 m/s.

6. International cooperation

CREATE has active international collaborations at the level of the centre, partners and through the centre's individual projects. The research partners of CREATE, all are international leading within their research field and have extended international collaboration.

Collaboration with North American institutes (UNH/USNA) The University of New Hampshire has been an active international collaborator within CREATE since its inception. The collaboration was established through a sabbatical visit by Dr Pål Lader (SFH) to UNH in 2006-07. Prof. Hunt Howell and Michael Chambers from the Open Ocean Aquaculture program have participated in project development and discussions at each of the annual CREATE days (2007-2010). CREATE PhD student Martin Føre undertook a 3-month stay with UNH in 2008 to investigate the behaviour of Atlantic cod in sea-cages at different densities in collaboration with Prof. Howell and Prof. Win Watson. A scientific publication describing the results from the cod study is planned in 2010. In addition, Arne Fredheim (SFH) and Richard Langan (UNH) published a review summarizing the status of technological development for off-shore and open ocean aquaculture. CREATE researcher Dr. Pål Lader has an active collaboration with Assoc. Prof. David Fredriksson from the United States Navel Academy (USNA) and has conducted model scale experiments of fish farm cages in current and waves at the USNA towing tank facilities. As CREATE continues, UNH and the USNA will collaborate on projects to design and test new cages systems and technologies for warm-water aquaculture.

Collaboration with Shanghai Jiao Tong University Projects and model tests for fish farms have been carried out in cooperation with Professor Shixiao Fu, from Shanghai Jiao Tong University. Further model test are under planning. Professor Shixiao visited CREATE in October 2010 and will again visit CREATE for a period of three months in 2013. Researcher from SINTEF Fisheries and Aquaculture and CREATE visited SJTU in January 2013 to further strengthen the cooperation with SJTU. Plans for a bi annual joint workshop with SJTU and SINTEF Fisheries and Aquaculture on modelling and analysis of floating fish farms are under development.

Dr. Gui (Zhejiang University) has been a visiting post-doctoral fellow at the centre for 2009 -10, and collaborated on projects to design new cage systems for warm water aquaculture.

Collaboration with SALTT at the University of Melbourne In 2010, CREATE established a new international collaboration with the Sustainable Aquaculture Laboratory – Temperate and Tropical (*SALTT*) based at the University of Melbourne, Australia.

In 2012, CREATE continued international collaboration with the Sustainable Aquaculture Laboratory – Temperate and Tropical (SALTT) based at the University of Melbourne, Australia. SALTT researchers Dr. Tim Dempster & Isla Fitridge are currently participating in CREATE projects within the research themes of behavioural studies to underpin new technologies and biofouling control. Samantha Bui conducted her Masters research within the SMARTSUB project and is presently involved in the ReduceLICE project.

7. Recruitment

Researcher training is mainly organised through Centre for Ships and Ocean Structures (CeSOS) and Department of Engineering Cybernetics (DEC) at the Norwegian University of Science and Technology (NTNU). NTNU is a partner of CREATE. Through Institute of marine research and NOFIMA Marin, research training and PhD education is also conducted at University of Bergen and Norwegian University of Life Science respectively. These universities are not formally partners of CREATE.

It has been challenging to recruit students within the engineering topics of the centre. And it has especially been difficult to recruit Norwegian students. By 2012 nine PhD students have been or are funded directly through CREATE, at present four of theses PhD students have defended their thesis with success. By 2012 five PhD students with external financing has been or are working on projects in the centre. One PhD student with external financing has successfully defended his PhD. Five of the total 14 PhD students are Norwegian.

In 2012 two Postdoctoral researches are financed by the centre. Three Postdoctoral researchers have previously been financed by the centre. One Postdoctoral fellowship is planned with start up in 2013, and a person is identified for the fellowship.

At present, one advertised post doc fellowships have not managed to receive qualified candidates.

8. Communication and dissemination activities

CREATE executes communication on several levels; among the partners in the centre, by scientific publications, and wider dissemination to the industry and to the public in general. CREATE is focusing on scientific publications and articles in peer-reviewed journals as the standard mean for scientific reporting. Except for industrial focused projects, journal publication is a main goal of all of the projects. Researchers from CREATE participate at international scientific conferences.

Among the partners the main communications occur through management meetings, project meetings, workshops and the yearly CREATEday. Approximately three to four workshop are arranged yearly among the different projects within CREATE. These activities are important to not only ensure communication and dissemination of results, but also to enable discussions and exchange of ideas and room for innovation.

CREATE has been sited numerous times in the most common industrial news sites such as “kyst.no” and “Intrafish”, both in general terms and on specific topics. CREATE has also been presented at several meetings with the Norwegian Seafood Federation, and at industry events like TEKMAR (www.temar.no).

CREATE makes and publishes a graphically set up and designed annual report. The reports not only present the scientific results, but also present the ideas of the centre and its partners and is important in promoting the identity of the centre.

CREATE has its own website, www.sintef.no/create, which is presently under revision, but will be a major tool for communication and dissemination of results and scientific publications.

9. Personnel

9.1. Key Researchers

Name	Institution	Main research area
Arne Fredheim	SINTEF Fisheries and Aquaculture	Marine hydrodynamics/Fish farming constructions
Pål Lader	SINTEF Fisheries and Aquaculture	Marine hydrodynamics/Fish farming constructions
Lars Gansel	SINTEF Fisheries and Aquaculture	Bio fouling
Gunnar Senneset	SINTEF Fisheries and Aquaculture	System modelling
Tore Kristiansen	Institute of marine research	Fish welfare and behaviour
Frode Oppedahl	Institute of marine research	Fish welfare and behaviour
Torbjørn Åsgård	NOFIMA Marin	Fish feed and nutrition
Turid Synnøve Aas	NOFIMA Marin	Fish feed and nutrition
Professor Odd M. Faltinsen	CeSOS/NTNU	Marine hydrodynamics/Fish farming constructions
Associate Professor Jo Arve Alfredsen	NTNU	Engineering cybernetics

9.2. Visiting researchers

Name	Affiliation	Duration	Topic
Dr. Shim Kyujin	Post. Doc.	2008 - 2009	CFD simulation of flow through fish cage
Dr. Fukun Gui	Post. Doc. from China Zhejiang Ocean University	2009 - 2010	Design of cage systems for exposed shallow waters
Dr. Shixiao Fu	Shanghai Jiao Tong University	2010, 2013	Numerical analysis and experimental verification of respons for marine structures
Dr. Isla Fitridge	University of Melbourne	2011, 2012, 2013	Biofouling

9.3. Postdoctoral researchers

With financial support from the centre

Name	Nationality	Period	Topic
Dr. Bailey Jason	Canadian	2007 - 2008	Cage environment
Dr. Guenther Jana	German	2008 - 2010	Biofouling on aquaculture constructions
Dr. Axel Tidemann	Norwegian	2009 - 2011	Case based reasoning systems for aquaculture operations
Dr. Korsøen Øyvind Johan	Norwegian	2010 - 2013	Smart submergence of sea cages with salmon and cod
Dr. Mette Remmen	Norwegian	2012 - 2015	Effects of fluctuating oxygen levels on welfare and growth of salmon (Salmo salar) in net cages

With financial support from other sources

Name	Nationality	Period	Topic
Dr. Trygve Kristiansen	Norwegian	2011 - 2012	Hydrodynamical loads and respone of floating fish farms

9.4. PhD students

With financial support from the centre

Name	Nationality	Period	Topic
Korsøen Øyvind Johan	Norwegian	2007 - 2010	Biological criteria for successful submergence of physoclistous Atlantic cod and physostomous Atlantic salmon reared in sea-cages
Føre Martin	Norwegian	2007 - 2011	Modelling and simulation of fish behaviour in aquaculture production facilities
Remen Mette	Norwegian	2008 - 2012	Effects of fluctuating oxygen levels on welfare and growth of salmon (Salmo salar) in net cages
Lubis Enni Lisda	Indonesian	2008 - 2012	Reliability-based design of Aquacultural Plants
Nina Blöcher	German	2009 - 2012	Bio-fouling on marine cage systems
Maike Oehme	German	2010 - 2013	Quality - optimal conveying and biological response
Bardestani Mohsen	Iran	2009 - 2013	Wave and current loads on fish farms
Peng Li	Chinese	2010 - 2013	Hydroelastic behavior of the floater of an aquaculture cage in waves and current
Kristoffer Rist Skøien	Norwegian	2012 - 2016	Modelling and detection of feed distribution in sea cages

With financial support from other sources

Name	Nationality	Period	Topic	Funding
Melberg Rune	Norwegian	2007 - 2010	Fish farming modelling, simulation and control	University of Stavanger
Gansel Lars	German	2007 - 2011	Flow through and around fish cages	NTNU
Mohamed Shainee	Maldives	2010 - 2013	Design considerations for offshore fish farms	NTNU
Zhao He	Chinese	2010 - 2013	Current effects on an aquaculture cage	NTNU
Samantha Bui	Austrailian	2011 - 2014	Fish behaviour and welfare	University of Melbourne

10. Publications

10.1. Journal Papers

Aquaculture technology			
Jensen Ø, Wroldsen AS, Lader PL, Fredheim A, Heide M	2007	Finite element analysis of tensegrity structures in offshore aquaculture installations.	*Aquacultural Engineering 36: 272-284*
Lader P, Olsen A, Jensen A, Sveen JK, Fredheim A, Enerhaug B	2007	Experimental investigation of the interaction between waves and net structures - Damping mechanism.	*Aquacultural Engineering 37(2): 100-114 1*
Lader PF, Jensen A, Sveen JK, Fredheim A, Enerhaug B, Fredriksson D	2007	Experimental investigation of wave forces on net structures.	*Applied Ocean Research 29(3): 112-127 1*
Moe H, Olsen A, Hopperstad OS, Jensen Ø, Fredheim A	2007	Tensile properties for netting materials used in aquaculture net cages.	*Aquacultural Engineering 37(2): 252–265 1*
Lader PL, Dempster T, Fredheim A, Jensen Ø	2008	Current induced net deformations in full-scale sea-cages for Atlantic salmon (*Salmo salar*).	*Aquacultural Engineering 38: 52-65*
Moe H, Hopperstad OS, Olsen A, Jensen Ø, Fredheim A	2009	Temporary-creep and post-creep properties of aquaculture netting materials.	*Ocean Engineering 36: 992-1002*
Moe H, Fredheim A, Hopperstad OS	2010	Structural analysis of aquaculture net cages in current.	*Journal of Fluids and Structures (in press)*
Gansel L.C., McClimans T.A. and Myrhaug D.	2012	Flow Around the Free Bottom of Fish Cages in a Uniform Flow With and Without Fouling	*J. Offshore Mech. Arct. Eng., Vol. 134, Iss. 1. doi: 10.1115/1.4003695.*
Gansel L.C., McClimans T.A. and Myrhaug D.	2012	The Effects of Fish Cages on Ambient Currents	*J. Offshore Mech. Arct. Eng., Vol. 134, Iss. 1. doi: 10.1115/1.4003696*
Gansel L.C., McClimans T.A. and Myrhaug D.	2012	Average Flow Inside and Around Fish Cages With and Without Fouling in a Uniform Flow	*J. Offshore Mech. Arct. Eng. 134, 041201*
Klebert P, Gansel L, Lader P , Oppedal F,	2013	Flow hydrodynamics through nets and floating cages: a review.	*Ocean Engineering 58, 260-274.*
Gansel, L., Rackebrandt, S., Oppedal, F., McClimans, T.A.,	2012	Flow fields inside stocked fish cages and the near environment.	*Journal of Offshore Mechanics and Arctic Engineering 134, 041201 (2012)*
Shainee, M., Ellingsen, H., Leira, B.J., Fredheim, A.	2012	An Optimum Design Concept For Offshore Cage Culture	*OMAE2012-83601*
Kristiansen T, Faltinsen OM	2012	Modelling of current loads on aquaculture net cages	*Journal of Fluids and Structures Volume 34, October 2012, Pages 218–235*
Shainee, M., Ellingsen, H., Leira, B.J., Fredheim, A.	2013	Design theory in offshore fish cage design	*Aquaculture 392–395 (2013) 134–141*

Biofouling			
Guenther J, Carl C, Sunde LM	2009	The effects of colour and copper on the settlement of the hydroid *Ectopleura larynx* on aquaculture nets in Norway.	*Aquaculture 292: 252-255*
Guenther J, Wright AD, Burns K, de Nys R	2009	Chemical antifouling defences of tropical sea stars: Effects of the natural products hexadecanoic acid, cholesterol, lathosterol and sitosterol.	*Marine Ecology Progress Series 385: 137-149*
Guenther J, Misimi E, Sunde LM	2010	The development of biofouling, particularly the hydroid *Ectopleura larynx*, on commercial salmon cage nets in Mid-Noway	*Aquaculture 300: 120-127*
Guenther J, Misimi E, Sunde LM	2010	Spatial and temporal effects of the underwater washing of salmon cage nets on the net aperture occlusion due to biofouling.	*Aquaculture 300:120-127*
Guenther J, Fitridge I, Misimi E	2011	Potential antifouling strategies for marine finfish aquaculture: the effects of physical and chemical treatments on the settlement and survival of the hydroid Ectopleura larynx	*Biofouling: The Journal of Bioadhesion and Biofilm Research 27:9, 1033-1042, doi:10.1080/08927014.2011.627092*
Carl C, Guenther J, Sunde LM	2011	Larval release and attachment modes of the hydroid Ectopleura larynx on aquaculture nets in Norway	*Aquacult Res 42:1056-1060*
Fitridge I, Dempster T, Guenther J, de Nys R	2012	The impact and control of biofouling in marine aquaculture: a review	*Biofouling: The Journal of Bioadhesion and Biofilm Research*
Bloecher, N., de Nys, R., Poole, A. J., Guenther, J.	2013	The fouling hydroid Ectopleura larynx: a lack of effect of next generation antifouling technologies	*Biofouling: The Journal of Bioadhesion and Biofilm Research 29:3, 237-246*

Fish behaviour			
Dempster T, Juell JE, Fosseidengen JE, Fredheim A, Lader P	2008	Behaviour and growth of Atlantic salmon (*Salmo salar*) subjected to short-term submergence in commercial scale sea-cages.	*Aquaculture 276: 103-111*
Dempster T, Korsoen Ø, Oppedal F, Folkedal O, Juell JE	2009	Submergence of Atlantic salmon (*Salmo salar*) in commercial scale sea-cages: a potential short-term solution to poor surface conditions.	*Aquaculture 288: 254-263*
Føre M, Dempster T, Alfredsen J-A, Johansen V, Johansen D	2009	Modelling of Atlantic salmon (*Salmo salar*) behaviour in aquaculture sea-cages: a Lagrangian approach.	*Aquaculture 288: 196-204*
Johansson D, Ruohonen K, Kiessling A, Oppedal F, Stiansen J-E, Kelly M, Juell J-E	2006	Effect of environmental factors on swimming depth preferences of Atlantic salmon (*Salmo salar* L.) and temporal and spatial variations in oxygen levels in sea cages at a fjord site.	*Aquaculture 254: 594-605*

Johansson D, Ruohonen K, Juell J-E, Oppedal F	2009	Swimming depth and thermal history of individual Atlantic salmon (*Salmo salar* L.) in production cages under different ambient temperature conditions.	*Aquaculture 290: 296-303*
Korsøen Ø, Dempster T, Fjelldal PG, Oppedal F, Kristiansen TS	2009	Long-term culture of Atlantic salmon (*Salmo salar L.*) in submerged cages during winter affects behaviour, growth and condition.	*Aquaculture 296: 373-381*
Korsøen Ø, Dempster T, Fosseidengen JE, Fernö A, Kristiansen T	2010	Behavioural responses to pressure changes in cultured Atlantic cod (Gadus morhua): defining practical limits for submerging and lifting sea-cages	*Aquaculture 308: 106–115*
Oppedal F, Dempster T, Stian L	2011	Environmental drivers of Atlantic salmon behaviour in sea-cages: a review	*Aquaculture, Volume 311, Issues 1-4, 3 February 2011, Pages 1-18*
Oppedal F, Vågseth T, Dempster T, Juell J-E, Johansson	2011	Fluctuating sea-cage environments modify the effects of stocking densities on the production and welfare of Atlantic salmon (*Salmo salar* L.).	*Aquaculture Volume 315: 361–36, doi:10.1016/j.aquaculture.2011.02.037*
Dempster T, Kristiansen T, Korsøen Ø, Fosseidengen J-E, Oppedal, F	2011	Technical note: Modifying Atlantic salmon (*Salmo salar*) jumping behavior to facilitate innovation of parasitic sea lice control techniques	*Journal of Animal Science 89:4281-4285*
Remen, M., Oppedal, F., Torgersen, T., Imsland, A., Olsen, R.E.	2012	Effects of cyclic environmental hypoxia on physiology and feed intake of post-smolt Atlantic salmon: Initial response and acclimation.	*Aquaculture 326-329, 148-155.*
Korsøen Ø, Dempster T, Oppedal F, Kristiansen T	2012	Individual variation in swimming depth and growth in Atlantic salmon (*Salmo salar* L.) subjected to submergence in sea-cages	*Aquaculture 334-337. 142-151*
Korsøen Ø, Fosseidengen J E,Kristiansen T S, Oppedal F,Bui S, Dempster, T.	2012	Atlantic salmon (Salmo salar L.) in a submerged sea-cage adapt rapidly to re-fill their swim bladders in an underwater air filled dome	*Aquaculture Engineering, 5, 1-6*
Skulstad, O.F., Karlsen, Ø., Fosseidengen, J.E., Kristiansen, T., Taranger, G.L. and Oppedal, F.	2012	Vertical distribution and sexual maturation in cage-farming of Atlantic cod (Gadus morhua L.) exposed to natural or continuous light.	*Aquaculture Research, 1-15.*
Føre, M., Dempster, T., Alfredsen, J.A., Oppedal, F.	2013	Modelling of Atlantic salmon (Salmo salar L.) behaviour in sea-cages: Using artificial light to control swimming depth.	*Aquaculture 388-391, 137-146*
Bui, S., Oppedal, F., Korsøen, Ø.J., Sonny, D., Dempster, T.,	2013	Modifying Atlantic salmon (Salmo salar L.) behaviour to facilitate parasite control techniques: applying light or feed during submergence increases surface behaviours.	*Aquaculture Environment Interactions 3, 125-133*
Korsøen, Ø., Fosseidengen, J.E., Kristiansen, T.S., Oppedal, F., Bui, S., Dempster, T.,	2012	Atlantic salmon (Salmo salar L.) in a submerged sea-cage adapt rapidly to re-fill their swim bladders in an underwater air filled dome.	*Aquacultural Engineering 51, 1-6.*

Papandroulakis N., Lika K., Kristiansen T., Oppedal F., Divanach P., Pavlidis M.,	2013	Behaviour of European sea bass, Dicentrarchus labrax L., in cages - impact of early life rearing conditions and management.	*Aquaculture Research*
Remen, M., Aas, T.S., Vågseth., T., Torgersen, T., Olsen, R.E., Imsland, A., Oppedal, F.	2013	Feed intake, feed utilization, metabolism and growth of Atlantic salmon (Salmo salar L.) post-smolts during long-term cyclic hypoxia and subsequent compensatory growth.	*Aquaculture Research*
Bui, S., Oppedal, F., Korsøen, Ø.J.,, Dempster, T.	2013	Group behavioural responses of Atlantic salmon (Salmo salar L.) to light and infrasound stimuli.	*PLoS One*

Aquaculture-Environment Interactions			
Moe H, Dempster T, Sunde L M, Winther W, Fredheim A	2007	Technological solutions and operational measures to prevent escapes of Atlantic Cod (*Gadus morhua*) from sea-cages	*Aquaculture Research 38: 91-99*
Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere J, Valle C, Dempster T, Tuya F, Juanes F	2008	Interactions between bluefish *Pomatomus saltatrix* (L.) and coastal sea-cage farms in the Mediterranean Sea.	*Aquaculture 282: 61-67*
Uglem I, Dempster T, Bjørn P-A, Sanchez-Jerez P, Økland F	2009	High connectivity of salmon farms revealed by aggregation, residence and repeated movements of wild fish among farms.	*Marine Ecology Progress Series 384: 251-260*
Dempster T, Uglem I, Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere J, Nilsen R, Bjørn PA	2009	Coastal salmon farms attract large and persistent aggregations of wild fish: an ecosystem effect.	*Marine Ecology Progress Series 385: 1-14*
Bustnes JO, Lie E, Herske D, Dempster T, Bjørn PA, Nygård T, Uglem I	2010	Salmon farms as a source of organohalogenated contaminants in wild fish	*Environmental Science and Technology 44: 8736–8743*
Dempster T, Sanchez-Jerez P, Uglem I, Bjørn P-A	2010	Species-specific patterns of aggregation of wild fish around fish farms	*Estuarine, Coastal and Shelf Science 86(2): 271-275*
Jensen Ø, Dempster T, Thorstad EB, Uglem I and A Fredheim	2010	Escapes of fish from Norwegian sea-cage aquaculture: causes, consequences, prevention	*Aquaculture Environment Interactions 1: 71-83*
McClimans, T.A., A. Handå, A. Fredheim, E. Lien, K.I. Reitan	2010	Controlled artificial upwelling in a fjord to stimulate non-toxic algae	*Aquaculture Engineering 42 (2010) 140-147*
Dempster T, Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere, Nilsen R, Bjørn PA, Uglem I	2011	Proxy measures of fitness suggest coastal fish farms can act as population sources and not ecological traps for wild fish	*PLoS One*
Korsøen, Ø.J., Fosseidengen, J.E., Oppedal, F., Stien, L.H.,	2013	Towards cod without spawning: artificial continuous light in submerged sea-cages maintains growth and delays sexual	*Aquaculture Environment Interactions*

Karlsen, Ø., Kristiansen, T.S., Dempster, T.		maturation for farmed Atlantic cod (Gadus morhua).	

Feed quality and nutrition			
Aas TS, Oehme M, Sørensen M, He G, Åsgård T	2011	Analysis of pellet degradation of extruded high energy fish feeds with different physical quality in a pneumatic feeding system	*Aquacultural Engineering, Volume 44, Issue 1, January 2011, Pages 25-34*
Aas TS, Terjesen BF, Sigholt T, Hillestad M, Holm J, Refstie S, Baeverfjord G, Rørvik K-A, Sørensen M, Oehme M, Åsgård T	2011	Nutritional value of feeds with different physical qualities fed to rainbow trout (*Oncorhynchus mykiss*) at stable or variable environmental conditions.	*Aquaculture Nutrition*
Aas,T.S., Terjesen,B.F., Sigholt,T., Hillestad,M., Holm,J., Refstie,S., Baeverfjord,G., Rørvik,K.-A., Sørensen,M., Oehme,M., & Åsgård,T.	2011	Nutritional responses in rainbow trout (Oncorhynchus mykiss) fed diets with different physical qualities at stable or variable environmental conditions.	*Aquacult.Nutr. 17, 657-670.*
Oehme M, Aas TS, Sørensen M, Lygrene I, Åsgård T	2012	Feed pellet distribution in a sea cage using pneumatic feeding system with rotor spreader	*Aquaculture Engineering*

Aquaculture Computing			
Tidemann A, Bjørnson FO, Aamodt A	2012	Operational Support in Fish Farming through Case-based Reasoning	*IEA-AIE 2012*

10.2. Published Conference Papers

Dempster T, Moe H, Fredheim A, Sanchez-Jerez P	2007	Escape of Marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention.	*CIESM workshop Monograph no. 32.*
Gansel LC, McClimans TA, Myrhaug D	2008	The effects of fish cages on ambient currents.	*Proceedings of the 27th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2008, Estoril, Portugal, June 15-20 2008*
Gansel LC, McClimans TA, Myrhaug D	2009	Flow around the free bottom of fish cages in a uniform flow with and without fouling.	*Proceedings of the 28th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2009, Hawaii, USA, June*
Gansel LC, McClimans TA, Myrhaug D	2010	Average flow inside and around fish cages without and with fouling in a uniform flow.	*Proceedings of the 29th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2010, Shanghai, China, June*
Aas TS, Terjesen BF, Sigholt T, Hillestad M, Holm J, Refstie S, Baeverfjord G, Rørvik K-A, Sørensen M, Oehme M, He G, Åsgård T,	2010	The optimal pellet quality is a trade-off between durability and responses in the fish.	*The 14th International Symposium on Fish Nutrition and Feeding 2010, Qingdao, China, June 1st-4th 2010.*
Gansel, L., Rackebrandt, S., Oppedal, F., McClimans, T.A.	2011	Flow fields inside stocked fish cages and the near environment	*Proceedings of the 30th International conference on ocean, offshore and Arctic engineering, OMAE2011, 19-24 June 2011. Volume 5, 201-209, doi:10.1115/OMAE2011-50205*
Tidemann, A., Bjørnson FO, Aamodt, A.	2011	Case-Based Reasoning in a System Architecture for Intelligent Fish Farming	*11th Scandinavian Conference on Artificial Intelligence, NTNU, Trondheim, Norway, 24-26 June 2011*

10.3. Books

de Nys R, Guenther J	2009	The impact and control of biofouling in marine finfish aquaculture.	*In: Advances in marine antifouling coatings and technologies. Eds.: Hellio C, Yebra D. Woodhead Publishing ISBN 1845693868*
de Nys R, Guenther J, Uriz MJ	2009	Natural fouling control.	*In: Biofouling. Eds.: Durr S, Thomason J. Blackwell Publishing. ISBN 9781405169264*
Fredheim A, Langan R	2009	Advances in technology for offshore and open ocean aquaculture.	*In: New technologies in aquaculture: Improving production efficiency, quality and environmental management. Eds: Burnell G & Allen G, Woodhead Publications 2009, Cambridge, UK*
Sanchez-Jerez P, Fernandez-Jover D, Uglem I, Arechavala P, Dempster T, and 3 others	2010	Coastal fish farms act as Fish Aggregation Devices (FADs): potential effects on fisheries.	*In: Artificial Reefs in Fisheries Management. Eds.: Steve Bortone et al., Taylor and Francis/CRC Press*

10.4. PhD Thesis

Korsøen Ø	2011	Biological criteria for submergence of physostome (Atlantic salmon) and physoclist (Atlantic cod) fish in sea-cages	*Universitetet i Bergen, ISBN 98-82-308-1716-2*
Føre M	2011	Individual based modelling and observation of Atlantic salmon (Salmo salar L.) behaviour in sea-cages	*Doctoral theses at NTNU, 2011:322 ISBN 978-82-471-3224-1*
Remen M	2012	The oxygen requirement of Atlantic salmon (Salmo salar L.) in the on-growing phase in sea cages	*Doctoral theses, Universitetet i Bergen, ISBN: 978-82-308-2137-4*
Maike Oehme	2013	Feed utilization can be improved by optimizing physical pellet quality and feeding equipment in salmonid farming	*Doctoral thesis 2013:07 Norwegian university of Life ScienceISBN 978-82-575-1110-4*