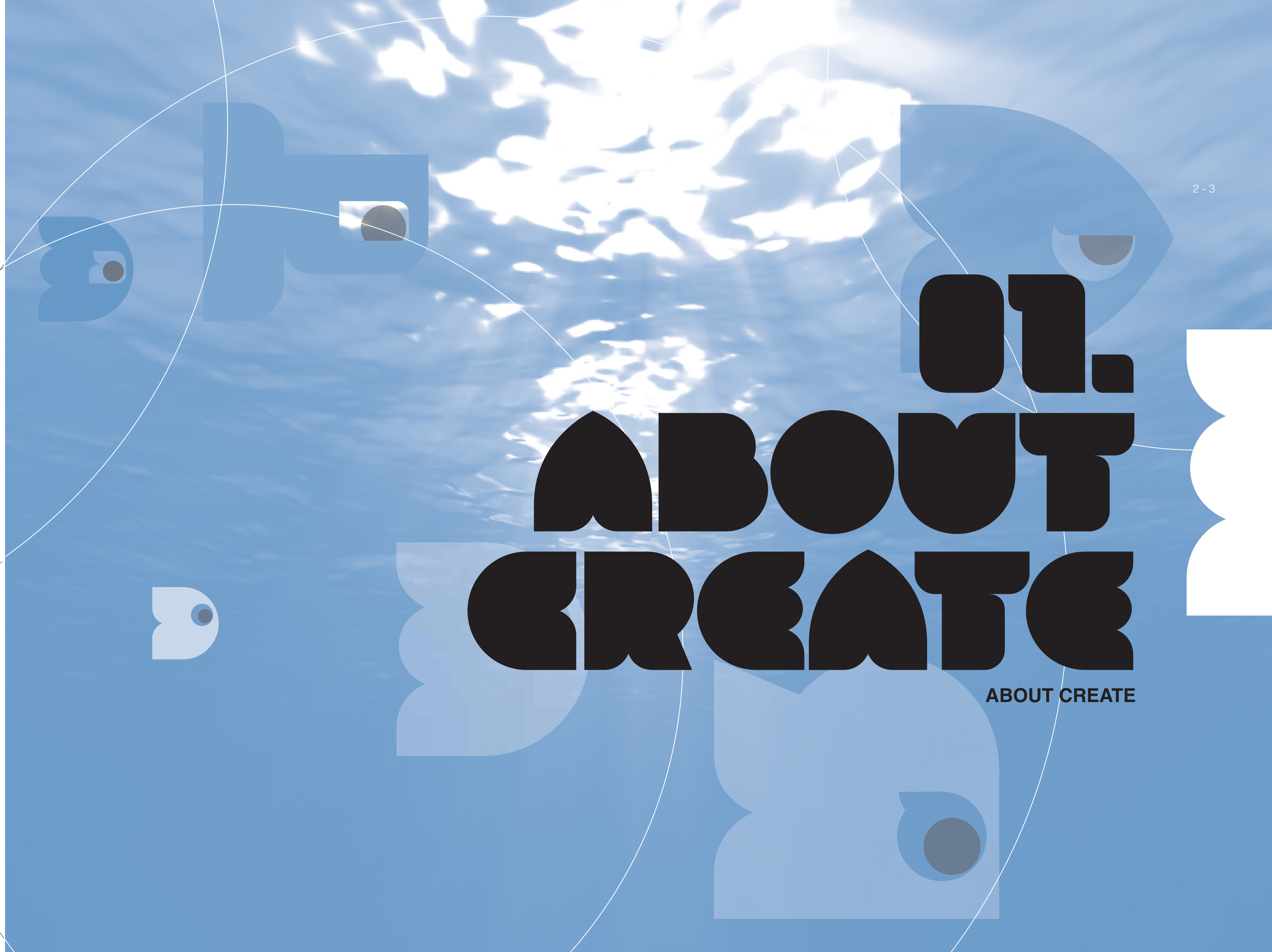
CREATING AQUA-CULTURE FOR THE FUTURE

CREATE

Centre for research-based innovation in aquaculture technology

ANNUAL REPORT 2008



01. ABOUT CREATE

ABOUT CREATE

About CREATE. 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 centre for research-based innovation, established and 50% funded by the Research Council of Norway. SINTEF Fiskeri og havbruk AS (SINTEF Fisheries and Aquaculture) is the host institution for the centre. The three Norwegian industry partners involved in the centre, AKVA Group AS, Egersund Net AS and Erling Haug AS, are all word-leading suppliers of equipment and technology in their respective market segments. Five internationally recognized research institutions are active research partners within the centre: NOFIMA Marin, the Institute of Marine Research (IMR), Centre for Ships and Ocean Structures (Centre of Excellence), the Department of Engineering Cybernetics at the Norwegian University of Science and Technology, and SINTEF Information and Communication Technology. The centre also has research collaborations with the Open Ocean Aquaculture (OOA) Engineering group at the University of New Hampshire, USA (UNH).

Vision and objective

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.

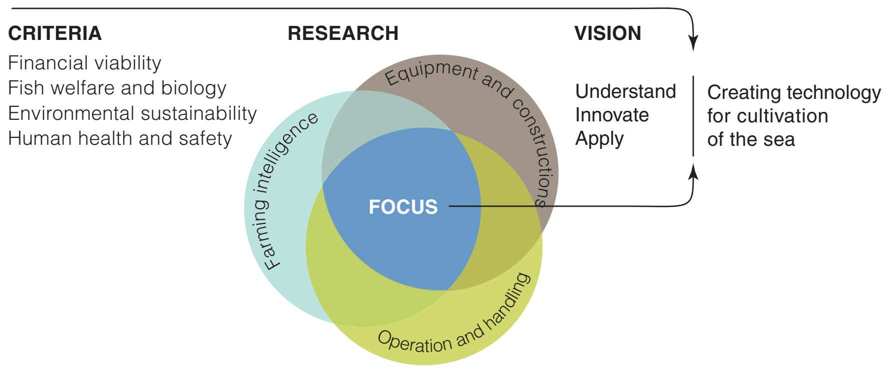
CREATE focuses research and development within the following three main research pillars and aims to integrate knowledge between them:

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.

Figure 1 : Vision and research pillars for CREATE



Organization

CREATE is organized as an independent part of SINTEF Fisheries and Aquaculture, with its own Board, Scientific committee and management. CREATE is physically located at SINTEF Sealab at the waterfront in Trondheim, Norway.

The Board

The Board of directors are responsible for decisions on project activities and budget. It has a majority of members from the industry partners. The Board consists of five members with representatives from all the industry partners, SINTEF Fisheries and Aquaculture and one aditional representative from the research partners. In 2008 the following people were members of the board:

Jone Gjerde, AKVA Group ASA
Chairman of CREATE

Karl A. Almås
SINTEF Fisheries and Aquaculture

Tore Kristiansen
Institute of Marine Research

Ove Veivåg
Egersund Net AS

Bjørn Karlsen
Erling Haug AS

Scientific Committee

The main task of the Scientific Committee is to review and develop project proposals and the research plan for CREATE. The Scientific Committee makes recommendations for the research plan and projects to the board of directors. The scientific committee has one member from each of the partners. In 2008, the following people were members of the committee:

Svein Ove Rabben
Egersund Net AS

Erling Skjevrak
AKVA Group ASA

Kristine Brobakke
Erling Haug AS

Alf Kristian Fjelldal
Polarcirkel, AKVA Group ASA

Torbjørn Åsgård
NOFIMA Marin AS

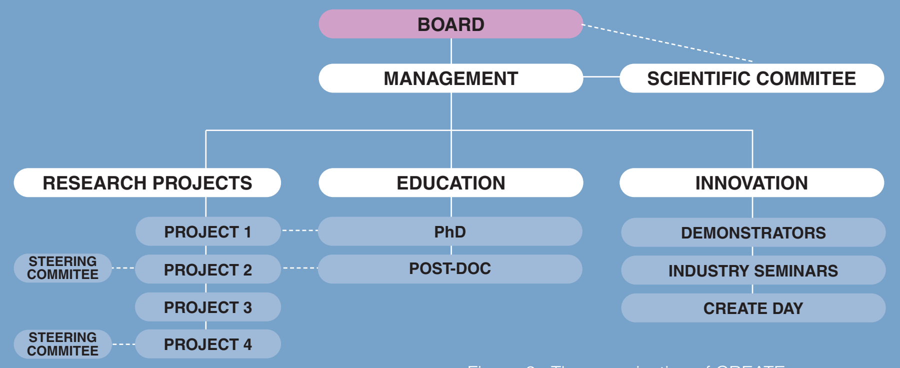


Figure 2 : The organization of CREATE

Pål Lader
SINTEF Fisheries and Aquaculture

Tom Hansen
Institute of Marine Research

Tom Kavli
SINTEF Information and Communication Technology

Jo Arve Alfredsen
Department of Engineering Cybernetics (DEC), Norwegian University of Science and Technology (NTNU)

Torgeir Moan
Centre for Ships and Ocean Structures (CeSOS), Norwegian University of Science and Technology (NTNU)

Management

The management team has responsibility for the daily run of the centre. Arne Fredheim is the Director of the centre and Lillian Tronsaune is the Administrative Coordinator.

Education

Centre for Ships and Ocean Structures and NTNU Department of engineering cybernetics share the educational responsibility for PhD candidates.

CREATEday

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.

Facilities

SINTEF Sealab houses new facilities and laboratories designed especially for the marine research activities within SINTEF.

Experimental research related to hydrodynamics and structural mechanics is conducted at the Marine Technology Centre in Trondheim. This is a unique laboratory infrastructure, comprising the world's largest ocean basin, towing tank and wave flumes.

Experimental activity where steady currents are the main focus, and observations of models can be made, is carried out in the SINTEF Fisheries and Aquaculture flume tank in Hirtshals, Denmark. The flume tank is the second largest in the world and its size makes it possible to use large models with "full-sized" netting panels in tests.

Experimental studies related to fish behaviour and water flow dynamics is carried out at the Cage Environment Laboratory located at the IMR field station at Matre, a fjord-based full-scale fish farm. The Cage Environment Laboratory has a basic set-up of ten 15 m deep cages where behavioural and environmental screening can be carried out with high resolution in time and space in all cages.

CREATE Research and Industry partners

SINTEF Fisheries and Aquaculture 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 headquarters 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 targets fish farming companies worldwide with a main focus on the present major salmon farming countries, Norway and Chile, as well as other salmon producing countries and the Mediterranean region.

Egersund Net AS has since the early 1970's, been one of the leading producers and suppliers 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 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 a trading house, supplying both the offshore and onshore markets since 1936. We provide the aquaculture industry with engineering of and products related to complete mooring systems, components for mooring systems, lifting equipment and life saving equipment as well as several other product groups.

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

Figure 3A : Products by AKVA Group

Egersund Net - facts

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

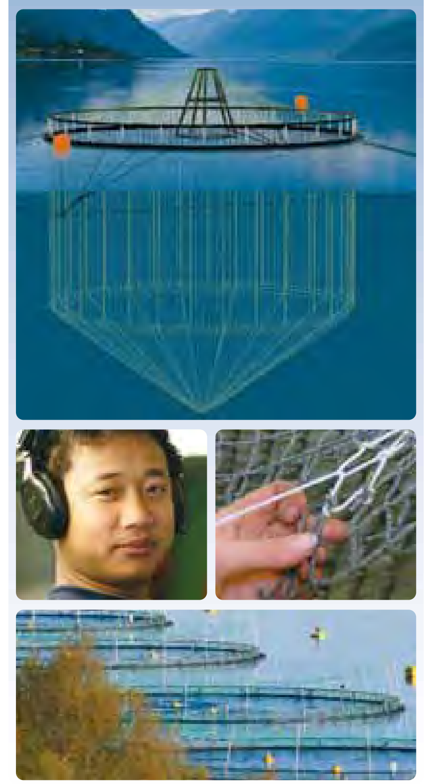


Figure 3B : Products by Egersund Net.

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

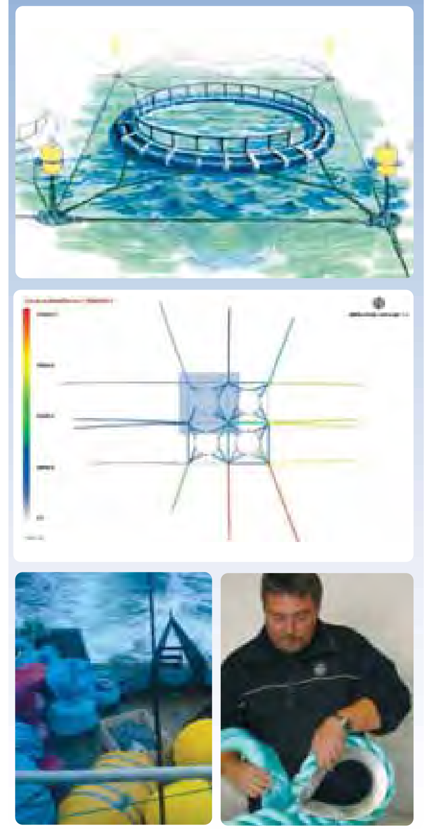


Figure 3C : Products by Erling Haug

Innovation has been part of the Erling Haug AS philosophy from the beginning, always focusing on technical knowledge. Our drive for quality solutions to the challenges of the industry leads us to research and development projects like Create. Our in-house engineering competence and state of the art dynamic analysing tools gives our clients custom-made and flexible moorings for their fish farms plants.

Our head quarter is located in Trondheim, at the middle of Norway's long coastline, with offices in Kristiansund, Harstad, Hammerfest, Ålesund, Florø and Puerto Montt, Chile. Erling Haug AS is part of the CERTEX / Axel Johnson Group.

"A reliable connection" is our motto, because at the root of our business is the safety and protection of life and investments. If it concerns a heavy lift, we are there. If it involves loading and unloading we are there. In howling gales and heaving seas, we are there.

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 a 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 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).

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 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.

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 fresh-water 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 parameters and behaviour.

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.

GUNNAR SENNESET - 55

Title research project:
CREATE Simulation and Optimization Framework (SimFrame)

Education: MSc.

Company/Institution:
SINTEF Fisheries and Aquaculture

Place of residence: Trondheim, Norway
Place of birth: Trondheim, Norway

Leisure activities:
Boating and grandchildren (currently one, another in the pipeline)

Latest publication:
"Information models leveraging identification of returnable transport items" (accepted for publication in British Food Journal)

Nationality: Norwegian

3 research keyword:
Information modelling, simulation, logistics

3 keyword about yourself:
Professionally curious, easy-going, prefers red wine to white

TURID SYNNØVE AAS - 40

Title research project:
Physical properties of feed, hardness and durability

Education: Dr. Scient (PhD) in 2006 at the Dept. of Animal and Aquacultural Sciences (IHA) at the Norwegian University of Life Sciences (UMB).

Company/Institution: Nofima

Place of residence: Sunndalsøra, Norway
Place of birth: Haugesund, Norway

Leisure activities:
Exercising, music, scrapbooking

Latest publication: Aas, T.S., Hatlen, B., Grisdale-Helland, B., Terjesen, B.F., Penn, M. Bakke-McKellep, A.M. and Helland, S.J. (2007) Feed intake, growth and nutrient utilization in Atlantic halibut *(Hippoglossus hippoglossus)* fed diets containing a bacterial protein meal. Aquacult. Res. 351-360.

Nationality: Norwegian

3 research keyword:
Nutrition, feed, feed ingredients

3 keyword about yourself: Social, loyal, happy

TIM DEMPSTER - 35

Title research project:
SubFish Biology – Biological tolerances of fish to submerged cage culture

Education:
PhD Fish ecology, University of Sydney, Australia

Company/Institution:
SINTEF Fisheries and Aquaculture

Place of residence: Melbourne, Australia

Place of birth:
Brisbane, Australia

Leisure activities:
Skiing, Hiking, Cycling

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

Nationality: Australian

3 research keyword:
growth, behaviour, submergence,

3 keyword about yourself: publish or perish

02. SCIENTIFIC ACTIVITIES & RESULTS

SCIENTIFIC ACTIVITIES AND RESULTS

Scientific activities and results. CREATE has as a philosophy to involve personnel from several partners in each project and it is an aim to have project personnel physically working together at the centre, to ensure joint involvement, creativity and transfer of knowledge. At least two industry partners and two R&D partner are involved in all projects. All projects are organized with a project leader and a Steering Committee. The project leader will normally be selected from the R&D partners. The Steering Committee will have members from relevant industry and R&D partners, CREATE management and possibly from outside of CREATE. The leader of the Steering Committee is normally selected from one of the industry partners.

To strengthen the industry involvement and focus for all the projects, a set of demonstrators are defined, with the purpose to:

- Serve as a delivery point for results from all the projects
- Visualize possible industrial use of the project results
- Identify relevance of the research
- Identify further research needs

Each project, whether industry or fundamental research focused, including PhDs, need to define deliverables towards one or more demonstrators. .

Projects

CREATE currently has seven main projects, 5 PhD students and 2 post-doctoral researchers within the centre.

The projects, PhD and Post-doc topics and their relation to the three research pillars of CREATE are shown in Figure 4. An outline of the research projects and some of the Post-doc and PhD projects are given in the following pages.

Figure 4 : Overview of projects, PhD and Post-doc topics and demonstrators within CREATE

2.1 Cage Environment

Project leaders: Frode Oppedal (Institute of Marine Research) and Pål Lader (SINTEF Fisheries and Aquaculture)

Partners: Egersund Net, Erling Haug, SINTEF Fisheries and Aquaculture, Institute of Marine Research, Centre for Ships and Ocean Structures and Norwegian University of Science and Technology (NTNU)

The objective is to develop improved standards for oxygen management in marine net cages to secure fish welfare and efficient production.

Background - Fluctuating hypoxia and flow field in sea cages

Fluctuating hypoxia is commonly seen in commercial salmon farming today while its impact on the fish is largely unknown. Hypoxia has been related to the oxygen consumption of the fish and the flow through the cages but an extensive description of the dynamics, and in particular the effects of the fish are lacking. The overall aim of the project is to describe the effects of fluctuating hypoxia on the fish, the dynamics of the oxygen consumption and flow through the cages and finally improve oxygen management in sea cages.

The project utilises a wide range of research tools; experimental cage environmental lab and commercial cages; tank environmental lab; experimental flow through tanks; towing tanks. Egersund Net has provided some of the nets used in experiments.

Tank trial on fluctuating hypoxia

This study investigated the performance and rate of habituation and acclimation of Atlantic salmon subjected to repeated fluctuating hypoxic levels ranging from 40-70% saturation by looking at appetite, stress indicators and oxygen uptake. The flexibility of the responses were considered based on the difference between hypoxic and normoxic periods. The results are being analysed in detail, but a general overview showing increasing negative consequences for the fish with the level of hypoxia are given in Table 1.

HYPOXIC LEVEL (% SATURATION)	EFFECT ON THE FISH
90:90	•
90:70	• REDUCED APPETITE AT LAST MEAL
90:60	• REDUCED APPETITE PARTLY COMPENSATED DURING FEEDING IN NORMOXIC PERIOD FOLLOWING 9 DAYS. • ANAEROBIC METABOLISM – LACTATE NO LONGER MEASURABLE AFTER 2 WEEKS. • INCREASED PROPORTIONS OF SKIN LESIONS.
90:50	• STRESS RESPONSE MEASURED AS INCREASED CORTISOL RELEASE, DOWNREGULATED AFTER 2 DAYS. • REDUCED APPETITE PARTLY COMPENSATED DURING FEEDING IN NORMOXIC PERIOD AFTER 9 DAYS. • REDUCED FEED CONVERSION AND GROWTH. • ANAEROBE METABOLISM – LACTATE LEVELS LOWERED AFTER 2 WEEKS. • INCREASED PROPORTIONS OF SKIN LESIONS.
90:40	• STRONG STRESS RESPONSE MEASURED AS INCREASED CORTISOL RELEASE, DOWN-REGULATED AFTER 4 DAYS. • IMPAIRED OSMOREGULATION AT FIRST HYPOXIC PERIOD. • MORTALITY AT DAY 1. • STRONGLY REDUCED APPETITE PARTLY COMPENSATED DURING FEEDING IN NORMOXIC PERIOD. • REDUCED FEED CONVERSION AND GROWTH. • ANAEROBE METABOLISM – LACTATE LEVELS LOWERED AFTER 2 WEEKS. • HIGH PROPORTION OF FISH WITH SKIN LESIONS.
90:30	• 30 % OXYGEN SATURATION FOR 2 HOURS DUE TO TECHNICAL FAILURE, 50 % MORTALITY.

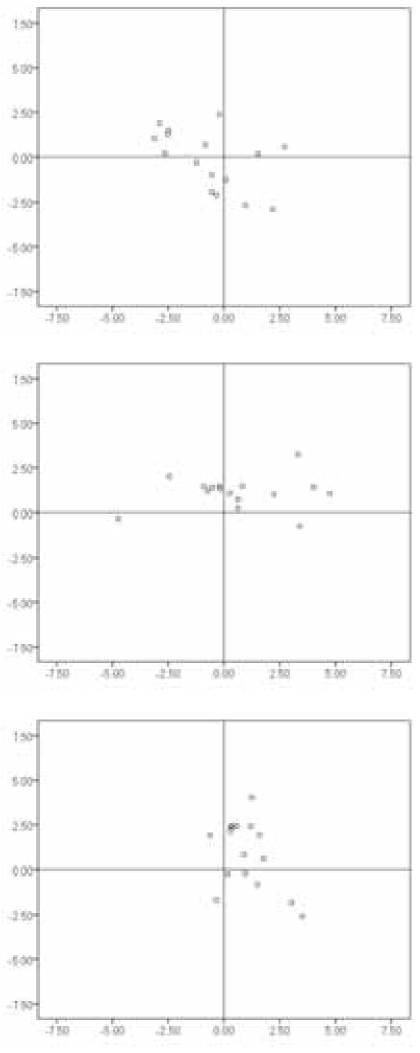
Table 1 : Effects of 2 hr of hypoxia 4 times daily on postsmolt Atlantic salmon grown in seawater tanks at 16 °C.

These results indicate that fluctuating hypoxia with oxygen levels lower than 60% induce severe effects on non-acclimated Atlantic salmon post-smolts. If given time to acclimate, the post-smolts seem to increase their hypoxic tolerance, but further research will be done to evaluate the acclimation process and long-term effects of fluctuating hypoxia.

Field trial at tank environmental lab and commercial site – flow and oxygen inside cages

The field measurements aimed at broadly describing the effects of an empty cage and a cage with fish on water flow and oxygen levels. The data show a distinct effect of the fish with a reduction of the water speed up to 60% and a change in direction related to the position in the cage. An example of the fish influence is given in Figure 5.

At the commercial site, large fluctuations in oxygen levels were observed in autumn, with short periods of alarmingly low levels several times every day (Figure 6). Within the single cage differences between positions were up to 35% saturation units of oxygen. Outside cages the oxygen level were 80 to 100% while inside cages values down to 30% were measured.



Velocity reduction through a net panel with different porosity

Net panels with different porosities were mounted in the flume tank in Hirtshals and force together with water flow in front of and behind the panel was measured. These data were used to make a 3d simulation of the effects of net panels on the flow. The simulation model will be further developed using cage models in the flume tank. The overall aim is to use the model to test different cage configurations to improve the position of cages at farms.

Figure 5 : Water velocity in north-south (vertical) and east-west (horizontal) direction (ms[1]) at three positions within a cage with Atlantic salmon at 5-8 m depth during daytime. The stocking density was around 9 kg/m³, while observed density at the plotted depths was 18-22 kg/m³. The data display a change in the angle of the water flow set by the circular schooling behaviour of the fish.

Flow field around a circular cage stocked with salmon.

Water velocities were measured using single-point current meters around an empty and a stocked circular sea-cage. The fish showed behaviour typical of caged salmon, forming circular schools with most fish swimming in the same direction. Preliminary analyses indicate 1) an horizontal outward flow from the centre of the cage in the depth of the main biomass of fish; and 2) a negative vertical flow in front of the cage and a positive vertical flow behind the cage. The caged fish therefore appear to have an influence on the flow previously not described.

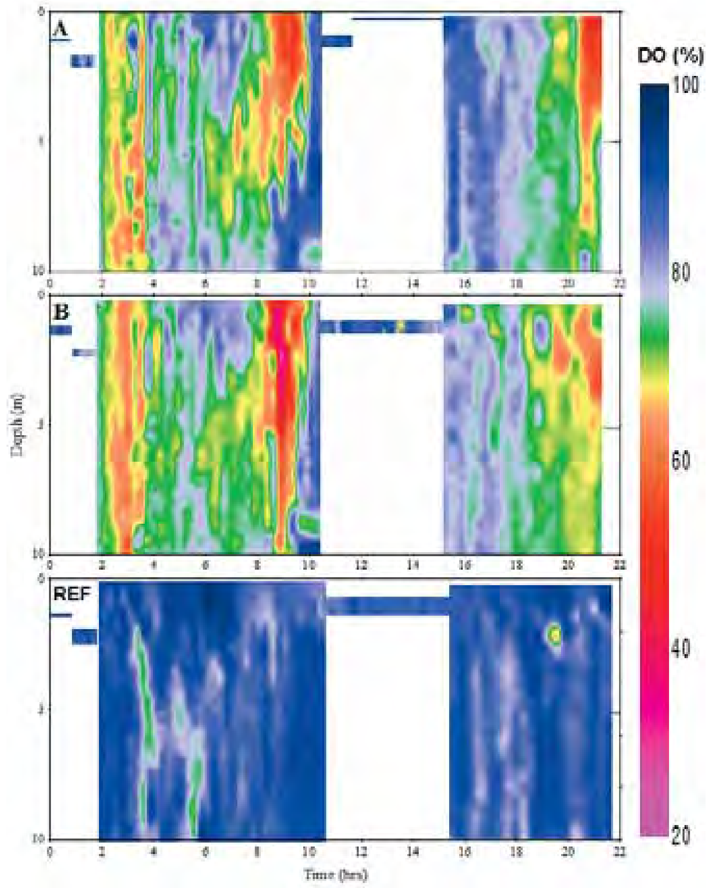


Figure 6 : Dissolved oxygen levels (DO %) at two different positions within the seacage (A, B) and a reference point (REF) outside the cage. Time 1 represent 8 PM. Oxygen levels reached below 30 % saturation certain periods during the night when the water flow was weak.

2.2 Non-disruptive fish weight estimation

Project leader:
Erling S. Skjevrak (AKVA Group)

Partners:
AKVA Group and SINTEF Information and Communication Technology

The objective is to assess and demonstrate the feasibility of automatic analysis and estimation of fish weight distribution based on images obtained from the Akva Group VICASS system.

Knowing the total amount of fish and the distribution of the weight of the fish in the cage is a critical factor for monitoring the growth and well being of the fish, for optimal feeding of the fish, and for planning of slaughter. This project aims at developing an instrument for semiautomatic measurement of the fish weight distribution throughout the growth period from smolt to slaughter. The instrument will use a stereo camera system and automatic image analysis to identify and estimate the fish weight from the images.

Images will be captured randomly at several locations within the cage (Figure 7). The number of locations

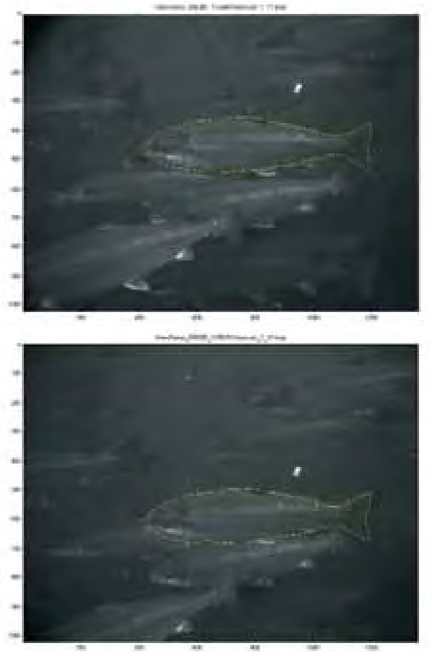


Figure 7 : A fish identified from a stereo image pair. The mouth is identified separately and marked with an asterisk. By comparing the shapes and positions of the fish identified in the two images, erroneous fish can to a large extent be detected and removed.

and the number of images from each location should be sufficient to get a statistically representative sample of the total population. The presence and outline of the fish in the images are determined automatically by image analysis and the weight of the fish is estimated based on the measured fish area. The image analysis is very challenging due to the tendency of the salmon to move in dense schools, the high degree of overlap between different fish in the images and the low contrast between the foreground and the background fish.

We investigated the potential that lies in the use of short sequences of images (video) in order to obtain a more reliable segmentation of the fish, and to verify the accuracy of an identified fish (Figures 8). Modern image analysis techniques are used, including variational image processing (optimization by means of partial differential equations), level sets segmentation and statistical shape variation models.

The project aims to first develop a semi-automatic version of the system where each identified fish needs to be verified by manual inspection before the fish is accepted, whereas the long term goal is to develop a fully automated instrument that can measure continuously over longer periods.

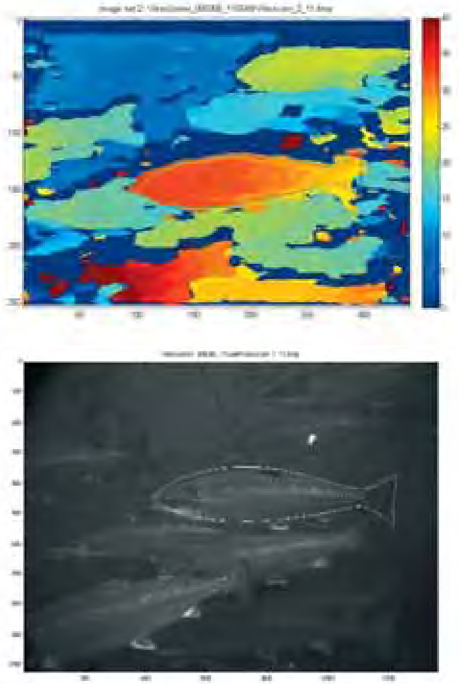


Figure 8 : Examples of intermediate results from the analysis.

Top: identification of the fish in the image based on a computed range image (different colors represent different distances to the objects). The front-most fish stands out clearly as red/orange in the image.

Bottom: starting point for the final search for a fish outline.

2.3 Physical properties of feed

Project leader:
Erling Skjevrak (AKVA Group)

Partners:
AKVA Group and NOFIMA Marin

The objective is to development a feedback system to minimize physical damage of feed during transport in feed systems.

Background

Today's fish feeds are produced from a large variety of feed ingredients. These have different properties in feed production, resulting in considerable variation in the physical quality of commercial feeds. Feed represents more than 50% of the costs in Norwegian fish farming, and the total yearly cost of feed is approximately 7 billion NOK. Thus, even small fractions lost or poorly utilised will amount to large sums.

The feed is commonly transported from a storage silo to the sea pens using a pneumatic conveying system, where the feed pellets are carried through pipes by an air stream. The collisions between pellets and pipe walls cause pellet breakage and formation of small particles, which represent loss, and the degree of breakage depends on the physical pellet quality. Consequently, high physical quality of the feed is demanded. However, the physical properties of the feed may influence the nutritional value of the feed. Suboptimal feed intake or feed utilisation resulting in reduced growth of the fish is difficult to quantify, but may cause considerable economic loss for the fish farmer.

Two trials were performed in 2008. In the first trial, breakage during feed conveying was investigated, whereas in the second trial, the effect of physical feed quality on nutritional values was investigated.

Methods

In the first experiment, three different 12 mm commercial salmon feeds (denoted A, B and C) were tested in a pneumatic conveying system (AkvaMarina CCS Feed System, Akvasmart, AKVA Group, Bryne, Norway), using different airspeeds

JANA GUENTHER - 29

Title research project:
Biofouling on aquaculture constructions

Education: 2008 PhD in Aquaculture, James Cook University, Australia.

Company/Institution:
SINTEF Fisheries and Aquaculture

Place of residence: Trondheim, Norway
Place of birth: Dresden, Germany

Leisure activities:
Snowboarding, walking, travelling, learning Norwegian

Latest publication:
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 (in press)

Nationality: German, Australian

3 research keyword:
Identification and quantification of biofouling.
Development of bioassays.
Settlement preferences of marine organisms.

3 keyword about yourself:
Flexible, resilient, happy to live in Norway.

Figure 9 : After 4 hr shaking in water, the pellets with high water stability (top) were almost intact, whereas the pellets with low water stability

(25, 30 and 35 ms^{-1}) and feeding rates (9, 18 and 36 kg min^{-1}). Samples of 2 kg were run through the system, sieved with different screen sizes, and each fraction weighed to quantify the formation of small particles. The physical quality of the feeds was measured with several different tests. The aim was to investigate the effect of air speed and feeding rate on degradation of three extruded fish feeds, and, if possible, to find a value for physical pellet quality that can serve as a steering parameter to adjust the settings of the conveying system.

In the second experiment, the aim was to compare the effect of different physical feed qualities on the nutritional value. Two feeds were fed to rainbow trout kept in constant or fluctuating environments (temperature, salinity and oxygen saturation). One feed had high water stability, whereas the other disintegrated rapidly in water (Figure 9). The nutrient digestibility was estimated by analysing feed and faeces collected from an experiment previously performed by NOFIMA in collaboration with BioMar.

Results and discussion

Feed quality was the main factor in pellet degradation in the conveying system in the first experiment (Figure 10). From the feed qualities used in this trial, no single parameter was found that cold predict the pellet degradation pattern, and thus be used to optimise the settings of the system. However, in general, high air speed increased the formation of small feed particles, whereas high feeding rate protected the pellets from breakage (Figure 10). As became evident in this trial, the relationship between feed ingredients, extruder parameters, pellet breakage during transportation and physical quality parameters of the feeds is poorly understood, and more research is required in this area.

The results already available for the second experiment showed that the feed intake was highest in trout fed the diet with low water stability, and when kept at constant environment. The growth tended to follow the same pattern, although the experiment was too short to produce significant

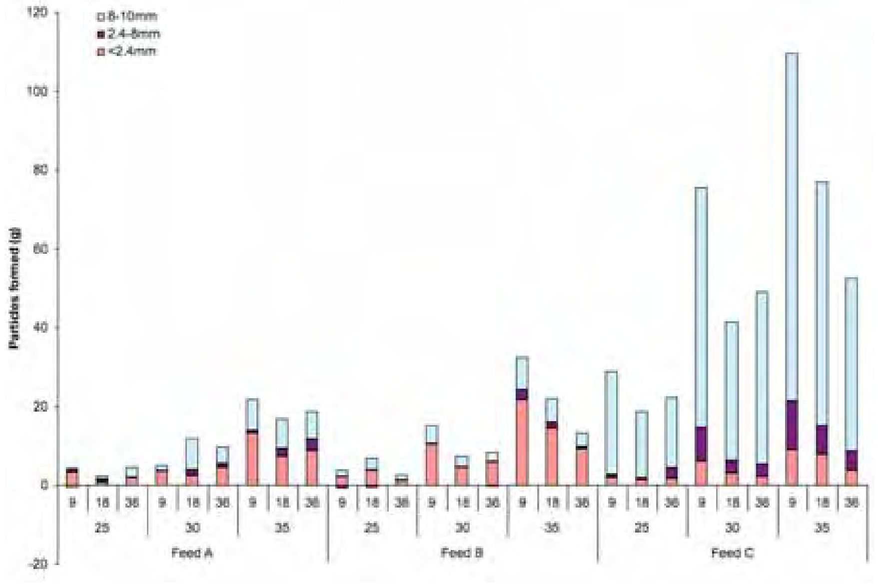


Figure 10 : Particles formed (g) from 2 kg sample of three different feeds (A, B and C) in the feed conveying system at different air speeds (25, 30 and 35 m sec^{-1}) and feeding rates (9, 18 and 36 kg min^{-1}).

differences in growth. Separated water and oil were also found in the stomachs of trout with the highest feed intake, which could potentially lead to fat belching. The apparent digestibility (%) of nutrients that was examined in the present project was in general highest in the diet with high water stability. This may be related to the feed intake, being lowest in fish fed this feed, and maybe having the longest transit time and thus being most effectively absorbed from the intestine. These results clearly showed that the physical properties of the feed affect its nutritional value, and that more attention should be paid to this relationship, both in research and in commercial fish farming.

2.4 Biofouling on aquaculture constructions

Project leader:
Leif Magne Sunde
(SINTEF Fisheries and Aquaculture)

Post-doctoral fellow:
Jana Guenther

Partners:
Egersund Net, SINTEF Fisheries and Aquaculture, NOFIMA Marin.

International collaboration:
University of Oldenburg (Germany) and James Cook University (Australia)

Additional collaborations:
Lerøy Midnor, Steen-Hansen Maling

The main objective is to develop a knowledge-fundament, capacities and solutions to bio-fouling, bio-fouling control, bio-fouling loads and bio-fouling sensors dedicated to net constructions.

Background

Marine biofouling is the undesirable accumulation of organisms on submerged surfaces, which poses a major problem for the aquaculture industry. To reduce biofouling and its associated negative impacts on farm constructions, operations and fish welfare, the Norwegian fish farming industry mainly uses red-brown copper-based coatings on nets combined with regular underwater washing. Over the last decade, the hydroid *Ectopleura larynx* has become one of the most common fouling species in the Norwegian fish farming industry (Figure 11), dominating the fouling community on aquaculture nets in South- and Mid-Norway between July and November. During the peak of the biofouling season, the fish farmers need to clean their nets every two weeks, which is a resource-demanding task. Therefore, the aim of this project is to understand the settlement preferences, growth and feeding biology of the hydroid *E. larynx* using both laboratory and field experiments, and develop strategies to reduce, control and remove hydroids on aquaculture nets in a more efficient and sustainable way.

Figure 11 : The hydroid *Ectopleura larynx* on nets

Methods

To investigate the settlement preferences of the hydroid *E. larynx* with regards to surface colour and micro-topography, we conducted settlement assays with *E. larynx* larvae in the laboratory. We also investigated the attachment of *E. larynx* on the fish cage nets and identified different strategies, which maintained their attachment to the nets. Furthermore, when the nets are washed underwater, small pieces of hydroids may remain on the nets, and we conducted two growth experiments in the laboratory to determine the effects of cutting hydroids on their ability to re-grow.

Finally, during field experiments at a commercial salmon farm near Hitra, we investigated the effects of colour and copper on the settlement and growth of biofouling. We also took underwater pictures of the biofouling community on cage nets at different depths (1, 5, 10 and 15 m) and over time (weekly to fortnightly sampling from August to December 2008). These pictures are currently being processed with an image analysis program to calculate the net aperture occlusion.

Results and discussion

The results of our laboratory study demonstrated that colour did not influence the settlement of *E. larynx*. While there was a statistically significant difference in the settlement of *E. larynx* between white and black surfaces in the single choice settlement assays, this difference was not biologically, or consequently economically, significant given high levels of settlement. Furthermore, when given a choice between these two colours in a multiple choice settlement assay, *E. larynx* did not preferentially settle on either colour. The field experiments with white and red nets also showed that there was no significant difference in the wet weight of biofouling after 10 weeks of immersion. In contrast to colour, cuprous oxide in coatings on nets effectively reduced the settlement of *E. larynx*, with no *E. larynx* settling on these nets within 10 weeks of immersion. However, given that discharges of copper from antifouling agents used in Norway are to be substantially reduced before 2010 and alternative copper-free biocidal coatings are currently lacking, novel solutions for the effective and environmentally sustainable control of biofouling on aquaculture constructions need to be developed.

This study also showed for the first time that hydroids maintain their attachment to the nets by three strategies: winding the hydrophyton around the net, growing between loose filaments and threads, and incorporating filaments into their chitinous perisarc. Therefore, current net constructions with multi-filament nylon threads provide a structure for maintaining the attachment of both juvenile and adult *E. larynx* on the nets and hinder their removal.

Finally, the growth experiments in the laboratory demonstrated that *E. larynx*, whose polyps had been cut off, could re-grow to complete adults within 5 days. Even when *E. larynx* were cut repeatedly every 2 days for 6 days, they could re-grow. These results suggest that hydroids need to be removed completely during the underwater washing procedure to delay their re-growth on the nets.

Future research in 2009 will focus on the effects of (1) nano-structured surfaces on the settlement of *E. larynx* larvae, (2) fish feed and faeces on the feeding of *E. larynx*, and (3) the underwater washing procedure on the net structure, coating and biofouling development on cage nets.

2.5 Creating new submersible cage systems - Subcage Technology

Project leaders:
Alf Kristian Fjelldal (AKVA Group)

Partners:
AKVA Group, Egersund Net AS, Erling Haug og SINTEF Fisheries and Aquaculture

Objective and goals: Improve the reliability of the processes of cage submergence and lifting by means of process control, automation and remote control.

Main expected result: Create and improve existing cage systems, feeding systems, nets and moorings as one submersible unit in order to be used offshore.

Background

A detailed survey of the status of current submersible cage technologies has been undertaken. Several different technological solutions for submersible cages exist but none have been particularly successful, mainly due to poor control of the submerging and lifting processes, insufficient cage volumes for commercial culture and poor integration between all the necessary farm components. Most of these existing solutions have been trialed and abandoned with the result that farmers still have to use conventional surface-based cages. The survey also identified the key technological requirements for the success of a submersible cage system. These can be classified in three parts:

1. Nets: depth, twine and mesh size, requirements for access, submerged and in surface position, positioning of the net roof in surface position, system to maintain the net volume, cleaning system
2. Environmental information: wind, current, waves
3. Choice of mooring solutions: limitation of area, depth of seabed, method of submerging, type of mooring, single or in a cage-frame system

Methods

The SubCage project is being developed in two phases: 1) development of a system for short-term submergence at offshore sites to avoid bad weather, poor temperatures or other suboptimal conditions e.g. a system that can be submerged for 1 to 5 days without the need for specialised feeding and surveillance systems; this will be done using conventional cages and development of a simple yet controllable system to sink the cage; and 2) development of a *next generation* submersible cage that satisfies all design requirements listed above.

Results and discussion

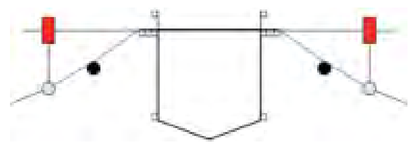
Development of a system to sink conventional cages: This system will be used when bad weather, poor surface temperatures or other conditions negative to production in surface waters occur at a farm. A detailed experimental study in the SINTEF Fisheries and Aquaculture Hirtshals flume tank using a scale model of a conventional commercial cage has been undertaken. Egersund Net has delivered the nets used and the cage has been designed by AKVA group.

In parallel a simulation tool has been developed to reproduce the behaviour of the submerged cage.

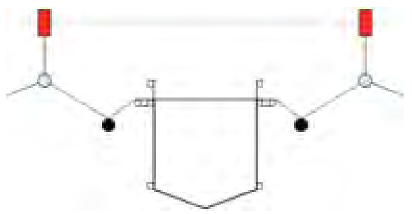
Experiments: A cage sinking and lifting concept was tested in the Hirtshals lab (Figure 12). Different cage positions were obtained by moving the loads (black dots) along the mooring lines and the behaviour of the cage was studied by increasing the flow velocity. Stresses were measured along each line and cage deformations due to currents were recorded with a 3D camera system.

The combination of the load positions and the current flow velocity produced different strains in the anchoring lines in the front and back of the cage and resulted in different angles of rotation of the cage (Figure 13).

Results from the flume tank trials will be used as inputs for the simulation which is under development (Table 2). Simulations will enable deeper understanding of the complex behaviour of the conventional cages during submergence.



A.



B.

Figure 12 : Concept of the system to sink conventional cages:

A. Floating cage

B. Submerged cage during flow

Figure 13 : Example of submerged cage behaviour in the flume tank.

LOADS POSITION ALONG THE LINES	STRESS IN THE FRONT LINES	STRESS IN THE BACK LINES	ROTATION OF THE CAGE
LOWER FOR ALL 4 LOADS	DECREASE WITH VELOCITY FLOW	DECREASE WITH VELOCITY FLOW	ANTICLOCKWISE
HIGHER FOR ALL 4 LOADS	SLIGHT INCREASE WITH VELOCITY FLOW	SLIGHT INCREASE WITH VELOCITY FLOW	ANTICLOCKWISE
MEDIUM POSITIONS FOR ALL 4 LOADS	STRONG INCREASE WITH VELOCITY FLOW	SLIGHT INCREASE WITH VELOCITY FLOW	ANTICLOCKWISE
MEDIUM POSITIONS FOR 2 LOADS IN THE FRONT AND LOWER FOR 2 LOADS IN THE BACK	STRONG INCREASE WITH VELOCITY FLOW	STRONG DECREASE WITH VELOCITY FLOW	ANTICLOCKWISE
LOWER POSITIONS FOR 2 LOADS IN THE FRONT AND MEDIUM POSITION FOR 2 LOADS IN THE BACK	STRONG DECREASE WITH VELOCITY FLOW	STRONG DECREASE WITH VELOCITY FLOW	ANTICLOCKWISE
LOWER POSITIONS FOR 2 LOADS IN THE FRONT AND HIGHER FOR 2 LOADS IN THE BACK	STRONG INCREASE WITH VELOCITY FLOW	STRONG DECREASE WITH VELOCITY FLOW	CLOCKWISE

Table 2 : Results from the stress and camera measurements

Simulation tool: Mathematical models of three different submersible cage concepts are being develop to allow simulations to perform stability analyses of the models. All models are fully dynamic and in 3D, based on a common basic model of the cage, but with different concepts for the submergence process. These three concepts are: 1) movable point mass on the (only) top bridle line; 2) fixed mass on the bottom bridle line at various positions, connected to the bottom ring; and 3) variable buoyancy devices attached to the bottom ring. This model is still under development.

Next generation submersible cage concepts: Phase two of the project will explore alternatives for next generation cages, with a focus on fish welfare. The concept aims to address the critical aspects for cage performance and innovate new solutions. Ideas and concepts are under development. The final concept is taking shape and is expected to be ready for testing before mid-2009.

MARTIN FØRE - 27

Title research project: Modelling of fish behaviour in sea-cages

Education: MSc in Engineering Cybernetics, Norwegian University of Science and Technology. PhD in Engineering Cybernetics (ongoing, finished 2010)

Company/Institution: SINTEF Fisheries and Aquaculture/Department of Engineering Cybernetics, NTNU

Place of residence/birth: Trondheim/Bodø

Leisure activities: Fishing, hiking, swimming, skiing (cross-country and down-hill), didgeridoo-playing

Latest publication: Modelling of Atlantic salmon (*Salmo salar L.*) behaviour in sea-cages: A Lagrangian approach(2009). Aquaculture 288 (3-4): 196-204.

Nationality: Norwegian

3 research keyword: Mathematical modelling, biology, programming

3 keyword about yourself: Happy, patient, likes challenges

2.6 Biological tolerances of fish to submerged cage culture - SubCage Biology

Project leader:
Tore Kristiansen
(Institute of Marine Research)

Partners:
Institute of Marine Research and
SINTEF Fisheries and Aquaculture

Additional collaboration:
University of Bergen

Background

Numerous circumstances exist whereby surface conditions become sub-optimal for salmon production. These may directly affect the salmon (e.g. excessively high or low temperatures, low dissolved oxygen, algal and jellyfish blooms, surface aluminium levels, and sea lice) or negatively affect farm structures (e.g. storms, currents, icing, and biofouling; Table 3). Clear instances exist where submerging salmon could avoid mass mortalities. For example, a salmon farm in Canada lost 260 tons of salmon during toxic algal blooms in autumn 2007. Further, 500 tons of salmon died in Northern Ireland in November 2007 due to a dense swarm of jellyfish at depths of 0 to 11 m. Despite the potential advantages, submerged systems for salmon have not been adopted by the industry partly because of a lack of knowledge regarding the effects of submergence.

The uncertainty surrounding submergence is related to the assumption that salmon become negatively buoyant when submerged beneath a cage roof as they cannot access the surface to gulp air and fill their open swim bladders. Salmon regulate their buoyancy largely by swallowing air from the surface into the swim bladder which is joined to the stomach and then releasing air when necessary through 'burping'.

Through three successive experiments at the Cage Environment Laboratory of the Institute of Marine Research in southern Norway, the effects of submergence on swimming speeds, schooling, feeding, body and fin condition, and growth rates of salmon in full-scale sea-cages with simultaneous monitoring of environmental conditions were investigated.

CAUSE	DEPTH OF INFLUENCE (M)	DURATION	SOURCE
STORM	0-10	HOURS - WEEKS	JENSEN 2006
CURRENT/NET	0-20*	HOURS - WEEKS	LADER ET AL. 2008
ICE	SURFACE STRUCTURES	HOURS - DAYS	JENSEN 2006
ALGAL BLOOM	0-20	DAYS - WEEKS	JOHNSEN & SAKSHAUG 2000
JELLYFISH BLOOM	0-10	HOURS - WEEKS	SAMMES & GREATHEAD 2004
SALMON LICE LARVAE	0-5	DAYS - MONTHS	JOHANNESSEN 1978
REDUCED OXYGEN	VARIABLE	HOURS - WEEKS	JOHANSSON ET AL. 2006
UNSUITABLE TEMPERATURE	0-10*	HOURS - WEEKS	JOHANSSON ET AL. 2006
HIGH ALUMINIUM LEVELS	0-2	DAYS - WEEKS	BJERKNES ET AL. 2003
BIOFOULING	0-10*	SUMMER, AUTUMN	BRAITHWAITE ET AL. 2007

Table 3 : Causes, depth of influence and duration of unsuitable surface conditions for salmonid aquaculture in sea-cages.

Methods and Results

Experiments 1 and 2 assessed the affect of submergence to shallow depths (cage roof at 3-5 m) for periods from 17 (Experiment 1) to 22 (Experiment 2) days on fish of average sizes of 1.7 kg (Experiment 1, 500 fish per cage) and 0.5 kg (Experiment 2, 4000 fish per cage) (Figure 14). In experiment 2, artificial lights were also used so that fish had enough light to school during night time (Figure 15).

Figure 14 : Salmon beneath the roof of a submerged cage.

Figure 15 : Night time view of the sea-cages with underwater lights at 10 m deep.

In both experiments, salmon in submerged cages swam 1.5-1.6 times faster than salmon in surface control cages and schooled more tightly. No evidence of acute buoyancy control problems was observed in the submerged fish and submergence did not affect feed intake. Small reductions in growth were found in the submerged fish in Experiment 1, relative to control fish, however, submerged fish also experienced lower temperatures which likely contributed to this difference. No differences in growth rates were found between submerged and control fish in Experiment 2 when control and submerged fish experienced similar environmental temperatures. While salmon lost air from their swim bladders over time (Figure 16), they appeared to tolerate submergence by swimming faster, possibly as a behavioural adaptation to generate lift to counter negative buoyancy. These results contrast with the strongly negative effects on submergence found by previous trials that used small-scale enclosures in which fish did not have sufficient room to swim freely. Our results open the possibility of shallow submergence of sea-cages for short periods matched to the time scales of negative surface events in search of more favourable conditions at depth.

The third experiment assessed the effects of submergence on large salmon subjected to submergence during the dark of winter. On average, 2345 salmon of ~3.5 kg were kept in each of six 2000 m^3 sea-cages for 6 weeks; three of which were submerged to 10-24 m depth and three acted as surface controls (0-14 m). The submerged salmon seemed unable to refill any gas into the swim bladder, as a linear decrease in echo reflection to <5% of pre-submergence levels after 22 days of submergence indicated loss of almost all gas from the physostomous swim bladders and negatively buoyant fish. Around day 22, submerged salmon swam at night time with a distinct "tail-down, head-up" tilt (26°) compared to the horizontal swimming position of control fish (-3°). Average swimming speeds of submerged salmon were 1.3-1.4 times faster than control fish both during day and night. Almost no mortality was seen, and the submerged salmon maintained similar diurnal vertical migrations as the surface fish, indicating that deep submergence did not exhaust the fish. However, submerged fish fed less efficiently, resulting in lower growth and reduced feed utilization. Fins and snouts of the submerged fish had small, but significantly more erosion than the control fish. Vertebrae in the tail region were significantly compressed in the submerged fish compared to control fish. This could be an early symptom of development of vertebral deformities.

METTE REMEN - 29

Title research project:
Effects of fluctuating hypoxia on sea-water Atlantic salmon

Education:
Master of Science (Aquaculture Biology)

Company/Institution:
Institute of Marine Research

Place of residence: Bergen, Norway
Place of birth: Malvik, Norway

Leisure activities: Hiking, skiing, spending time with friends and family

Latest publication: Remen M., Imsland A., Stefansson, Jonassen, Foss A (2008). Interactive effects of oxygen and ammonia on growth and physiological status of juvenile Atlantic cod (*Gadus morhua*). Aquaculture, 274, 292-299.

Nationality: Norwegian

3 research keyword:
Hypoxia, Metabolism, Stress

Discussion

The results from the three trials suggest that while continuous sub-mergence reduces the growth and welfare of Atlantic salmon, salmon cope remarkably well with short sub-mergences. Therefore, submergence may prove to be a highly useful cage management technique to avoid sub-optimal surface conditions for salmon production over different time scales. Our results open the possibility of submergence for periods matched to the time scales of negative surface events in search of more favourable conditions at depth. Shorter, sequential submergences may be an option that allows salmon to periodically re-fill their swim bladders at the surface before being returned to depths where better conditions prevail.

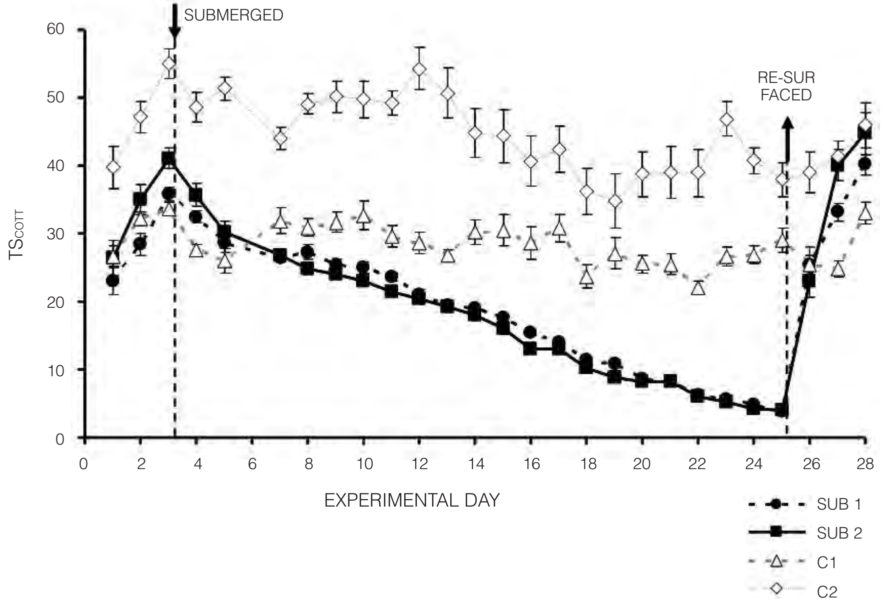


Figure 16 :
Gradual loss of air in the swim bladders of salmon in Experiment 2 following the submergence of sea-cages on day 3 and re-filling of the swim bladders through gulping at the surface when cages were re-surfaced after day 25. TS_{corr} shows the strength of the signal from the echo-sounder, which directly depends on swim bladder size. Sub 1 and Sub 2 show the submerged cages and C1 and C2 the control cages where salmon had access to the surface.

2.7 Bio statistical analysis

Project leader:
Eivind Brendryen (AKVA Group)

Partners:
AKVA Group, SINTEF Information and Communication Technology and NOFIMA Marin

The main objective is to develop a cage-by-cage analytical tool capable, by applying standard and relevant statistical procedures, of identifying the main explanatory factors involved in the differential performance of fish populations in cages.

Background

Fishtalk is a software product used in production control for farming fish. Biological, financial and environmental information is recorded, reported and analysed. Fishtalk uses several models to simulate growth based on a number of factors, like feed consumption and environmental measurements.

The harvest size distribution is often presented as a normal distribution. At harvest time the CV (Coefficient of Variance) can be in the range of 18-25%, and this variation has a huge impact on the actual product to deliver, which is typically boxes of fish in intervals of 1 kg. Orders are placed on specific sizes, so if the distribution is far different from the estimate, the producers end up with too much fish in some weight intervals, and too little in others. This makes the distribution and sales operation more expensive, as alternate solutions must be found in short time, typically on the day of harvest.

This project aims to add size and quality distribution estimation to Fishtalk by means of models using a large database of harvested fish groups as input. We also aim to find markers in the data set that indicates when there is an increase in possibility that there will be a large deviation between estimated and actual stock in the fish cage.

Methods

The project has used different statistical methods for identifying parameters or factors influencing the stock status and the size distribution.

Among the methods used are the ASMOD framework developed at SINTEF. The ASMOD (Adaptive Spline Modelling of Observation Data) algorithm is an algorithm for empirical modelling. It uses B-splines to represent general nonlinear and coupled dependencies in multivariable observation data. The model is iterative to find the best parameter representation of the data. Methods like student's t-test and ANOVA (analysis of variances) have been used to test hypotheses regarding features initially believed to have a significant influence on the fish population in the cages.

Results and discussion

The majority of work so far has been based on data from the 2006 generation. We see that the data verify the biological theories on growth like the importance of temperature and feeding.

We also have identified that the size distribution seems to have a:

- Larger spread the longer the cage is in sea
- Smaller spread for larger average weight fish
- Cages that are split without grading results in a larger spread of fish weight when harvested compared to cages that are graded into small and large
- Sea temperature at the end of the growth might be of influence to the size distribution

2.8 SimFrame – CREATE Simulation and Optimization Framework

Project leader:
Gunnar Senneset
(SINTEF Fisheries and Aquaculture)

Partners:
All CREATE Scientific and industry partners participate in the project.

The main objective is to develop a framework for simulation, optimization and monitoring of all aspects of modern fish farming.

Background

Integration of knowledge and models from specialized fields is essential for improving fish farming planning and operations. The end results of an aquaculture production cycle in terms of product properties, quality and economy depend on many different factors as illustrated below.

Project goals

The project started early this year, and the overall objective is to develop a framework for simulation, optimization and monitoring of all aspects of modern fish farming. To limit the complexity, the scope of the initial framework is floating fish farms. Main goals for 2009 are:

- Use selected cases/application areas to identify functional specifications and to identify relevant technical components/ tools the framework should include
- Demonstrate the feasibility of the framework by prototyping the framework and integrating models for selected cases
- Describe roadmap for further development

The project has R&D challenges along several directions:

- Establishing common platforms for data capture, ontology, knowledge representation etc. across multiple disciplines
- Integration of heterogeneous model environments
- Data synchronization and performance issues
- HMI design and evaluation

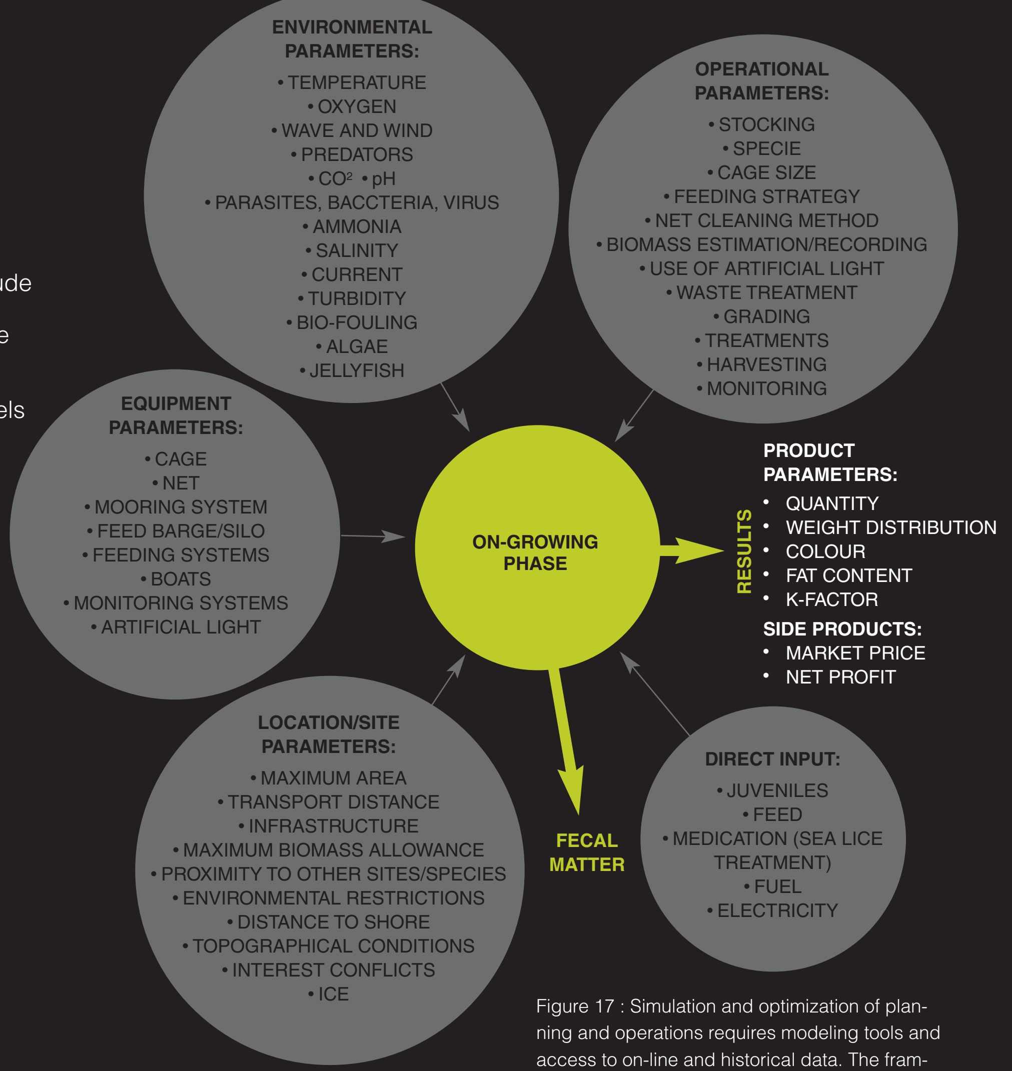
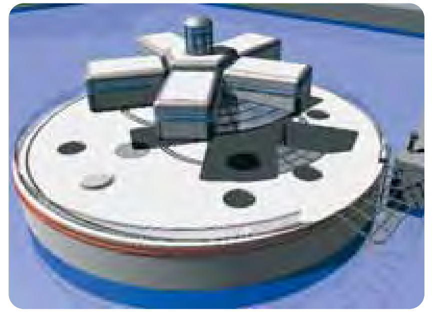


Figure 17 : Simulation and optimization of planning and operations requires modeling tools and access to on-line and historical data. The framework will facilitate the integration of both existing models and models developed in CREATE.

It is also expected that the work on the CREATE platform will identify lack of knowledge or models within some disciplines. This implies that the platform needs to be dynamic, i.e. support continuous development and exchange of components as the industry evolves. One focus area in the initial project phase is the development of use cases for future application areas.



2.9 Post-doc project title: CFD simulations of flow through fish cages

Post-doctoral fellow:
Shim Kyujin,

Co-researches:
Pascal Klebert and Arne Fredheim,
(SINTEF Fisheries and Aquaculture)

Background

Structure and design of fish cages can be improved by the knowledge of the flow pattern around and inside the net cages. To address this problem, commercially available computational fluid dynamics (CFD) software is used to analyze this problem by calculating the drag and the flow velocity distribution around cylinders with different porosities. Aquaculture cages are very large structures that consist mainly of netting, which can be approximated by small cylinders connected at knots. Due to the large number of these cylinders (millions for a single salmon farming cage), it is computationally expensive to model the exact geometry. Biofouling is another factor which is of particular interest as fouled nets (lower porosity) can significantly reduce flow of well-oxygenated water reaching the fish during normal rearing conditions. Therefore the numerical approach used to simulate the flow through and around the net cage is to consider it as a circular cylinder with a porous jump boundary. Drag coefficient and flow pattern are compared with available experimental data. Vertical cylinders are used for this study. Different porosities have been used for the simulations as for the experiments in order to simulate the impact of the fouling on the load of the net structures and the flushing of the cage. The results show that a porous jump with a pressure drop proportional to velocity squared has the best agreement with measured data.

Methods

Numerical simulations of solid cylinders with 20% - 90% porosity towed at 0.05 ms^{-1} velocity have been performed. In this study, FLUENT a commercial CFD program is used for the simulation; it is based on the Finite Volume Method. The fluid dynamics for analysis of fish cages with porous boundary condition basically consists of continuity equations and momentum conservation equations. Incompressible flow is used for these steady state simulations and turbulence is modelled by using the realizable k-ϵ model. The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm was used for pressure–velocity coupling. A first order upwind scheme is used for discretization. Maximum residual tolerance was set at under 1×10^{-6}. Figure 18 shows the grid system for solid and porous cylinders. A mixed (hexa-hedral and tetrahedral) cell model was used for numerical simulation, and was chosen by a mesh independent test. In order to simulate the porosity of a net cage, the porous jump boundary condition available in the FLUENT package was used. The porous boundary condition can be used for modeling a wide variety of engineering applications, including flows through packed beds, filters, perforated plates, flow distributors and tube banks. It is

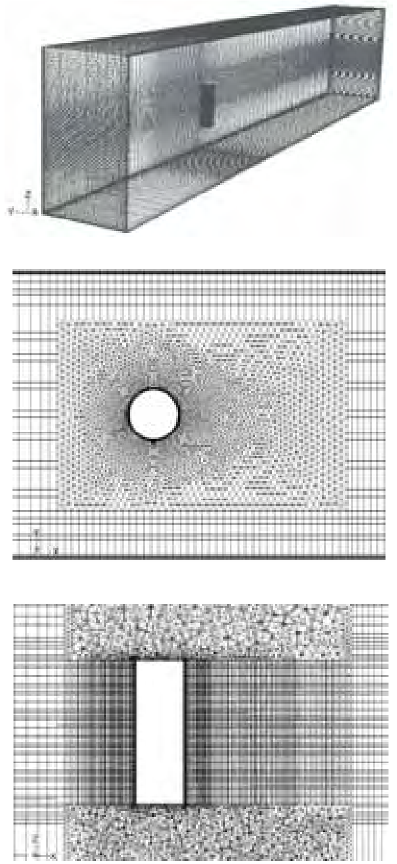


Figure 18 : 3D view of the complete grid (top), sectional view in XY plane (middle) and sectional view in XZ plane (bottom).

generally desirable to determine the pressure drop across the porous area and to predict the flow field in order to optimize a given design. Porous jump conditions are used to model a thin membrane that has known velocity (pressure-drop) characteristics. This simpler model has been used instead of the full porous media model also available, because of its robustness and better convergence.

Results and Discussion

CFD simulations proved suitable to investigate flows around fish cages. The drag coefficient in the model was calculated as

$$C_D = \frac{F_D}{\frac{1}{2} \cdot \rho \cdot A \cdot v^2}$$

where C_D is the drag coefficient, F_D is the drag force, ρ is the density of fluid A is the projected area of the cylinder and v is the inflow velocity. Figure 19 shows the drag coefficient comparison of solid and porous cylinders at Re=5000. Drag force from the experiment of Gansel et al. (2008) with time averaged has been calculated on 20 cm. Random events usually happen on smaller time scales than periodic events like vortex shedding. It is therefore necessary to use time series for the time averages calculation that are long enough to include several cycles of periodic events. The towing arrangement consisted of one cylinder attached to a circular end-plate. The diameter of the plate was 3D. For this reason, the experimental drag coefficient of the solid cylinder for Re=5000 showed higher drag coefficient than the simulation results. However, the trend of drag coefficient showed a good agreement with regular intervals between experiment and simulation. The drag coefficient decreased with the increasing open area (%) of the porous models after 30 and 35% open area. 20 and 25% open area cylinder indicated lower drag coefficients than 30 and 35% open area cylinders. Noymer et al. (1998) used the Darcy model to describe the flow through a porous cylinder. A peak zone in the drag ratio was observed at Re=100 and Re=1000. Present simulation results showed a very similar pattern with increased open area (%). The streamlines for increased open area is presented in Figure 20 a-e for Re=5000. For a solid cylinder, the vorticity diffuses from the surface into the external flow field, whereas, for all porous cylinders vorticity diffuses into both the external and internal flow fields. At 20% open cylinder, a stream entering the porous cylinder generates a recirculation zone on the inside of the cylinder due to the recirculation set up by the external field at the rear end. At 25% open cylinder, a stream can not pass right through the porous cylinder, because of the recirculation that still exists by the external field one diameter downstream from the centre of the cylinder. Hence, the streamline passes along the cylinder and then bypasses the recirculation zone. 30% and 40% open cylinders do not produce recirculation zones on the inside and rear of the cylinder. Less bypass flow and the increased velocity of the fluid at the interface may lead to an increased drag coefficient for the 30% open cylinder. The angle of flow separation from the porous cylinders is 124° for 20% open cylinder, 118° for 30% open cylinder and 127° for 40% open cylinder. The separation angle is measured from the front stagnation point. Corroborative evidence from the pick zone in the drag coefficient is that the separation point shifts towards the front and rear stagnation point with 30% open area cylinder as the centre.

The porous cylinder allows a finite amount of fluid to pass through with a non-zero velocity at the interface. With increasing open area after 30%, the velocity of the fluid at the interface increases. This velocity has the effect of reducing the relative importance of the inertial forces in the external field.

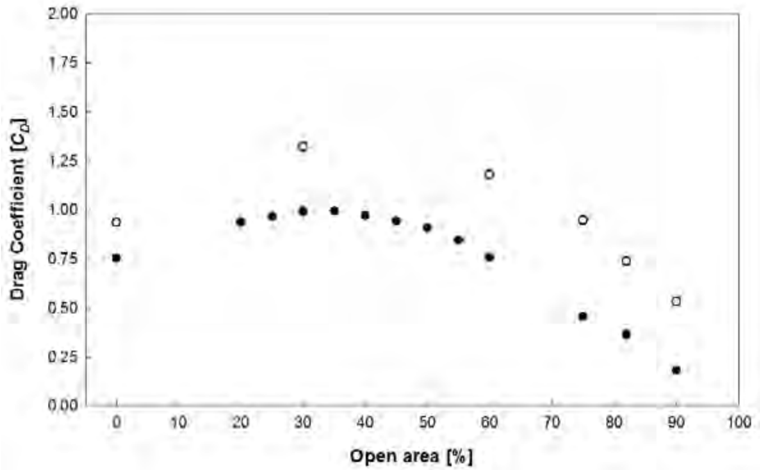
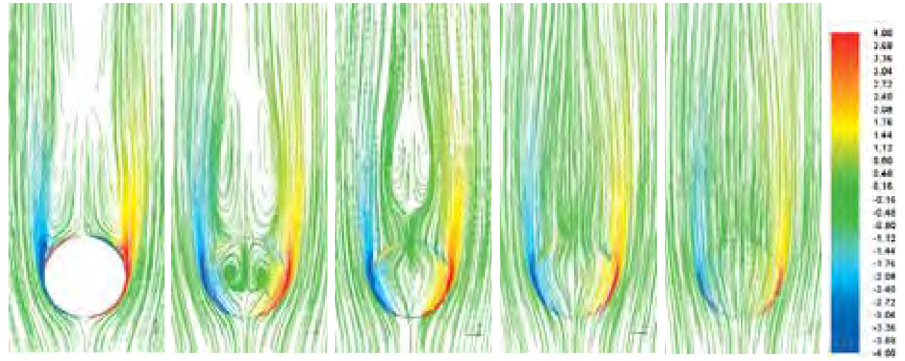


Figure 19 : Drag coefficient comparison with experiment and simulation for 0% ~ 90% open cylinder at Re=5000. ○ : Gansel et al. (2008) experiment; • : present simulation.



a) b) c) d) e)

Figure 20 : Streamlines for the flow through the cylinder rendered by contours of the z-vorticity in the z/D=1.5 at Re=5000 (a) 0% open cylinder; (b) 20% open cylinder; (c) 25% open cylinder; (d) 30% open cylinder and (e) 40% open cylinder.

JO ARVE ALFREDSEN - 39

Title research project: Model-based estimation tool for monitoring and control of fish farming operations SimFrame.

Education:
PhD Engineering Cybernetics
Assoc. Professor

Company/Institution:
Norwegian University of Science and Technology

Place of residence: Trondheim, Norway

Latest publication:
Martin Føre, Tim Dempster, Jo Arve Alfredsen, Vegar Johansen, David Johansson (2009). Modelling of Atlantic salmon (*Salmo salar L.*) behaviour in sea-cages: A Lagrangian approach. Aquaculture 288: 196-204.

Nationality: Norwegian

3 research keyword:
Cybernetics, Mathematical modelling, Embedded systems.

2.10 Biological criteria for successful submergence of physoclistous Atlantic cod *(Gadus morhua)* and physostomous Atlantic salmon *(Salmo salar L.)* reared in sea-cages

PhD fellow:
Øyvind Korsøen

Co-supervisors:
Tim Dempster (SINTEF Fisheries and Aquaculture), Frode Oppedal, Jan-Erik Fosseidengen and Tore Kristiansen (Institute of Marine Research).

PhD content

Øyvind's PhD research is within the SubCage Biology project. In addition to research investigating the tolerances of both salmon to submergence described earlier, specific experiments are aimed at determining safe limits for raising and sinking Atlantic cod in submerged cages.

Background

Farmed cod forced rapidly to the surface from 20 m depth in sea-cages experience severe barotrauma, indicated by ballooning of the swim bladder and leading to poor welfare and, on occassion, mortality. In the relatively new cod farming industry, a distinct trend is to use deeper nets to provide greater volume and allow cod to access deeper waters where environmental fluctuations, such as temperature, are less frequent. If submersible cages are to become a common farming method, the rate of lowering and lifting of the cage will be a critical factor for farming of fish with closed (physoclistous) swim bladders.

In contrast to the open swim bladder of salmon, the closed swim bladder system in cod causes limitations for rapid vertical movement. The time needed for cod to double the pressure in their swim bladder increases with increasing pressure, from a few hours near the surface, to several days at hundreds of metres. The rate of gas secretion also increases with temperature.

Deflating the swim bladder is a faster process; a 50% pressure reduction takes 3-4 hours (Harden Jones & Scholes 1985, Strand et al. 2005). Buoyancy challenges related to pressure reduction are greatest near the surface where the largest relative change in pressure occurs. A fast ascent corresponding to 60-70% pressure reduction caused swim bladder rupture in cod kept in a pressure chamber (Tytler and Blaxter, 1973). Righton et al. (2001) followed individual cod in the sea, and suggested 25% reduction and 50% increase in pressure as limits for cod to maintain proper buoyancy control. Based on observed maximum pressure reduction chosen by free swimming DST-tagged cod in a 35 m deep cage, a pressure reduction of 40% is suggested by Kristiansen et al. (2006) as the upper limit for handling farmed cod. In this study we aimed to make a safe procedure for lifting of Atlantic cod kept in sea cages.

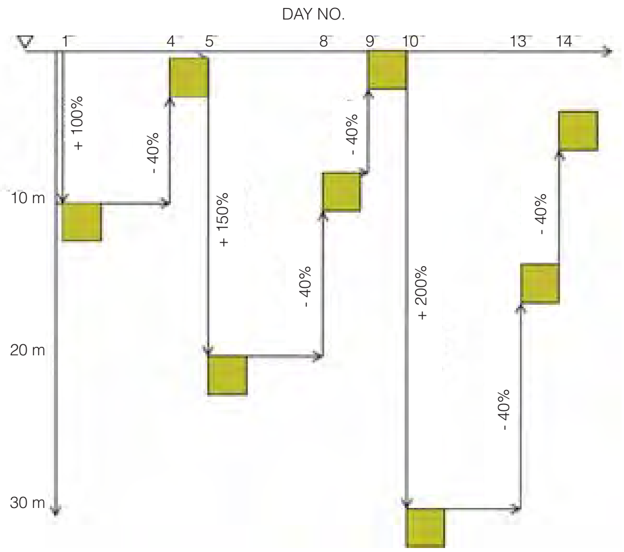
Material and methods

We investigated whether a 40% pressure reduction relative to neutral buoyancy depth was a safe limit for lifting of cod, if this was independent of depth and temperature (16°C and 4°C), and how long an acclimation time was necessary to acquire neutral buoyancy at the new depth. A submerged sea-cage (5x5x2.5 m³) containing 100 cod (~1200 g) with neutral buoyancy at start depth, were lifted to 40% pressure reduction from three depths (10, 20, 30 m; Figure 21). In the same experiment, we also estimated the swim bladder secretion rate and time to neutral buoyancy after a rapid descent near the surface to 10, 20 or 30 m (Figure 21). Swimming behaviour (tilt angle, swimming speed, tail beat frequency) based on video observations was used to judge positive or negative buoyancy and coping ability. A feeding test was used to evaluate stress levels and behavioural control at fixed intervals after the pressure changes.

Results and discussion

In general, cod coped with all of the vertical lifting and sinking steps in this regime through behavioural adaptation. Submergence from the surface to 20 and 30 m caused negative buoyancy, indicated by tilted swimming (head up) and extended periods where cod lay upon the net bottom, especially during dusk and dawn. After each lifting step, positive buoyancy was indicated by increased swimming speeds and 'yo-yo' swimming where cod drifted upwards without swimming until they reached the top of the cage and then swam downwards to the bottom of the cage with powerful tail beats. A duration of 2-4 hours was normally sufficient for cod to return to a good appetite response and more relaxed swimming behaviour. Neutrally buoyant cod therefore appear capable of being rapidly lifted vertically in sea-cages for distances equivalent to a 40% pressure reduction, independent of depth. Rapid descent of neutrally buoyant cod from the surface to 30 m sometimes resulted in large amounts of cod resting upon the net bottom, which may have implications for both cod welfare and loadings on net cages.

Figure 21 : Submergence and lifting steps for Atlantic cod in the experiment.



FRODE OPPEDAL - 39

Title research project:
Cage Environment

Education: Dr. scient., University of Bergen

Company/Institution:
Institute of Marine Research

Place of residence: Bergen, Norway
Place of birth: Bergen, Norway

Leisure activities:
Active in hiking, diving, skiing and care of my family

Latest publication:
Oppedal F, Juell J-E, Johansson D (2007). Thermo- and photoregulatory swimming behaviour of caged Atlantic salmon: Implications for photoperiod management and fish welfare. Aquaculture 265: 70-81.

Nationality: Norwegian

3 research keyword:
Welfare, behaviour, hypoxia

2.11 Modelling and simulation of fish behaviour in aquaculture production facilities

PhD fellow:
Martin Føre

Supervisor:
Jo Arve Alfredsen (Dept. of Engineering Cybernetics, NTNU)

Co-supervisors:
Tim Dempster (SINTEF Fisheries and Aquaculture), Frode Oppedal (Institute of Marine Research)

Background

The environment facing a fish in a sea-cage is complex, and consists of both natural conditions (e.g. oxygen, salinity, temperature and natural light) and conditions controlled by humans (e.g. food, the cage, artificial light and stocking density). Understanding how these factors affect the behaviour and physiology of the fish, and furthermore how the fish respond to changes in them, is paramount when seeking to enhance current production techniques and developing new cage management strategies.

Performing experiments with live fish to investigate the interactions between fish and the environment is a time-consuming and expensive process. Furthermore, since some of the conditions mentioned above are outside human control (e.g. water temperature), it may sometimes be difficult to produce the desired environmental conditions. Mathematical models that replicate how caged fish interact with their environment may therefore represent valuable tools for research and development of new technologies.

Our focus is to develop mathematical models of the behaviour of finfish in aquaculture facilities.

Methods

Our model is based on a Lagrangian, or individual-based, approach. This means that each individual fish in a population is modelled as a separate entity. We chose this approach since it gives us the ability to observe the fish behaviour on both the individual and population levels. Furthermore, individual-based models allow for an easier inclusion of small-scale behaviours of individual fish and also allows for a greater degree of individual variation.

The modelled fish are affected by an external environment comprised of water temperature, light intensity, food concentration, the sea-cage structure and other individuals. These factors have been demonstrated to exert an effect on fish behaviour. Since we focus upon modelling the behaviour of the fish, the main states in the model are position, orientation and swimming velocity. Hunger is known to exert an important effect on behaviour, thus we have also included a state monitoring the stomach content of the fish.

The model is developed as a stand-alone JAVA-application giving full flexibility in terms of including new model features. Furthermore, the object-oriented nature of JAVA is very suitable for developing individual-based models.

Results and Discussion

Our main focus so far has been to develop a model of the behaviour of Atlantic salmon in response typical environmental conditions experienced in coastal locations. The model was parameterised by using data from research trials performed by Institute of Marine Research. The main result from this study was that it reproduced the vertical migration patterns induced in Atlantic salmon by spatially and temporally varying temperatures and light levels. Figure 22 shows a comparison between the observations from the research trials (left column) and model output (right column).

The ability of the model to predict the general pattern of distribution in the cage implicates that the modelled behavioural mechanisms were similar to those actually present in live fish.

We assumed that the interaction between individual fish was driven by a desire to avoid collision with conspecifics. This resulted in two simple behavioural rules; 1) avoid neighbours getting too close, and 2) align with fish that are close but outside the avoidance range. Together with the rule that programmed the fish to avoid hitting the cage structure and a stochastic disturbance on the swimming velocity vector, these behavioural rules were seen to be sufficient for inducing schooling behaviour in an initially dispersed and unorganised group of fish. This is illustrated in Figure 23 where the trajectories of ten fish for four different time intervals are shown. There were 1000 fish in the simulation; consequently each of the fish demonstrated in the figure represents approximately 100 fish.

The development from Figure 23a to Figure 23d demonstrates how the initially dispersed and chaotically swimming fish were able to organise themselves gradually with time, eventually resulting in school-like behaviour.

The present work on this project concerns including behavioural responses toward artificial light sources submerged in the cage. This is a technique used to prohibit maturation of fish in sea-cages and has been proven to elicit behavioural responses in fish. By using a model to predict the behavioural responses of artificial lights at different depths and under different environmental conditions, it may be possible to predict the environmental conditions under which management and use of artificial light sources is most effective.

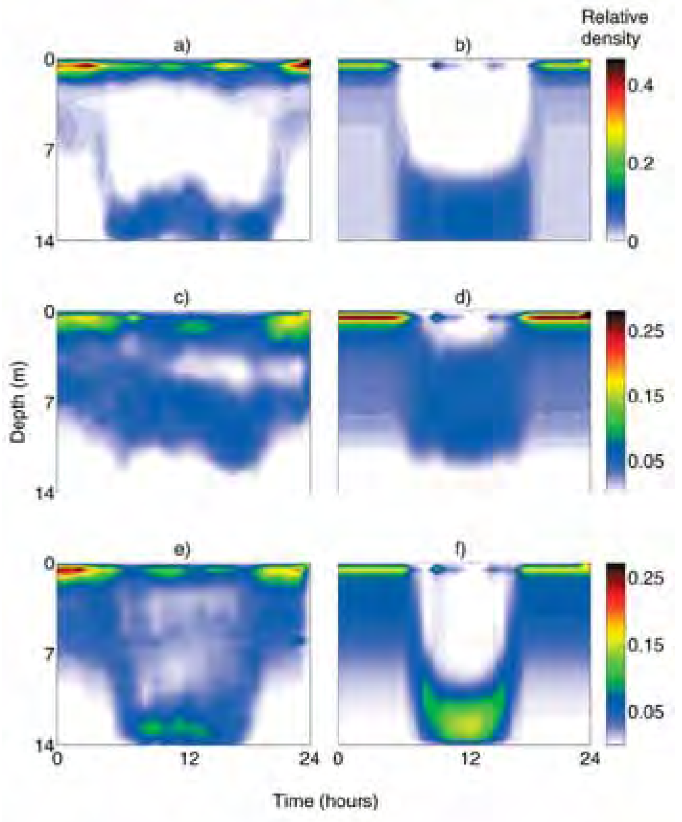


Figure 22 : Observed and simulated vertical distribution of salmon in a sea-cage for thee periods in autumn. a), c) and e) represent observations for periods 1, 2 and 3, while b), d) and f) are corresponding model estimates

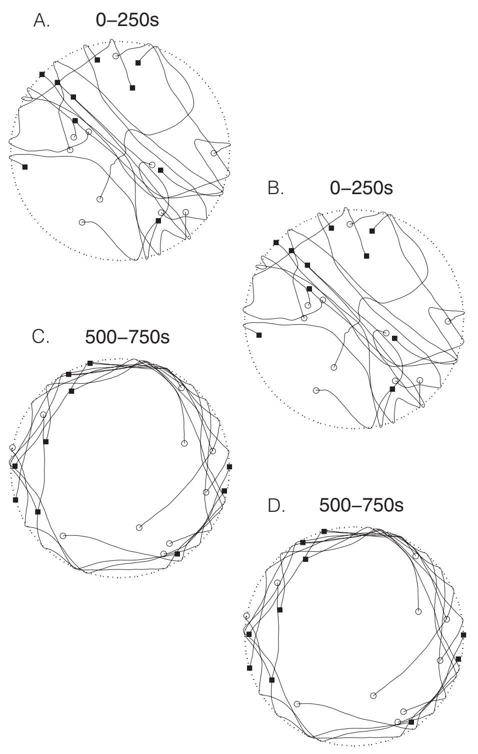


Figure 23 : Swimming trajectories (solid lines) for ten randomly selected fish from a population of 1000 fish in a sea-cage (dashed line) over four 250 s time intervals. Open circles denote initial positions in each interval, while filled squares denote the corresponding end positions.

03. INTERNATIONAL CO-OPERATION

INTERNATIONAL CO-OPERATION

CREATE has active international collaborations at both the level of the centre and through individual projects. The University of New Hampshire has been an active international collaborator within CREATE since its inception. Prof. Hunt Howell and Michael Chambers from the Open Ocean Aquculture program have participated in project development and discussions at each of the annual CREATE days (2007, 2008 and 2009). In addition, CREATE PhD student Martin Føre completed a 3-month visit to 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.

CREATE researchers Tim Dempster, Arne Fredheim, Østen Jensen and Heidi Moe have initiated a major international project through the European Union's 7th Research Framework. The project, titled *Prevent Escape: Assessing the causes and developing measures to prevent the escape of fish from sea-cage aquaculture*, seeks to conduct and integrate biological and technological research on a pan-European scale to improve recommendations and guidelines for aquaculture technologies and operational strategies that reduce escape events. The project will focus on the prevention of escapes of all major species under production in sea-cages in Europe (salmonids, cod, sea bream, sea bass and meagre). 10 research partners from 6 countries (Norway, Ireland, Scotland, Spain, Greece and Malta) will undertake the €3.9 million project from 2009-2012. The project will directly involve the industry participants within CREATE due to their technological expertise and direct links to the farming industry and results obtained will be integrated into future technological development and innovation of technologies to reduce escapes.

The Biofouling on Aquaculture Constructions project has established an active collaboration with Prof. Rocky DeNys and his 'Biofouling in Aquaculture' research group at James Cook University, Australia. The collaboration involves testing the performance of various nano-textured surfaces developed in Australia in inhibiting settlement of the most common biofouling organisms that grow on sea-cages in Norway. The aim of this collaborative research is to develop technologies to prohibit larval settlement and reduce the intensity of biofouling.

04. PERSONNEL

PERSONNEL

Key researchers

NAME	INSTITUTION	MAIN RESEARCH AREA
DR. ARNE FREDHEIM	SINTEF FISHERIES AQUACULTURE	MARINE HYDRODYNAMICS/AND FISH FARMING CONSTRUCTIONS
DR. PÅL LADER	SINTEF FISHERIES AND AQUACULTURE	MARINE HYDRODYNAMICS
DR. TIM DEMPSTER	SINTEF FISHERIES AND AQUACULTURE	FISH BEHAVIOUR
LEIF MAGNE SUNDE	SINTEF FISHERIES AND AQUACULTURE	BIO-FOULING
GUNNAR SENNESET	SINTEF FISHERIES AND AQUACULTURE	SYSTEM MODELLING
DR. TORE KRISTIANSEN	INSTITUTE OF MARINE RESEARCH	FISH WELFARE AND BEHAVIOUR
DR. FRODE OPPEDAHL	INSTITUTE OF MARINE RESEARCH	FISH WELFARE AND BEHAVIOUR
PROFESSOR TORGEIR MOAN	CESOS/NTNU	MARINE STRUCTURES
ASSOCIATE PROFESSOR JO ARVE ALFREDSEN	NTNU	ENGINEERING CYBERNETICS
DR. TORBJØRN ÅSGÅRD	NOFIMA MARIN	FISH FEED AND NUTRITION

Visiting researchers

NAME	AFFILIATION	NATIONALITY	SEX	DURATION	TOPIC
DR. SHIM KYUJIN	POST.DOC.	KOREAN	M	2008-09	CFD SIMULATION OF FLOW THROUGH FISH CAGE

Postdoctoral researchers

NAME	NATIONALITY	PERIODE	SEX	TOPIC
DR. BAILEY JASON	CANADIAN	2007-08	M	CAGE ENVIRONMENT
DR. GUENTHER JANA	GERMAN	2008-10	F	BIOFOULING ON AQUACULTURE CONSTRUCTIONS

PhD students with financial support from the Centre budget

NAME	NATIONALITY	PERIOD	SEX	TOPIC
KORSØEN, ØYVIND JOHAN	NORWEGIAN	2007-10	M	BIOLOGICAL CRITERIA FOR SUCCESSFUL SUBMERGENCE OF PHYSOCLISTOUS ATLANTIC COD AND PHYSOSTOMOUS ATLANTIC SALMON REARED IN SEACAGES
FØRE MARTIN	NORWEGIAN	2007-10	M	MODELLING AND SIMULATION OF FISH BEHAVIOUR IN AQUACULTURE PRODUCTION FACILITIES
LUBIS ENNI LISDA	INDONESIAN	2008-12	F	RELIABILITY-BASED DESIGN OF AQUACULTURAL PLANTS
REMEN METTE	NORWEGIAN	2008-11	F	EFFECTS OF FLUCTUATING OXYGEN LEVELS ON WELFARE AND GROWTH OF SALMON (*SALMO SALAR*) IN NET CAGES

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

NAME	FUNDING	NATIONALITY	PERIOD	SEX	TOPIC
GANSEL LARS	NTNU	GERMAN	2007-10	M	FLOW THROUGH AND AROUND FISH CAGES
MELBERG RUNE	UNIVERSITY OF STAVANGER	NORWEG.	2009-10	M	FISH FARMING MODELING, SIMULATION AND CONTROL

Master degrees

NAME	PERIOD	SEX	TOPIC
VIGEN JANNICKE	2007-08	F	OXYGEN VARIATION IN CAGES
OEHME MAIKE	2007-08	F	NUTRIENT DIGESTIBILITY OF FEEDS
CARL CHRISTINA	2007-08	F	BIO-FOULING
HARENDZA ASTRID	2007-08	F	PIV ON INCLINED CYLINDER SHAPED FISH CAGES
RAANES HÅKON	2008-09	M	NEXT GENERATION SUBCAGE - CONCEPT DEVELOPMENT

05. STATEMENT OF ACCOUNTS 2008

STATEMENT OF ACCOUNTS 2008

FUNDING	2008	2007
THE RESEARCH COUNCIL	9 934	5 709
THE HOST INSTITUTION	1 325	481
RESEARCH PARTNERS	3 002	860
ENTERPRISE PARTNERS	4 925	3 774
PUBLIC PARTNERS	0	0
TOTAL	19 186	10 824

COSTS	2008	2007
THE HOST INSTITUTION	5 460	3 049
RESEARCH PARTNERS	6 460	2 982
ENTERPRISE PARTNERS	7 136	4 694
PUBLIC PARTNERS	0	
EQUIPMENT	130	99
TOTAL	19 186	10 824

(ALL FIGURES IN 1000 NOK)

PUBLI CATIONS AND DISSEMI NATION

PUBLICATIONS AND DISSEMINATION

Peer-reviewed journal articles

Carl C, Guenther J, Sunde LM (2009) Depth distribution, larval release and attachment of the hydroid *Ectopleura larynx* (Ellis and Solander, 1786) in relation to current fish farming practices in Norway. Aquaculture (in review)

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

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

Dempster T, Moe H, Fredheim A, Sanchez-Jerez P (2007) Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention. Impact of mariculture on coastal ecosystems. *CIESM Monograph* 32: 55-60 (www.ciesm.org/online/monographs/Lisboa.html)

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

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* (in review)

Korsøen Ø, Dempster T, Fjelldal PG, Folkedal O, Kristiansen T, Oppedal F (2009) Long-term submergence of Atlantic salmon (*Salmo salar L.*) during winter affects behaviour, growth and condition. *Aquaculture* (in review)

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(1): 52-65

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

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

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

Moe H, Dempster T, Sunde LM, Winther W, Fredheim A (2007) Technological solutions and operational measures to prevent escapes of Atlantic Cod (*Gadus morhua*) from sea-cages. *Aquaculture Research* 38(1): 90-99

Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere J, Valle C, Dempster T, Tuya F, Juanes (2008) Interactions between bluefish *Pomatomus saltatrix* (L.) and coastal sea-cage farms in the Mediterranean Sea. Aquaculture 282: 61-67

Peer-reviewed book chapters

de Nys R, Guenther J (2009) The impact and control of biofouling in marine finfish aquaculture. In: Hellio C, Yebra D (eds.) Advances in marine antifouling coatings and technologies, Woodhead Publishing. ISBN 1845693868

International conferences with reviewed articles

Harendza A, Visscher J, Gansel L and Pettersen B (2008) PIV on inclined cylinder shaped fish cages in a current and the resulting flow field. Proceedings of the the 27th International Conference on Offshore Mechanics and Arctic Engineering OMAE2008 June 15-20, 2008, Estoril, Portugal. OMAE2008-57748

Gansel L, McClimans T A and Myrhaug D (2008) The effect of fish cages on ambient currents. Proceedings of the the 27th International Conference on Offshore Mechanics and Arctic Engineering OMAE2008 June 15-20, 2008, Estoril, Portugal. OMAE2008-57746

Presentations at international conferences

Carl C, Sunde LM (2008) *In situ* feeding of the hydroid *Tubularia* sp. on aquaculture nets and their larval release as a response to the washing procedure. 14th International Congress on Marine Corrosion and Fouling, Kobe, Japan, 27-31 July 2008 (Oral presentation)

Fredheim A (2008) New concepts in sea-cage technology - solutions for open ocean fish farming. World Aquaculture 2008, Busan Exhibition & Convention Center, Busan, Korea, May 20 – 24, 2008.

Fredheim A (2008) How to prevent escape of fish from floating fish farms - the need of a multi-disciplinary approach to cage design. World Aquaculture 2008, Busan Exhibition & Convention Center, Busan, Korea, May 20 – 24, 2008.

Fredheim A (2007) New concepts in cage technology, based on multi-disciplinary research. European Aquaculture Society, AquaNor Forum, Trondheim, August 2007.

Fredheim A (2007) How to prevent escapes. Workshop on "Development of management options to reduce genetic impacts of aquaculture activities". Evaluation of genetic impact of aquaculture activities on native populations - A European network (GENIMPACT) Thessaloniki, Greece, April 19-22, 2007

Gansel LC, McClimans TA, Myrhaug D (2008) Drag forces on and flow around and through porous cylinders. Coastal Technology Workshop – Coast 2008

Guenther J, Carl C, Olafsen T, Sunde LM (2008) Biofouling on aquaculture nets in Norway: current status and future directions. 14th International Congress on Marine Corrosion and Fouling, Kobe, Japan, 27-31 July 2008 (Poster presentation)

Kyujin S, Klebert P, Fredheim A (2009) Numerical investigation of the flow through and around a net cage. ASME 28th International Conference on Ocean, Offshore and Arctic Engineering, Honolulu, USA, 31 May- 5 June, 2009

Føre M, Dempster T, Alfredsen JA (2007) Modelling of fish behaviour in sea-cages, Aquaculture Europe 07, Istanbul, Turkey, October 24-27, 2007

Oppedal F, Vigen J, Remen M, Bailey J (2008) Salmon in sea cages affect the water flow. Oral presentation at Aquaculture Europe 2008, Krakow, Poland, September 16-18, 2008

Vigen J, Remen M, Bailey J, Oppedal F (2008) Oxygen variation within a seacage. Poster at EAS Aquaculture Europe 2008, Krakow, Poland, September 16-18, 2008

Presentations at national conferences and workshops

Aas TS, Terjesen BF, Sigholt T, Holm RS, Bæverfjord G, Oehme M, Rørvik K-A, Åsgård T (2008) Hva har fôrteknologi og teknisk fôrkvalitet å si for fisken? Biomarint Industriseminar, Bergen Decembe 2-3, 2008

Fredheim A (2007) "En kreativ mulighet for norsk havbruksteknologi?". Årsmøte til FHL Midt-Norge 2007

Føre M, Dempster T, Alfredsen JA (2008) Matematisk modellering av fiskeatferd i merd. Programkonferansen HAVBRUK NFR, Tromsø, 9 April 2008 (Oral presentation)

Gansel LC, McClimans TA, Myrhaug D (2008) Virkning av fiskemerder på lokale strømforhold. Programkonferansen HAVBRUK 2008, 7-9 April 2008, Tromsø, Norway

Guenther J, Carl C, Sunde LM (2008) Biofouling on aquaculture constructions: current status and future directions. Egersund Net, Egersund, 30 September 2008

Kristiansen, TS (2009) Sterk strøm gir dødelighet. Hvorfor? Sats på torsk, Torskenettverksmøtet 11-13 February 2009, Scandic hotell, Bergen

Korsøen Ø, Oppedal F, Folkedal O, Dempster T, Kristiansen TS (2008) Nedsenking av stor laks. Dypt, mørkt, og over en lengre periode. Foredrag Havbruk 2008, Norges forskningsråd, Havbruksprogrammet, konferanse SAS hotellet, Tromsø 7-9 April 2008.

Oppedal F, Vigen J, Remen M, Bailey J (2008) Vannstrøm gjennom en laksemerd. Foredrag ved Programkonferansen HAVBRUK, Tromsø 7-9 April 2008, Forskningsrådet.

Oppedal F, Johansson D, Juell J-E (2007) Vanngjennomstrømning, oksygentilgang og faktorer som påvirker fiskens atferd i store merder. Akvaveterinærenes høstkurs 07, Park Inn hotell, Stavanger, 23-24 October, 2007

Oppedal F, Bratland S, Stien L, Nilson J, Folkedal O (2008) Må vi tenke mer på dyrevelferd i norsk fiskeoppdrett? - Akutt stress hos settefisk, Fiskeridirektoratet, lunsjmøte , Bergen, 7 February, 2008

Oppedal F (2008) Flow reduction in sea-cages. Biofouling Workshop CREATE, Egersund 30 September 2008.

Remen M, Olsen RE, Oppedal F (2009) Stressrespons og habituering til fluktuerende hypoksi hos laks i sjøvann. Foredrag Frisk Fisk konferanse 20-21 January, Scandic Bergen city hotel.

Remen M, Olsen RE, Oppedal F (2009) Fluctuating hypoxia experiment on Atlantic salmon- preliminary results. Marine Harvest 23 September 2009.

Vigen J, Oppedal F (2008) Kartlegging av merdmiljø og fiskeatferd ved badebehandling. Akvaveterinærforeningens høstkurs, Trondheim 14-15 October 2008.

Vigen J, Remen M, Bailey J, Oppedal F (2008) Oksygenvariasjon innenfor en merd. Poster presentert ved Programkonferansen HAVBRUK 2008, Norges Forskningsråd, Tromsø 7-9 April 2008.

Theses

Carl C (2008) Hydroid growth on aquaculture nets. Masters thesis, University of Oldenburg, Germany.

Gaojie H (2008) Feed pellet durability in pneumatic conveying systems for fish farming. Master thesis, Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences, Ås, Norway.

Harendza A (2008) Particle Image Velocimetry (PIV) on inclined cylinder shaped fish cages in a current and the resulting flow field. Master thesis, University of Oldenburg, Germany.

Vigen J (2008) Oxygen variation within a seacage. European Master in Aquaculture and Fisheries. Department of Biology, University of Bergen, June 2008, 73 pp.

CREATE presentations

Carl C, Guenther J (2008) Biofouling on aquaculture nets. CREATE day, 4-5 March 2008 (Oral presentation)

Føre M, Dempster T, Alfredsen JA (2008) Mathematical modelling of fish behaviour in sea-cages. CREATE day, SINTEF, 4-5 March 2008 (Oral presentation)

Føre M, Dempster T, Alfredsen JA (2008) Mathematical modelling of fish behaviour in sea-cages. University of New Hampshire, 24 July 2008 (Oral presentation)

Føre M, Ward D (2008) Modelling fish behaviour and cod density trials 2008. CREATE day, 27 August 2008 (Oral presentation)

Guenther J, Carl C, Sunde LM (2008) Biofouling on aquaculture nets: results so far. CREATE day, August 2008 (Oral presentation)

Guenther J (2008) Biofouling on aquaculture nets. Lerøy Midnor, 14 November 2008 (Oral presentation)

Korsøen Ø (2008) SubFish - Farming in submerged cages. CREATE day, SINTEF, 4-5 March 2008, Trondheim. (Oral presentation)

Kyujin S, Klebert P, Fredheim A (2008) CFD simulation of flow through fish cage. CREATE day, August 2008 (Oral presentation)

Remen M (2008) Effects of fluctuating hypoxia on behaviour and physiology – background and setup. CREATE day, Sintef, Trondheim, Nova konferansesenter, 4-5 March 2008.

Vigen J (2008) Oxygen variation within a sea-cage – preliminary results. CREATE day, SINTEF. Nova konferansesenter, Trondheim, 4-5 March 2008

Other

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