Annual Report 2011

CREATE

Centre for research-based innovation in aquaculture technology

Contents

1. Summary

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

The centre have finished five year of work, and is presently running ten projects, ranging from fundamental research to acquire basic knowledge on biology for technology development to development of new technological solutions. The centre is presently engaged in eight PhD and two Post doc fellowships. In 2011 the two first CREATE PhD students, Øyvind Johan Korsøen og Martin Føre defended their thesis successfully.

CREATE researchers have so far published 43 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.

BioMar, one of the leading suppliers of high performance fish feed to the aquaculture industry become a partner in CREATE during 2011. Their expertise in feed production and feed compositions is greatly valuable to CREATE and strengthen the focus on multi disciplinary approach to research and solutions.

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.

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

- 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.

- Development of an individual-based numerical model of salmon behaviour of in a net cage, enabling simulations at both the individual and group level. The model at present simulates the effect of water temperature, light, feed and other individuals. The model demonstrates that schooling of salmon in net cages may be an emergent effect of simple behaviour rules of not colliding with close individuals and aligning with individuals that are further away.
- The Simulation and optimization framework (SimFrame) project. A system approach to build a framework for easy integration of

knowledge, biological and technical models and monitoring equipment. The aim is to simulate, monitor and optimize all aspects of modern fish farming to develop better control and decision support systems. Tools from the fields of knowledge based system/artificial intelligence is used for identifying deviations, analyze probable causes for deviations, and suggest corrective measures.

- 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.

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

2. Vision/objectives

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

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

Secondary objectives

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

3. Research plan/strategy

CREATE focuses research and development within three main research pillars:

Equipment and constructions The physical equipment used to farm fish.
Operation and handling The process of executing and carrying out operations necessary to farm fish.
Farming intelligence Control of the total process of farming by understanding the integrated use of equipment and the process of operations and combining this with knowledge of biological issues and the physical environment.

Within these three research pillars CREATE presently runs ten main projects, has eight PhD students and three post-doctoral researchers working within the centre. Figure 1 below show the projects (orange), PhD (blue) and post-doctoral topics (light blue), and their relation to the three main research pillars of CREATE in 2012.

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

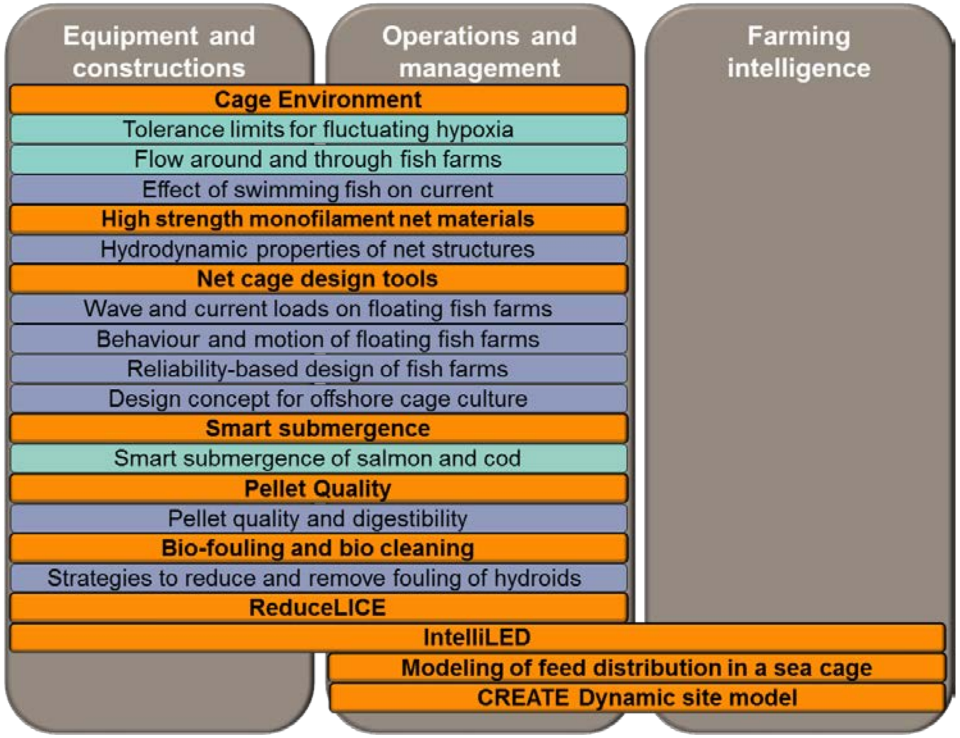


Figure 1 The projects (orange), PhD (blue) and post-doctoral topics (light blue), and their relation to the three main research pillars of CREATE

partners, as well as roles and responsibilities of the different parts of the organisation. CREATE is physically located at SINTEF Sealab,

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

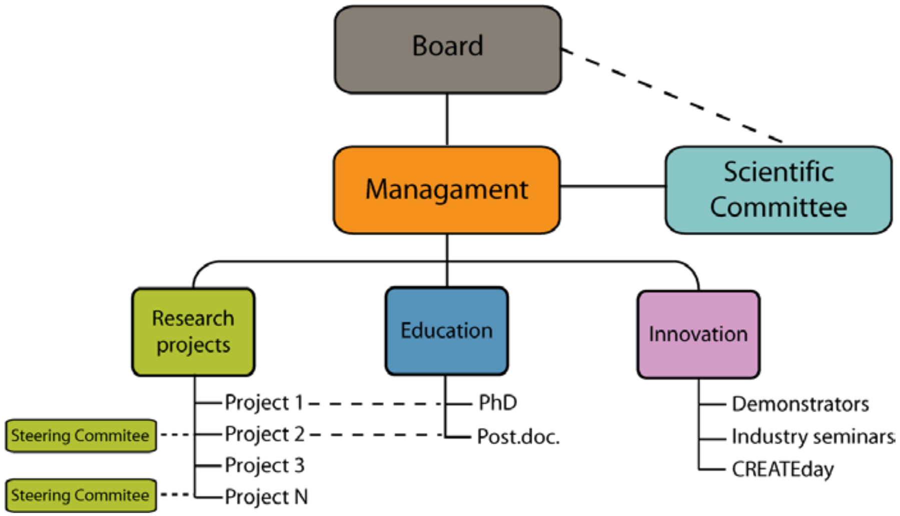


Figure 2 The organisation of CREATE, including projects and education

The Board of directors are has a majority of members from the industry partners and consists of in total six members, one member representing the Host Institution, one representing the research partners and four members representing the industry partners. The Board takes the decisions on organisation, budget, activities and working plan for CREATE. The development and content of the yearly working plans is carried out by the Scientific Committee. In 2011 the following people were members of the board:

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

The Scientific Committee (SC) has members from all partners, research and users. The mandate of the Scientific Committee is to ensure development of new project ideas, new projects, and overall quality and scientific control of the research carried out in the centre. The Scientific Committee makes recommendations for the research plan and projects to the Board of directors. In 2011, the following people were members of the SC:

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

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

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

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

4.2. Research facilities of the centre

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

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

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

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

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

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

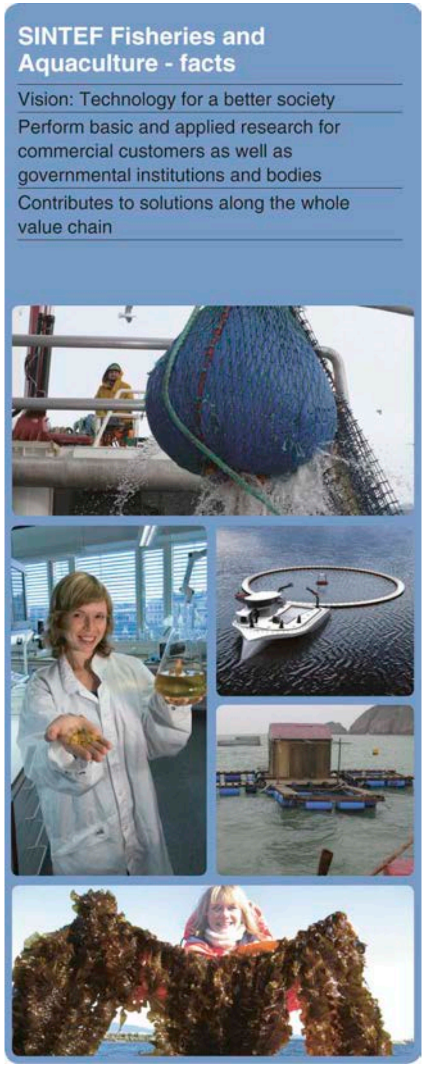
Marine Technology Centre. This is a unique laboratory infrastructure, comprising the world's largest ocean basin, towing tank, wave flumes and other marine technology related laboratories for hydrodynamics and structural mechanics studies.

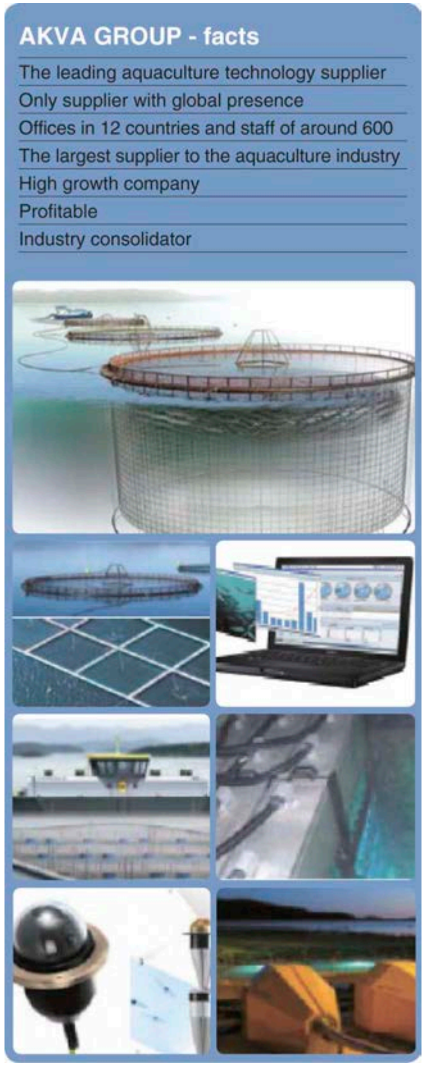
AKVA group and Marine harvest is part owner together with Skretting in the Cage Aquaculture Centre, a research facility for feeding technology and feed.

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.



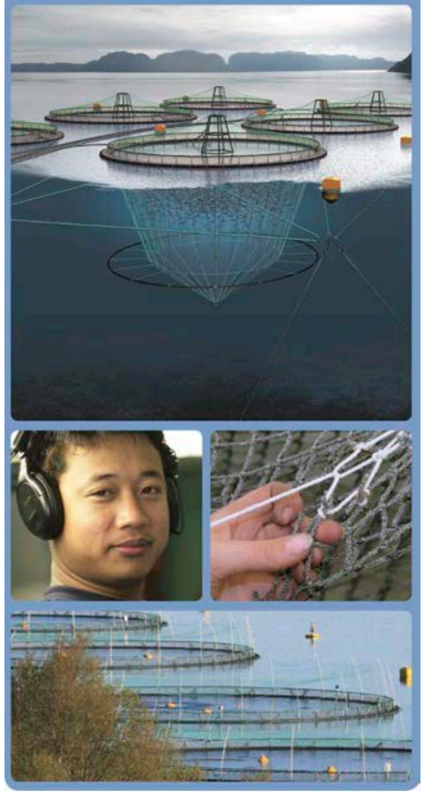


BioMar AS - facts

- 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.

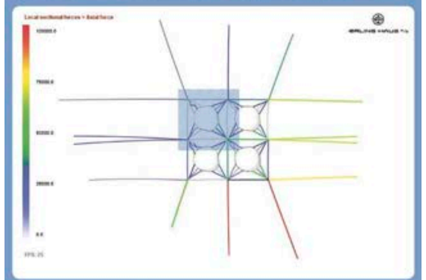
Erling Haug AS is part of the Axel Johnson Group. Customers range from private consumers to international companies, and products range from groceries to high-tech products. Foresight, entrepreneurship and creativity have been the watchwords of their past and will be the lights of the future. The group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

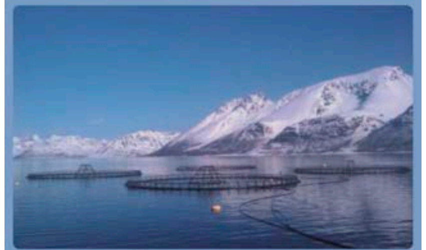
ERLING HAUG - facts

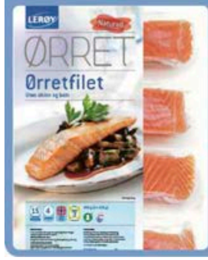
- Quality mooring components
- Dynamic analysis of mooring systems
- Flexible engineered mooring solutions
- Provides lifting- and HSE products, lice-skirts and LED marking buoys



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 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 AS 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.

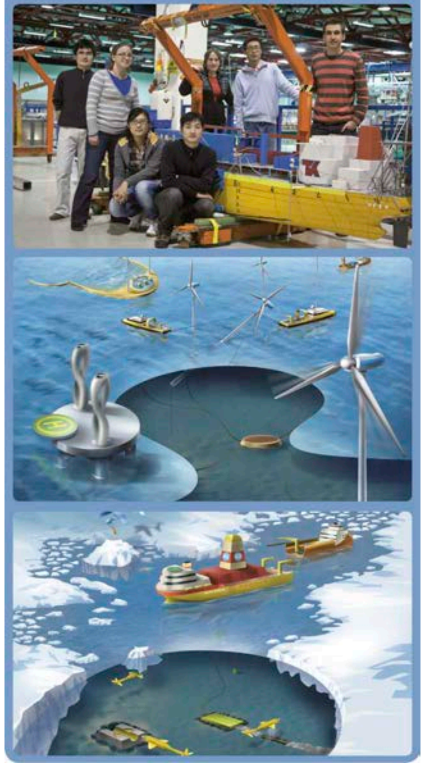
Centre for Ships and ocean Structures, CeSOS, at the Norwegian University of Science and Technology, integrate theoretical and experimental research in marine hydrodynamics, structural mechanics and automatic control. Research at CeSOS aims to develop fundamental knowledge about how ships and other structures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

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.

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

computer 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).

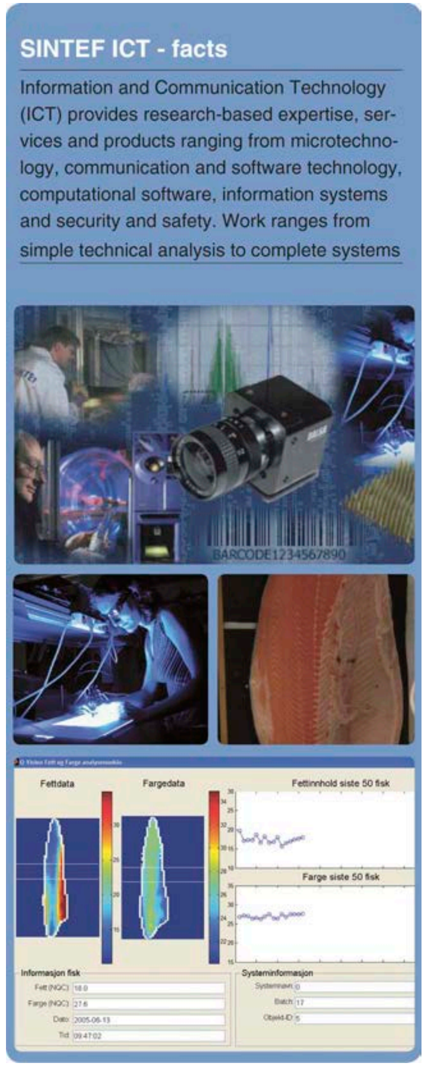
The Institute of Marine Research (IMR) is with a staff of almost 700, Norway's largest centre of marine science. The main task is to provide advice to Norwegian authorities on aquaculture and the ecosystems of the Barents Sea, the Norwegian Sea, the North Sea and the Norwegian coastal zone. For this 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 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.

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 thus this is the main source of cooperation between partners are going on. All the research projects are set up with several 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 are all the projects set up with a Steering Committee, in which all the industry partners invoveld in the project is members. This has shown to be a good link 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.

Further the centre arranges the yearly 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.

Especially in the last three year of the centre period, CREATE focus 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: Jana Guenther, Lars Gansel, Nina Bloecher, Ekrem Misimi, Per Rundtop (SINTEF Fisheries and Aquaculture)

Industry partners: AKVA group, Egersund Net, SalMar

Background

Fish farmers use a multifaceted approach to control biofouling on nets, including the use of antifouling coatings on nets, underwater or shore-based net cleaning, net drying or changing, and the use of biological controls (reviewed in de Nys and Guenther, 2009). The most common approach of Norwegian salmon farmers is the use of copper-based coatings on nets, followed by the cleaning of nets *in situ* after biofouling has started to develop (Olafsen, 2006). The effect of copper-based coatings might depend on the copper concentration as well as on the binding agents used in the coatings. New coatings might allow for lower copper concentrations or have an increased anti-fouling effect over time. On site underwater net cleaning is usually carried out with net cleaners consisting of rotating discs with small nozzles from which seawater is ejected at high pressure (approx. 300 bar). High pressure washing puts a strain on nets and coatings and it is desirable to reduce the water pressure from the washing discs to a minimum without reducing the immediate washing effect. In any case, the disturbance caused by underwater cleaning of cage nets has several effects on the development of biofouling. For example, the underwater cleaning may cause an increase in the release of propagules into the water column, which has been demonstrated for larvae of the hydroid *Ectopleura larynx* (Carl et al., 2011). These larvae could then rapidly settle and grow on the newly washed nets, given that hydroids are also one of the first macrofouling species to colonise a new substrate (Dean and Hurd, 1980; Madin et al., 2009). Furthermore, cleaning may not result in the mortality of fouling organisms, and fragments of colonial fouling organisms, such as the hydroid *E. larynx*, may regrow rapidly (CRAB 2004-2007; Guenther et al., 2010). New washing methods, killing remaining fouling organisms after high pressure washing, might give an additional washing effect by reducing the re-growth from fragments of colonial organisms and by downgrading the quality of nets as a substrate for larvae to settle on directly after the washing process. Understanding the biology of fouling organisms might allow for better strategies against their settlement and growth.

Methods

Effect of coatings: Coated nylon net panels with various copper concentrations from 0% to 30% Cu_2O and two different binding agents (A and B) were attached to steel frames and deployed at 5 m depth on the outside of a cage at two fish farms (Rabben, Austevoll and Rosendal, Hardanger fjord). The wet weight and photographs of the net panels were taken after 5, 9, 15 and 20 weeks for the fish farm near Rabben, and after 5, 9 and 15 weeks for the fish farm near Rosendal.

Effect of water pressure and volume: Both nylon and EcoNet net panels were attached to PVC frames and immersed at a commercial Atlantic salmon (Salmo salar) farm in June 2011. After 9 weeks of immersion, these net panels were cleaned with a 1-disc cleaner with the following water pressure and volume combinations: (1) 200 bar and 30 l min^{-1}, and (2) 290 bar and 20 L min^{-1}. The wet weight and photographs of the net panels were taken before and after washing.

Effects of heated water and acetic acid: Both nylon and EcoNet net panels were attached to PVC frames and immersed at a commercial Atlantic salmon (Salmo salar) farm in August 2011.

After 9 weeks of immersion, most of these net panels were cleaned with a 1-disc cleaner, while the remaining net panels served as a control. One third of the cleaned net panels were then treated with hot water and one third was treated with acetic acid. Before and after cleaning, the wet weight and photographs of the net panels were taken. After cleaning at AKVAgroup's facility, the net panels were re-immersed at the fish farm. After 2 weeks, the total weights and photographs of net panels were taken again.

Feeding of hydroids: To investigate the main nutrient sources of the hydroid E. larynx in a fish farm environment, the carbon and nitrogen stable isotope signature of 5 potential food sources was compared to hydroid samples from a fish farm cage and a reference location. As potential food sources plankton and particulate organic matter up- and downstream of the farm, caprellid amphipods, and fish feed and faeces were analysed.

Temporal variability of fouling on nets: A 1-year field study at a commercial salmon farm in Mid Norway was conducted to determine the effects of immersion time (1, 3, 6 and 12 months), mesh size (13 and 25 mm half mesh) and cage (3 different cages) on the fouling biomass, net aperture occlusion and community composition on net panels.

Data analysis and statistics: The wet weight of clean nets was subtracted from the wet weight of fouled nets in order to gain the weight of only the biofouling. The results are given as kg/m^2.The photographs were used for further image analysis and the calculation of the increase of net solidity due to fouling organisms and PNO (percentage net aperture occlusion, see Guenther et al., 2010 for further explanation).

All statistical analyses were performed with PASW Statistics, version 18. The results of the wet weights and net aperture occlusions of net panels over time were analysed with repeated measures analysis of variance, followed by Tukey's HSD multiple comparison test ($\alpha = 0.05$). If Mauchly's Test of Sphericity was significant, the results were evaluated based on the Greenhouse-Geisser correction (Quinn and Keough 2002; Field 2009). All data are presented as mean ± SE.

Results

Effect of coatings: The statistical analysis shows an effect of the Cu_2O concentrations, but no effect of the binding agent at the site near Rosendal, Hardanger on the growth of biofouling. For the site in Austevoll, the results do not allow for the analysis of an effect of single factors. However, all results suggest that coatings containing 0% Cu_2O where much less effective against biofouling than the other coatings (see example in Figure 3). This is especially evident at the Austevoll site. Nets with coatings containing 30%, 20% and 15% Cu_2O experience little growth of biofouling within the first few weeks.

However, after longer immersion times, the growth of biofouling seems to increase. The biggest differences between the two sites where in the increase of biofouling from week 9 to week 15 after immersion: there was a large increase on all nets at the Hardanger site, while the increase was much less on nets with coatings containing ≥ 15% Cu_2O. The weight increase of the biofouling between week 9 and week 15 at the Hardanger site was mainly due to mussels. Mussels are relatively large organisms and thus might be less affected by the Cu_2O in the coatings. The results suggest a good anti-fouling effect of coatings 1, 2 and 3 (containing 15% Cu_2O or more) for both binding agents tested. However, the effect will be different on different fouling organisms and mussels seem to grow rapidly on all coatings tested, at least after the mussels reach a certain size. The use of coatings 4 and 5 are not recommended as anti-fouling coatings.

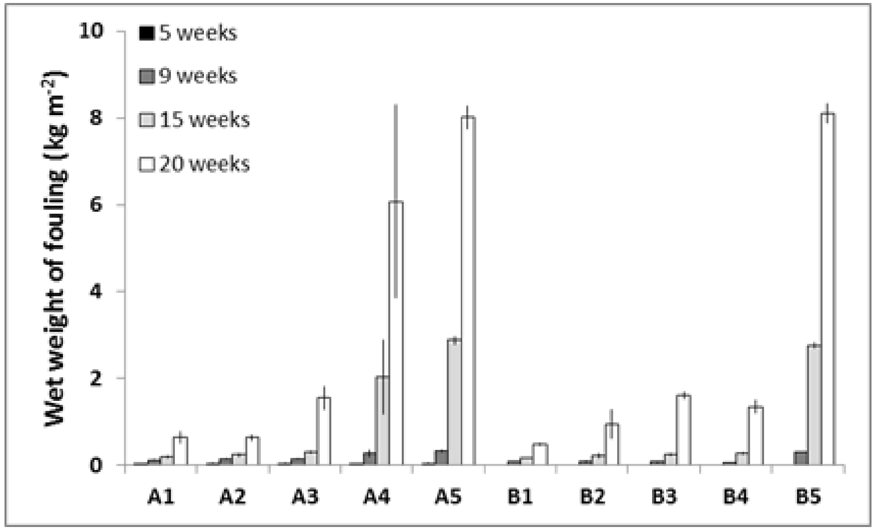


Figure 3 Example for results from the coating study: Wet weight of fouling (kg m-2) on nets coated with various Cu2O concentrations (1: 30%, 2: 20%, 3: 15%, 4: 10% and 5: 0% Cu2O) and two different binding agents (A and B) at the fish farm near Rabben. Data are mean ± SE.

Effect of water pressure and volume and ***Effects of heated water and acetic acid:*** After 9 weeks of immersion from June 2011 on at a commercial Atlantic salmon (Salmo salar) farm near Gjelsøya , Hitra, approximately 2.5 times more biofouling was found on nylon nets than on EcoNet.After the same immersion time, but from August 2011 on, there were no significant differences in the amount of fouling on these net types. There was no clear difference of the cleaning performance using 200 bar and 30 l min^{-1} and 290 bar and 20 L min^{-1}and both pressure/volume combinations performed well with over 75% of the fouling on the nets being removed.

The effect of the use of acetic acid and hot water after underwater high pressure washing of nylon nets and EcoNet was inconclusive. It seems likely that the tests were conducted too late in the fouling season, resulting in little growth within 5 weeks after the washing procedure on all nets, including control nets (that were not washed).Therefore, it is recommended to repeat the experiments. However, the tests gave some insights that will help to improve the experimental design for future experiments and the design of hot water and acetic acid applicators.

Figure 4 Example of the fouling distribution on coated nets with different Cu2O concentrations.

Feeding of hydroids and ***Temporal variability of fouling on nets:*** The sampling for the last two studies is completed and the data is currently being processed. Preliminary results from the temporal variability study show that younger communities (1- and 3-month panels) are influenced by an interaction between sampling time and location while older panels (6 months) are only affected by sampling time. The 12-month panels showed a uniform species composition and biomass accumulation. The highest amounts of biofouling were found in late summer.

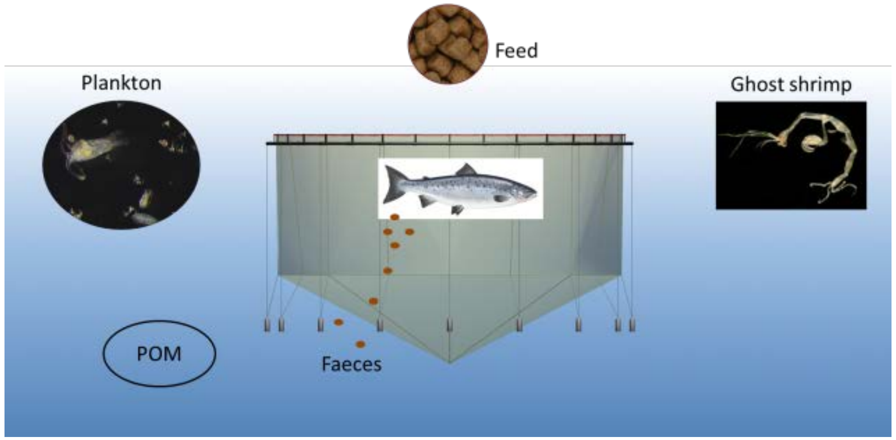


Figure 5 Possible hydroid food sources close to fish cages.

5.2. Cage Environment

Researchers: Frode Oppedal, Mette Remen, Rolf Erik Olsen, Thomas Torgersen, Jannicke Vigen, Jason Bailey and Jan Aure (Institute of Marine Research)
Pascal Klebert and Pål Lader (SINTEF Fisheries and Aquaculture)
Lars Gansel, Siri Rackebrandt (Norwegian Institute of Science and Technology, NTNU)
Turid Synnøve Aas (Nofima)

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

Background

Sufficient supply of oxygen is critical for optimal growth and welfare of salmon in intensive aquaculture, as oxygen is the main limiting factor of fish metabolism. Recent studies of the environment in sea cages have shown that oxygen levels may fluctuate, and that oxygen may drop to alarmingly low levels (30-70% O_2). In order to develop husbandry systems and legislation that maximises fish welfare and production efficiency, it was necessary to understand how the fluctuating oxygen levels arose based on the flow conditions in and around stocked fish farms and how the low oxygen levels may affected growth and physiology of the fish. Correspondingly, the main objectives were to develop improved standards for oxygen management in net cages to secure fish welfare and efficient production.

Methods

Field measurements of hypoxia and water flow were studied in small and large commercial cages. Experimental trials of hypoxia and fish physiology/ production performance were performed in Tank Environmental Lab of IMR at Matre. Studies of water flow dynamics through and around cages were studied in flow through tanks and in cages. The effects of fish behaviour influence of water flow were studied in cages. Models for water flow were developed and are taken further through other projects. Protocols for oxygen management are being developed based on final scientific publication and upcoming PhD dissertation.

Results

Water flow trials:

Flow around and through fish cages is three dimensional and very complicated, and it depends on many variable factors that are hard to predict (even when considered in isolation). Nets and fouling deflect the current, leading to reduced water exchange inside net cages. Laboratory experiments show that the flow inside fish cages might change dramatically at solidities between 0.4 and 0.7, with recirculation areas occurring inside cages. Fish can lead to additional water blockage, but circular fish motion (that is fish swimming in circles along the cage wall) can have a pumping effect. Increasing net solidity decrease the water flow through the cage and interrupt continuity of stream lines. A portion of the flow bypasses the cage and may create an eddy current behind the cage (Figure 6). Fish schooling behaviour reduces the water flow within cages, change flow direction and generally generate hypoxic levels compared to reference measurements outside. However, in particular during slack conditions, fish movements create a flow pattern with horizontal outward flow from the centre of the cage (Figure 6) with water entering the cage from the top or bottom. As such, the fish themselves may aid in the water exchange rate.

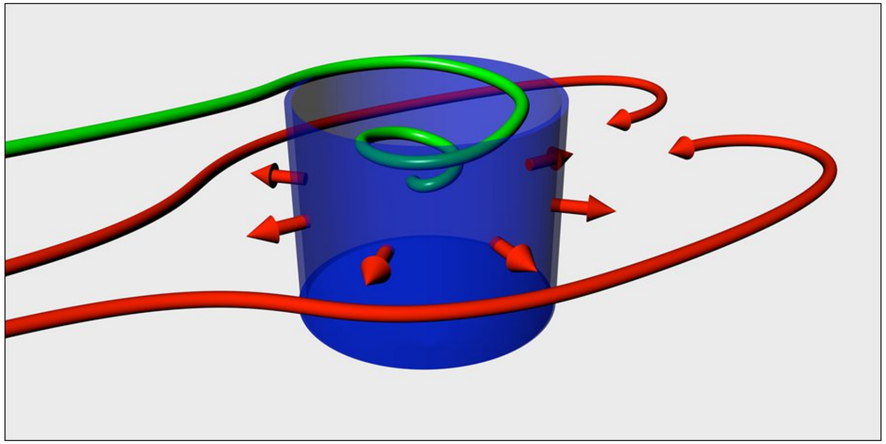


Figure 6 Schematic overview of water flow around a stocked salmon cage. Net and fish partly block the water flow and water masses are forced to bypass the cage to a variable degree creating eddy currents behind. Fish swimming in circles need to accelerate towards the centre of their circular path. This acceleration leads to an outwards directed force and as a result water is pushed outwards and a low pressure area is created in the centre of the fish motion, causing water to enter from the top or the bottom.

Hypoxia trials.

During a range of trials, effects of fluctuating hypoxia were found on production performance and physiology of Atlantic salmon post-smolts. In essence, negative effects were dependent on level of environmental hypoxia and temperature (see Figure 7).

Trial 1: Fluctuating hypoxia reduced feeding level according to hypoxia severity and oxygen dept induced stress during exposure to oxygen levels below 60% O_2. Stress was down-regulated after <7 days and followed by increased feeding in normoxia. Acclimation did not alleviate appetite depression in hypoxic periods within the 21 days trial.

Trial 2: Cyclic hypoxia did not alter the oxygen uptake rates of fish. When feeding was performed in normoxic periods only, fish subjected to 50 and 60% O_2 reduced feeding rates compared to the controls, with corresponding reductions in growth rates. Feed utilization was not reduced. Compensatory growth was observed in fish from the 50 % O_2 group, but full compensation was not achieved. The main conclusions were that feeding in normoxia does not fully alleviate negative effects of cyclic hypoxia on feeding and growth when oxygen is reduced to 60% or below in hypoxic periods, that feed utilization is maintained, and that compensatory growth may lessen negative effects.

Trial 3: Hypoxia thresholds were investigated in full-feeding Atlantic salmon postsmolts at three distinct temperatures (6, 12 and 18°C). A clear relationship was found between temperature and the critical level for the fish to maintain their oxygen uptake. Both the oxygen uptake rate (MO_2) and the limiting oxygen concentration (LOC) was found to increase exponentially with temperature.

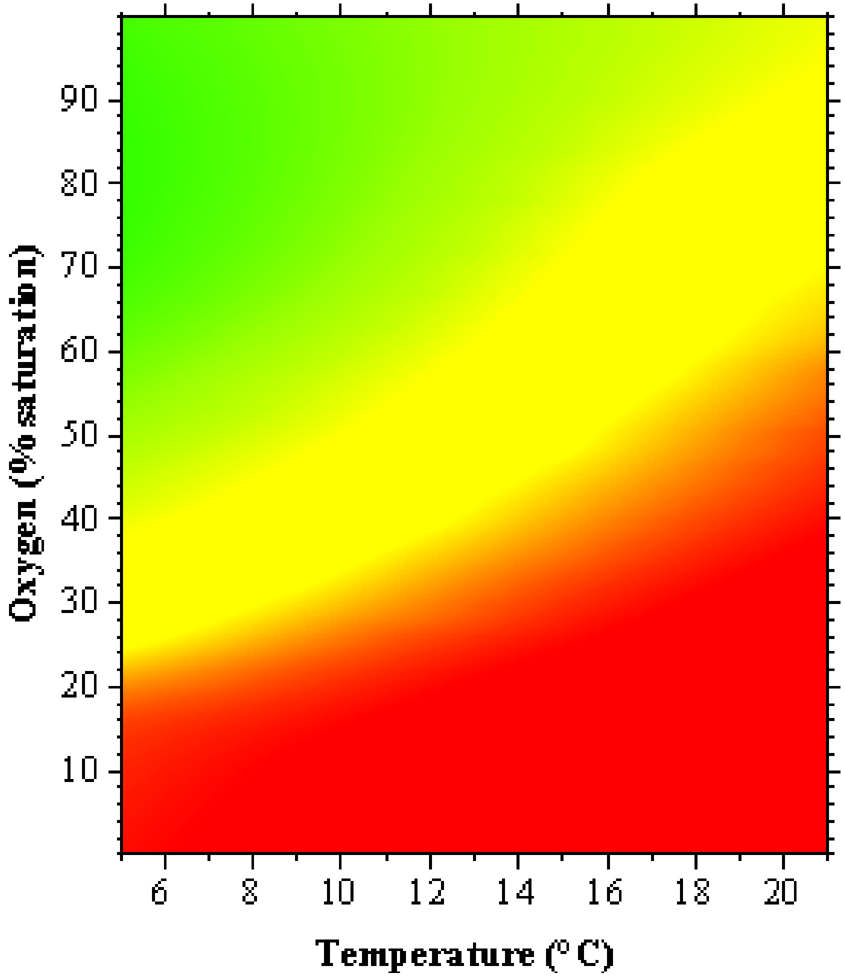


Figure 7 Evaluation of the effect of temperature and oxygen conditions on welfare and performance of Atlantic salmon. Orange/ red border: Lower limits for sustained oxygen consumption of 400 g salmon fed to satiation. Colours: optimal (green), suboptimal (yellow), at tolerance limit (orange) and critical (red). Note that the position of the green-yellow boundary is still uncertain.

5.3. Pellet Quality - optimal conveying and biological response

Researchers: Torbjørn Åsgård, Maike Oehme (PhD student), Mette Sørensen and Turid Synnøve Aas (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, in a previous CREATE-project, we showed that the physical feed quality affects the biological responses in fish (Aas *et al.*, 2011). The results showed that the most durable pellet type may not be optimal for the fish. Also, there is a large variation in the physical quality of commercial feeds, and it is poorly documented how this affects the fish.

In the present trial, the aim was to measure feed intake and digestibility of nutrients in salmon fed diets of different physical quality. One of the feeds was soaked before feeding to obtain a moist pellet. Also, a period of similar feed intake in all tanks was included to separate a potential effect of feed intake on nutrient digestibility from the effect of feed quality on nutrient digestibility.

Methods

Five feeds with different physical quality were fed to Atlantic salmon. Four feeds with identical composition were produced under similar conditions. The difference in physical quality was obtained by varying the drying intensity, so that the finished feeds contained 90, 92.5, 95 and 97.5 % dry matter, respectively. The feed with 95% dry matter was also fed to fish after soaking. To obtain large differences in physical feed quality, a large pellet size (10 mm) was used, and the start weight of the salmon was 800 g. The fish was kept in 1 m^3

tanks with sea water of ambient temperature at Nofima's research facilities at Sunndalsøra.

Figure 8 Stripping of feaces. (Picture from a different trial with smaller fish)

The salmon was fed *ad libitum* for three months, and then the fish was stripped for faeces. Subsequently, the fish was fed a fixed ration for a period, and the fish was stripped again. Feed spill was collected daily so that feed intake can be estimated. The feeds and faeces will be analysed, and apparent digestibility of energy and nutrients will be estimated. Data for apparent digestibility from the last sampling will be used to investigate how feed intake affects apparent digestibility.

Results

The analyses are not complete, and the data are under processing. However, preliminary data indicate that soaking of feed increases feed intake, particularly when feed intake is low.

This work will be part of Maike Oehme's PhD thesis.

5.4. NetCageDesignTools

Researcher: Finn Olav Bjørnsen, Martin Føre, Brad Schofield, Per Runtop, Per Christian Endresen, Østen Jensen (SINTEF Fisheries and Aquaculture)

Industry partners: Egersund Net

Background

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

Methods

The main method used for the project has been a scrum inspired agile method. The project group has had regular meetings every two weeks where we have looked at a list of requirements for the software and prioritized what is feasible to implement during the next two week period. To ensure feedback from the customer we have had several meetings with Egersund Net where we presented the software so far and gathered feedback on wanted functionality and future priorities. In February 2012 the first beta version was released and presented to Egersund Net.

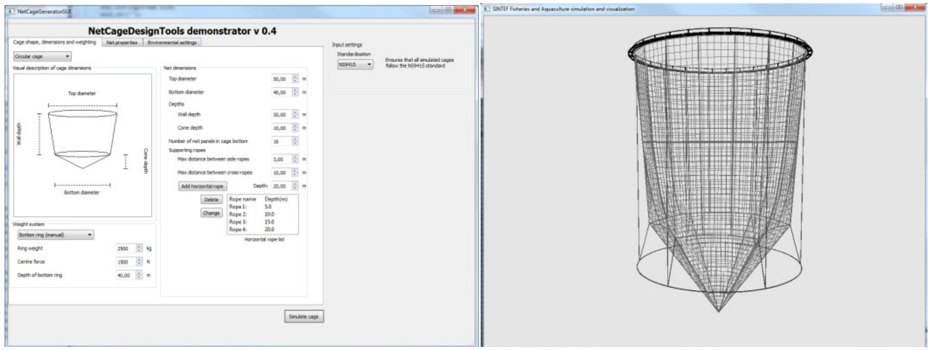


Figure 10 Screenshot of the first tab in the NetCageDesignTools demonstrator GUI. This tab is used to specify cage shape and dimensions, as well as which weighting method should be used in the simulation (Left). Screenshot of an undeformed circular net cage with rigid floating collar (right).

Results and Discussion

The result so far is a demonstrator currently at version 0.7. The demonstrator consists of a graphical user interface where users can specify the physical dimensions of a net cage, the physical properties of the net and ropes, and environmental loads like current and waves. The software takes this input and translates it to an input xml file for the fhSim Core 1.0, which then takes over and runs a simulation on the specified net structure. Both circular and rectangular nets can be modeled; with different geometries. Supportropes can be added vertically and horizontally. For circular cages the floating collar can be either rigid or flexible. The weight system can be either individual weights connected to the crossropes or a sinkertube, the weights can be calculated automatically or given manually. The demonstrator supports environmental conditions through current simulations on the net structure as well as regular and irregular waves.

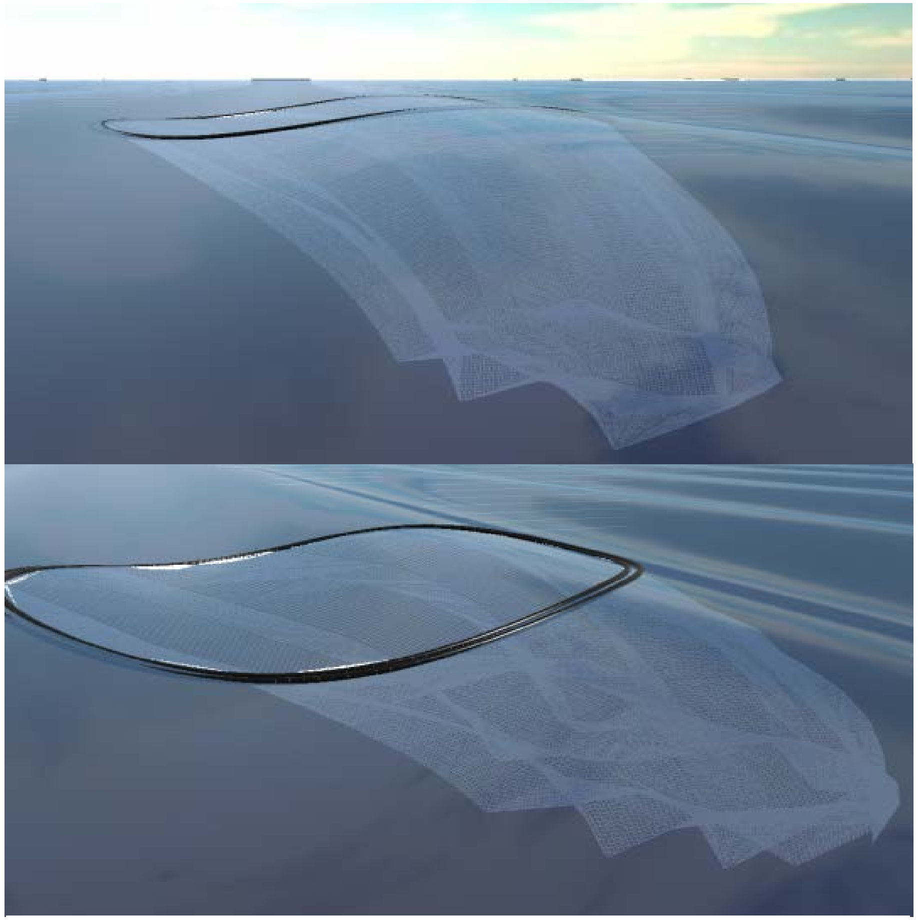


Figure 9 Screenshot of a deformed circular net cage with flexible floating collar in waves and current (left) and a deformed circular net cage with flexible floating collar in waves and current (right).

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

Researcher: Tore S Kristiansen (leader), Øyvind Korsøen (post doc), Jan Erik Fosseidengen, Frode Oppdal, Ørjan Karlsen (all Institute of Marine Research), Tim Dempster, Samantha Bui (Sintef FH and Melbourne University).

Industry partners: Egersund Net, Lerøy, Marine Harvest , Salmar, Akva

Experiment SUBCOD II: Artificial continuous light to Atlantic cod (*Gadus morhua*) in submerged sea cages maintain growth and delay, but not arrest, sexual maturation

Early sexual maturation is a major problem in Atlantic cod farming. In indoor tanks cod readily responds to shifts in photoperiod, and continuous light arrests sexual maturation. In outdoor tanks and sea cages similar treatments only delay maturation by 3-5 months. The reasons for this is probably that even with continuous lighting the strong sunlight intensity in spring give a seasonal signal to start the maturing process. The light intensity decreases rapidly with depth and is only a small fraction of the surface level at 20 m depth. By submerging the cages below 20m we wanted to reduce the difference between day and nighttime illuminations and test if this was sufficient to arrest maturation.

1600 cod at ~0.6 kg were randomly distributed to 4 separate experimental (5 x 5 x 7 m) submersible cages in July 2010 (Figure 11). A submersible lamp (400 W) was placed 0.5 m above the roof of two illuminated cages. The two other cages with no lights served as controls. The fish were submerged to 20 m depth from July 2010

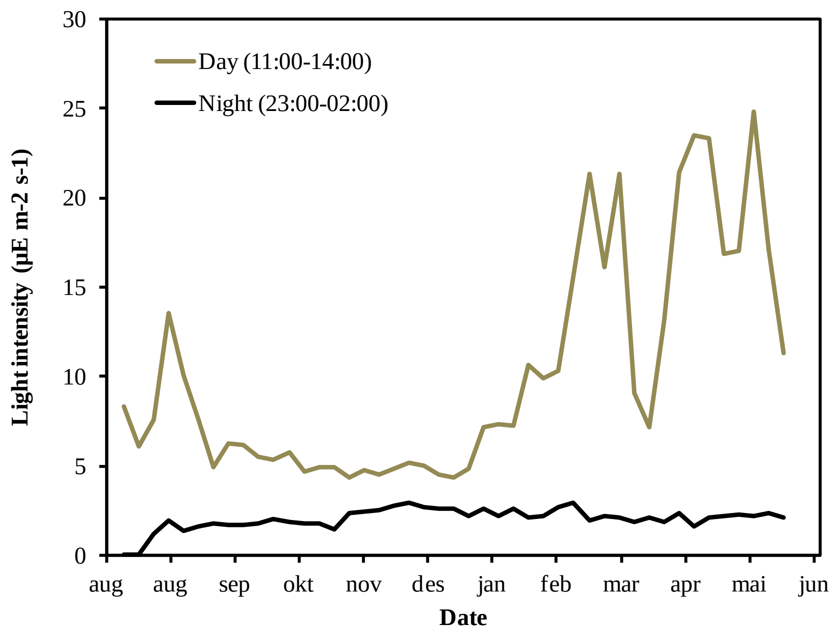


Figure 11 Average light intensity at the artificial illuminated submerged cage at 20 m depth during day and night.

to September 2011. 50 random fish per cage were sampled 01/07/10 (start), 22/11/10, 23/02/11, 03/05/11, and 01/11/11 for measurement of length, weight, gutted weight, liver and gonad weight, and egg development stage. The fish were fed daily in excess, and appetite and mortality were registered daily.

Light measurements taken at the cage roof day and night during the experiments showed that the daylight intensity increased rapidly from January and during spring at 20 m the daylight were 5-10 times stronger than the artificial lightening (Figure 11). The cod in the illuminated cages started to mature in the spring and did delay maturation for about 4-5 months compared to the control groups (Figure 12). While the control groups had a short an synchronized spawning period, the light groups spawning were longer and more asynchronous spawning period from April to September, similar to what has been in light treated cages in surface cages. The fish grew faster than what has been observed in previous studies. The pattern of growth pattern was significantly different between treatments, but both resulted in harvest weight around 3.2 kg at the end of the experimental period. There was almost no observed mortality in the cages, not even during spawning, indicating a positive effect of submergence.

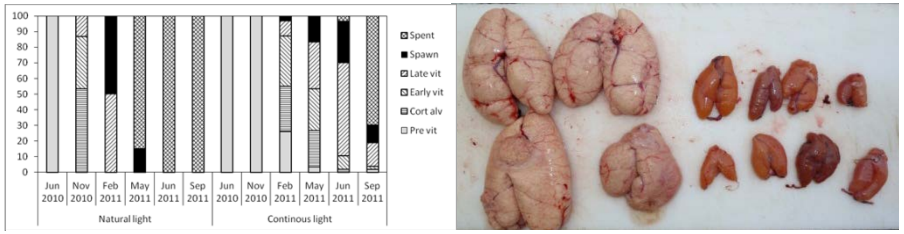


Figure 12 Difference in female gonad maturation in February between controls (photo of four mature gonads to the left) and light groups (eight not mature gonads to the right), and distribution of female maturation stage at the different sampling periods. Black columns indicate spawning fish.

Experiment SUBSALMON V: Technological solutions for improvement of coping ability during winter submergence of A.salmon (air dome, light, frequent resurfacing). Results from pilot study show that Atlantic salmon (*Salmo salar* L.) in a submerged sea-cage adapt rapidly to re-fill their swim bladders in an underwater air filled dome

Our previous experiments in Create have demonstrated that long-term culture of Atlantic salmon in submerged cages is presently unfeasible. Submergence causes loss of air from salmon's physostomous (open) swim bladder, leading to negative buoyancy, modified swimming behaviours, and finally reduced growth and feed utilisation. We tested a possible solution to resolve negative buoyancy using an underwater dome filled with approximately 120 L of air, and attached beneath the roof netting. A 175 m^3 net pen was submerged below 10 m depth for 14 days in two repetitive rounds. The dome was filled with air the 8th day of submergence in each round. 15 adult salmon (mean weight 3.3 kg) were individually PIT tagged and placed in the submerged cage. The dome was equipped with a PIT antenna which detected individuals within a distance of approximately 0.5 m. We expected that salmon could access the dome to refill air into their swim bladders.

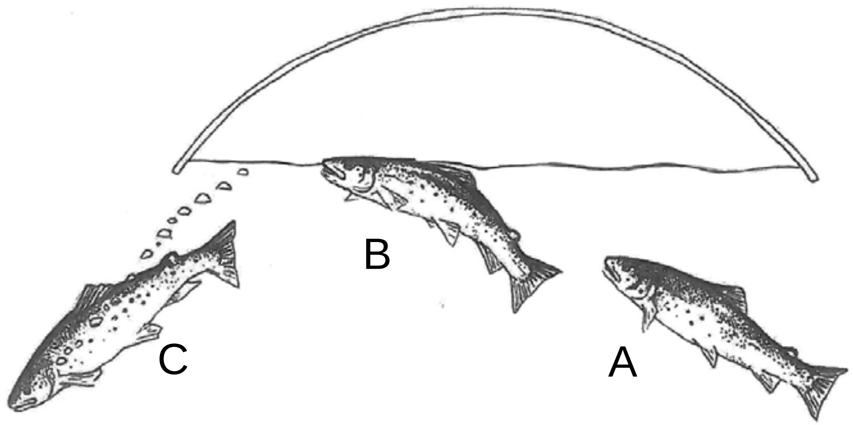


Figure 13 Typical behaviour during a swim bladder re-filling event for Atlantic salmon in a submerged air-filled dome; burst swimming towards the air pocket (A), breaking the surface (B) and rapid swimming in a downward direction, often with air bubbles escaping from the mouth or opercula region (C).

During the periods with no air in the dome, fish approached the dome on average 20 times per day, indicating that they were searching for air or the surface. When air was provided to the dome, salmon rapidly swallowed air repeatedly from the underwater air-pocket (average 5 fills per fish within 24 hours of air being present).

After this pronounced initial intense bout of swim bladder filling behaviour, they swallowed air from the surface less frequently over the following days (average 1.0 fill per fish per day). Swimming speeds increased by 1.5 – 2.0 times on average when no air was available, and quickly returned to normal speeds when air was made available in the dome. Our results demonstrate that salmon rapidly adapted their behaviour to use this new equipment, and open the possibility for the use of underwater air domes in sea-cages. The next step (2012) will be to confirm these results in a large scale experiment three thousand salmon.

5.6. Individual based modelling and observation of Atlantic salmon (Salmo salar L.) behaviour in sea-cages (Summary of the PhD thesis of Martin Føre)

Main contributions from this thesis comprise the development and testing of two novel technological tools for estimating and observing the individual behaviours of farmed salmon. The first of these tools is a mathematical model of Atlantic salmon behaviour in sea-cages built using an individual-based state-space modelling approach. Numerical simulation is used to solve the model, and the main model outputs are the positions and swimming velocities of the simulated individual fish. The fish were programmed to respond to a realistic cage environment featuring a set of factors that vary with both time and 3D-space. Comparisons between model output and observed fish behavioural responses indicate that the model is able to replicate most of the dynamics behind vertical distribution of salmon in sea-cages (Figure 15).

The second tool developed in the thesis was based on acoustic telemetry and was aimed at producing information on the feeding behaviours of individual salmon in a sea-cage rearing situation. Based on preliminary literature studies and use of underwater video cameras, vertical movement, increased swimming activity and

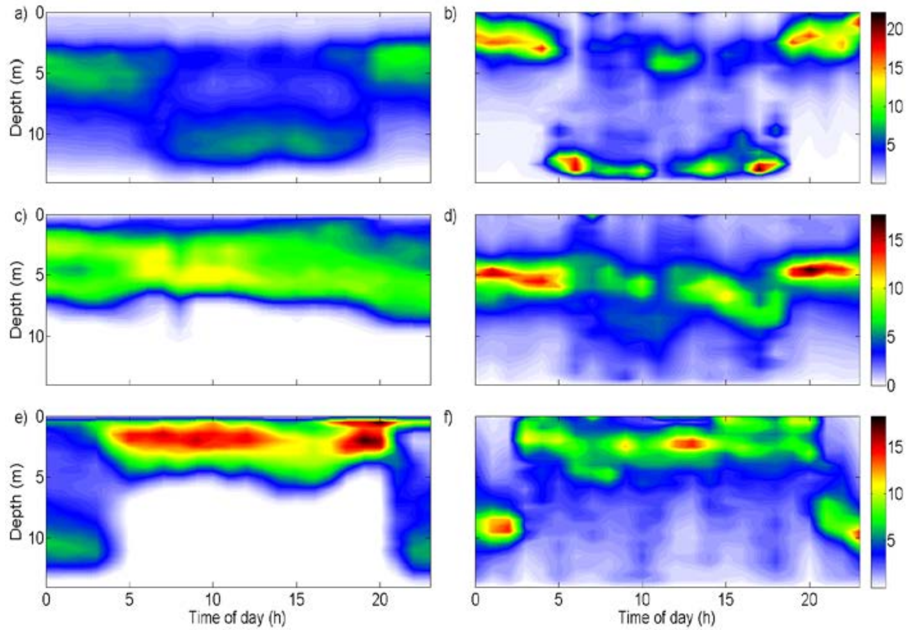


Figure 14 Comparison between observed vertical distribution (a, c and e, data from Oppedal et al. (2007)) of Atlantic salmon in a 14 m deep sea-cage, and estimates generated by the individual-based mathematical model (b, d and f). Horizontal axes denote time of day in hours (0-24), the vertical axes denote depth in the cage, while different colours denote different densities of fish given in % of the total population.

inertial suction (i.e. active generation of an underpressure within the oral cavity by rapid expansion of the mouth) were identified as behavioural expressions which typically tend to arise when salmon are actively feeding on pellets. Three acoustic transmitter tag types containing different sensor technologies were developed with the intent of detecting these behavioural characteristics and thus be able to provide new information on the feeding patterns of salmon. The transmitter types were tested in sea-cages through two consecutive experiments, and the main findings were that the transmitter tags targeting vertical movement and increases in swimming activity performed well at distinguishing feeding activity from other behaviours (Figure 16). The depth based transmitter tags detected feeding activity as increased variations in preferred swimming depth coinciding with bursts in swimming speed toward the surface, while activity transmitters typically reported increased swimming activity during feeding events (Figure 16). In contrast, the data reported by the inertial suction transmitter during feeding periods was undistinguishable from data collected in other periods, suggesting that this particular tag type requires more development in order to effectively pinpoint feeding behaviour through detection of inertial suction.

The main impact of the tools developed in this thesis is founded in that they both target the behaviours of individual fish, meaning that the information they produce is complementary to that obtained by using more established techniques for observing fish behaviour in an aquaculture setting (e.g. cameras and echo-sounders). Consequently, the use of these and similar techniques could produce new knowledge and insights into salmon behaviour in sea-cages. Furthermore, the tools may represent useful components in potential future solutions which seek to obtain a more comprehensive overview of the processes occurring within salmon sea-cages through simultaneous monitoring or estimation of various aspects of the culture environment and the fish biology. Finally, information on individuals is a prerequisite for a promising new concept within agriculture called *Precision Livestock Farming* (PLF). With tools such as the ones developed in this thesis, it could be possible to start adapting the growing mass of concepts and techniques within PLF to fish aquaculture.

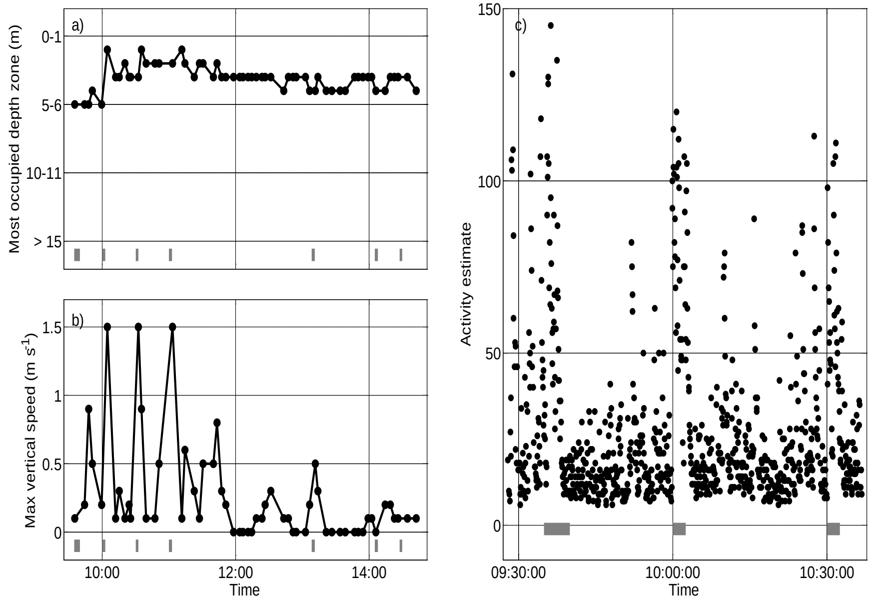


Figure 15 Telemetry data from controlled feeding experiments in a small sea-cage. Horizontal axes denote time of day, while grey bars at the bottom of the figures denote hand-feeding events (approximately 150 pellets delivered per event). a) Most occupied depth zone in m for a fish carrying a depth transmitter over a period of about 5 hrs; b) maximum vertical movement speeds in m s^{-1} for the same fish over the same time interval; c) activity estimates for a fish carrying a transmitter sensitive to activity a period of about 2 hours.

5.7. Biological criteria for submergence of physostome (Atlantic salmon) and physoclist (Atlantic cod) fish in sea-cages (Summary of the PhD thesis of Øyvind Johan Korsøen)

This thesis aims to describe behavioural responses and welfare parameters for the physostome Atlantic salmon and physoclist Atlantic cod when out of neutral buoyancy at different degrees and periods of time. The background for this approach is to improve the culture conditions by fully submergence of the farming installations, as the water below 10 m depth often is more stable in terms of environmental factors such as temperature and current in addition to the lack of waves, which again opens for alternative sites in more exposed oceanic areas.

Salmon were submerged in large-scale fully submersible cages at depths between 4 to 15 m for 22 days and 10 to 25 m for 42 days under different light conditions and at various times of year. The behaviour of individual salmon in a school under submerged conditions was studied to reveal whether a range of coping abilities among individuals exists during the new and more challenging conditions. Atlantic cod in an experimental submersible cage were raised from five different starting depths (between 30 and 8 m) and lowered from surface position to 10 m, 20 m and 30 m to test a protocol for safe lifting and lowering steps. Based on the behavioural responses, safe acclimation times before the next vertical step at high and low sea temperatures were identified.

The general patterns of swimming depth and schooling density were studied at group level using echo-sounders in addition to swimming speed and swimming angle based on instantaneous observations with underwater cameras. Welfare parameters were defined as weight gain, feed intake, feed utilisation and fin and vertebral condition during the experimental period. The behaviour of individual salmon was studied by monitoring the swimming depth and body temperature using data storage tags implanted in randomly selected fish. Whether the development of diel vertical migration (DVM) activity during feeding was linked with individual growth rates was analysed to study individual coping styles. The immediate response and recovery time after lifting and lowering of Atlantic cod were estimated through measurements of swimming speed, swimming tail beat rate and swimming angle based on underwater camera recordings, and additionally by echo-sounder data obtained from resting fish on the net-floor.

Atlantic salmon submerged without the opportunity to refill their swim bladder lost gas steadily over time, and the bladder was empty after about three weeks. Swimming speeds were elevated on the first day after submergence and schooling became more structured (more constant speed and a greater distance to neighbouring fish). The diurnal vertical swimming pattern for the salmon in spring was broadly similar to that observed prior to submergence, as the artificial underwater lighting allowed the salmon to keep high swimming speed and lift during night. In contrast, about 90% of the salmon submerged below 10 m during the dark winter reversed their diurnal pattern from swimming at shallow depths at night and deeper during the day to swimming deep at night and shallower during the day (reversed DVM) or to swimming with a normal or reversed diurnal pattern on different days (irregular). A separation of faster- and slower-growing salmon also gradually appeared, where the faster-growing individuals occupied the deeper part of the water column. This situation occurred also at night at the end of the experiment among the salmon given continuous light. Growth was clearly reduced in the salmon that were submerged during the winter, with more injuries recorded on their fins and snout. Slightly compressed vertebrae in the tail region were also observed, probably due to their tilted head-up tail-down swimming angle during the dark nights.

Lifting farmed cod from five different start depths, equivalent to a 40% pressure reduction, resulted in strong downwards swimming movements dependent on the water temperature. The depth before cage lifting affected the immediate response, as the fish became more active after lifting events from shallow compared to deeper depths. Appetite decreased after lifting, but loss of behavioural control was never observed. During the subsequent 8-10 hr recovery periods, swimming activity gradually decreased to the same level as before lifting. The overall recovery time did not depend on start depth or temperature. Independent of final depth or temperature, rapid lowering of cod only resulted in a moderate short-term increase in upwards swimming movements, while appetite was less affected than after lifting. A compressed swim bladder after descents from the surface to 10-30 m leads to negative buoyancy, which required 18-90 h to re-fill by gas secretion, which is a temperature-related process.

In conclusion, this thesis demonstrates that air gulping is a behavioural need for Atlantic salmon, and that long term denial of surface access will reduce their welfare.

Atlantic cod cope well in fully submerged cages, but 40% pressure reduction is near the upper limit for lifts of healthy farmed cod. Secondary lifts should not be done until at least 10 h after the first lift. Cage lowering should be done slowly to avoid potentially stressful crowding of negatively buoyant fish on the cage bottom, especially at low temperatures.

6. International cooperation

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

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

Collaboration with Chinese institutes (SJTU and Zheijang University) Project and model tests for fish farms are under development with Professor Shixiao Fu, from Shanghai Jiao Tong University, planned for the fall of 2010. Professor Shixiao visited CREATE in October 2010. Dr. Gui (Zhejiang University) has been a visiting post-doctoral fellow at the centre for 2009-10, and collaborated on projects to design new cage systems for warm water aquaculture.

Collaboration with *SALTT* at the University of Melbourne In 2010, CREATE established a new international collaboration with the Sustainable Aquaculture Laboratory – Temperate and Tropical (*SALTT*) based at the University of Melbourne, Australia. *SALTT* researchers Dr. Tim Dempster & Isla Fitridge are currently participating in CREATE projects within the research themes of behavioural studies to underpin new technologies and biofouling control.

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. In 2011 eight PhD students were funded directly through by CREATE, at present two of theses PhD students have defended their thesis with success. In 2011 three PhD students with external financing was working on projects in the centre. One PhD student with external financing has successfully defended his PhD. It is planned one additional PhD fellowship within CREATE . Four of the total 12 students are Norwegian.

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

In 2011 two Postdoctoral researches was financed by the centre. Two Postdoctoral researchers have previously been financed by the centre. In audition is two Postdoctoral fellowships planned with start up in 2012 and 2013, and personnel are identified for both fellowships.

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

Key Researchers		
Name	**Institution**	**Main research area**
Arne Fredheim	SINTEF Fisheries and Aquaculture	Marine hydrodynamics/Fish farming constructions
Egil Lien	SINTEF Fisheries and Aquaculture	Marine structures
Tim Dempster	SINTEF Fisheries and Aquaculture	Fish behaviour
Jana Günther	SINTEF Fisheries and Aquaculture	Bio fouling
Gunnar Senneset	SINTEF Fisheries and Aquaculture	System modelling
Tore Kristiansen	Institute of marine research	Fish welfare and behaviour
Frode Oppedahl	Institute of marine research	Fish welfare and behaviour
Torbjørn Åsgård	NOFIMA Marin	Fish feed and nutrition
Turid Synnøve Aas	NOFIMA Marin	Fish feed and nutrition
Trine Kirkhus	SINTEF Information and communication technology	
Professor Odd M. Faltinsen	CeSOS/NTNU	Marine hydrodynamics/Fish farming constructions
Associate Professor Jo Arve Alfredsen	NTNU	Engineering cybernetics

Visiting Researchers				
Name	**Affiliation**	**Nationality**	**Duration**	**Topic**
Dr. Shim Kyujin	Post. Doc.	Korean	2008-2009	CFD simulation of flow through fish cage
Dr. Fukun Gui	Post. Doc. from China Zhejiang Ocean University	Chinese	2009-2010	Design of cage systems for exposed shallow waters
Dr. Shixiao Fu	Shanghai Jiao Tong University	Chinese	2010	Modell experiments of slender floating bodies

Postdoctoral researchers with financial support from the Centre budget			
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 - 2012	Smart submergence of sea cages with salmon and cod

Postdoctoral researchers working on projects in the centre with financial support from other sources			
Name	**Nationality**	**Period**	**Topic**
Dr. Trygve Kristiansen	Norwegian	2011-2012	

PhD students with financial support from the Centre budget			
Name	**Nationality**	**Period**	**Topic**
Korsøen Øyvind Johan	Norwegian	2007-2010	Biological criteria for successful submergence of physoclistous Atlantic cod physostomous Atlantic salmon reared in sea-cages
Føre Martin	Norwegian	2007-2010	Modelling and simulation of fish behaviour in aquaculture production facilitie
Remen Mette	Norwegian	2008-2011	Effects of fluctuating oxygen levels on welfare and growth of salmon (Salmo 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	UMB	2010 - 2013	Quality - optimal conveying and biological response
Bardestani Mohsen	NTNU	2009 - 2012	Wave and current loads on fish farms
Peng Li	NTNU	2010 - 2013	Hydroelastic behavior of the floater of an aquaculture cage in waves and cu

PhD students working on projects in the centre with financial support from other sources

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

Master degrees		
Name	Sex M/F	Topic
Vigen Jannicke	F	Oxygen variation in cages
Carl Christina	F	Bio-fouling
Harendza Astrid	F	PIV on inclined cylinder shaped fish cages
Raanes Håkon	M	Next generation subcage - concept development
Henriette Flathaug Ramberg	F	Interaction between the net structure, the weight system and the floater of a fish farm
Håkon Ådnanes	M	Consequence for dimensioning of mooring system
Per Christian Endresen	M	Wave forces on floating fish farms
Hyunsuk Yoon	F	Design of Offshore Fish Farms