Annual Report 2013

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. 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.

CREATE have now finalized seven years of research and are in its last year of activities. At present nine projects are active, ranging from fundamental research to acquire basic knowledge on biology for technology development, to development of new technological solutions. The centre is further at present engaged in eight PhD and three Post doc fellowships. In 2013 three CREATE PhD's finilzed their work;

- Dr. Maike Oehme defended her thesis on "Feed utilization can be improved by optimizing physical pellet quality and feeding equipment in salmonid farming",
- Dr. Nina Blücher defended her theisis on "Biofouling in the Norwegian salmon farming industry" and
- Dr. Lars Gansel his thesis on "Flow past porous cylinders and effects of biofouling and fish behaviour on the flow in and around Atlantic salmon net cages"

CREATE researchers have so far published 78 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. For more information and results see chapter CREATE biofouling and biocleaning
- Modelling tools for estimating sedimentation as a basis for site selection and determination of optimal site configuration. This is based on integration of numerical models from various disciplines as a sedimentation model (DREAM) and an oceanographic model (SINMOD). For more information see chapter CREATE Site Sedimentation Model – SSM
- 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
- New insight into the physical behaviour of feed pellets and how it is affected by properties such as size and coating density. The data have been used to enhance a pellet distribution model. For more information and results see chapter Modelling and optimization of feed distribution in sea cages
- A user-friendly software tool for the design of net cage systems with a relatively high level of detail and flexibility in design parameters and the additional capability of testing the cages *in silica* through numerical simulations has been developed. When using the GUI, the user may specify all essential parameters required to set up and test a net cage system. This means that it is possible to design and simulate a wide

variety of different cage configurations. For more information and results see chapter NetCageDesignTools

- Development of an innovative snorkel system, denying the salmon access to the depths with sea lice, but allowing the salmon to have access to air. This innovative solution reduces lice infestations by 66-86%. 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).
- Results show it might be possible to use low intensity lights at decreasing day-lengths that may not affect sexual maturation and remain suitable for guiding salmon away from surface waters rich in lice infective stages. For more information and results see chapter IntelliLED - Intelligent use of L.E.D. lights to prevent sexual maturation and reduce sea lice infestation

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 nine main projects, has eight PhD students and three post-doctoral researchers working within the centre. Figure 1 present the projects (orange), PhD (blue) and post-doctoral topics (light blue), and their relation to the three main research pillars of CREATE in 2013.

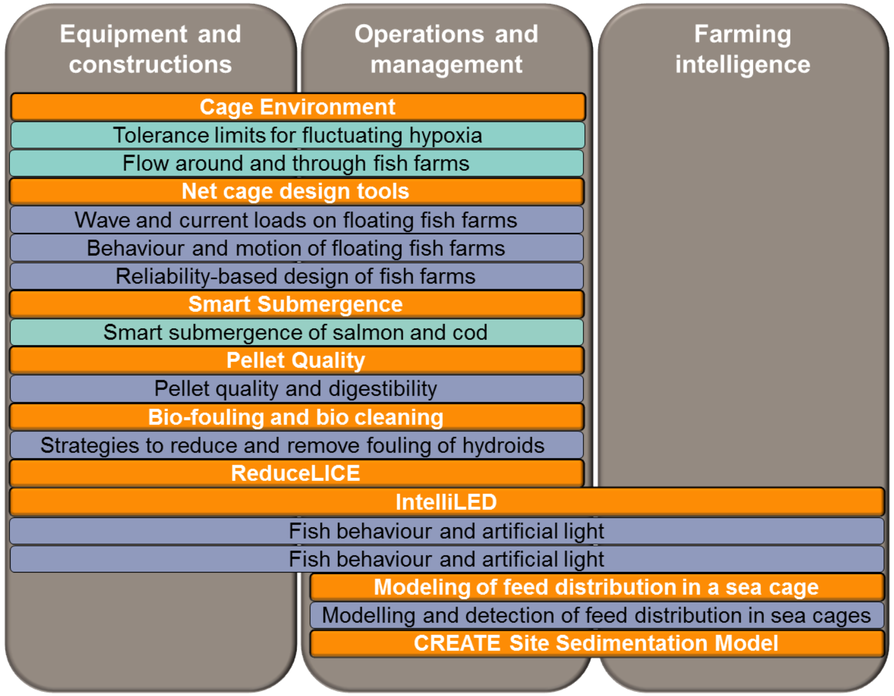


Figure 1 The projects (orange), PhD (blue) and post-doctoral topics (light blue), and their relation to the three main research pillars of CREATE

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, with activities and laboratories at all research partner locations. For more information see chapter Research facilities in the centre

SINTEF Fisheries and Aquaculture is the host institution for the centre, and the Centre Director is an employee of SINTEF Fisheries and aquaculture.

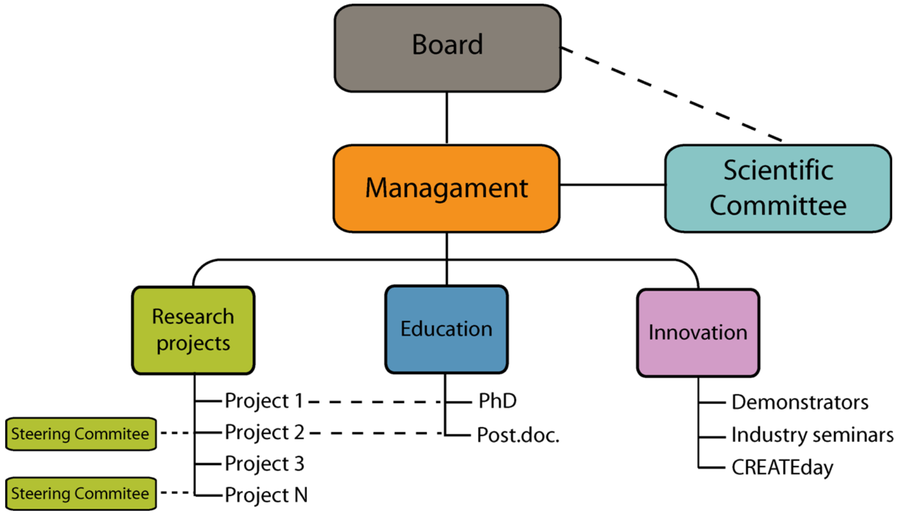


Figure 2 The organisation of CREATE, including projects and education

The Board of directors are has a majority of members from the industry partners and consists of in total seven members, one member representing the Host Institution, one representing the research partners and five 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 2013 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
Eldar Åsgård Bendiksen	Salmar ASA
Olav Breck	Marine Harvest ASA
Harald Sveier	Lerøy Seafood Group

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 2013, the following people were members of the SC:

Geirmund Vik	Egersund Net AS
Morten Malm	AKVA group ASA
Olav Breck	Marine Harvest Norway AS
Harald Sveier	Lerøy Seafood Group ASA
Eldar Åsgard Bendiksen	SalMar ASA
Torbjørn Åsgard	NOFIMA AS
Hanne Jorun Sixten	Biomar 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 (CeSOS), Centre for Autonomous Marine Operations and Systems (AMOS), 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 in 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 Aquaculture Engineering (ACE), industrial scale test facilities.

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

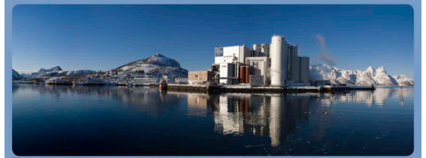
- Vision: Technology for a better society
- Perform basic and applied research for commercial customers as well as governmental institutions and bodies
- Contributes to solutions along the whole value chain

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

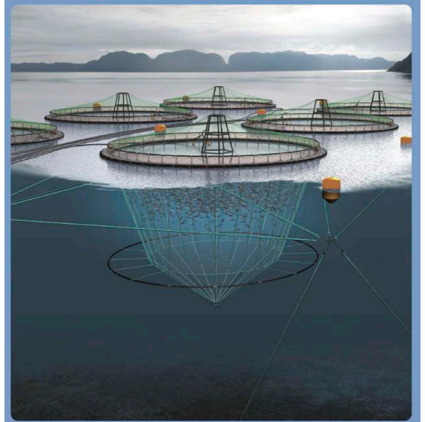
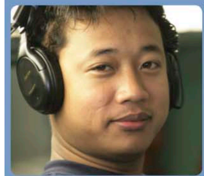
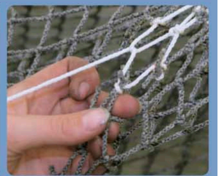
- Novel feed solutions for global aquaculture
- Healthy and sustainable growth
- Research-based innovation
- Interaction feed technology and biology
- Strong focus on fish nutrition and health






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.

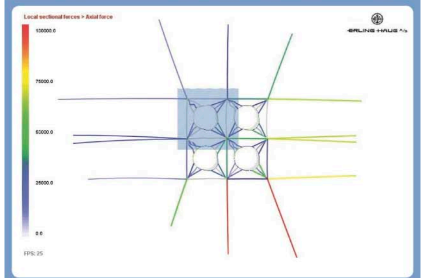
Erling Haug AS is part of the Axel Johnson Group. Customers range from private consumers to international companies, and products range from groceries to high-tech products. Foresight, entrepreneurship and creativity have been the watchwords of their past and will be the lights of the future. The group 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.

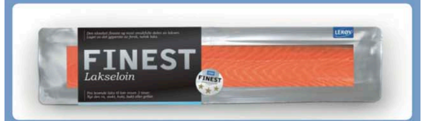
ERLING HAUG - facts

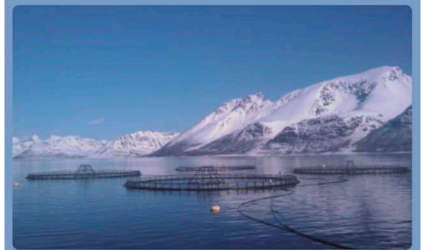
- Quality mooring components
- Dynamic analysis of mooring systems
- Flexible engineered mooring solutions
- Provides lifting- and HSE products, lice-skirts and LED marking buoys

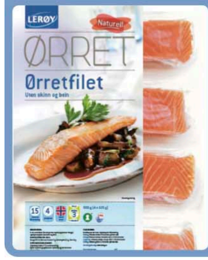


Lerøy - facts

- 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.

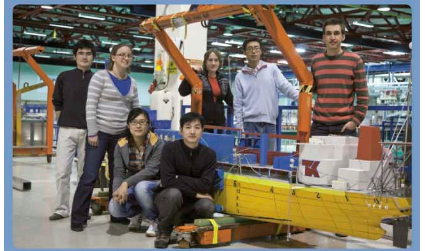
Centre for Ships and ocean Structures (CeSOS) at the Norwegian University of Science and Technology, integrate theoretical and experimental research in marine hydrodynamics, structural mechanics and automatic control. Research at CeSOS aims to develop fundamental knowledge about how ships and other structures 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).

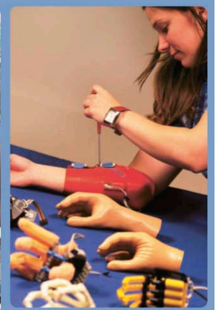
CeSOS - facts

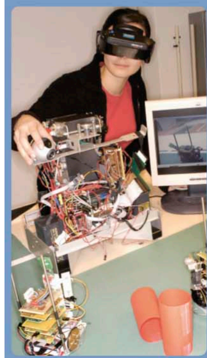
- Centre of Exellence initiated by RCN in 2003
- Internationally recognised research on ships and ocean structures
- Higly interdisciplinary approach
- About 100 affiliated PhD candidates and researchers
- More than 100 scientific publications per year

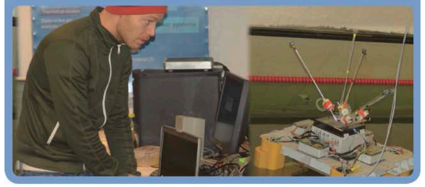


Department of Engineering Cybernetics - NTNU - facts

- 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.

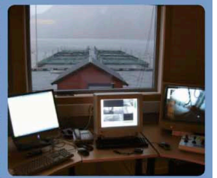
NOFIMA AS is an industry focused research corporation which aims to increase the competiveness of the food industry, including aquaculture, catch based fishing and the agriculture sector. The corporation is organized into four business areas: Marin, Food, Ingredients and Market. NOFIMA has its head office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

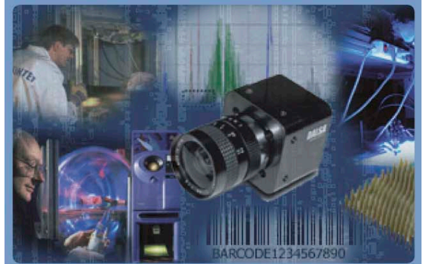
- R&D, innovation and knowledge transfer for fisheries and aquaculture
- Breeding and genetics
- Feed and nutrition
- Fish health
- Efficient and sustainable production
- Seafood processing and product development
- Marine bioprospecting

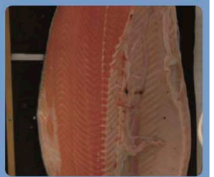


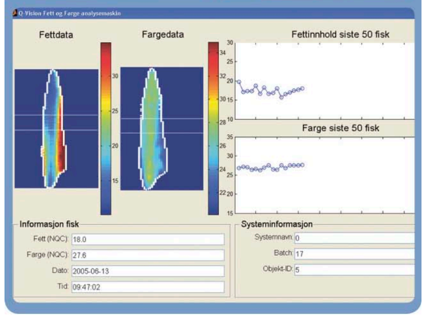


SINTEF ICT - facts

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, Jens Birkevold, Oliver Floerl (SINTEF Fisheries and Aquaculture), Ben Clokie (University of Stirling), Isla Fitridge (University of Melbourne)

Industry partners: AKVA group, Egersund Net, SalMar

Background

Biofouling is a major challenge for marine and maritime industries. Fouling organisms growing on aquaculture nets may add weight and reduce the water flow across nets, thus potentially affecting the structural integrity of net cages, changing the flow patterns past and hydrodynamic forces on nets and reducing the water quality inside cages. Strategies in the battle against biofouling include the suppression of fouling growth and the removal of fouling organisms. While this project was involved in both strategies in the past, field tests conducted in 2013 focused on antifouling coatings and potential adaptations of fouling organisms to Cu_2O, a commonly used antifouling compound.

Copper coatings are commonly used to manage biofouling in both the shipping and aquaculture industries. Although copper coatings are effective against a range of species, others are able to settle despite the toxicity of the coatings. Some species show variable copper tolerance among genetically distinct colonies, suggesting that resistance to copper may be a heritable trait that allows settlement under unfavourable conditions. The fouling hydroid Ectopleura larynx shows a high copper tolerance of both larvae and adult animals and fish farmers report this species as one of the first to settle on nets with copper-impregnation. This leads to the question if the constant copper use in the aquaculture industry facilitates the development of copper resistances in key species.

Since copper may negatively affect the environment through potential toxicity to non-target species and accumulation in sediments, alternative coatings containing less or no copper are of keen interest. An additional motivation may be that the Aquaculture Stewardship Council (ASC) Standard restricts the use of copper containing coatings for farms aiming for certification. Coating tests are needed to assess the most feasible combinations of coatings and net types that work best with regard to regional differences in biofouling pressure and dominating species.

This project lead to some long term developments for the quantification of biofouling on nets, of net cleaning methods and for the parameterization of biofouling for numerical models. This work was done in collaboration with researchers from the Universities of Melbourne, Australia and Stirling, Scotland and NIWA, New Zealand. Recent developments in these areas are presented together with results from field studies conducted in 2013.

Methods

Copper resistance in the hydroid *Ectopleura larynx*

To investigate if previous exposure to copper used in antifouling coatings has led to an increased copper tolerance in the biofouling hydroid *Ectopleura larynx*, the copper tolerance of animals growing at a conventional (regular copper use) and an ecological (no copper use) salmon farm was compared. Hydroid settlement on PVC panels (13 × 13 cm) coated with increasing concentrations of cuprous oxide (Cu_2O) between 0% Cu_2O (=control) and 30% Cu_2O (=common concentration in conventional coatings) was analysed in a 9-week field experiment.

Coating test

In a field experiment 10 different coatings with varying amounts of copper (between 0% and 20% Cu_2O) on black or white nylon nets were tested together with alternative coatings. Trials were conducted between May and October 2013 at two commercial salmon farms, one in Hardanger Fjord and one in a coastal environment at Rataren off the Island of Frøya. Samples were analysed with regard to biofouling community composition and biomass accumulation, measured as Percentage Net-aperture Occlusion (PNO).

Results

Copper resistance in the hydroid *Ectopleura larynx*

No differences in settlement could be found between hydroids from conventional and ecological farms (Figure 4). On all samples settlement was restricted to concentrations below 7.5% Cu_2O. The results of this small scale study indicate a general tolerance towards copper coatings in the hydroid *E. larynx* but no increased resistance caused by constant copper exposure.

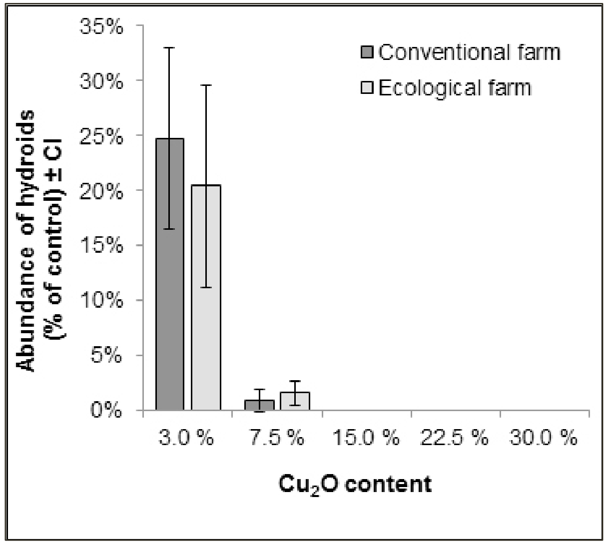


Figure 4 Abundance of hydroids (n = 4 for conventional farm, n = 8 for ecological farm) calculated as % of the controls on panels with increasing Cu2O concentration.

Coating test

Preliminary results indicate that Cu_2O concentrations between 5 % and 20 % may affect the amount of fouling on nets coated with white and black coatings. Furthermore, the use of copper potentially affects the fouling community composition. These results do not necessarily reflect final results, as they are based on a fast qualitative analysis at only one time during the experiments. Figure 5 shows an example of fouling that accumulated on coated nets at one time during the tests at the Rataren fish farm. Final results and conclusions will be published as a SINTEF report.

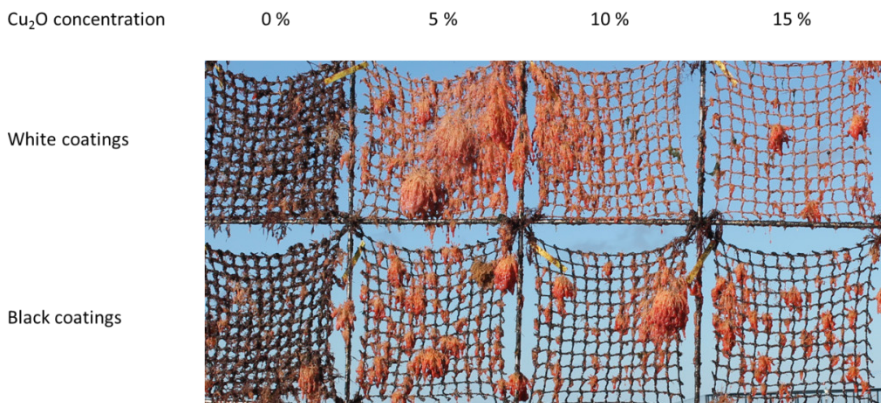


Figure 5 Example of fouling on coated nets at the Rataren Fish farm off Frøya, Norway in September 2013 after 4 months of submersion. The fouling community differs between nets containing no Cu2O (Cu2O concentration: 0 %) and coatings containing Cu2O. The amount of fouling decreases with the Cu2O concentration.

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 percentage net-aperture occlusion from images of clean and fouled nets was previously developed within this project. This technique allows a fast analysis of net images with high accuracy and reliability, but depends on high quality images. A number of factors influence image quality, amongst those being differences in ambient light (which varies with depth, season and time of day), net color and type of fouling. In 2012 this issue was addressed with a project that identified lighting techniques to assure high quality underwater images suitable for a semi-automated image analysis. Ben Clokie at the University of Stirling continues working on the images we acquired and the results will be submitted to a scientific Journal for publication.

Modeling biofouling: Impacts of fouling on drag forces and net deformation

Biofouling is divers and ever changing and it is therefore difficult to model fouling organisms on nets. In recent years researchers at SINTEF fisheries and aquaculture in collaboration with other institutions including the C.v.O. University in Oldenburg, Germany and NIWA , New Zealand, have made an effort to measure the impact of biofouling on the drag of fouled nets. The drag was measured on a rage of different clean nets with and without antifouling coatings and on a large number of fouled nets. The work resulted in the development of a database that shows the drag on clean and fouled nets in dependency of net solidity and amount and type of fouling. So far three types of fouling are included: hydroids, seaweed and mussels. The database can be build upon in the future and it allows the parameterization of fouling. That means that we now can implement biofouling into existing numerical models that describe the interactions between nets and currents. This will allow the prediction the effect of fouling on drag forces and net deformation. This work was submitted to PLoS ONE where it is currently under review.

Turning up the heat on biofouling

In 2010 former SINTEF scientist Jana Guenther and visiting researcher Isla Fitridge discovered in laboratory experiments that heated seawater and acetic acid (vinegar) were very successful treatments to kill biofouling hydroids at all stages in their life cycle: larvae, juveniles and adults. Field tests that followed in 2011/2012 gave inconclusive results on the effect of these measures on the re-growth of hydroids after washing events.

Recently, Isla assessed the possibility of combining these treatments for greater efficiency. The results show that combined heat and acetic acid treatments were synergistic, and could achieve similar hydroid mortality at low temperatures through the addition of small concentrations of acetic acid than observed at much higher temperatures using seawater alone. This may represent some cost savings to farmers if heated seawater techniques were employed to control fouling outbreaks.

PhD: Nina Bloecher

In November 2013, Nina Blöcher defended her PhD thesis "Biofouling in the Norwegian salmon farming industry". The thesis was supervised by Prof. Yngvar Olsen (NTNU) and Dr. Jana Guenther (SINTEF) and combined work of the CREATE Biofouling project with SINTEF's "Hydrofoul" project. The aims of this thesis were to increase the overall understanding of the development, the impacts and the prevention and management of biofouling on salmon farms. The four main experiments focused on (i) how natural and farm operational factors influence the biomass, species richness and community composition of biofouling on cage nets. In a 1-year study, the effects of immersion period, sampling time, mesh size and variability between three individual cages at a commercial salmon farm were investigated; (ii) the analysis of the potential food sources of hydroids and caprellid amphipods living on fish cages in order to identify a possible link between fish farm wastes and high biofouling abundances; (iii) whether hydroid biofouling can affect the oxygen levels in a fish cage not only through the reduction of the water exchange across the net but also through the oxygen consumption of the hydroid population growing on the cage nets; (iv) finding a non-toxic alternative to copper-based antifouling coatings. Therefore, the effects of the physical surface properties wettability and microtopography on the settlement of the hydroid *E. larynx* were analysed. The settlement preferences of hydroid larvae for materials with wettabilities ranging from hydrophobic to hydrophilic were tested. In a second experiment, surfaces with microtextures between 40–600 µm were analysed.

CREATE publications related to bio fouling and cleaning

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
Bloecher, N., Y. Olsen, and J. Guenther. 2013. Variability of biofouling communities on fish cage nets: A 1-year field study at a Norwegian salmon farm. Aquaculture 416–417:302-309.
Bloecher, N. 2013. Biofouling in the Norwegian salmon farming industry. Norwegian University of Science and Technology, Trondheim, Norway. Doctoral thesis at NTNU, 2013:320, ISSN 1503-8181

5.2. Cage Environment - Hypoxia management and flow through cages

Researchers: Frode Oppedal, Mette Remen, Thomas Torgersen (Institute of Marine Research), Michael Sievers (University of Melbourne), Lars Gansel, Jens Birkevold (SINTEF Fisheries and Aquaculture)

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

Hypoxia management

Background

Oxygen is the main limiting factor of fish metabolism, and sufficient supply is therefore critical for optimal growth and welfare of salmon in intensive aquaculture. Observations within commercial sea cages show fluctuating oxygen levels, and periods with alarmingly low levels (30–70% O_2). A previous trial in the CREATE Environment project has provided a lower limit for acceptable drops in O_2 (termed the “limiting O_2 saturation”, LOS), below which stress hormones are released and survival is time-limited. LOS was found to be temperature dependent, ranging from to 30-55% O_2 at 6-18 °C. Further trials have shown that reduced feed intake is an early indicator of insufficient O_2 supply, and that salmon gradually reduce their feed intake in order to reduce O_2 demand as O_2 decreases. We suggest that the O_2 level where feed intake is initially restricted (termed the “initial limiting O_2 saturation”, ILOS) is suitable as a practical oxygen threshold for optimal growth and welfare. The main aim of the present experiment was to investigate the relationship between temperature and ILOS for A. salmon postsmolts at temperatures relevant for Norwegian aquaculture (7-19 °C).

Methods

The trial was performed in the Tank Environmental Lab of Institute of Marine Research during spring 2013, with 328 postmolts (mean weight 305 g) distributed amongst 16 tanks (455 L). Four different temperatures were used; 7, 11, 15 and 19 °C. O_2 levels were set to change every second day in each tank, using 7 different, randomly occurring O_2 levels for each temperature (e.g. 32-92% O_2 at 7 °C, see Figure 6). All O_2 levels were repeated three times (42 days in total). Fish weights and lengths were recorded at start and at end, and the feed intake was recorded for all meals (fed twice daily). After completing 42 days with varying O_2, fish were fed to satiation at 100% O_2 for one day before measuring the LOS for each temperature.

Results

Results are currently being analyzed. Preliminary data are shown in Figure 6. The daily feed intake increased with temperature, and reached a maximum of 0.98 at 82% O_2 and 19 °C. Increasing O_2 beyond this level did not have any positive effect on daily feed intake (DFI). For each temperature, DFI was relatively stable until O_2 saturation reached a certain breakpoint level. Below this level, DFI decreased gradually with decreasing O_2 (Figure 6 A). From a visual inspection the relationship between O_2 level and DFI, the breakpoint, which represents the ILOS, was estimated and found to increase from 43 to 76% O_2 when temperature increased from 7 to 19 °C (Figure 6 B).

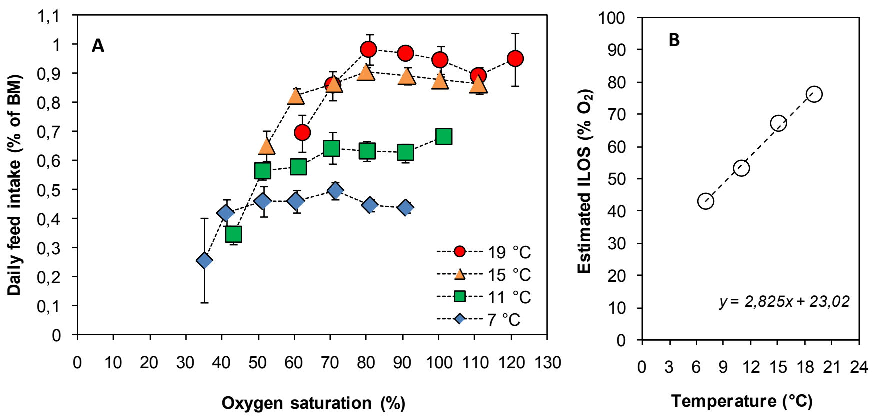


Figure 6 **A**. Daily feed intake (DFI, % of biomass, means±SE) in postsmolt Atlantic salmon in response to seven different O_2 levels (32-122% O_2) per temperature (7, 11, 15 and 19 °C). **B.** The relationship between temperature and the initial limiting oxygen saturation (ILOS), which represents the threshold for optimal growth and welfare. ILOS was determined visually from Figure 6 A, as the curve breakdown for each temperature, below which feed intake started to decrease with further reduction in O_2. Data are preliminary.

Discussion

Results from the current experiment show that the O_2 saturation needed to maintain full appetite and growth is highly temperature dependent. This has never been shown for A. salmon and will have implications for feeding practices and management protocols. Further analysis will reveal the relationship between temperature and LOS measured at end of the experiment. This will give a range of O_2 levels (ILOS→LOS) where growth and welfare can be expected to gradually decrease from optimal to detrimental. It should be emphasized that these thresholds are provided for postsmolts. Data for larger fish (2-4 kg) have been obtained, and are currently being analysed.

Flow through cages

Background

Currents affect the structural integrity of fish farm structures and the water flow affects the forces on nets and moorings. Nets deform in currents and strong deformations significantly reduce the volume available to farmed fish. The flow past cages also governs the water exchange inside net pens, thus affecting the water quality and oxygen supply that the fish experience. For these reasons it is important to have a good understanding of the fluid structure interactions on fish farms.

Methods

Effects of the water flow can be studied in small scale experiments in the laboratory or at large scales in the sea. Laboratory tests allow for controlled conditions, but scaling effects have to be considered and usually fish cannot be used inside cage models. Field experiments commonly suffer from a lack of knowledge and control over environmental conditions, but scaling issues can be avoided and fish may be included in the tests. This project developed a new approach to combine the use of a large scale fish cage in field tests with controlled and systematic changes in the flow speed. A net cage with a diameter of 12 m and a depth of 6 m was pushed at different speeds in a fjord environment (Figure 7). Deformation of the empty and stocked cage was measured at all speeds using pressure (depth) tags mounted on the net at 12 positions. A towing test was performed to measure drag forces at different speeds.

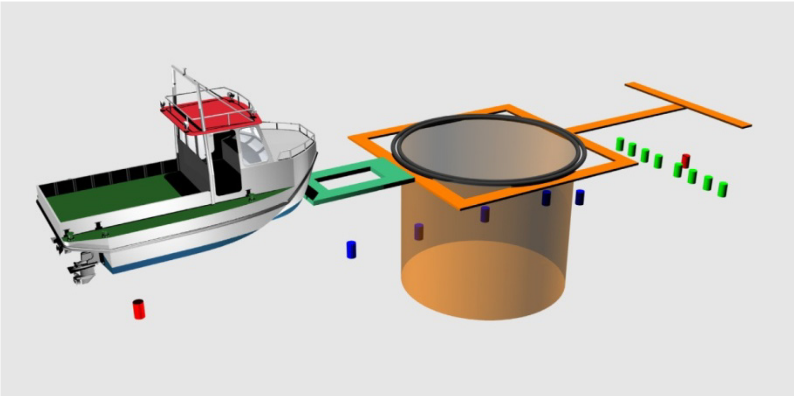


Figure 7 Sketch of cage pushed by boat at speeds from 0 up to 1.6 m s^{-1}. Red and blue dots indicate current velocity meters. Green dots indicate positions for dye addition.

Results

In the pilot test the cage was pushed at several speeds in the range between 0.0 m/s and 0.7 m s^{-1} without fish and stocked with 1000 fish with an average weight of 2.5 kg. It is shown that the cage can be pushed along pre-defined paths and that this technique allows control of the flow speed and direction. The flow speed upstream of, inside and downstream from the cage was measured to investigate the flow reduction inside cages and in their wake. Dye was used to investigate the mixing induced by nets (empty cage) and by fish (stocked cage). An example of preliminary results is given in photos in Figure 8.

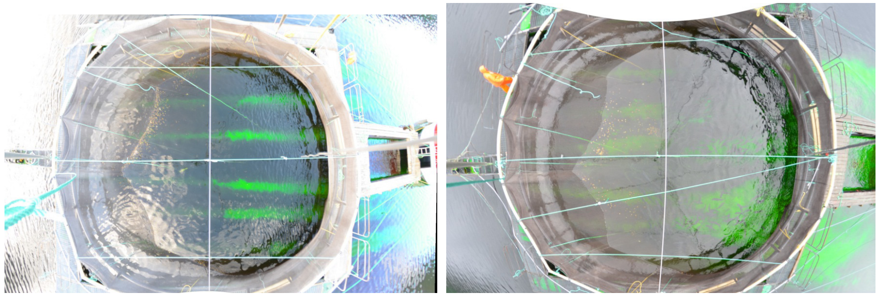


Figure 8 Photos showing dye distribution inside a cage from pilot study were the cage was pushed at an approximate speed of 40 cms^{-1} without (left photo) and with (right photo) fish. Water flows through the cage from left to right. Increasing turbulence is seen through the cage with major impact of fish presence.

The drag increased with increasing flow speed and the rate of drag increase became lower with flow speed, especially at high flow speed, at which the net deformation was largest. This trend corresponds well with the findings of other authors employing small-scale tests and numerical models. That means that while an increase of the flow velocity leads to increased hydrodynamic forces on the cage, additional drag causes more net deformation. Net deformation, in turn, causes the drag coefficient of the net to be reduced, which then lowers the drag on nets. The deformations and drag forces measured and calculated are compared with results from several models. The net caused some turbulence in the flow, leading to some dye spreading in the wake of the net cage (example in Figure 8, left panel), while fish inside the net cage lead to strong mixing of dye inside of and downstream from the cage (Figure 8, right panel).

Discussion

It is shown that the use of this technique opens for relatively controlled flow conditions in large scale experiments in the sea. The results may act as a case study on the effect of flow speed on cage deformation of empty and stocked net cages and on the velocity reduction inside net cages and in their wake. Fish is shown to have a major effect on mixing of water passing net cages. Actual drag forces measured is compared to present models and revisions are indicated to improve future calculations.

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 TA (2012) Flow fields inside stocked fish cages and the near environment. J Offshore Mech Arct Eng.

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.

Føre M, Dempster T, Alfredsen JA, 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

Remen M, Oppedal F, Imsland A, Olsen RE, Torgersen T (2013). Hypoxia tolerance thresholds for post-smolt Atlantic salmon: Dependency of temperature and hypoxia acclimation. Aquaculture 416, 41-47

Gansel L (2013). Flow past porous cylinders and effects of biofouling and fish behavior on the flow in and around Atlantic salmon net cages. Trondheim: NTNU 2013 (ISBN 978-82-471-4760-3) 103 s.

5.3. Pellet Quality - optimal conveying and biological response

Researchers: Torbjørn Åsgård, Trine Ytrestøyl, Bjarne Hatlen and Turid Synnøve Aas (project leader), (Nofima)

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

Background

Feeds with high physical quality are required in order to minimise pellet breakage and dust formation during transport and storage of feed in modern aquaculture. However, previous results from this CREATE-project have shown that the physical pellet quality affects the feed intake in fish, and that this may be related to the rate of stomach emptying.

In the present trial, the hypothesis to be tested was that the pellet quality affects the gastrointestinal transit time in salmon. Therefore, the total transit time through the gastrointestinal system in salmon fed two feeds with different pellet quality was compared.

Methods

Two feeds with identical formulation were produced with different pellet quality, Diet 2 having harder pellets than Diet 1. The pellet quality of both feeds was within the range of what is common in commercial feeds. Each feed was produced in three batches and added three different markers (La, Yb and Y). The salmon was fed one meal daily, and prior to the trial the salmon was fed the feeds added La. At time 0 hours, the fish was fed diets added Yb. At time 24 and 48 hours and thereafter, the salmon was fed diets added Y.

Faeces was collected from the outlet of the tanks at time 0, 8, 16, 24, 32, 40 and 48 hours, and was analysed for dry matter, La, Yb and Y. The ratio of the concentration of each marker to total marker concentration was calculated and used to follow the gastrointestinal transit time of the meal given at time 0.

Results

For both Diet 1 and Diet 2, some of the feed had passed through the entire gastrointestinal tract already after 8 h, and after 48 hours, the meal had almost completely passed through the gastrointestinal tract (Figure 9). The change in marker concentrations happened rapidly in the time interval 8-16 hours, meaning that most of the faeces from one meal is produced 8-16 hours after feeding. In this time interval, the gastrointestinal passage rate was significantly higher for pellets with lowest hardness (Diet 1) than for the hardest pellets (Diet 2).

These data show that even for relatively similar pellet qualities, the gastrointestinal passage rate in salmon is affected by the pellet quality.

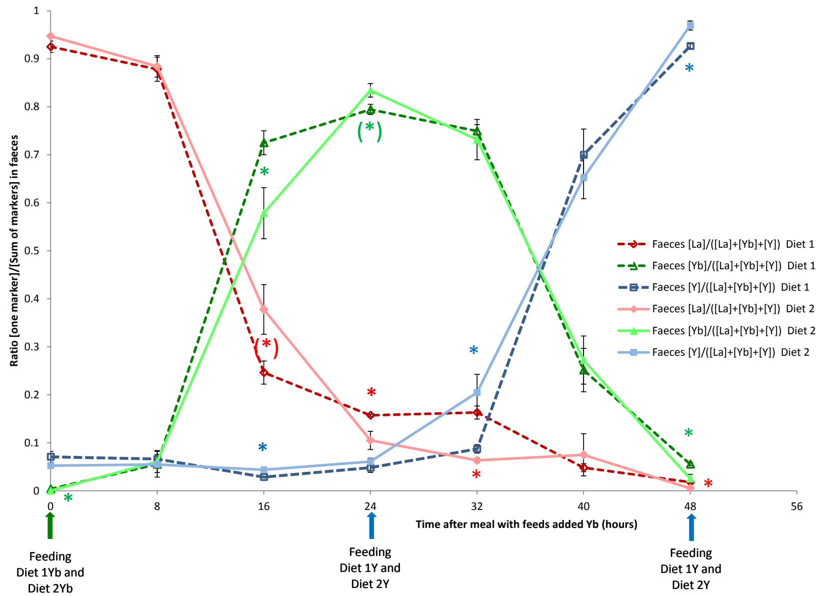


Figure 9 Ratio of markers in faeces from Atlantic salmon sampled at time 0, 8, 16, 24, 32, 40 and 48 hours. Prior to these samplings, the salmon was fed diets added La. The salmon was fed diets added Yb at time 0, and diets added Y at 24 and 48 h. Diet 1 and Diet 2 have different physical pellet quality (Mean±S.E.M., n=4). * Significantly different ($P \leq 0.05$). (*)Trend ($0.05 < P < 0.1$)

PhD: Maike Oehme

Maike Oehme defended her PhD thesis 'Feed utilization can be improved by optimizing physical pellet quality and feeding equipment in salmonid farming' at the Norwegian University of Life Sciences, Department of Animal and Aquacultural Sciences, on 1. March, 2013.

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,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.

Oehme, M., Aas., T.S., Olsen, H.J., Sørensen, M., Hillestad, M., Li, Y., Åsgård, T. (2013) Effects of dietary moisture content of extruded diets on physical feed quality and nutritional response in Atlantic salmon (*Salmo salar*). Aquacult. Nutr. In press. doi: 10.1111/anu. 12099

5.4. NetCageDesignTools

Researchers: Martin Føre (project leader), Finn Olav Bjørnson, Per Rundtop, Per Christian Endresen (SINTEF Fisheries and Aquaculture)

Industry partners: Egersund Net

Background

Graphical software tools for rapidly conducting the technical specification and configuration of net cages may prove useful when designing net cage systems for the aquaculture industry. By also incorporating a numerical simulator, such tools could estimate how a new design will respond to different environmental conditions. There are existing commercial software products that allow the user to set up an aquaculture fish farm and simulate its response toward the environment. However, these products are generally focused on simulating full farm systems, and thus have limited options in varying the design details of the net cages.

Egersund Net desired a user-friendly software tool for the design of net cage systems with the additional capability of testing the cages *in silica* through numerical simulations. The main requirements for this tool included a relatively high level of detail and flexibility in design parameters. To accommodate these requirements, the research project NetCageDesignTool was established; aiming to develop this tool through research based innovation rather than applying existing commercial solutions. This project has been realised as collaboration between Egersund Net and SINTEF Fisheries and Aquaculture.

Methods

The main task within the NetCageDesignTool project is to develop a graphical user interface (GUI), which allows the user to provide input parameters similar to those typically used when specifying net cage designs (e.g. cage circumference, net solidity, sinker tube mass). The GUI is also able to simulate the response of the specified design toward a set of specific environmental conditions. Numerical simulations are conducted using FhSim, which is a platform for mathematical modelling and numerical simulation developed by SINTEF F & A. Outputs from the simulations are presented within the same GUI, giving the designer information on how his/her net cage design performs under the selected environmental conditions.

To ensure that the functionality and design of the GUI is in accordance with the desires of Egersund Net, a close collaboration between Egersund and SINTEF has been maintained throughout the project period. This has been realised through regular phone meetings where SINTEF present new versions of the software to Egersund Net. After each meeting, the new version of the software is delivered to Egersund, who then test the software for two weeks. Throughout these test periods, Egersund Net report eventual software bugs or errors that are discovered, and make recommendations on possible improvements. This feedback is then used by SINTEF to update a list of design specifications for further development of the GUI. A scrum inspired agile method is applied in the software development process, where the project group has regular bi-weekly meetings. In these meetings, the requirement list is reviewed, prioritised and delegated among the project participants to ensure efficient progress in the software development while at the same time keeping a focus on the requirements forwarded by Egersund Net.

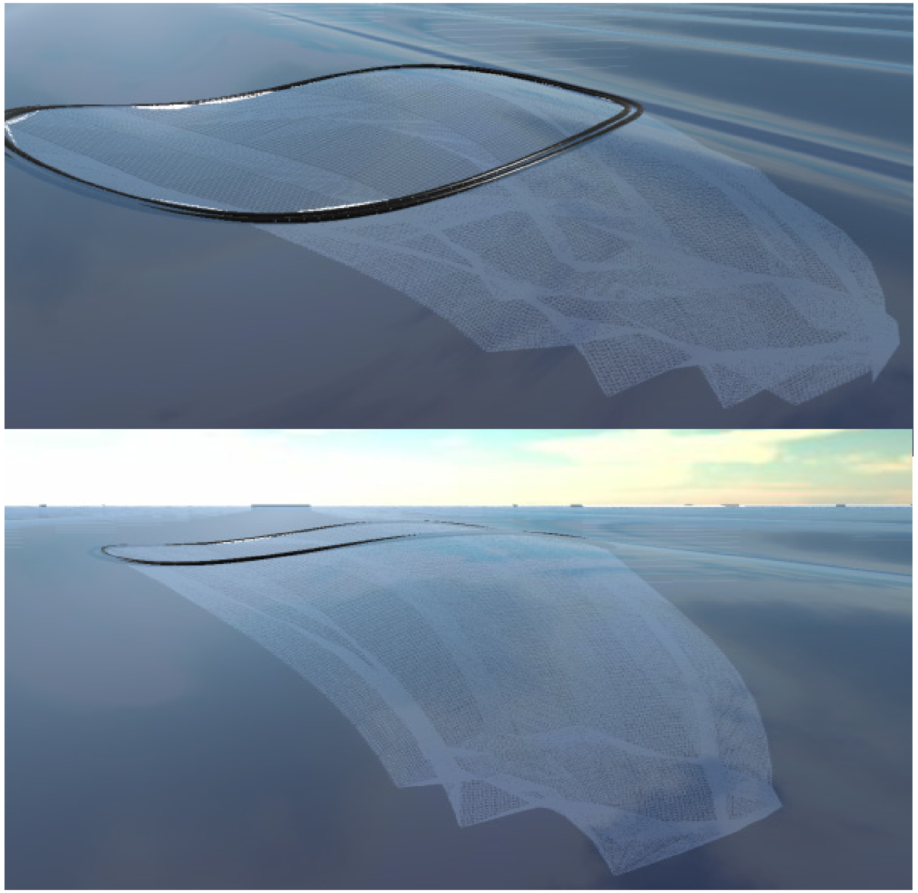


Figure 10 Screenshots of a deformed circular net cage with flexible floating collar in waves and current.

Results and Discussion

The present version of the NetCageDesignTool GUI represents the final result of the collaborative effort between Egersund Net and SINTEF F & A through the last year. When using the GUI, the user may specify all essential parameters required to set up and test a net cage system. This means that it is possible to design and simulate a wide variety of different cage configurations.

The full specification of a net cage system and the environmental conditions this system is subjected to requires a large number of parameter inputs from the user. To reduce the complexity of using the GUI, the setup of a case has therefore been divided into four different phases, the first of which is to specify the shape and main dimensions of the cage (Figure 11). The user may then choose between square and circular shapes, and assign the side widths or circumferences at the top and the bottom of the cage wall. Other parameters such as wall depth, depth of the bottom cone and number of support ropes (i.e. cross/side ropes, horizontal ropes) are also assigned during this phase. The final stage of this phase is to determine how the net will be weighed down. Options then are either to use point weights placed at the intersection between cross-ropes and the net, or to use a sinker tube which is attached to the bottom of the net and the floating collar (sinker tubes may only be used when the cage is of circular shape). All weights are specified as submerged weight in kg.

In the second phase, the user may set the material properties of the components comprising the cage system. The net is here specified by giving twine diameter and mesh width (together determining net solidity), and the density of the net material, while ropes and chains are determined by diameter and material density. Material properties of the sinker tube and floating collar are by default set to values which will produce realistic dynamics. However, it is possible to adjust these components by changing their tube diameters and wall thicknesses.

After the two first phases, the description of the net cage system is complete. The next natural step is then to specify how the cage should be moored. This represents the third phase in the GUI setup, and the user then needs to specify the components constituting a simplified version of a typical mooring frame system. These components include mooring buoys (height and radius), coupling plates (weight) and cables and ropes (length and percentage relaxation). In addition, the user needs to specify the main dimensions of the mooring system (distance between buoys, mooring frame depth and anchor depth). The user may choose to skip this phase, in which case the cage will be kept in place by four basic strings attached to the floating collar.

The final phase of using the GUI pertains to determining the environmental conditions. This is only necessary when the dynamic response of the cage design is to be examined through numerical simulation, and is limited to specifying water current conditions and the sea-state (i.e. wave conditions). Water current is specified by providing the direction and magnitude of the current, and may be further refined by adding a vertical gradient in magnitude. Waves may either be set to regular waves (amplitude and period) or irregular short/long crested waves (significant wave height, mean period and mean direction).

Once the final setup phase is concluded, the user may initialise the simulation. This prompts the GUI to read in all user-provided parameters, use these to construct setup files for FhSim and start a simulation with FhSim using the resulting setup file as input. If the user selects to include visualisation during simulation, a 3D animation describing the system response over time will appear on the screen. It is possible to store this animation as a video for review after the simulation is completed.

When the simulation has terminated, the user may choose to process the data within the GUI. The GUI will then parse the output file from FhSim and use the simulation output to derive relevant values such as maximum forces acting on individual bridles, the reduction of the internal volume in the cage over time and the minimum distance between the net and the sinker tube chains. These results are automatically plotted as charts or time series, but may also be exported as numerical values and tables to the clip-board or an Excel file for further processing in other software tools.

At present, we have managed to implement the majority of the elements that have been included into the list of design specifications throughout the project period, meaning that the software contains most of the improvements and features identified as useful by Egersund Net and SINTEF F & A. The NetCageDesignTool software is currently in use at both companies participating in the project, and is still being further improved and developed.

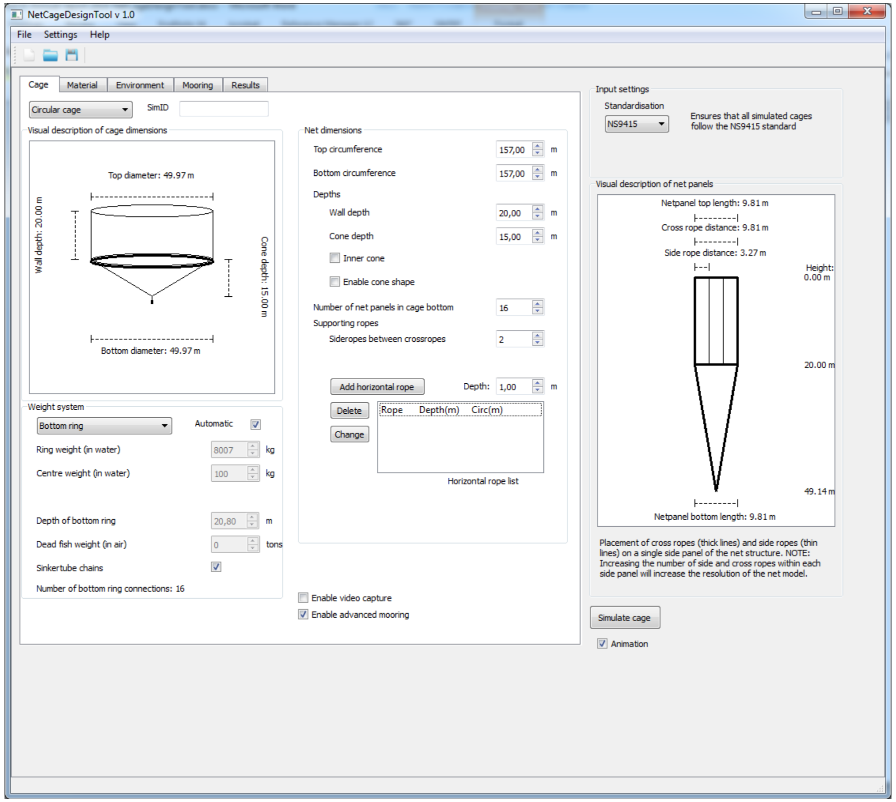


Figure 11 Screenshot of the first tab in the NetCageDesignTool GUI. This tab is used to specify cage shape and dimensions, as well as which weighting method should be used in the simulation (phase 1 in the design process as described in the text).

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

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

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)

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

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

Shainee, M., Ellingsen, H., Leira, B.J., Fredheim, A. (2013) Design theory in offshore fish cage design. Aquaculture 392–395

Shainee, M., DeCew, J., Leira, B. J., Ellingsen, H. Fredheim, A. (2013) Numerical Simulation of a Self-Submersible SPM Cage System in Regular Waves with Following Currents. Aquaculture Engineering. Volume 54, Pages 29–37

Shainee, M., Leira, B.J., Ellingsen, H., Fredheim, A. (2014) Investigation of a self-submersible SPM cage system in random waves. Aquacultural Engineering, pp. 35-44

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
Atlantic salmon in a submerged cage becomes negative buoyant. In previous experiments salmon submerged to 4 m depth for 17 days grew slower than fish in standard cages (Dempster et al. 2008), but given artificial light for 21 days they did not grow slower (Dempster et al. 2009), whereas salmon submerged to 10 m depth for 42 days grew slower, swam tilted at night and developed compressed vertebrae in the tail region (Korsøen et al. 2009). This experiment aimed to repeat the experiment by Dempster et al. 2009, and prolong the submergence period to find the breaking point for when the salmon start to compromise welfare parameters while being held away from the surface and the ability to refill their swim bladders.

Methods
Three commercial-scale cages (approx. 2000 m3) were submerged with each 6300 salmon at 300g, whereas three cages served as control treatments where fish had surface access (**Error! Reference source not found.**). A submersible lamp was placed 8 m below the surface in all 6 cages, the lamp bulb had a power rating of 400 W and was lit 24 h per day. All fish were fed in access every day, swimming speed was measured weekly from 30 random fish per cage (UW cameras) and target strength (swimbladder filling) was monitored by eco-sounder underneath each particular cage. The fish were planned to be submerged for at least 6 weeks, but due to heavy sea-lice infestation within a few weeks after start-up, all fish had to be treated and the submergence period lasted therefore 26 days from February 22 to March 20, 2013. All fish had been deloused 8 days prior to submergence. Number of sea-lice was counted at 50 fish per cage the same day as re-surfacing.

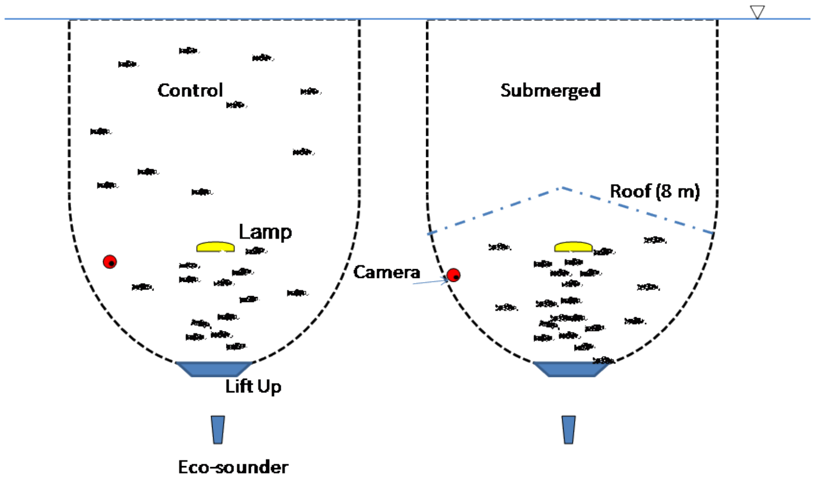


Figure 12 *The principle set-up, with the lamps providing continuous light at the same depth (8 m) in the control and submerged cages.*

Results
A difference in swimming speed developed during the experimental period, where the submerged fish the last day swam ~1.4 times faster than the control fish (Figure 13A), which is in accordance with previous experiments (Dempster et al. 2009). This occurred most likely due to lack of lift from swimbladder volume, as the gas content in the swimbladder gradually emptied (Figure 13B).

There was no significant difference in growth rate between treatments. The control fish performed a fairly similar growth rate in all cages, whereas the submerged group had larger variation (Figure 13D). The low growth and high body condition factor (Figure 13C) for the fish in submerged cage 6 cannot be logically explained, and most likely there has been a sampling error.

The total amount of sea lice (copepodites and adults) were in the same level for submerged (n=75) and control fish (n=63). At night the fish schooled near the lamps at 8 m depth in all cages. Sea-lice is attracted by light and is mainly found in the upper 10 m seawater level, hence this experimental set-up was not designed for sea-lice avoidance.

To clarify for how long and deep salmon can be submerged by use of continuous light without negative welfare impact, an experiment should be executed for a longer time and submerged deeper than in the present experiment.

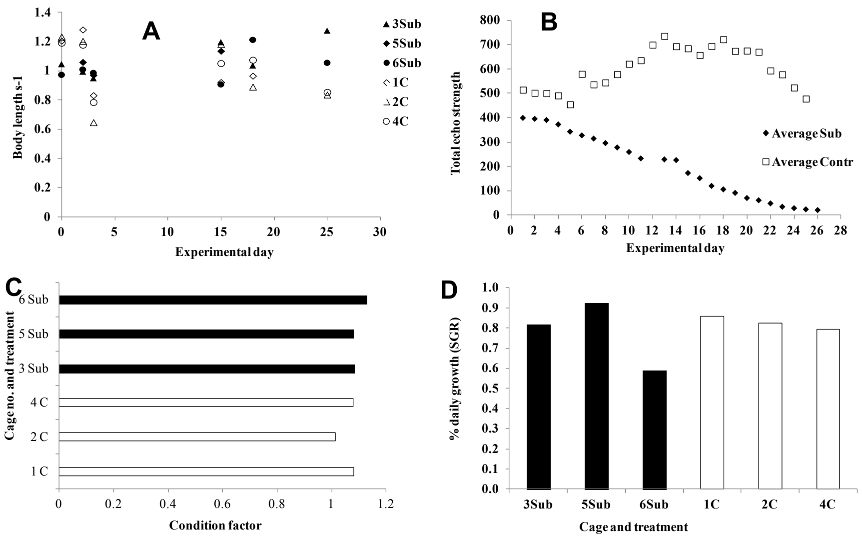


Figure 13 *Swimming speed, echo target strength (swimbladder gas content), body condition factor, and daily growth rates for salmon during the 26 days experiment.*

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

Kristiansen, T.S., Stien. L.H., Fosseidengen, J.E., Strand, E. and Juell, J-E. 2011. Subjective limit of tolerance to sudden swimbladder expansion in freely swimming Atlantic cod. Aquaculture International 19:625-636.

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.

Korsøen, Ø.J., Dempster, T., Fosseidengen, J.-E., Karlsen, Ø., Oppedal, F., Stien, L.H., Kristiansen, T.S., 2013. Towards cod without spawning: artificial continuous light in submerged sea-cages maintains growth and delays sexual maturation for farmed Atlantic cod .Gadus morhua. Aquacult. Environ. Interact. 3: 245-255

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).

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 Figure 14.

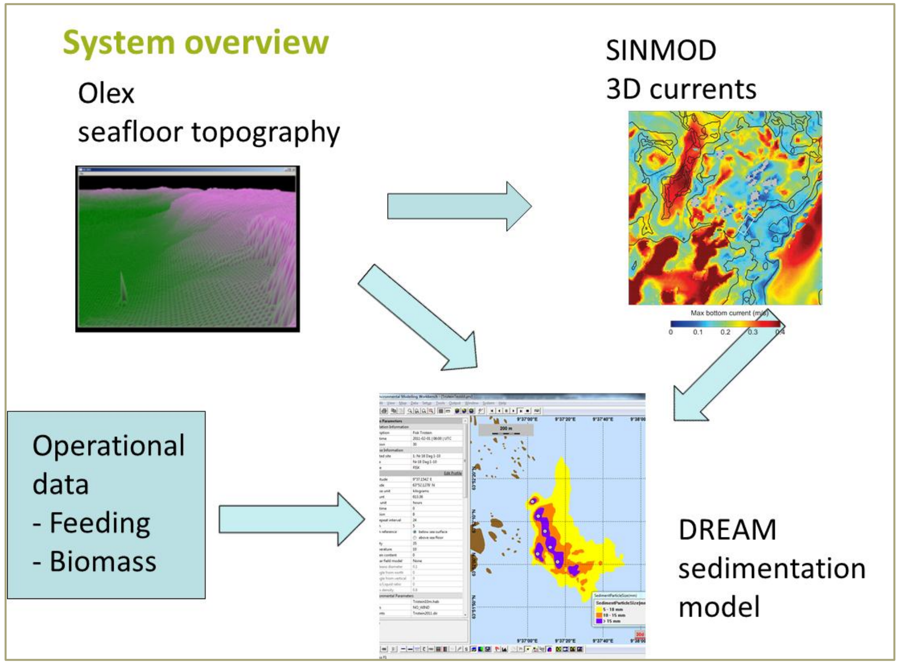


Figure 14 Site Sedimentation Model (SSM) systems overview.

Results

The work in 2013 had two main focus areas:

- Initial sensitivity analysis for input parameters
- Comparisons between model results and environmental inspections for additional sites

The sensitivity analysis was done using the dataset from the Tristein site, and included four important parameters:

- Number and location of sedimentation release points within the cages
- Particle size distributions
- Re-suspension
- SINMOD grid size (32 meters versus 160 meters)

One example from the sensitivity analysis is shown in Figure 15, and clearly shows differences between 32 meter and 160 meter grid size for calculating current fields. This indicates that the 32 meter grid size is required for detailed analysis, and that the added computational time is justified.

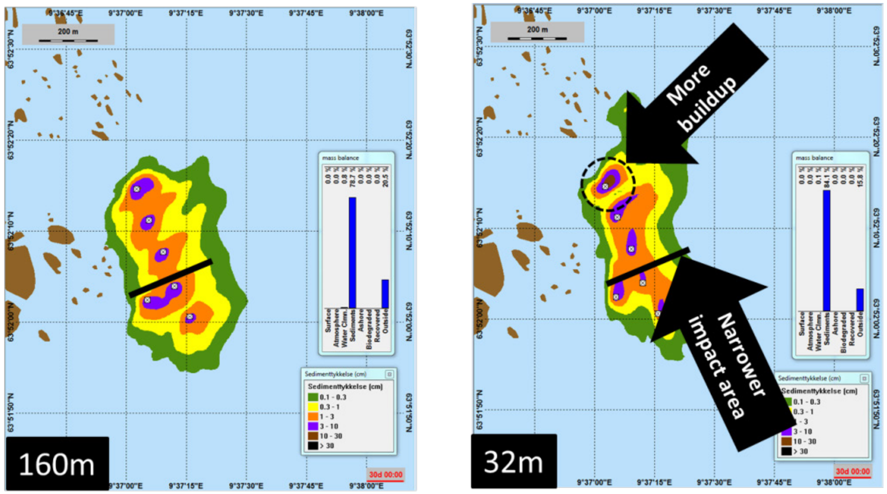


Figure 15 One example from the sensitivity analysis with dataset from the Tristein site.

The additional sites for further study in 2013/2014 were selected in cooperation with SalMar Farming and Lerøy SeaFood Group. The SalMar Farming site Rataren is located west of Frøya, in an area with several sites and several companies. It was decided to run the SINMOD 32 meter grid model for as large an area as possible, thus making it possible to do analysis for more sites at a later stage. This imposed the cost of long calendar time for computations, and combined with some technical problems in our computing cluster caused some delays. The Lerøy Seafood Group site chosen is Seglråa, located in Vinjefjorden. This model area also includes more sites to allow for later analysis. An overview of the model areas is shown in Figure 16.

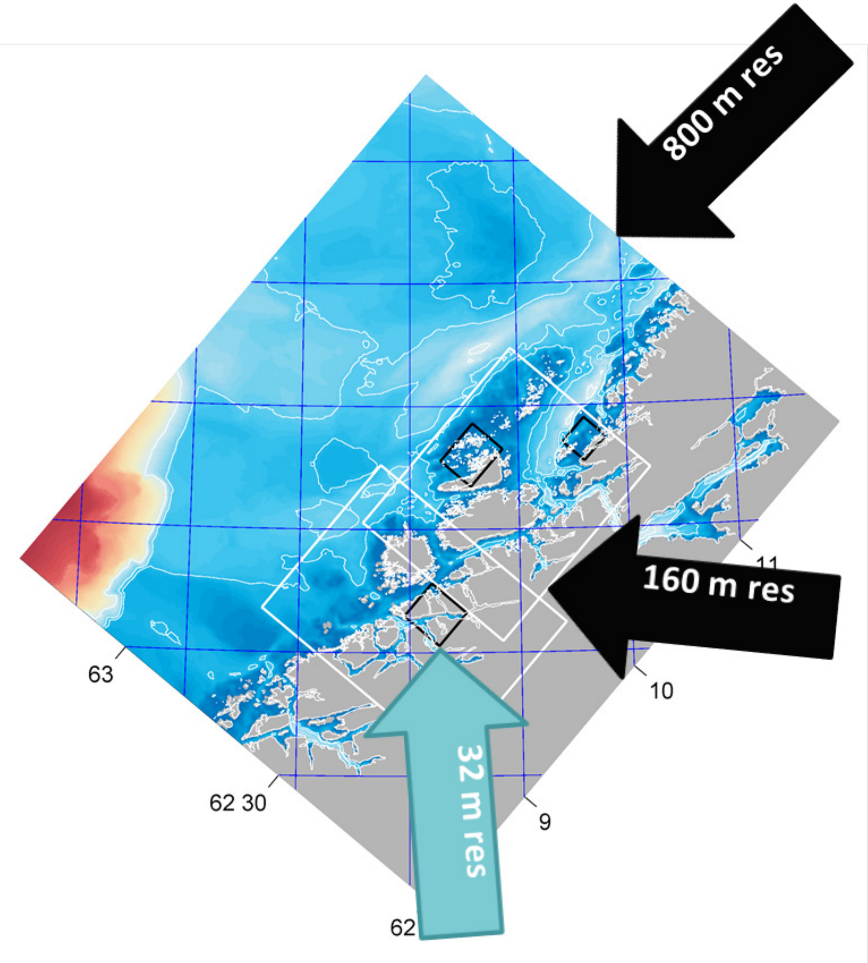


Figure 16 An overview of the model areas used for the analysis.

The figure also shows the areas used for creating boundary conditions for the 32 meter grid modelling.

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

Researcher: Lars Stien, Thomas Torgersen, Jan Erik Fosseidengen, Frode Oppedal (Institute of Marine Research), Daniel William Wright (University of Melbourne)

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

Background

Underwater anti-maturation-lights may be used to position sea-caged Atlantic salmon (*Salmo salar* L.) deeper at night in an effort to reduce infections by salmon lice (*Lepeophtheirus salmonis*) in surface layers. However, anti-maturation-light use is impermanent because lighting during decreasing day-lengths (autumn) stimulates sexual maturation which is detrimental for fish welfare, growth and meat quality. The effects from lights on maturation are related to both light intensity and light spectrum. High intensity anti-maturation-lights cannot be used as a general year-round method to modulate salmon swimming depth for salmon lice avoidance while lower intensities of specific wavelengths may be used. This study aimed to determine the lowest intensity of 7 different coloured lights needed to maintain daytime deep swimming of salmon in a sea cage throughout the night.

Materials and Methods

Here, we explored caged salmon depth use in response to lights of four low intensities (0.01, 0.10, 1.0 and 10.0 µE as measured 1 m from the lamps) and seven different colours (white, violet, blue, green, yellow, red and deep red),Figure 17. Custom made lamps with Light Emitting Diodes (LEDs) were produced by AKVA Group ASA. Triplicate sea cages (12 × 12 m and 11 m deep) holding approximately 5000 fish of 1.5 kg were exposed to each light positioned at 10 m depth for one night. Echo sounders registered fish vertical positioning on nights of light treatments and no light (control nights) before and after each light exposure.

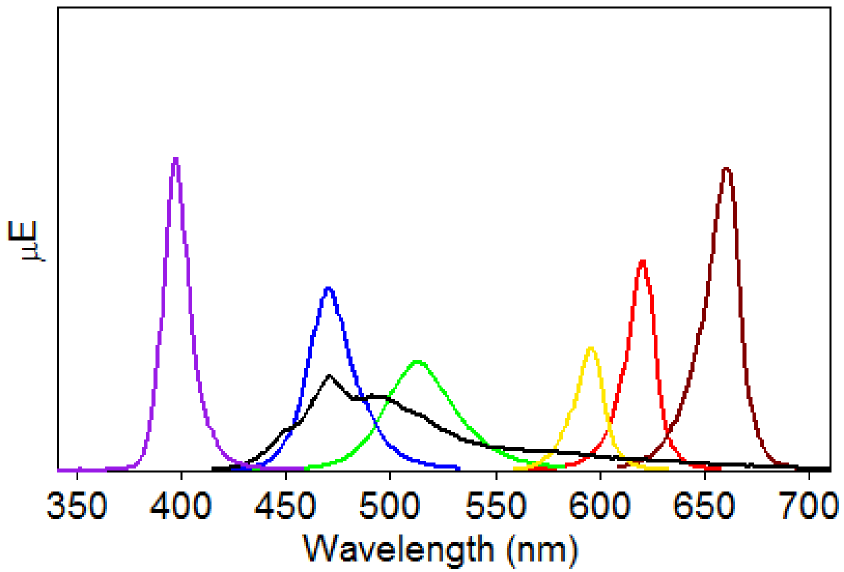


Figure 17 Measured irradiance spectrums for lamp colours: white (black line) (peak at 470 nm, range: 425–700 nm), violet (400 nm, 370–430 nm), blue (470 nm, 440–515 nm), green (495 nm, 475–560 nm), yellow (595 nm, 575–610 nm), red (620, 590–640 nm) and deep red (660, 620–680 nm).

Results and Discussion

Results showed that submerged lights caused fish to maintain their day-time swimming depth near 10 m (light depth) during the night, opposed to the typical migration of salmon to upper cage depths at dusk observed on control nights (Figure 18). For the night when the red light of intensity level >10 µE was deployed (9-10.01) the fish swam deeper than the control and relatively few fish were in the upper 6 meters. For the nights with green (10-11.01) and blue (11-12.01) light most fish swim at the same depth as the lights (9-11 m) and very few fish occupied the upper 6 meters. Generally, quantities of fish staying deep decreased with lowered light intensity, but even 0.1 µE had effects. All light colours, except deep red, significantly affected swimming depth, with a trend of increased effect at lower wavelength colours. Temperature interactions were evident as stratification strengthened light effects when warmer water was near the lamps and weakened effects in the case of warmer water near the surface. The study showed clear effects on swimming depth during the night for light intensities as low as 0.1 µE (measured 1 m from lamp). This intensity is far less than in previous studies on submerged light and salmon behaviour using anti-maturation-lights ranging in intensities from about 40 to 112 µE (recalculated to match measurement 1 m from lamp). Since a 0.1 µE light source is orders of magnitude less than what is commonly used for anti-maturation-lights in the industry and in previous trials, the potential for only affecting fish swimming depth and not the sexual maturation cycle is present.

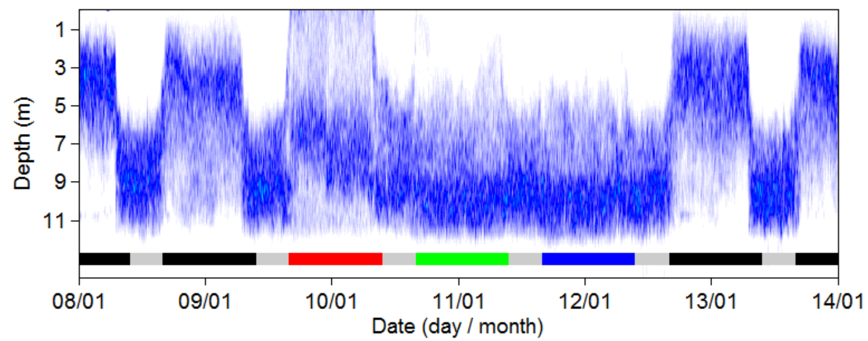


Figure 18 Example of fish vertical distribution data (between 0.25–11 m depth) derived from echo sounders for one replicate cage on nights before, after and during a sequence of three light exposure nights with light source at 10 m testing red, green and blue light of intensity level >10.0 µE. The ticks on the horizontal axis indicate midnight. The horizontal colour bar indicates daytime (grey), control nights of darkness (black) and exposure nights with their respective light colour (red, green and blue). Colour scale of fish density from white (no fish), blue (moderate) to turquoise (high).

Conclusions

From the trial we conclude that low intensity lights (10.0, 1.0 and 0.1 μE) allow salmon to stay deep during the night, and hence avoid more sea lice-infested surface waters. Amount of fish swimming deep decreased with lowered light intensity. All light colours, except deep red, affected swimming depth, and lower wavelength light colours (violet, blue and green) outperformed the high wavelength light colours (yellow, red and deep red). Temperature stratification may weaken or strengthen the light effects. This study opens up the potential of using low intensity lights at decreasing day-lengths that may not affect sexual maturation and remain suitable for guiding salmon away from surface waters rich in lice infective stages.

From 2013 a study in sea cages is carried out to test if low intensity violet lights can be used in the summer and autumn period without having unwanted effects on salmon sexual maturation.

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:	AKVAgroup, 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 spatio-temporal feed concentration within the sea cage is calculated. 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 behaviour of the fish. A pellet distribution model of reasonable accuracy has several interesting application areas, for example:

- As a simulation tool for performing off-line analyses of feeding efficiency with respect factors such as physical feed properties, feeding rate and spreading pattern, and the influence of current and feed behaviour
- As an operational tool running in parallel with the actual feeding process, with applications such as optimal feed camera positioning, real-time 3D visualization of feed distribution within the cage, and model-based control and optimization of feeding

Methods

The proposed pellet distribution model is based on physical and biological theory. The original 2D pellet distribution model has been further developed into a full 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.

In order achieve reasonable accuracy in the model predictions several validation studies have been undertaken. Validation against published data on feeding dynamics (Talbot et al., 1999) has been accomplished with promising results. 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.

Moreover, several experiments on the kinetic properties of feed pellets have been conducted. A batch consisting of 12 different feed types of varying size (3, 6, 9 and 12 mm) and coating density (low, medium high) was produced. The feed types were selected to cover a representative range of feed qualities used in commercial salmon farming in Norway. Experiments were designed to establish important parameters such as the natural horizontal spread/diffusion and sinking speed distribution of the different feed types, and the experiments were accomplished at NOFIMA Sunndalsøra and NTNU during 2013. Results from these experiments were analysed and the feed distribution model was updated accordingly with new and more accurate feed property parameters.

To support the feed kinetics experiments a pellet sensor based on underwater machine vision technology was developed. The pellet sensor consists of a high definition digital camera, positioned horizontally, and pointed against a uniformly backlit opaque surface. The camera and light are mounted in a rigid frame with a funnel mechanism that guides the sinking pellets into the detection area. The camera transmits digital high resolution images at a high frame rate to a PC which runs specially developed image processing algorithms for pellet detection and quantification, as well as pellet motion analysis. The pellet sensor has so far tested in tank experiments, but may be further developed and prepared for use in regular sea cages.

Results

Figure 19 shows examples of comparisons between the measured spreading patterns in two directions for three air speeds and two different feed types, and the modelled spreading patterns.

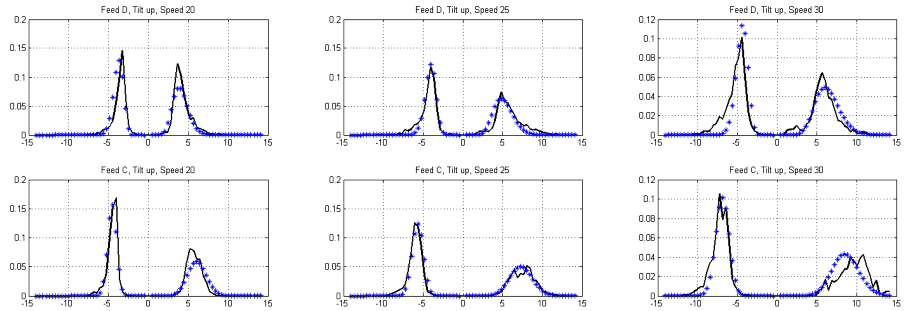


Figure 19 Examples of comparison between modelled and measured feed spreader patterns

Figure 20 shows example output from the modelled 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, Aquacult. Eng.).

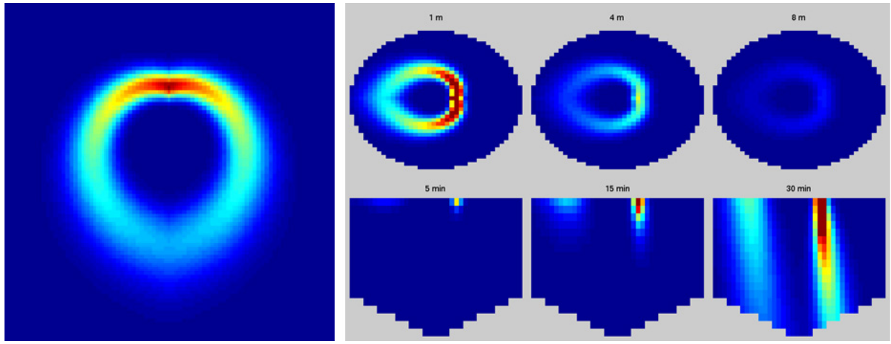


Figure 20 Left panel: example of modelled surface distribution of feed. Right panel: example of 3D distribution of feed, seen from above and from the side. The side plots show the pellet distribution at different times during a short, intensive, feeding bout.

The pellet kinetics experiments brought new insight into the physical behaviour of feed pellets and how it is affected by properties such as size and coating density. Measurements of the natural horizontal spread of the different pellet types are summarized in Table 1. Horizontal spread is caused by complex hydrodynamic effects governed by the more or less irregular shape and surfaces of the pellet and the sinking speed. Results suggest spread of significant magnitude, particularly for the larger sizes which can be as high as 1:2 (1 m horizontal pr. 2 m vertical movement). The data have been assimilated in the pellet distribution model to enhance the horizontal diffusion component of the pellet property description. Similar experiments were done for the vertical spread of the different pellet types using the pellet sensor. Vertical spread is caused by natural variations in pellet sinking speed in a feed batch, and, based on its properties, may have significant impact on how pellet spread should be represented in the physical model. In the current model vertical spread is represented by a diffusion process, but could alternatively be modelled as a discretized distributed parameter. The distributions observed for the sinking speeds are shown in Figure 21. From the experiments it was concluded that the current method of representing vertical spread by diffusion provides sufficient accuracy in the simulation results.

Table 1 Natural horizontal spreading of feed pellets for 12 different feed types. Numbers indicate mean diameter and standard deviation (in cm) of a circle enclosing 95% of all observed pellets after sinking 2.5 m.

Pellet	3 mm	6 mm	9 mm	12 mm
LOW density	75.6 +/- 5.4	92.4 +/- 20.4	103.2 +/- 11.6	138.0 +/- 11.3
MED density	65.4 +/- 9.7	90.9 +/- 18.8	94.6 +/- 8.1	145.2 +/- 9.0
HIGH density	69.4 +/- 25.6	71.7 +/- 8.9	92.8 +/- 4.5	137.6 +/- 11.9

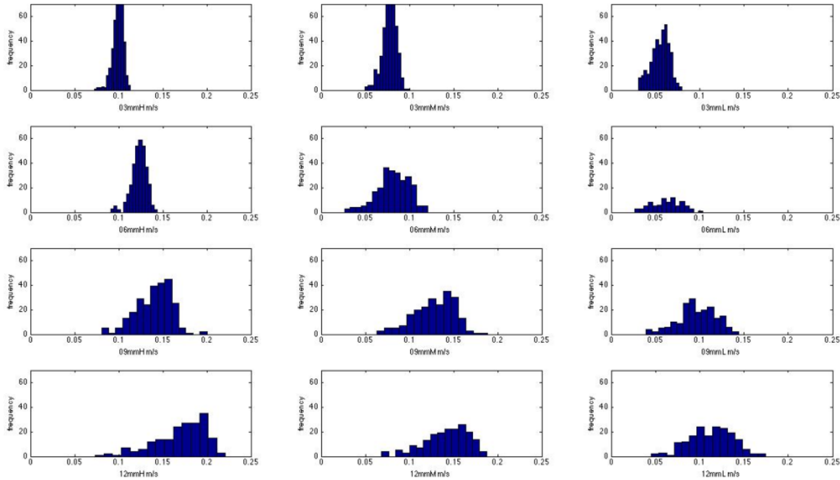


Figure 21 Distribution of sinking speeds (m/s) for the 12 different feed types (size: 3, 6, 9 and 12 mm; density: Low, Medium and High)

A machine vision pellet detection system has been designed, implemented and tested extensively during the pellet experiments. Figure 22 shows the general outline of the instrument. 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 other foreign objects, as well as detecting overlapping pellets. Figure 23 shows an example of the output of the pellet detection algorithm.

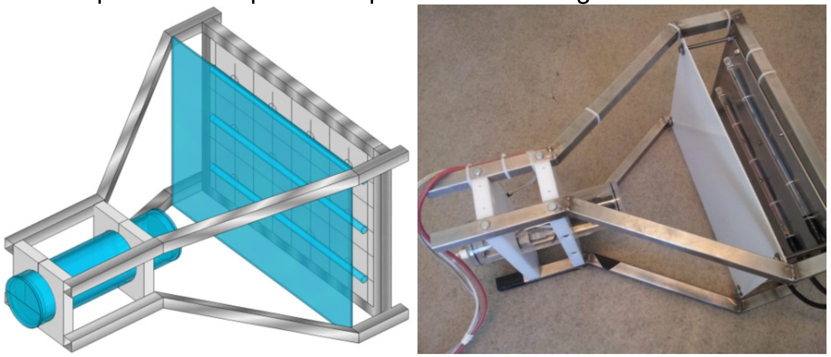


Figure 22 Mechanical outline (left) and realization (right) of the prototype pellet sensor unit. The camera is situated in a waterproof housing, pointed towards an opaque, uniformly backlit surface. This configuration yields high-contrast images of passing pellets, which are transmitted through an Ethernet link to a PC for image processing and analysis.

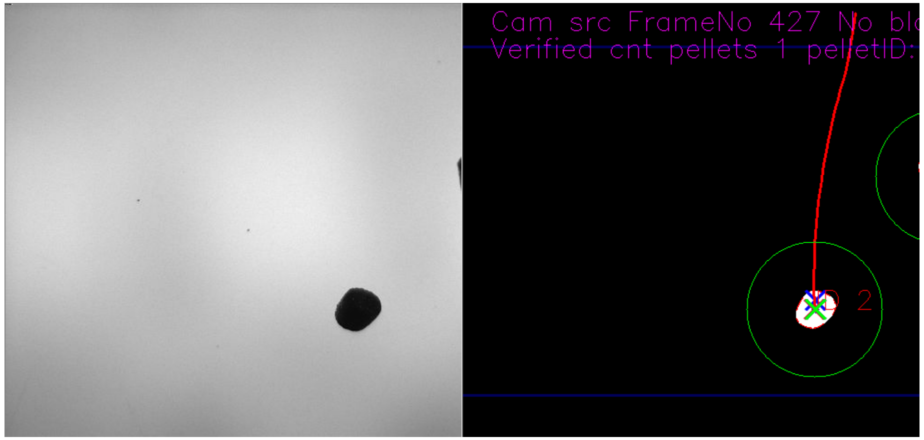


Figure 23 Pellet detection using image analysis. Raw image (left) and analyzed image with pellet motion trace overlay (right).

CREATE publications related to pellet distribution model

Skøien KR, Alver MO, Føre M, Solvang-Garten T, Aas TS, Åsgård TE, Alfredsen JA (2013) Pellet distribution modelling: a tool for improved feed delivery in sea cages. International Aquafeed, Nov-Dec 2013, 24-27.

References

Alver MO, Alfredsen JA, Sigholt T (2004) Dynamic modelling of pellet distribution in Atlantic salmon (*Salmo salar* L.) cages. Aquacult. Eng. 31, 51-72.

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. Aquacult. Eng. 51, 44-52.

Talbot C, Corneillie S,Korsøen Ø (1999) Pattern of feed intake in four species of fish under commercial farming conditions: implications for feeding management. Aquacult. Res. 30, 509-518.

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, Daniel William Wright (University of Melbourne), Alexios Glaropoulos (University of Crete), 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 and negative environmental impact of releasing treatment chemical after topical de-lousing or 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. Combining the past and present results provided a fruitful future method to efficiently treat salmon for lice with minimum impacts on fish and environment. However, it is still needed to find a more efficient oil-soluable drug in order to complete the last experiments for the technique to be up running.

Alternatively to treating the fish for the parasite, prophylactic management reducing infestations is beneficial. The infestative stage of the salmon lice is a free-swimming larvae 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 within CREATE developed a net roof solution to hold the fish away from surface layers but still provide surface access to refill the swim bladder through a tube-like chimney structure called snorkel (Figure 23). This new sea cage technology, the 'snorkel cage', is an environmentally friendly way to reduce sea lice.

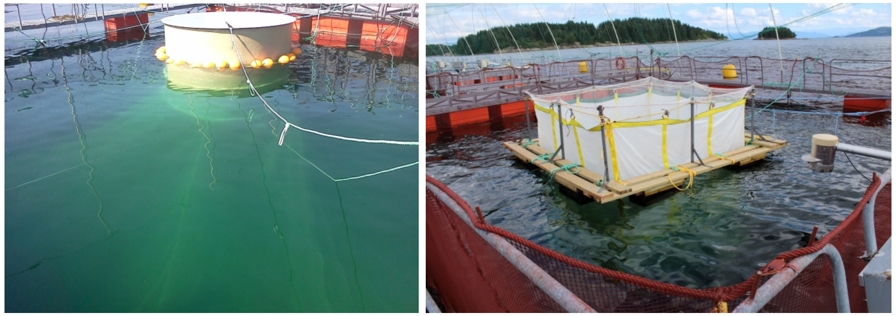


Figure 24 Photos of set-up for three large-scale experiments with two different prototypes of snorkels extending 3-4 m underwater, with a roof net extending from the snorkel's base to the sea-cage wall. Salmon swim up through the snorkel to the surface and refill their swim bladders without coming in contact with surface waters where most sea lice larvae are found

Methods

Three experiments were completed with support from the CREATE project and later the industry fund (FHF). Mathematical models were used to calculate forces in different designs and testing of down-scaled models in flume tank facilities in Hirtshals. Full-scale trials at the research sea farms of the Institute of Marine Research, Austevoll and Matre, Norway were performed during summer 2012, winter 2013 and autumn 2013 using small, medium sized and large salmon at variable stocking densities (Figure 24). Overall setup included triplicate cages with surface access (control), and triplicate cages equipped with a net roof at 3 or 4 m depth inserted with a snorkel-like chimney. Every third week a random sample of 20 fish per cage were anaesthetized and number of lice and stage registered. Behaviour, growth and production performance were monitored closely.

Results

The mismatch of swimming depth of the fish and the copepodids resulted in reduced lice infestations by up to 84% (Figure 24). Lice infestation was reduced repetitively over time and variable environmental conditions. Behaviour of the fish was observed to be normal. Salmon were still able to access surface waters and exhibit their full behavioural repertoire through the central chamber that was impermeable to parasites. Production efficiency was not affected when commercial stocking densities were used.

In the fjord experiment the brackish layer were expected to hold the parasites in greatest densities below the level of the lice barrier. Accordingly, we showed that louse infections in the fjord were not reduced with the same snorkels as used under the coastal homogenous full saline water at all depths. Some of the variable reduction effects at the coastal site can be attributed to periods of inflowing brackish water combined with periods of deep swimming of the salmon in the control cages.

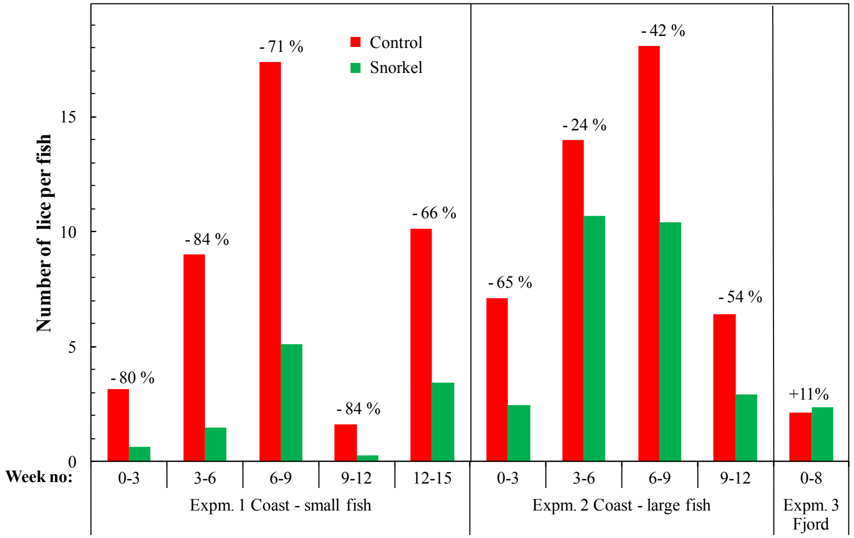


Figure 25 Average number of sea lice per fish in standard sea-cages (Control) or sea-cages with a roof at 3-4 m depth and an opening to the surface (Snorkel). Percentage reduction is noted above columns for every three week infestation period. Experiments 1 and 2 were done in a typical coastal environment (Austevoll) from May to August with 90-600 g fish (Exp 1) and from September to December with 2.3-4.6 kg fish (Exp 2). Experiment 3 was done in a typical fjord environment (Masfjorden) with a brackish water layer from the surface to 3-4 metres depth from February to April with 1.4-2.2 kg fish. Average numbers of lice are based on three replicate cages per treatment, with counting of new lice infectious stages every third week in Exp 1and 2 and at the end of Exp 3.

Discussion

The method has the potential to advance the salmon farming industry towards increased sustainability. This is one of the first, but not last, ecology-based prophylactics technological practices to mitigate parasitic problems within aquaculture. Fine-tuning and developing this preventive technique towards larger industrial use is carried out during the final stage of this CREATE project. During the 2014 summer 10 commercial scale snorkels will be put to sea in 160 m circumference cages holding > 185 000 fish each.

CREATE publications related to reduced lice levels and behaviour

Frenzl B, Stien LH, Cockerill D, Oppedal F, Richards RH, Shinn AP, Bron JE, Migaud H (2014). Manipulation of farmed Atlantic salmon swimming behaviour through the adjustment of lighting and feeding regimes as a tool for salmon lice control. Aquaculture 424-425, 183-188

Stien LH, Nilsson J, Oppedal F, Kristiansen TS, Lien AM, Folkedal O (2012). Skirt around a salmon sea cage to reduce infestation of salmon lice resulted in low oxygen levels. Aquacultural Engineering 51, 21-25.

Bui S, Oppedal F, Korsøen ØJ, 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

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 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.

Since then CREATE has developed an extensive continued international collaboration with the University of Melbourne, Australia. SALTT researchers Dr. Tim Dempster, Dr. Isla Fitridge, Samantha Bui and Daniel William Wright 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 through here PhD work.

Collaboration with North American institutes (UNH/USNA) The University of New Hampshire has been an active international collaborator within CREATE since its inception, but have decreased over the last couple of years due to reduced activities at UNH related to CREATE research topics. 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. 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 several model scale experiments of fish farm cages in current and waves at the USNA towing tank facilities.

Collaboration with Chinese universities, Shanghai Jiao Tong University and Zhejiang 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 visit CREATE again for a period of three months in 2013. Further visits are planned for 2014. 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 from 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.

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 2013 nine PhD students have been or are funded directly through CREATE, at present five of these PhD students have defended their thesis with success. By 2013 seven PhD students with external financing has been or are working on projects in the centre. Three PhD students with external financing have successfully defended their PhD thesis. Five of the total 16 PhD students are Norwegian.

In 2013 three Postdoctoral researches were financed by the centre. Three Postdoctoral researchers have previously been financed by the centre.

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 Oppedal	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
Professor 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
Dr. Lars Gansel	German	2013 - 2014	Flow around and through fish farms

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
Daniel William Wright	Australian	2013 -	Fish behaviour and artificial light	University of Melbourne
Alexios Glaropoulos	Greece	2013 -	Fish behaviour and artificial light	University of Creete

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*
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)*
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*
Stien, L. H., Nilsson, J., Oppedal, F., Kristiansen, T.S., Lien, A.M., Folkedal, O.	2012	Skirt around a salmon sea cage to reduce infestation of salmon lice resulted in low oxygen levels.	*Aquacultural Engineering 51, 21-25.*
Klebert P, Gansel L, Lader P , Oppedal F,	2013	Flow hydrodynamics through nets and floating cages: a review.	*Ocean Engineering 58, 260-274.*
Shainee, M., Ellingsen, H., Leira, B.J., Fredheim, A.	2013	Design theory in offshore fish cage design	*Aquaculture 392–395 (2013) 134–141*

Shainee, M., DeCew, J., Leira, B. J., Ellingsen, H. Fredheim, A.	2013	Numerical Simulation of a Self-Submersible SPM Cage System in Regular Waves with Following Currents	*Aquaculture Engineering. Volume 54, May 2013, Pages 29–37*
Shainee, M., Leira, B.J., Ellingsen, H., Fredheim, A.	2014	Investigation of a self-submersible SPM cage system in random waves	*Aquacultural Engineering, pp. 35-44 DOI information: 10.1016/j.aquaeng.2013.10.003*

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*
Bloecher, N., Olsen, Y., Guenther, J.	2013	Variability of biofouling communities on fish cage nets: A 1-year field study at a Norwegian salmon farm	*Aquaculture 416–417:302-309*

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.	*PLoS One, ONE 8(5): e63696. doi:10.1371/journal.pone.0063696*
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, ONE 8(5): e63696. doi:10.1371/journal.pone.0063696*
Remen M, Oppedal F, Imsland A, Olsen RE, Torgersen T	2013	Hypoxia tolerance thresholds for post-smolt Atlantic salmon: Dependency of temperature and hypoxia acclimation	*Aquaculture 416: 41-47*
Frenzl B, Stien LH, Cockerill D, Oppedal F, Richards RH, Shinn AP, Bron JE, Migaud H	2014	Manipulation of farmed Atlantic salmon swimming behaviour through the adjustment of lighting and feeding regimes as a tool for salmon lice control.	*Aquaculture 424-425, 183-188*

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.	2010	Controlled artificial upwelling in a fjord to stimulate non-toxic	*Aquaculture Engineering 42 (2010) 140-147*

Fredheim, E. Lien, K.I. Reitan		algae	
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., Karlsen, Ø., Kristiansen, T.S., Dempster, T.	2013	Towards cod without spawning: artificial continuous light in submerged sea-cages maintains growth and delays sexual maturation for farmed Atlantic cod (Gadus morhua).	*Aquaculture Environment Interactions*

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,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	*Aquacultural Engineering. 51, 44-52.*
Oehme, M., Aas., T.S., Olsen, H.J., Sørensen, M., Hillestad, M., Li, Y., Åsgård, T.	2013	Effects of dietary moisture content of extruded diets on physical feed quality and nutritional response in Atlantic salmon (Salmo salar)	*Aquacult. Nutr. doi: 10.1111/anu. 12099*

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.*
Harendza, A., Visscher, J.,Gansel, L., Pettersen, B.,	2008	PIV on inclined cylinder shaped fish cages in a current and the resulting flow field.	*Proceedings of 27th International Conference on Offshore Mechanics and Arctic Engineering, OMAE2008. 15-20 June 2008, Estoril, Portugal.*
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, L.C., McClimans, T.A., Myrhaug, D.	2008	Drag forces on and flow around and through porous cylinders	*In: Coastal Technology - Coast 2008. Trondheim: NTNU 2008 ISBN 978-82-92506-62-2. s.130-138*
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*
Shainee, M., Ellingsen, H., Leira, B.J., Fredheim, A.	2012	An Optimum Design Concept For Offshore Cage Culture	*Proceedings of the ASME 2012 31st International Conference on Ocean,*

			Offshore and Arctic Engineering. OMAE2012-83601
Endresen, PC, Føre, M, Fredheim, A, Kristiansen, D, Enerhaug, B	2013	Numerical Modeling of Wake Effect on Aquaculture Nets	*32nd International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2013), OMAE2013-11446*
Shainee, M., DeCew, J., Leira, B. J., Ellingsen, H. Fredheim, A.	2013	"Self-Submersible Spm Cage Simulation In Regular Waves With Oblique Currents.	*32nd International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2013), OMAE2013-11446*

10.3. Books

Gansel LC, McClimans TA, Myrhaug D	2008	Drag forces on and flow around and through porous cylinders.	*In: Coastal Technology - Coast 2008. Trondheim: NTNU 2008 ISBN 978-82-92506-62-2. s.130-138*
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 Øyvind	2011	Biological criteria for submergence of physostome (Atlantic salmon) and physoclist (Atlantic cod) fish in sea-cages	*Doctoral theses, Universitetet i Bergen, ISBN 98-82-308-1716-2*
Føre Martin	2011	Individual based modelling and observation of Atlantic salmon (Salmo salar L.) behaviour in sea-cages	*Doctoral theses, NTNU, 2011:322 ISBN 978-82-471-3224-1*
Remen Mette	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 theses, Norwegian University of Life Science, 2013:07 ISBN 978-82-575-1110-4*
Shainee Mohamed	2013	Conceptual Design, Numerical and Experimental Investigation of a SPM Cage Concept for Offshore Mariculture	*Doctoral thesis, NTNU, 2013:260 ISBN 978-82-471-4647-7*
Gansel Lars	2013	Flow past porous cylinders and effects of biofouling and fish behaviour on the flow in and around Atlantic salmon net cages	*Doctoral thesis, NTNU, 2013:312 ISBN 978-82-471-4759-7*
Blücher Nina	2013	Biofouling in the Norwegian salmon farming industry	*Doctoral theses, NTNU, 2013:320 ISBN 978-82-471-4778-8*