Annual Report 2009

CREATE

Centre for research-based innovation in aquaculture technology

Contents

Introduction. 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 Fisheries and Aquaculture are the host institution for the centre. The three Norwegian industry partners involved in the centre, AKVA group ASA, Egersund Net AS and Erling Haug AS, are all world-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), the 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) and other active international collaboration through research partners, individual researchers, and the centre's individual projects.

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.

Research and Philosophy

Fish farming is a truly multi-disciplinary industry, involving live animals living in floating farm constructions where they are fed and taken care of by humans using equipment and machinery. Modern, industrial-scale fish farms lie in coastal waters; they contain up to a million fish, which are fed high energy diets daily by automatic feeding systems. For successful farming, broad knowledge from a range of scientific disciplines such as veterinary science, nutritional science, biology, engineering, and information and communication technology is essential.

To develop new and improved solutions for marine finfish farming, the complex needs and behaviour of fish must be understood. This knowledge can then be used to develop operations, procedures and protocols to design technology and systems. This design approach is a strength of the centre and serves as the core research philosophy of CREATE. The wide range of expertise among the centre's partners, within both biological and technological aspects of fish farming, enables true multi-disciplinary research and development.

Each CREATE project involves personnel from several partners and project personnel physically work together at the centre and in the field, to ensure joint involvement, creativity and transfer of knowledge. At least two industry partners and two R&D partners are involved in all of the major research projects.

All the projects are organized with a project leader and a Steering Committee. The project leader will normally be selected from among 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.

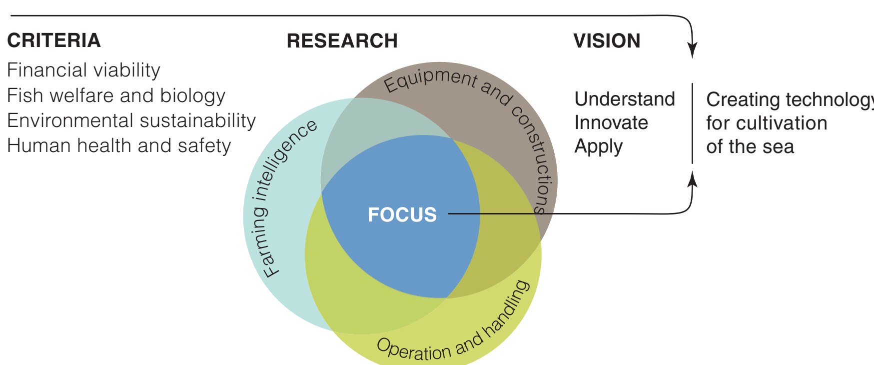
To strengthen the industry's involvement and focus for all the projects, a set of 'demonstrators' have been defined. The purpose of the demonstrators is several:

- 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 or PhD, whether focused on determining fundamental knowledge or a direct industry need, must define deliverables towards one or more of the demonstrators.

CREATE focuses research and development within the following three main research pillars (Fig. 1) and aims to integrate knowledge between them:

Figure 1 : Vision and research pillars for CREATE



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.

CREATE presently runs nine main projects, and has eight PhD students and three post-doctoral researchers working within the centre. The projects, PhD and post-doctoral topics, and their relation to the three main research pillars of CREATE are shown in Fig. 2.

Figure 2 : Overview of projects, PhD and Post-doc topics and demonstrators within CREATE

TRINE KIRKHUS - 37

Title research project:
Bio statistical analysis

Education:
Cand. Scient in physics from the University of Bergen and the University of Oslo, Norway

Company/Institution:
SINTEF Information and Communication Technology

Place of residence: Oslo, Norway
Place of birth: Haugesund, Norway
Nationality: Norwegian

Leisure activities:
Cycling, running, skiing, hiking, theater, friends and family.

Latest publication:
"A DMD (Digital Micro-Mirror Device) Based Multi-Object Quasi-Imaging Spectrometer", ProCams 2009.

3 research keyword:
image capture, data analysis, spectroscopy

3 keyword about yourself:
curous, impatient, happy camper

CAGE ENVIRONMENT

Cage environment

Project leaders:
Dr. Frode Oppedal (IMR) and
Dr. Pål Lader (SINTEF).

Investigators:
Mette Remen, Dr. Rolf Erik Olsen,
Dr. Thomas Torgersen, Dr. Jan Aure,
Jannicke Vigen, Dr. Jason Bailey (IMR)
Dr. Pascal Klebert, Dr. Arne Fredheim,
Lars Gansel (NTNU),
Dr. Turid Synnøve Aas (NOFIMA)

CREATE Industrial Partners:
Egersund Net AS, Erling Haug AS

Other Partners:
Centre for Ships and Ocean Structures (CeSOS), Norwegian University of Science and Technology (NTNU)

Background - Fluctuating hypoxia and flow field in sea cages

The overall objective is to improve standards for oxygen management in marine net cages through the establishment of limiting oxygen levels and understanding of water flows around and through the combined net and fish biomass. These findings will help to ensure fish welfare and efficient production during on-growth in seawater.

The combined effects of variable flow of incoming waters, uneven oxygen consumption by the fish, dynamic changes in fish biomass and seasonal oscillating abundance of oxygen create fluctuating hypoxia within salmon cages. To date, conditions of constant hypoxia have been investigated in respect to important production parameters, while the impact of fluctuating hypoxia on the fish is largely unknown. Flow dynamics through net panels have been studied to a limited degree, while extensiv description of the flow dynamics through the cage and cage configurations are absent. In particular, effects on the flow from the fish biomass itself and their behaviour are lacking.

Methods - Environmental cages and tanks

Fluctuating oxygen levels effect on salmon production parameters, physiology and welfare were investigated in large seawater tanks within the Tank Environmental Lab at IMR-Matre. Habituation and acclimation rates were studied at repeated fluctuating hypoxic levels from 40 to 70% oxygen saturation (Fig. 3).

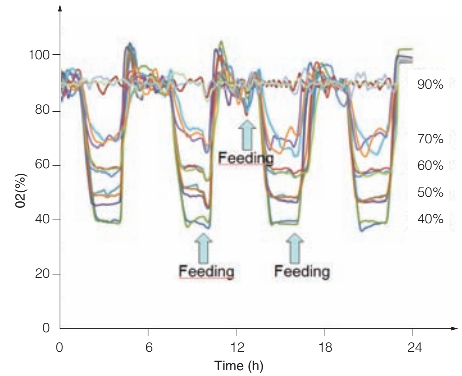


Fig. 3 : Experimental setup triplicate tanks of daily repeated fluctuating hypoxia at 40-70% with a control of 90%. Feeding was performed during both hypoxic and normoxic conditions.

Cage structure, net panels, fish biomass and behavioural effects on water flow were studied using multiple facilities: experimental cage environmental lab and commercial cages; tank environmental lab; experimental flow through tanks; and towing tanks.
A range of instruments were used to monitor environment and flow patterns.

Results from fluctuating hypoxia

Full-feeding Atlantic salmon held in seawater at 16 °C and given fluctuating hypoxic saturation levels of 70% reduced appetite; 60% additionally initiated acute anaerobic metabolism and increased skin lesions; 50% additionally initiated acute stress responses, reduced feed conversion and growth; and 40% additionally caused impaired osmoregulation and mortalities (Remen et al., unpublished data). Growth rates and condition factors gradually decreased and proportions of fish with skin infections gradually increased in severity as hypoxia levels rose. Salmon displayed compensatory feeding during normoxic periods. The results from the second experiment seem promising but need further analysis before results are presented and discussed. Both studies reveal hypoxic limits that will be used to set standards for oxygen management and welfare in sea cage farming of Atlantic salmon.

Results from flow through and around cages

Fish schooling behaviour reduced the water flow within cages, changed flow direction and generally generated hypoxic levels compared to reference measurements outside. Changes in the flow field around a circular cage stocked with salmon forming a circular school with most fish swimming in the same direction. Preliminary analyses indicated a horizontal outward flow from the centre of the cage, a negative vertical flow in front of the cage combined with a positive vertical flow behind the cage. The caged fish appear to have an influence on the flow previously not described. Recent, additional field measurements using colour dye (Fig. 4) further illustrate these effects.

Fig. 4 : Colour dye is distributed in the centre of a commercial cage and dilution measured with time and distance in order to indirectly describe the water flow.

Results from flow through net panels

Net panels with different porosities were used and water flow in front of and behind the panel was measured. 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. Finally, the model will be used to test different cage configurations to improve the position of the cages at the farms.

The effect of increased net solidities on cage response in steady current

The problem of biofouling together with the industries tendency to use larger cages with correspondingly higher net solidities makes it important to study the effect of nets with solidities larger than 20%. In cooperation with the Fishery and Aquaculture Industry Research Fund, measurements were conducted in the Hirtshals Flume tank with several different cage models with high solidities (20%, 30%, 35% and 45%; Fig. 5). The measurements show the influence of increased solidities, and one of the more interesting findings is that for certain conditions, the global drag force on a cage can actually decrease when the solidity increases. This is interesting with respect to, for example, the influence of biofouling.

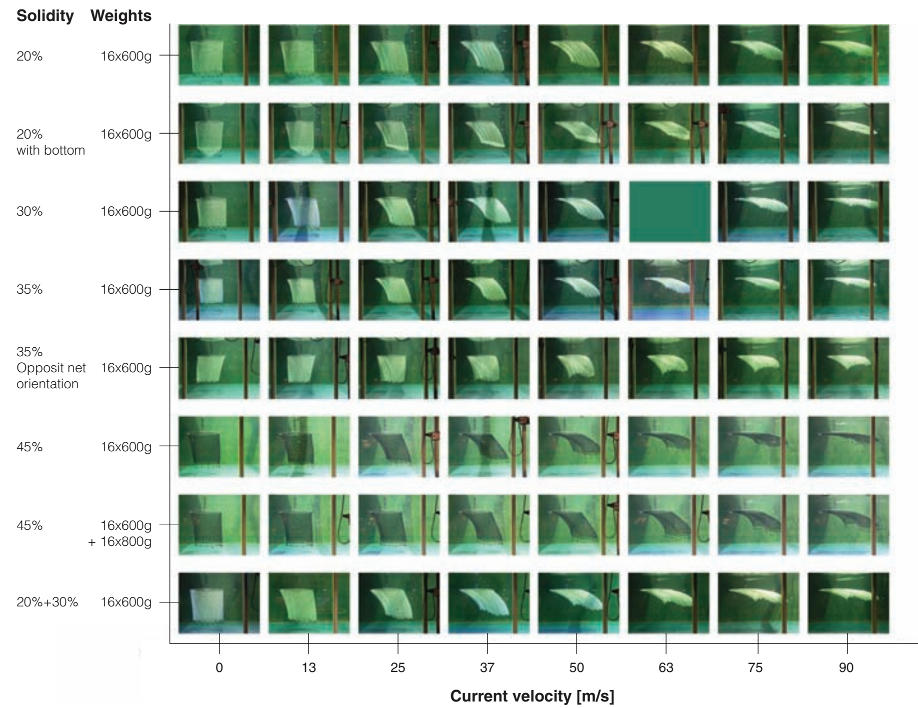


Fig. 5 : The experimental matrix of the flume tank experiments with different net solidities.

Habituation and acclimation of Atlantic salmon subjected to fluctuating hypoxia

PhD student:
Mette Remen (IMR)

Supervisors:
Dr. Frode Oppedal, Dr. Rolf Erik Olsen (IMR), Dr. Albert Imsland (UiB)

PhD focus
Understanding the importance of fluctuating hypoxia to the performance of fish in sea-cages is critical to help set criteria for aquaculture technologies that maintain growth and welfare thresholds.

Background

Atlantic salmon production is an important industry in Norway, with a total production that exceeded 700 000 tons in 2007. To ensure fish welfare and a successful production, it is important that environmental conditions in sea-cages, primarily temperature, oxygen and salinity, are kept within the tolerance limits of the species. Recent studies have shown that there are large fluctuations in these environmental factors, varying with depth, season and time of day. In particular, large fluctuations in oxygen levels were observed in autumn, with short periods of alarmingly low levels (30-50% oxygen saturation) several times every day.

The aim of this study was to investigate the performance and rate of habituation and acclimation of Atlantic salmon subjected to fluctuating hypoxia. Primarily, we wanted to investigate the ability of salmon to adapt to repeated hypoxic periods at levels ranging from 40-70% saturation by looking at appetite and stress indicators as well as oxygen uptake and transport properties. Secondarily, we looked at how flexible the responses were, by investigating the difference between hypoxic and normoxic periods.

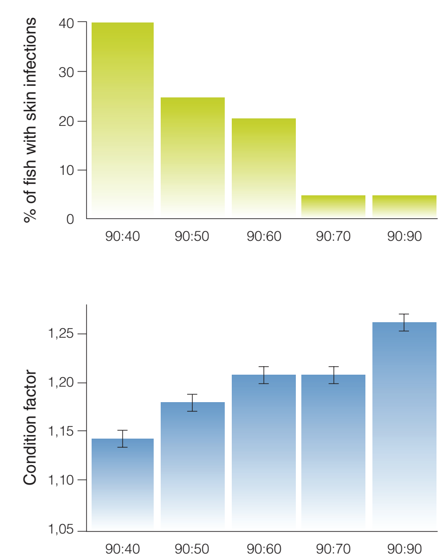
Methods

We tested the effects of periods of hypoxia for two hours, four times every day, at 5 different levels (40%, 50%, 60% and 70%, with 90% as a control) on salmon post-smolts (approximately 100 g). Each of the 5 hypoxia levels was replicated 3 times. Each replicate 480L tank contained 1680 salmon. Between the hypoxic periods, water flow was increased again and 90% saturation was kept stable by automatic regulation of oxygenation. To compare the effects of the 5 different hypoxia treatments, we measured mortalities, skin infections, condition factor, appetite and growth rate in each of the tanks and several blood physiology measures and histological samples from individual fish.

Results and Discussion

Exposure to fluctuating hypoxia resulted in greater levels of skin infections, poorer condition (Fig. 6), poorer feed intake and poorer growth. The magnitude of effects of hypoxia was most severe for the groups exposed to the greatest levels (i.e. 40% and 50%). Our 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 hypoxia tolerance, but further research must be done to evaluate the acclimation process and long-term effects of fluctuating hypoxia.

Fig. 6 : Percentage of fish with skin infections and mean (+/-S.E.) condition factor after 21 days of 4 times daily hypoxia to 40, 50, 60, 70 or control group at 90% oxygen saturation.



Influence of porosity and fish-induced internal circulation on the flow around fish cages: interactions of shear layers, the recirculation zone and vortex streets behind porous bluff bodies.

PhD student:
Lars Gansel (NTNU)

Supervisors:
Prof. Dag Myrhaug (NTNU),
Prof. (em.) Thomas McClimans (SFH)

PhD focus:
This PhD focuses on a full description of the flow field around and through stocked fish cages, thereby investigating the effects of changes in the governing parameters and creating benchmarks for numerical models.

Background

The flow around fish cages affects many aspects of marine fish farming. The flow patterns determine the forces acting on nettings and moorings, the water exchange rates inside net pens and transport routes of particles and dissolved nutrients and gases. Therefore, knowledge of the flow characteristics around fish cages will allow better design and management of fish farms for improved efficiency, operations and fish welfare. Numerical models based on the flow conditions around fish cages can be used as a tool for coastal zone management and will allow the assessment of alternative production methods, like integrated multi-trophic aquaculture, to reduce the ecological impact.

Results and Discussion

Three parameters were determined as the major factors influencing the flow patterns through and around fish cages: 1) the ambient flow, 2) the net porosity and 3) fish behaviour. Laboratory experiments on the effects of currents and net porosity, and field measurements of empty and stocked salmon farms give the general flow pattern past stocked net pens depicted in Fig. 7. Clean and lightly fouled fish cages will allow a major part of the oncoming water mass to flow through the net pen, leading to high water exchange rates. Water is pressed around the cage and the circular swimming motion of fish causes an outwards-directed force at depths with high fish densities. Here, most of the water will be pressed outward, creating a low-pressure region in the center of the cage. This draws water from the top and bottom layers to compensate for the outflow. Heavy fouling can lead to a blockage strong enough to reduce water exchange rates dramatically inside the cage, reducing the oxygen supply to the fish and the removal of wastes to dangerously low levels.

The use of these results as benchmarks for numerical models will be of great benefit to the fish farming industry and for the assessment of the ecological impacts.

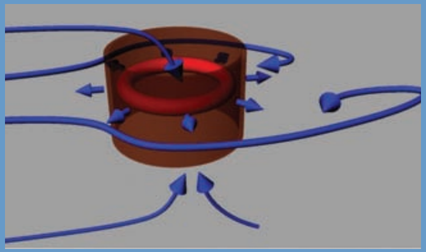


Fig. 7 : Sketch of the flow patterns around a stocked fish cage. The red ring indicates swimming fish inside the cage (brown cylinder).

NET PROPERTIES

Temporary-creep and post-creep properties of aquaculture netting materials

Publication Year: 2009
Source: Ocean Engineering 36: 992-1002

Authors:
Heidi Moe, Odd Sture Hopperstad, Anna Olsen, Østen Jensen, Arne Fredheim

Research Challenges:
- Investigate the key properties of netting materials used in aquaculture.
- Determine how netting material responds after exposure to loading

Industry Impacts:
- Improved models of material performance for making sea-cage netting.
- Provide input to improve safety of sea-cages by reducing the probability of hole formation

FISH BEHAVIOUR MODEL

Modelling of Atlantic salmon (*Salmo salar* L.) behaviour in sea-cages: A Lagrangian approach.

Publication Year: 2009
Source: Aquaculture 288: 196-2045

Authors:
Martin Føre, Tim Dempster, Jo Arve Alfredsen, Vegar Johansen, David Johansson

Research Challenges:
- Model the behavioural responses of salmon to environmental variables (e.g. temperature, light)
- Test if the model reflects vertical position and schooling behaviour of caged salmon

Industry Impacts:
- Predict the response of fish to changes in sea-cages designs and shapes
- Provide input to cage management strategies, such as feeding regimes
- May enable estimates of fish welfare in different culture conditions

ALF KRISTIAN FJELLDAL - 50

Education:
Mechanical Engineering

Company/Institution:
AKVA group ASA

Place of residence: Mo i Rana
Place of birth: Mo i Rana
Nationality: Norwegian

Leisure activities:
Ski, Kiting, Cycling, Outdoor


BIO
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Biofouling on aquaculture constructions

Project leader:
Dr. Jana Guenther

Investigators:
Nina Blöcher, Leif Magne Sunde, Dr. Heidi Moe and Dr. Østen Jensen (SFH)

CREATE Industrial Partners:
Egersund Net, AKVA group, NOFIMA, NTNU

Additional collaborators:
SalMar, Lerøy Midnor, Steen-Hansen Maling, James Cook University (Australia)

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 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 (Fig. 8), 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 2 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.

Methods

During a field study at a commercial salmon farm near Hitra from August to December 2008, we took underwater pictures of the biofouling community at 1, 5, 10 and 15 m depth of two cages, which were irregularly washed in situ. These pictures were analysed with an image analysis program and the net aperture occlusion was quantified.

We have also investigated the effects of the in situ washing of net panels (washed vs. unwashed nets) on the net structure and fouling community. Field experiments were conducted at a commercial salmon farm near Frøya from August to October 2009, which will provide a more in-depth understanding of the physical and biological processes involved in the mechanical cleaning of aquaculture nets.

Currently, a project plan on the development of a novel cleaning device utilizing hot water to kill fouling organisms is drafted. To provide baseline data for this project, laboratory experiments were conducted to determine the survival of the hydroid *E. larynx* and small specimens of the mussel *Mytilus edulis* after they were immersed in hot seawater (40, 50 and 60°C) for varying time intervals (1, 2 and 3 seconds).

ØSTEN JENSEN - 34

Title research project:
SubCage and Net Cages Design Tools

Education:
Dr. Ing (PhD) in Mechanical Engineering, Siv. Ing (Master of Science) in Marine Structures

Company/Institution:
SINTEF Fisheries and Aquaculture

Place of residence: Trondheim
Place of birth: Stavanger
Nationality: Norwegian

Leisure activities:
Sports, wine and books

Latest publication:
Moe H., Olsen A, Hopperstad OS, Jensen Ø, Fredheim A. 2009. Temporary creep and post creep properties of aquaculture netting materials. Ocean Engineering 36: 992-1002.

3 research keyword:
Structural integrity

3 keyword about yourself:
Calm, relaxed, likes coffee

TOM ØYSTEIN KAVLI - 54

Title research project:
VIBES

Education:
PhD Informatics and Master in Physics, UiO

Company/Institution:
SINTEF ICT

Place of residence: Nittedal
Place of birth: Eresfjord, Romsdalen
Nationality: Norwegian

Leisure activities:
Skiing, Tennis, bicycling

3 research keyword:
Computer vision, signal processing, statistics

Results and Discussion

The field experiment investigating the biofouling community development on salmon cage nets at different depths and over time showed that the net aperture occlusion was the highest at the upper depths of the water column. Afterwards, the fouling community dynamics and distribution changed; the net aperture occlusion varied significantly with time for both cages, and also with depth for one cage, which had significantly higher net aperture occlusions at lower depths. In combination with the demonstrated fast regrowth of hydroids after being cut (experiments conducted in 2008), these results suggest that in situ washing of nets is only a temporary measure to control biofouling as hydroids regrow and occlude the net apertures rapidly.

Logistical problems were encountered during the field experiments investigating the effects of the in situ washing of net panels and only two complete rounds of cleaning could be conducted. The results still have to be completely analysed, but there are indications that cleaning did not affect the tensile strength of the nets.

The immersion of hydroids and mussels in hot water may be an effective method to reduce their presence on nets. The survival of the hydroid *E. larynx* was reduced to only 4.2±1.3% at 40°C for 1 seconds, while the mussel M. edulis was completely killed at 50°C for 2 seconds.

Future research in 2010 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) drying of nets on the survival of *E. larynx.*

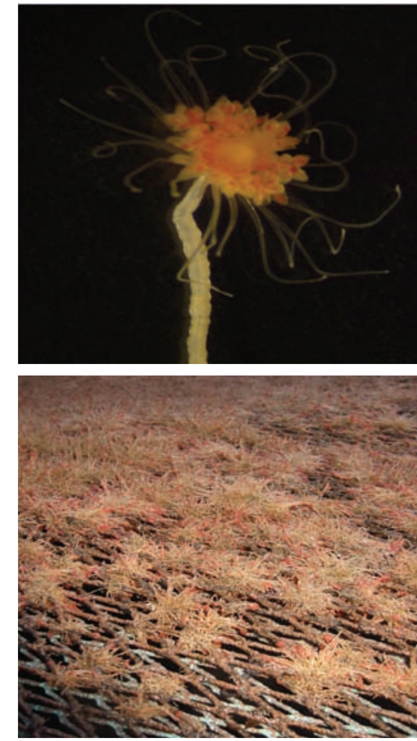


Fig. 8 : The problematic hydroid Ectopleura larynx on salmon farming nets.

Fouling of hydroids in the salmon aquaculture industry

PhD student:
Nina Blöcher (SFH)

Supervisors:
Prof. Yngvar Olsen (NTNU),
Dr. Jana Günther (SFH)

PhD focus

This PhD is part of the CREATE Biofouling project and the Norwegian Research Council funded HYDROFOUL project. It focuses on the settlement preferences, growth and diet of one of the main fouling organisms on aquaculture nets in Norway, the hydroid *Ectopleura larynx*.

Background

Biofouling is a major problem in net cage aquaculture, leading to a variety of difficulties regarding fish health, cage maintenance and cage stability. Between July and November the fouling community is dominated by the hydroid *Ectopleura larynx* that forms extensive colonies on the net cage (Fig. 9). Despite the large impact biofouling can have on the cage and its environment, little is known about its temporal and spatial scales. Therefore, the aim of this research is to expand the knowledge of settlement progression, community composition and influence on net materials. Additionally, the spatial extent of *E. larynx* presence around the farm will be investigated to gain insight into possible colonization origins and refuge areas. Furthermore, we plan to analyze the diet of *E. larynx* to determine if the hydroid uses fish feed or faeces as a source of nutrition.

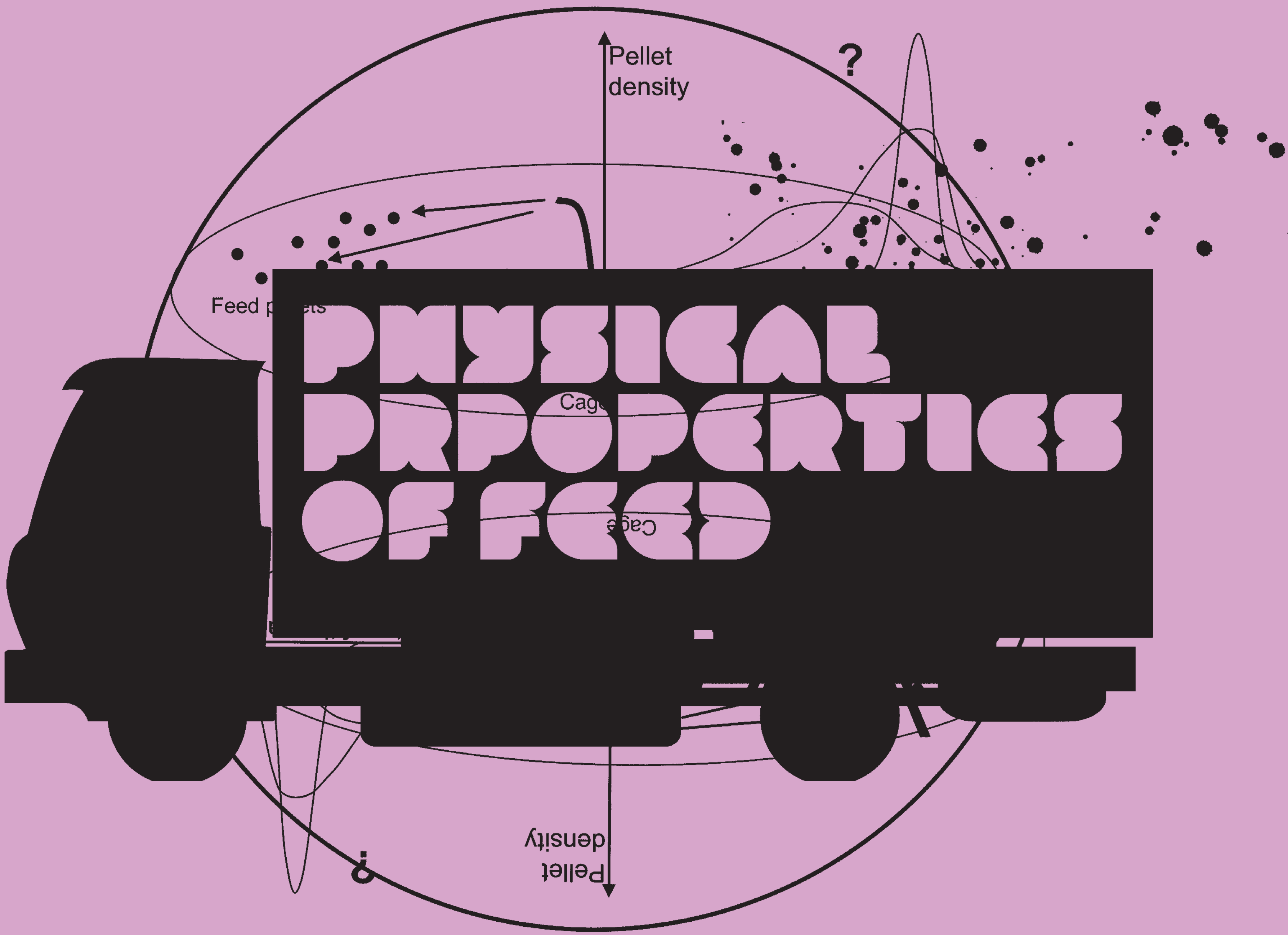
Planned experiments

To test the effects of mesh size (25 mm vs. 13 mm half-mesh), time of introduction of the net into the water (monthly), and immersion time (intervals of 1, 3, 6, and 12 months) on the accumulation of biofouling, net panels were first deployed at 5 m depth on the outside of three net cages at the ACE salmon farm at Tristein in December 2009. The net aperture occlusion, weight of the total amount of fouling, species composition and species abundance on the net panels were measured for further analyses.

The spatial extent of hydroid occurrence around a salmon farm will be investigated by deploying net panels at varying distances from the farm and monitoring them regularly during the main fouling season (June to November). To gain insight into the diet of *E. larynx* a, stable isotope analysis of prey items is planned. Hydroids from different farms and references sites will be compared with the signatures from fish feed, faeces and planktonic sources. Finally, in collaboration with the HYDROFOUL project, the settlement preferences of *E. larynx* with regards to surface hydrophobicity and topography will be investigated.

Fig. 9 : The hydroid *Ectopleura larynx* growing on a salmon farm net.

PHYSICAL PROPERTIES OF FEED



Physical properties of feed

Project leader:
Dr. Turid Synnøve Aas

Investigators:
Dr. Torbjørn Åsgård, Maike Oehme (NOFIMA Marin)

CREATE Industrial Partner:
AKVA group

The objective is to minimize degradation of pellets during feeding by optimising the use of the feeding equipment.

Background

Feed for commercial fish farming is transported from the manufacturer to the fish farming site, stored in large silos and transported from the silo to the cages by means of a pneumatic conveying system, and a spreader that throws the feed pellets into the cage. Handling, transport and storage of feeds cause some pellet breakage and formation of small feed particles, which represent economic loss and unintended addition of nutrients to the water. Consequently, feed pellets with high physical quality are demanded. However, commercial feeds vary in physical properties, and the fish farmer has to deal with the various feed qualities.

In a previous CREATE project, we showed that pellet degradation during pneumatic conveying differed between the feeds that were tested. We also showed that high air speed in the conveying system increased pellet breakage, whereas high feeding rate protected the pellets.

Data from another CREATE project showed that the physical properties of feeds are important for the biological response of the fish. One main finding in that study was that the feed intake was more than 20% higher in rainbow trout fed a diet with “soft” pellets, than in trout fed a diet with hard and more durable pellets. High feed intake is desirable for optimal growth, and these data indicate that the optimal physical pellet quality is a trade-off between losses due to attrition, and biological response.

Future Research

In a new trial, spreading of pellets in the cage will be measured. Spreading the feed over a large area in the cage is assumed to be beneficial for the feed intake, and thus, the growth of the fish. High air speed in the conveying system is used to spread the pellets in the cage, but is, as mentioned above, also associated with pellet degradation. The aim of this planned trial is to measure how the feed pellets are distributed in the cage during feeding at different settings (air speed and feeding rate) of the feeding system. Furthermore, how wind and water currents affect spreading of the feed will be examined (Fig. 10). The data from this trial is expected to provide valuable information for optimising the settings of the feeding system, which is particularly important when dealing with feeds of poor physical quality.

Other activities

In collaboration with the CREATE project “Cage environment”, the growth and feed utilisation in fish exposed to daily periods of hypoxia will be examined. A salmon trial was performed in 2009, but all data are not yet available. However, daily hypoxic periods did not affect digestibility of lipids, nitrogen, ash, dry matter or energy significantly.

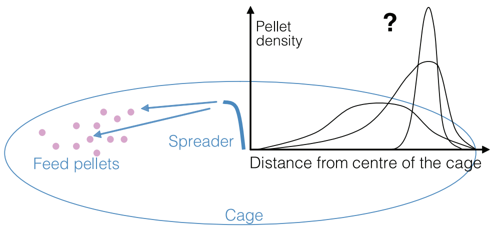


Fig. 10 : How are the feed pellets distributed in the cage during feeding?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Bio-statistical analysis

Project leader:
Dr. Trine Kirkhus (SINTEF ICT)

Investigators:
Eivind Brendryen, Arne Bjerge and Gunnar Hille (AKVA group)

Tom Kavli and Gøril Breivik (SINTEF ICT)

Background

Fishtalk is a software product used in production control for farming fish. Biological, financial and environmental information is recorded, reported and analyzed. 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 for 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 quickly, 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 the 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

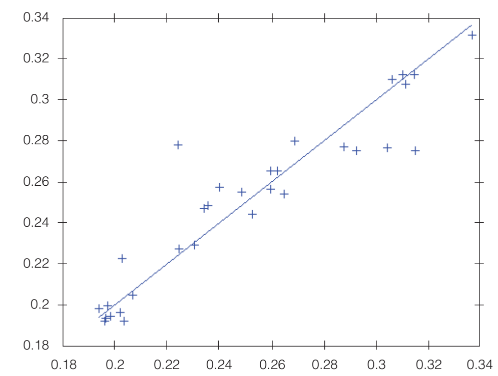


Fig. 11 : Estimated coefficient of variation (CV) in fish size relative to the measured CV (CV = standard deviation (fish weight) / mean (fish weight)).


SUB-CAGE

SubCage Biology and Technology

Project leaders:
Dr. Tore Kristiansen (IMR) and Dr. Østen Jensen (SFH)

Investigators:
Dr. Tim Dempster (SFH), Øyvind J. Korsøen (IMR), Dr. Frode Oppedal (IMR), Jan-Erik Fosseidengen (IMR)

CREATE Industrial Partners:
AKVA Group, Egersund Net, Erling Haug

Background

Submerged or semi-submerged sea-cage culture has been successfully demonstrated for several species. Examples when submergence may enable a better production environment to be accessed during poor surface conditions are numerous. Moreover, submergence may provide opportunities to reduce specific environmental impacts related to salmonid culture in sea-cages, such as escapes during storms and sea-lice loads in coastal waters. Despite these advantages, submerged have not been adopted widely by the industry. Technical development combined with biological knowledge is required to innovate submerged cage systems.

Submerged farming introduces specific challenges for fish with different types of swim bladders. Atlantic salmon have open swim bladders that must be filled by swallowing air at the surface, thus submergence results in fish becoming negatively buoyant. Fish with closed swim bladders will face very different challenges in sea-cages as they have slow swim bladder inflation- and deflation-rates. Therefore the rate at which sea-cages are lowered and lifted will be critical.

Methods

Earlier in the project, we investigated a mechanism to sink and lift cage systems and tested this with a cage model in a flume tank (Fig. 12). This work is continuing. In the SubCage Biology project, we have investigated the effects of submergence on the behaviour and growth of Atlantic salmon in industry-scale sea-cages and the effect of lowering and lifting cages on the buoyancy control of Atlantic cod (see PhD description of Ø. Korsøen). Here, we summarize the results from 3 full-scale sea-cage trails on Atlantic salmon at the Cage Environment Laboratory of the Institute of Marine Research in southern Norway (Fig. 13). 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. 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). In experiment 2, artificial lights were also used so that fish had enough light to school during nighttime. Experiment 3 investigated the effect of deeper submergence (cage roof at 10 m) for a period of 6 weeks on fish of average size of 3.5 kg (2000 per cage) during winter when days were short and nights were long.

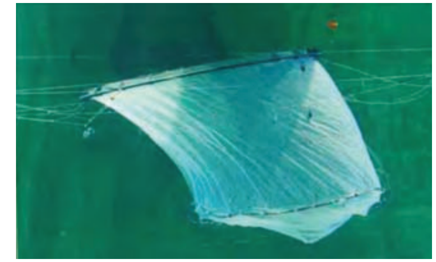


Fig. 12 : Example of submerged cage behaviour in the flume tank.

Fig. 13 : Inside and outside the Cage Environment Laboratory of the Institute of Marine Research in southern Norway where submergence experiments were conducted.

Results and Discussion

In experiments 1 and 2, 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, they appeared to tolerate submergence by swimming faster, possibly as a behavioural adaptation to generate lift to counter negative buoyancy.

In experiment 3, behavioural adaptations were similar to those seen in the first two experiments. 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. Our results suggest that continuous submergence below 10 m for longer than 2 weeks reduces the welfare and performance of Atlantic salmon.

Overall, our 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 short, 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. See Dempster et al. (2008, 2009) and Korsøen et al. (2009) for full details of the trials. Finally, as this project continues, we will investigate if behavioural manipulation of salmon through submergence may lead to the development of a new and effective technique for removing sea-lice *(Lepeophtheirus salmonis)* from Atlantic salmon.

KRISTINE SUUL BROBAKKE - 29

Education:
Siv. Ing. (Master of Science) in
Marine Technology

Company/Institution:
Erling Haug AS

Place of residence: Trondheim
Place of birth: Trondheim
Nationality: Norwegian

Leisure activities:
Sailing, sailing, sailing!

3 keyword about yourself:
always happy, enjoy meeting people,
must live close to the sea.

Behavioural responses to pressure changes in cultured Atlantic cod *(Gadus morhua)*: defining practical limits for submerging and lifting sea-cages

PhD student:
Øyvind J. Korsøen (IMR)

Supervisors:
Dr. Tim Dempster (SFH), Dr Tore Kristiansen (IMR), Prof. Anders Fernö (IMR)

Background

Farmed Atlantic cod *(Gadus morhua)* are occasionally exposed to buoyancy changes in sea-cages, through lifting or lowering of cage nets. Physiological processes regulate the level of gas in the closed swim bladders of cod (Fig. 14) and thus the ability of cod to control their buoyancy. Rapid net lifting may cause positive buoyancy, leading to barotrauma, while net lowering may lead to negative buoyancy and alter cod behaviours. We tested how groups of farmed cod responded immediately after lifting events from 5 different start depths equivalent to 40% reductions, and how long they took to recover to return to pre-lifting levels. In addition, we tested immediate responses and recovery times to cage lowering events equivalent to 100-200% pressure increases.

Methods

Trials were conducted with 100 cod of 1.0-1.6 kg in a 63 m^3 sea-cage at low (5°C) and high (16°C) water temperatures. Swimming behaviours were measured at fixed intervals before and after cage lifting or lowering, and a feeding test was used to assess appetite.

Results and Discussion

In general, lifting events increased swimming speeds 1.5-4 times and tail beats 2-3 times and fish swam with an average -14° head-down angle, indicating positive buoyancy (Fig. 15). The depth before lifting affected the immediate response as the fish became more active after lifting events from shallow compared to deeper depths. Appetite levels decreased for about 2 h after cage lifting, independent of temperature or start depth. The overall recovery time of 8 h after lifting did not depend upon start depth or temperature. Lowering events equivalent to 100, 150 and 200% pressure reductions, appeared to cause negative buoyancy. Swimming speeds (1.3-2.3 times) and tail beat frequencies (1.4-2.3 times) increased immediately after cage lowering, and cod swam with an average 30° head-up swimming angle. Neither pressure level nor temperature affected this immediate response. Time to recover to neutral buoyancy for 200% pressure increases took 42-90 h, but only 18-34 h for 100% pressure increases. We conclude that a 40% pressure reduction is an upper limit for lifts of healthy farmed cod. Secondary lifts should not be done until at least 10 h after the first lift. Cage lowering should be done slowly to avoid potentially stressful crowding of negatively buoyant fish on the cage bottom, especially at low temperatures.

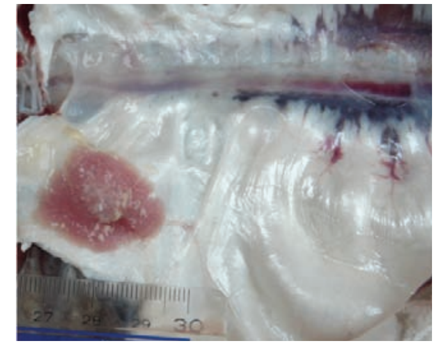


Fig. 14 : Inside the physoclistous swim bladder of an Atlantic cod

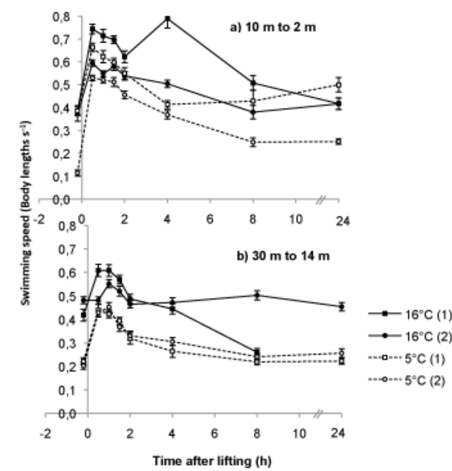


Fig. 15 : Average swimming speeds for groups of cod inside a cage lifted from a) 10 to 2 m, and b) from 30 to 14 m, both corresponding to a 40% pressure reduction. Measurments were done 10 min prior to and at 7 times after the lifting procedure. Solid and dotted lines represents two replicates at 16 °C and 5 °C, respectively.

NINA BLÖCHER - 27

Title research project:
Fouling of hydroids in the salmon aquaculture industry

Education:
Master in Marine Biology

Company/Institution:
NTNU / SINTEF Fisheries and Aquaculture

Place of residence: Trondheim
Place of birth: Marburg, Germany
Nationality: German

Leisure activities:
snowboarding, meeting friends, reading

3 research keyword:
fish farm, biofouling, experimental

3 keyword about yourself:
practical, creative, organized

MAIKE OEHME - 27

Title research project:
Physical properties of feed

Education:
Master in Agricultural Biology,
University of Hohenheim, Germany

Company/Institution: NOFIMA Marin
Place of residence: Sunndalsøra, Norway
Place of birth: Hamburg
Nationality: German

Leisure activities:
Sailing, Skiing

Latest publication:
Oehme, M., Frei, M., Razzak, M.A., Dewan, S., Becker, K. 2007. Studies on nitrogen cycling under different nitrogen inputs in integrated rice-fish culture in Bangladesh. Nutrient cycling in Agroecosystems 79, 181-191.

3 research keyword:
feed, pellet stability, nutritional value

3 keyword about yourself:
maritime, adventure, independent

TECHNOLOGY REVIEW

Advances in technology for offshore and open ocean aquaculture.

Publication Year: 2009
Source: New technologies in aquaculture: Improving production efficiency, quality and environmental management.
Eds.: Burnell G, Allen G. Woodhead Publications, Cambridge, UK.

Authors: Arne Fredheim, Richard Langan

Research Challenges:
- Summarise the current status of aquaculture technologies used in exposed locations
- Understand advantages and disadvantages of fish farming systems

Industry Impacts:
- Identification of technological innovation required to advance exposed location cage systems
- Increased focus on integrating cage systems and supporting technologies for feeding, monitoring and harvesting

NET DEFORMATION

Current induced net deformations in full-scale sea-cages for Atlantic salmon *(Salmo salar).*

Publication Year: 2008

Source:
Aquacultural Engineering 38: 52-65

Authors:
Pål Lader, Tim Dempster, Arne Fredheim, Østen Jensen

Research Challenges:
- Measure sea-cage deformations in strong currents
- Understand and analyse in situ sea-cage measurements

Industry Impacts:
- Quantification of sea-cage volume reduction due to current
- Possible development of a real time net volume indicator

SUBMERGED CAGES

Long-term culture of Atlantic salmon *(Salmo salar L.)* in submerged cages during winter affects behaviour, growth and condition.

Publication Year: 2009
Source: Aquaculture 296: 373-381

Authors:
Øyvind Korsøen, Tim Dempster, Per Gunnar Fjelldal, Frode Oppedal, Tore Kristiansen

Research Challenges:
- Can salmon be grown in submerged sea-cages for long periods?
- How does long-term submergence affect salmon behaviour and growth?

Industry Impacts:
- Submerged cages open the possibility of farming in more exposed locations
- Short-term (days to weeks) but not long-term (> 3 weeks) submergences of salmon are possible
- Storm damage and escapes could be avoided through short-term submergences

BIOFOULING

The development of biofouling, particularly the hydroid *Ectopleura larynx*, on commercial salmon cage nets in Mid-Norway.

Publication Year: 2010
Source: Aquaculture 300: 120-127

Authors: Jana Guenther, Ekrem Misimi, Leif Magne Sunde

Research Challenges:
- Does hydroid biofouling on nets vary with time and water depth?
- How rapidly do hydroids regrow after in situ washing of nets?

Industry Impacts:
- Hydroid biofouling increases with depth, so control strategies must account for this
- Hydroids regrow within 5 days of washing, meaning washing is a temporary control measure
- Better washing techniques or technologies are needed to more effectively control hydroids


CAGE AND
MOORING
SYSTEMS

New Cage Systems Design for Shallow Exposed Waters

Visiting post-doctoral researcher:
Dr. Fukun Gui
(Zhejiang Ocean University)

Co-researchers:
Dr. Arne Fredheim, Egil Lien (SINTEF)

Background

Many coastal countries in the world have long coastlines and shallow continental shelves. Shallow waters amplify the strength of tidal currents and waves, which must be considered when designing robust aquaculture structures for these environments. Despite good current and wave resistance of some existing cages, such as the Sea Station and Aqua Spar designs, their use is restricted as they are difficult to operate and are expensive. A cage based on new concepts, featuring high current and wave resistance, low construction cost and easy operation is urgently needed in the market.

Method

We compared the characteristics and functions of existing cage systems around the world. Based on this, we constructed a novel cage design idea, called the HexFly cage (Fig.16) Cages intended for use in exposed waters must have at least two basic functions: 1) maintain fish in an enclosed area and provide an effective culture volume; and 2) protect fish from 'attacks' from the marine environment. Hydrodynamic conditions are generally classified into five classes (I – V) of increasing intensity, according to wave & current conditions. At present, many cages only meet function 1, as they are used in sheltered culture sites (classes I and II). New cage systems designed for shallow exposed waters must also meet function 2, together with an improved function 1, due to the hostile hydrodynamic environments (class III-V) that they may be faced with.

Results and Discussion

The framework of the novel HexFly cage is divided into three layers (Fig. 16). The upper ring acts as an operating platform and is made of hexagonal pipes. The middle ring,

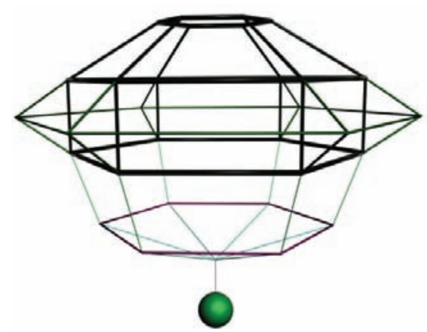


Fig. 16 The basic concept of the HexFly cage.

also of hexagonal shape, is connected to the upper layer through inclined pipes and controls cage buoyancy and functions as a harvest platform. The lower ring is designed for stabilizing the structure and providing hook points for the net cage. It is connected to the middle ring by vertical pipes. A special structure, the current diffluence part of the wedge shape which is set between the middle and lower rings, surrounds the cage's framework. All the rings are hollow when connected. The HexFly cage can be submerged or lifted by pumping air out and in the framework.

The HexFly cage is originally developed with an effective volume of 1500 m^3 and can be used at exposed sites with water depth deeper than 20 m. The HexFly cages can generally be deployed with cobweb mooring and can be stretched outward. This design reduces strong currents inside the cage by using the diffluence structure and the wave-induced loads on the cage are attenuated by submerging it. Effective volume is maintained and fishes inside the cage are protected.

We carried out basic structural calculations on the cage at the assembly and hoisting stages. In this case, the cage framework is made of PE pipes. For the assembly stage, maximum stresses (Fig. 17) appear at the top of the vertical connection pipes but are ten times less than the yield strength. For the hoisting stage maximum stresses appear at the hoisting points on the upper ring, but again are over ten times lower than the yield strength. Improvements can be made to the outer pipes of the current diffluence part as they are probably too flexible to resist strong current, which will require further verification and eventual testing of a prototype.

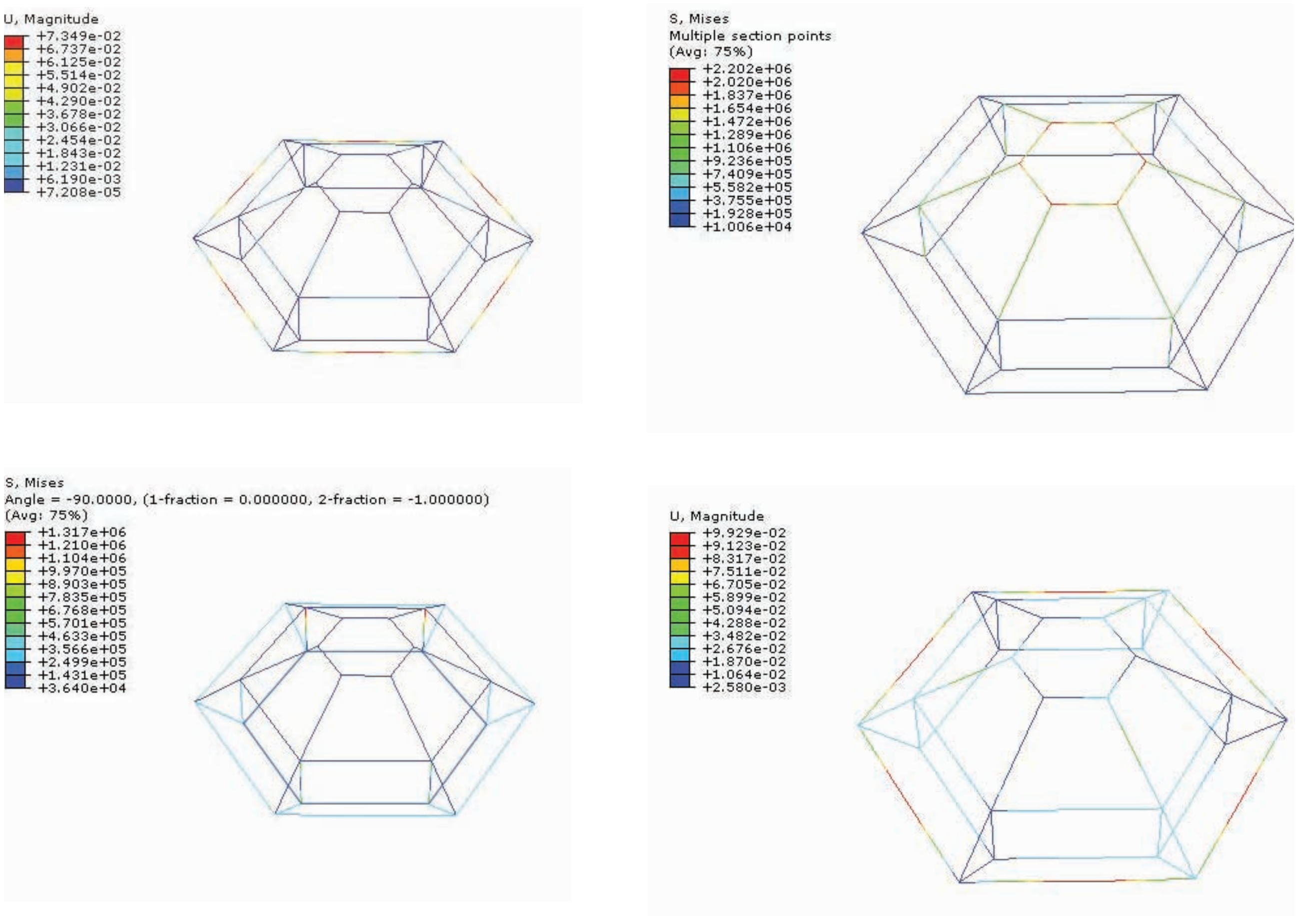


Fig. 17 : Stress and displacement distributions at the assembly and hoisting stages.

Reliability-Based Design of Aquacultural Plants

PhD student:
Enni Lisda Lubis (NTNU)

Supervisor:
Prof. Torgeir Moan (CeSOS, NTNU)

PhD focus:
The core objective of this research is to improve the basis for design codes for fish farms and improve reliability, thereby reducing the risk of farm failures and escapes of fish.

Background

Since the use of fish farms has been moved to more exposed locations with higher exposure to waves and current, escape of farmed fish in the oceans has received increasingly more attention. It is assumed that a significant number of escapes today are caused by structural collapse due to environmental loads. Hence in order to provide safer structures and thereby reduce escape, more advanced structural analysis of floating fish farms is necessary.

Fish farms are relatively large constructions. Due to the large size of the structures, wave load models based on regular waves are not relevant. In this sense, it is necessary to perform studies in irregular seas. The uncertainty in the effects of wave loads often dominates in the reliability analysis. Reliability methods can be used to calibrate ultimate strength code checks based on partial safety factors, to comply with a certain target reliability level.

Methods

The reference farm structure has a layout of 5 by 2 cage units (Fig. 16). The collar (support structure) of the cage structure consists of a number of pontoons/bridges that can be continuous or hinged. The focus of this research is to determine load effects and examine the inherent uncertainties in the loads and load effects (response). These uncertainties will be characterized by probabilistic measures.

The basic failure probability of a component is formulated in terms of a failure function g(x) as follows:

$$P_f = \int\int \ldots \int_{g(x)\leq 0} f_x(x)\, dx$$

where $f_x(x)$ is the joint distribution of the random variables describing the load effects and resistance. The failure functions g(x) will be formulated depending on failure modes. The failure probability of a given joint (i), may be updated on the basis of a given inspection event

$$P_{f,\mathrm{up}} = P[M_i(t) \leq O \mid IE_j] = P[(M_i(t) \leq O) \cap IE_j] / P[IE_j]$$

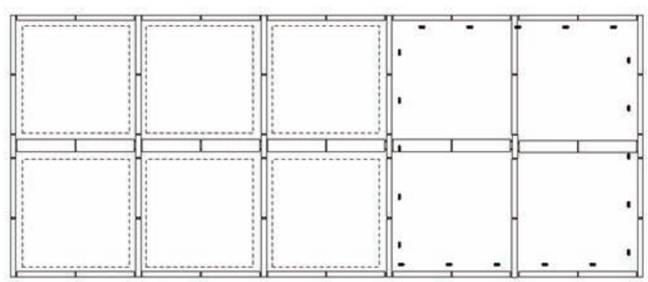
where $M_i(t)$ is the failure function for joint *i* in a time period t, and IE_j stands for a mathematical expression of inspection events, e.g. detection or no detection of a crack. This approach will be applied to document the effect of inspection on the fatigue reliability of the structure, depending upon the outcomes of inspections.

Design criteria for fatigue will be formulated as a function of the effect of inspections on the reliability level. The target fatigue reliability level is defined for the case when no inspection is made.

Expected Results

By conducting this research, we expect to be able to improve the design basis for aquacultural plants. As the aim of structural design of fish farms is to avoid collapse of structures and hence escape of fish into the open sea, this research is expected to create a better balance between the safety and costs of such facilities.

Fig. 18 : Basic farm construction with 5 by 2 cage units, with hinges, seen from above.




SIM
FRAME

Simulation and Optimization Framework – SimFrame

Project leader:
Gunnar Senneset (SFH)

Investigators:
All CREATE Scientific and industry partners participated in the project in 2009, including:
SINTEF Fisheries and Aquaculture
Institute of Marine Research
NOFIMA Marin
NTNU
SINTEF ICT
AKVA group
Egersund Net
Erling Haug

Background

The overall goal of the SimFrame project is to develop a framework for simulation, optimization and monitoring of all aspects of modern fish farming. This will enable researchers and industry to build more complex models by utilizing standardized interfaces and standard components. Access to historical and real-time data will be a part of the framework, also including methods for knowledge representation (Fig. 19).

The SimFrame project will work towards enabling easy integration of system "building blocks" from multiple disciplines (Fig. 20). This will encourage stepwise enhancements of decision support systems for fish farming planning and operations. This also includes development of common terminology and data models for standardized access to a combination of historical data, real-time data and knowledge representation models.

Methods

The scope of the work is the on-growing phase of salmon farming. The main focus in 2009 has been to define some of the main functional requirements for the framework. In order to do this, we chose to work both 'top-down' and 'bottom-up' (Fig. 21). The 'top-down' approach has consisted of defining long-term usage scenarios for decision support systems. This has been done by combining development in small working groups with workshops including all CREATE partners and the SimFrame steering committee.

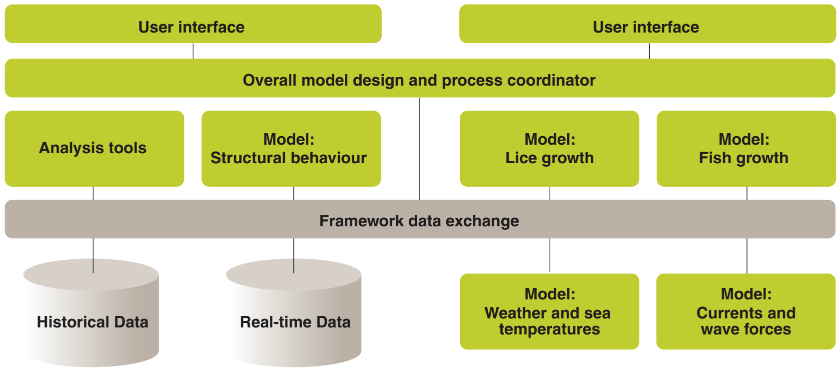


Fig. 19 : Integrating systems with disparate interfaces.

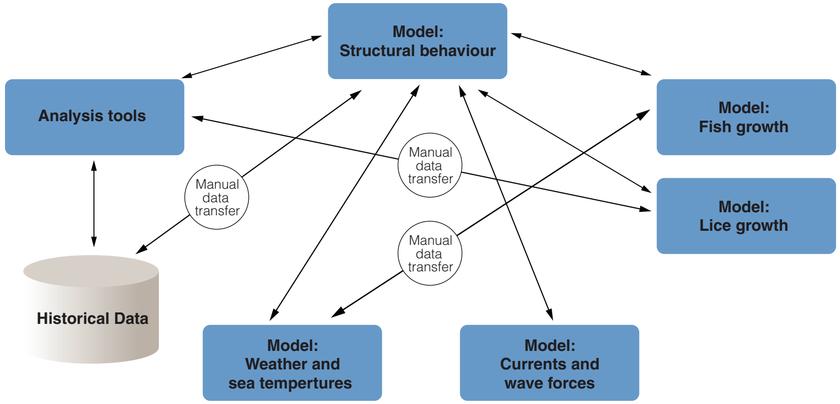


Fig. 20 : Integrating systems using a simulation and optimization framework

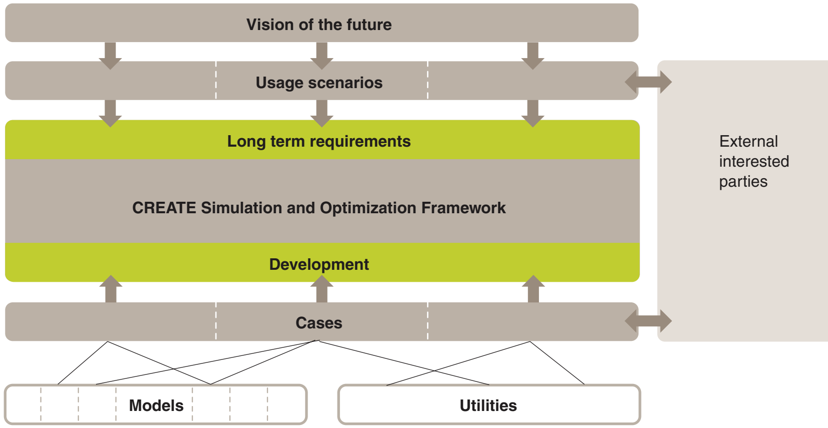


Fig. 21 : Method of work in 2009

The bottom-up approach was aimed at testing the fhSim model library (developed by SFH) as an integration tool for numerical models. The distribution of oxygen levels within a cage was chosen as a demonstrator (Fig. 22). Work has also started on developing common ontology and data models, in order to establish a basis for efficient integration of data from various sources. Input to this activity has been workshops with CREATE partners and experiences from the other project activities.

Results and discussion

The 2009 work on integrating numerical models using fhSim set out to integrate a model for net deformation with a model for oxygen consumption, simulating the resulting distribution of oxygen levels within a cage. Several technical integration problems were encountered, forcing the development team to focus on a more limited demonstrator. The conclusion so far is that fhSim can be a useful building block in the framework, but it is not suitable as an overall integration tool.

One of the main deliverables in 2009 was a comprehensive presentation made available for the CREATE industry partners for use at the Aqua Nor exhibition in august. This will also be an important basis for the main industry demonstrator to be developed in 2010. The demonstrator will focus on decision support systems for regional management. This is a complex task, typically involving 8-10 sites with a total of 60-100 cages. Tools from the fields of knowledge based system/artificial intelligence will be used for identifying deviations, analyze probable causes for deviations, and suggest corrective measures. Actual environmental and operational data from the large scale ACE (AquaCulture Engineering) research facility will be used. The ACE site is operated by SalMar, and SalMar will also provide access to data from other sites in the area.

Data from several sources need to be assembled (Fig. 23). Typically, the ACE and SalMar data are stored in several systems. ACE will also give access to data from an oceanographic buoy in the area. The data modeling activities in 2009 will be a basis for integrating data from various sources. This also includes data from numerical simulation models, the main case will be SINMOD, capable of simulating sea currents, temperature, oxygen levels, and propagation of infective agents.

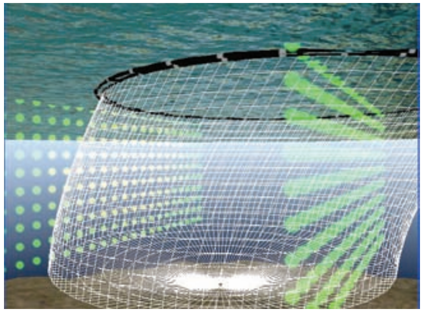


Fig. 22 : 3-dimentional distribution of oxygen levels within a cage

Step-wise development of an industry demonstrator will ensure focus on important issues and a basis for short-term results, as well as contributing to the long-term goal of establishing a simulation and optimization framework.

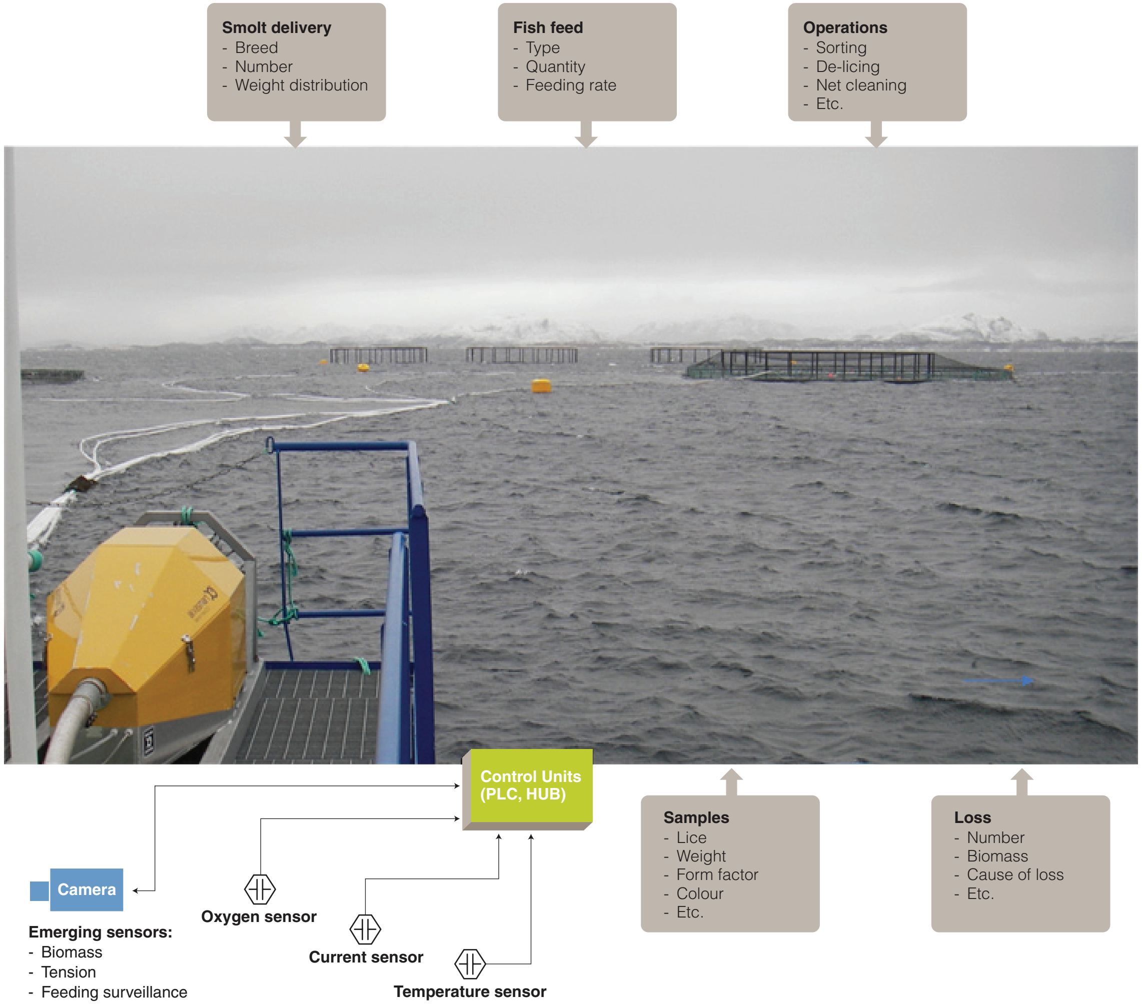


Fig. 23 : Typical data sources on a salmon farming site

ØYVIND JOHAN KORSØEN - 41

Title research project:
Biological criteria for successful submergence of fish (SubFish)

Education:
Engineer in Aquaculture, Cand Agric

Company/Institution:
Institute of Marine Research

Place of residence: Alversund
Place of birth: Bergen
Nationality: Norwegian

Leisure activities:
Kayaking, skiing, play guitar

Latest publication:
Long-term culture of Atlantic salmon *(Salmo salar L.)* in submerged cages during winter affects behaviour, growth and condition. Aquaculture 296:373-381

3 research keyword: Submerged farming, buoyancy for fish, fish behavior

3 keyword about yourself:
Social, all-rounder, patient

Modelling and simulation of fish behaviour in aquaculture production facilities

ENNI LISDA LUBIS - 34

Title research project:
Reliability-Based Design of Aquacultural Plants

Education:
MSc in Civil Engineering, ITB-Indonesia

Company/Institution:
Centre for Ships and Ocean Structures (CeSOS)

Place of residence: Trondheim, Norway
Place of birth: P. Sidempuan, Indonesia
Nationality: Indonesian

Leisure activities:
window shopping, playing with daughter

3 research keyword:
Reliability, design criteria, uncertainty

2 keyword about yourself:
happy, flexible

PhD student:
Martin Føre (SFH)

Supervisors:
Prof. Jo Arve Alfredsen (NTNU),
Dr. Tim Dempster (SFH)

Background

We have developed an individual-based model of salmon behaviour in sea-cages (Føre et al. 2009). The model includes the effects of water temperature, light, the sea-cage, food and other individuals, and its individual-based nature enables the observation of fish behaviour on both individual and group levels. Model parameters have been based on information from the literature and tuning of simulation output to datasets collected by the Institute of Marine Research. Possible applications of the model include estimation of welfare and *in silico* (virtual) testing of cage management strategies and new technologies.

Results and discussion

The main result of the model is currently its ability to predict the vertical distribution of salmon in sea-cages based on environmental factors. Fig. 24 contains a comparison between vertical distribution data collected in a trial performed by IMR (left column) and model predictions (right column). The environmental data collected during the trial was used directly in the model, suggesting that the model was able to reflect the vertical behavioural dynamics of salmon.

We assumed that responses between salmon were based on a desire to avoid collisions with neighbouring fish, culminating in two simple behavioural rules; 1) swim away from neighbours that are too close; and 2) align with individuals that are further away but within viewing distance. Along with a rule specifying the fish to avoid hitting the cage wall, these rules produced circular schooling patterns similar to those seen in caged salmon populations. Fig. 25 displays the movement trajectories of 10 fish randomly selected from 1000 fish simulated over 1000 seconds, demonstrating that schooling may be an emergent effect of the simple rules explained above.

Future planned research

The next step will be to incorporate telemetry data on individual-based salmon behaviours in full-scale sea-cages collected in 2009 in the model. Following this, we will continue to develop the model, beginning with the inclusion of responses toward artificial light sources.

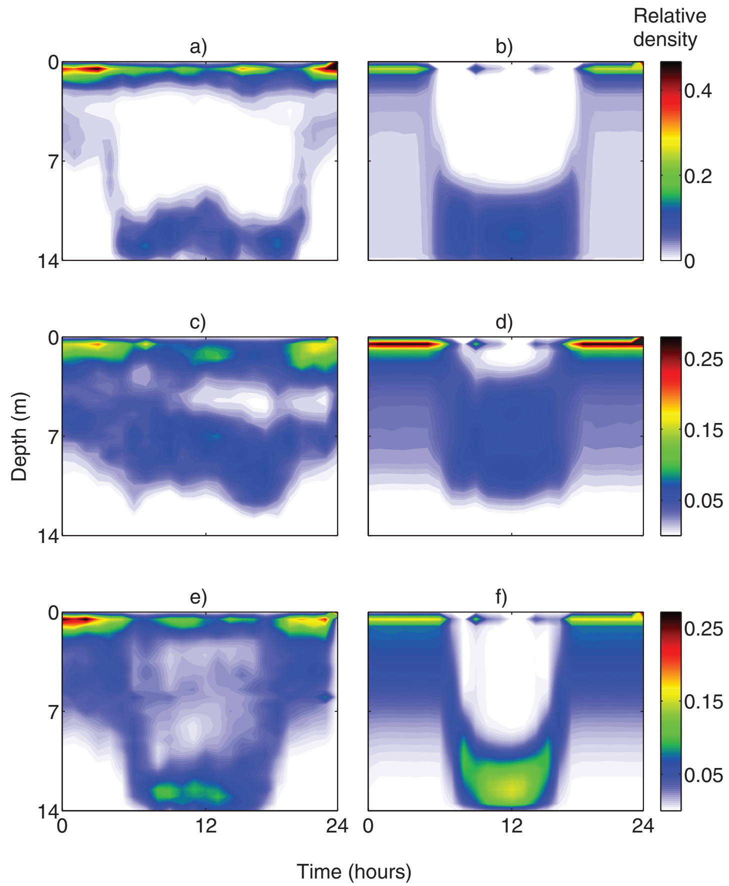


Fig. 24 : Observed and simulated vertical distribution of salmon in sea-cage for three periods in autumn. a), c) and e); observations by echo-sounder, b), d) and f); model simulation data.

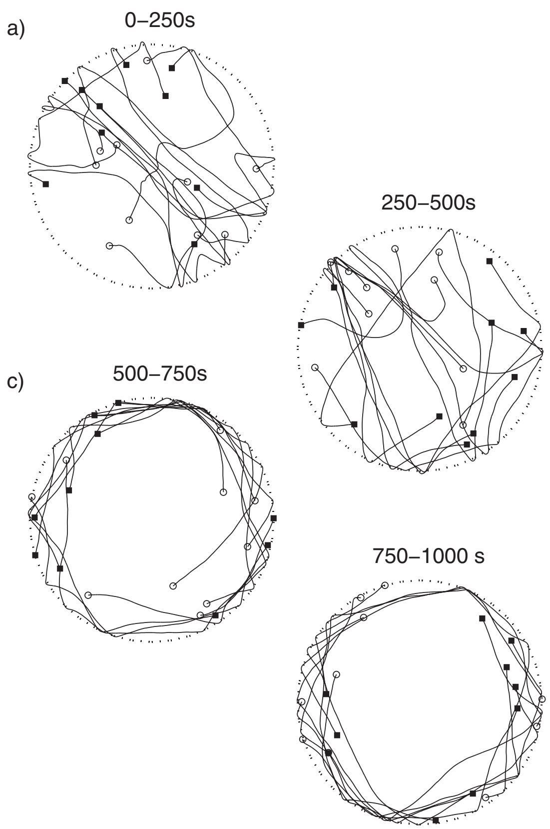


Fig. 25 : Swimming trajectories (solid lines) for ten fish randomly selected from a population of 1000 fish simulated in a sea-cage (dashed line) over four 250 s time intervals. Open circles denote initial positions, while filled squares mark end positions.


ABOUT CREATE

About 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 additional representative from the research partners. In 2009 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 2009, the following people were members of the committee:

Svein Ove Rabben
Egersund Net AS

Morten Malm
AKVA group ASA

Kristine Brobakke
Erling Haug AS

Alf Kristian Fjelldal
Polarcirkel, AKVA group ASA

Torbjørn Åsgård
NOFIMA Marin AS

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.

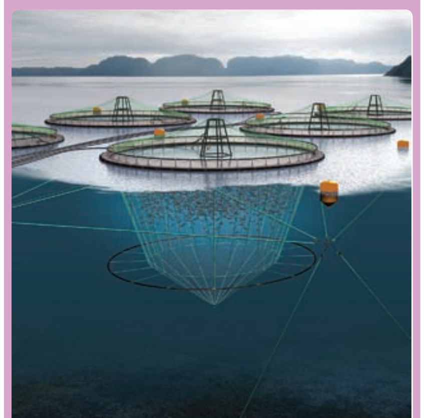
Experimental activity where steady currents are the main focus, and

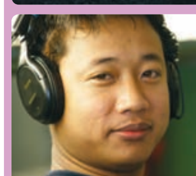
AKVA GROUP - facts

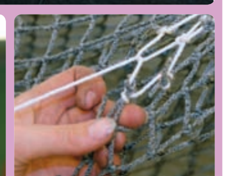
- The leading aquaculture technology supplier
- Only supplier with global presence
- Offices in 12 countries and staff of around 600
- The largest supplier to the aquaculture industry
- High growth company
- Profitable
- Industry consolidator

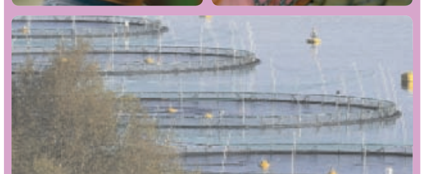
EGERSUND NET - facts

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









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

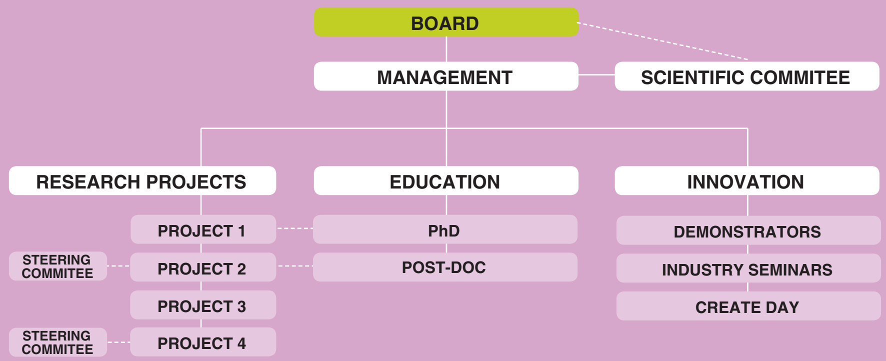


Figure 26 : The organization of CREATE

and product offering into two business areas, Farm Operations Technology, comprising centralized feed systems, sensors and camera systems, recir-culation 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 com-panies 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 1970s, 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 de-velopment in manufacturing nets and netting, and also in design and testing of new models. Research and development in collaboration with customers and partners, such as CREATE, makes the company able to continue its work for a better product, better quality and a better result for the fish farmers.

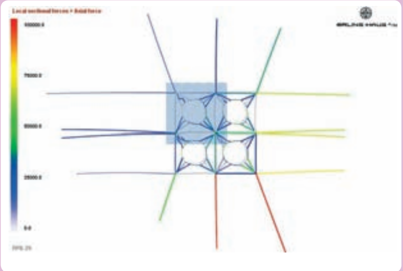
Erling Haug AS is a trading house, supplying both the offshore and onshore markets since 1936. We provide the aquaculture industry with engineering of and products related to complete mooring systems, com-ponents for mooring systems, lifting equipment and life saving equipment as well as several other product groups.

Innovation has been part of the Erling Haug AS philosophy from the begin-ning, always focusing on technical knowledge. Our drive for quality solu-tions 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.

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



Department of Engineering Cybernetics - NTNU - facts

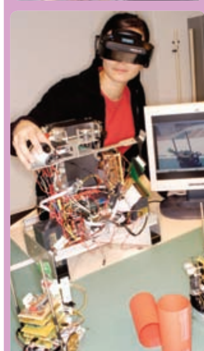
Engineering Cybernetics is the science of control and communications in dynamic systems.

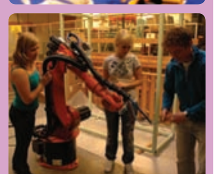
Vision to be one of Europe's most renowned research and education communities in the department's main areas.

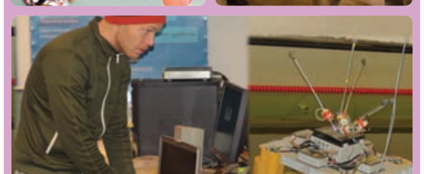
27 permanent employees and about 40 PhD students and temporary academic staff.

Educate about, 75 MSc and 10 PhD students per year (average last 3 years).

Cybernetics is a science with a very wide range of applications







"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 innovative design of structures and automatic control systems as well as for planning marine operations.

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 tech./adm. staff of 13. In a typical year, approximately 80 MSc and 5-10 PhD students 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:

Marine, Food, Ingredients and Market. NOFIMA has its head office in Tromsø with research centres at Ås, Stavanger, Bergen, Sunndalsøra and Averøy.

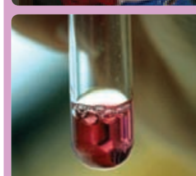
NOFIMA Marin engage in R&D, innovation and knowledge transfer for the national and international fisheries and aquaculture industry. The primary professional areas cover breeding and genetics, feed and nutrition, fish health, sustainable and effective production as well as capture, slaughtering and primary processing.

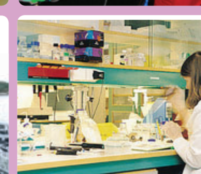
The Institute of Marine Research (IMR) is Norway's largest centre of marine science with close to 700 staff. IMR's main task is to provide advice to Norwegian authorities on aquaculture and the ecosystems of the Barents Sea, the Norwegian Sea, the North Sea and the Norwegian coastal zone. For this reason,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

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

NOFIMA MARIN - facts

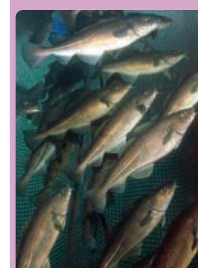
- R&D, innovation and knowledge transfer for fisheries and aquaculture
- Breeding and genetics
- Feed and nutrition
- Fish health
- Efficient and sustainable production
- Seafood processing and product development
- Marine bioprospecting

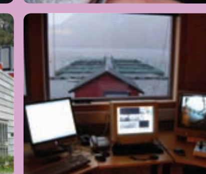



INSTITUTE OF MARINE RESEARCH - facts

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

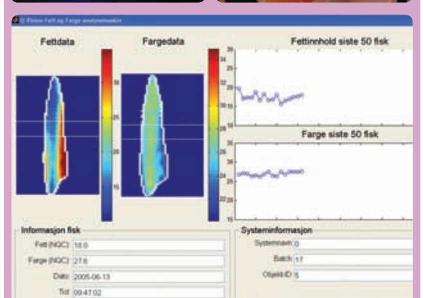



SINTEF Information and Communication Technology (SINTEF ICT) provides contract research-based expertise, services and products within the fields of micro technology, sensor and instrumentation systems, communication and software technology, computational software, information systems and security and 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.

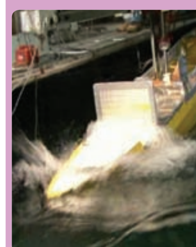
SINTEF ICT - facts

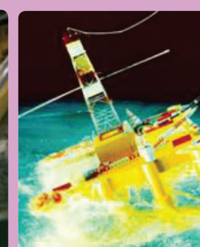
Information and Communication Technology (ICT) provides research-based expertise, services and products ranging from microtechnology, communication and software technology, computational software, information systems and security and safety. Work ranges from simple technical analysis to complete systems

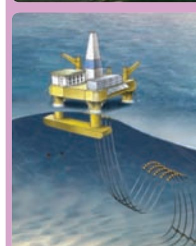


CeSOS - facts

- Centre of Excellence initiated by RCN in 2003
- Internationally recognised research on ships and ocean structures
- Highly interdisciplinary approach
- World-class testing facilities
- About 80 affiliated PhD candidates and researchers
- Above 100 scientific publications per year

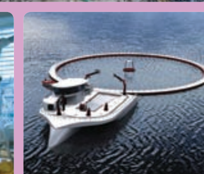


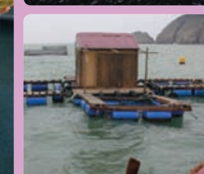


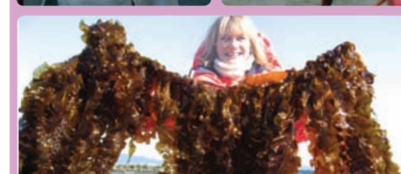


SINTEF Fisheries and Aquaculture - facts

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







Key researchers

NAME	INSTITUTION	MAIN RESEARCH AREA
Dr. Arne Fredheim	SINTEF Fisheries and Aquaculture	Marine hydrodynamics/ 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 Oppedal	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
Dr. Fukun Gui	Post. Doc.	Chinese	M	2009-10	Design of cage systems for exposed shallow waters

Postdoctoral researchers

NAME	NATIONALITY	SEX	DURATION	TOPIC
Dr. Bailey Jason	Canadian	M	2007-08	Cage environment
Dr. Guenther Jana	German	F	2008-10	Biofouling on aquaculture constructions
Dr. Axel Tidemann	Norwegian	M	2009-11	Case based reasoning systems for aquaculture operations

PhD students with financial support from the Centre budget

NAME	NATIONALITY	SEX	DURATION	TOPIC
Øyvind Johan Korsøen	Norwegian	M	2007-10	Biological criteria for successful submergence of physoclistous Atlantic cod and physostomous atlantic salmon reared in sea-cages
Martin Føre	Norwegian	M	2007-10	Modelling and simulation of fish behaviour in aquaculture production facilities
Mette Remen	Norwegian	F	2008-11	Effects of fluctuating oxygen levels on welfare and growth of salmon *(Salmo salar)* in net cages
Lisda Lubis Enni	Indonesian	F	2008-12	Reliability-based design of Aquacultural Plants
Nina Blöcher	German	F	2009-12	Biofouling on marine cage systems

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

NAME	FUNDING	NATIONALITY	SEX	PERIOD	TOPIC
Lars Gansel	NTNU	German	M	2007-10	Flow through and around fish cages
Rune Melberg	University of Stavanger	Norwegian	M	2007-09	Fish farming modeling, simulation and control

Master degrees

NAME	PERIOD	SEX	TOPIC
Jannicke Vigen	2007-08	F	Oxygen variation in cages
Maike Oehme	2007-08	F	Nutrient digestibility of feeds
Christina Carl	2007-08	F	Biofouling
Astrid Harendza	2007-08	F	PIV on inclined cylinder shaped fish cages
Håkon Raanes	2008-09	M	Next generation subcage - concept development


INTER
NATIO
NAL
Pellet
density
Distance from centre of the cage
Spread
Cage
Feed pellets
from centre of the cage
Distance from centre of the cage
Pellet
density

International co-operation

CREATE has active international collaborations at both the level of the centre, researchers and through the centre's individual projects.

Aquaculture Environment Interactions

A core component of CREATE's philosophy is to innovate aquaculture technologies that ensure the environmental sustainability of the industry. To do so, both researchers and the fish farming industry require an understanding of the most relevant and up-to-date research on the interactions of aquaculture with the environment. Research in this field has typically been scattered across many journals, because no publication outlet was available that had a specific focus on aquaculture-environment interactions. Early discussions within CREATE stimulated a desire to consolidate research in this diverse field. CREATE researcher Dr. Tim Dempster and Prof. Marianne Holmer (University of Southern Denmark) approached the scientific publisher Inter-Research in 2009 with a proposal to establish a new, peer-reviewed, international journal. The journal Aquaculture Environment Interactions (AEI) was founded by Inter-Research president, Prof. Otto Kinne, in late 2009. AEI will publish scientific results obtained in this increasingly vital field, foster the sharing of information among scientists, the aquaculture industry and environmental managers, and contribute to improving the long-term sustainability of aquaculture activities. The first articles will be published in early 2010. For more information see: www.int-res.com/journals/aei/

CREATE and University of New Hampshire collaboration

The University of New Hampshire has been an active international collaborator within CREATE since its inception. Prof. Hunt Howell and Michael Cham-

bers from the Open Ocean Aquaculture program have participated in project development and discussions at each of the annual CREATE days (2007-2010). This interaction led to CREATE PhD student Martin Føre undertaken a 3-month stay with UNH in 2008 to investigate the behaviour of Atlantic cod in sea-cages at different densities in collaboration with Prof. Howell and Prof. Win Watson.
A scientific publication describing the results from the cod study is planned in 2010. In addition, Arne Fredheim (SINTEF) and Richard Langan (UNH) have recently published a review summarizing the status of technological development for off-shore and open ocean aquaculture

Cage Environment

Within the Cage Environment project, Dr. Øystein Patursson from the research station of Fiskaaling, Faroe Islands, has participated in field experiments during 2009 and will publish the results in cooperation with CREATE. In addition, Dr. Kim Thompson from the University of Stirling, Scotland, took part in developing an immunological method in conjunction with the fluctuating hypoxia trials. Model scale experiments of fish farm cages in current and waves were conducted together with Assoc. Prof. David Fredriksson from the United States Navel Academy (USNA), at their towing tank facilities. A scientific publication describing the results from this model scale experiments is planned in 2010.

Biofouling on Aquaculture Constructions

In an attempt to discover and develop more environmentally sustainable antifouling surfaces, the Biofouling on Aquaculture Constructions project investigates surface characteristics, such as hydrophobicity and texture, which may reduce the settlement of dominant fouling species. The Biofouling project continues to collaborate actively with Prof. Rocky de Nys at James Cook University, Australia.

The collaboration involves testing the performance of various nano-textured surfaces 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.

The European Union 7th Research Framework project Prevent Escape

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 Prevent Escape project 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). 11 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 partners within CREATE due to their technological expertise and direct links to the farming industry.

AXEL TIDEMANN - 29

Title research project:
SimFrame

Education:
PhD, Artificial Intelligence

Company/Institution:
NTNU

Place of residence: Trondheim
Place of birth: Trondheim
Nationality: Norwegian

Leisure activities:
Playing drums and writing music

Latest publication:
My PhD thesis: "A Groovy Virtual Drummer: Learning by Imitation Using A Self-Organizing Connectionist Architecture"

3 research keyword:
Control systems for fish farms

3 keyword about yourself:
Creative, outgoing, determined

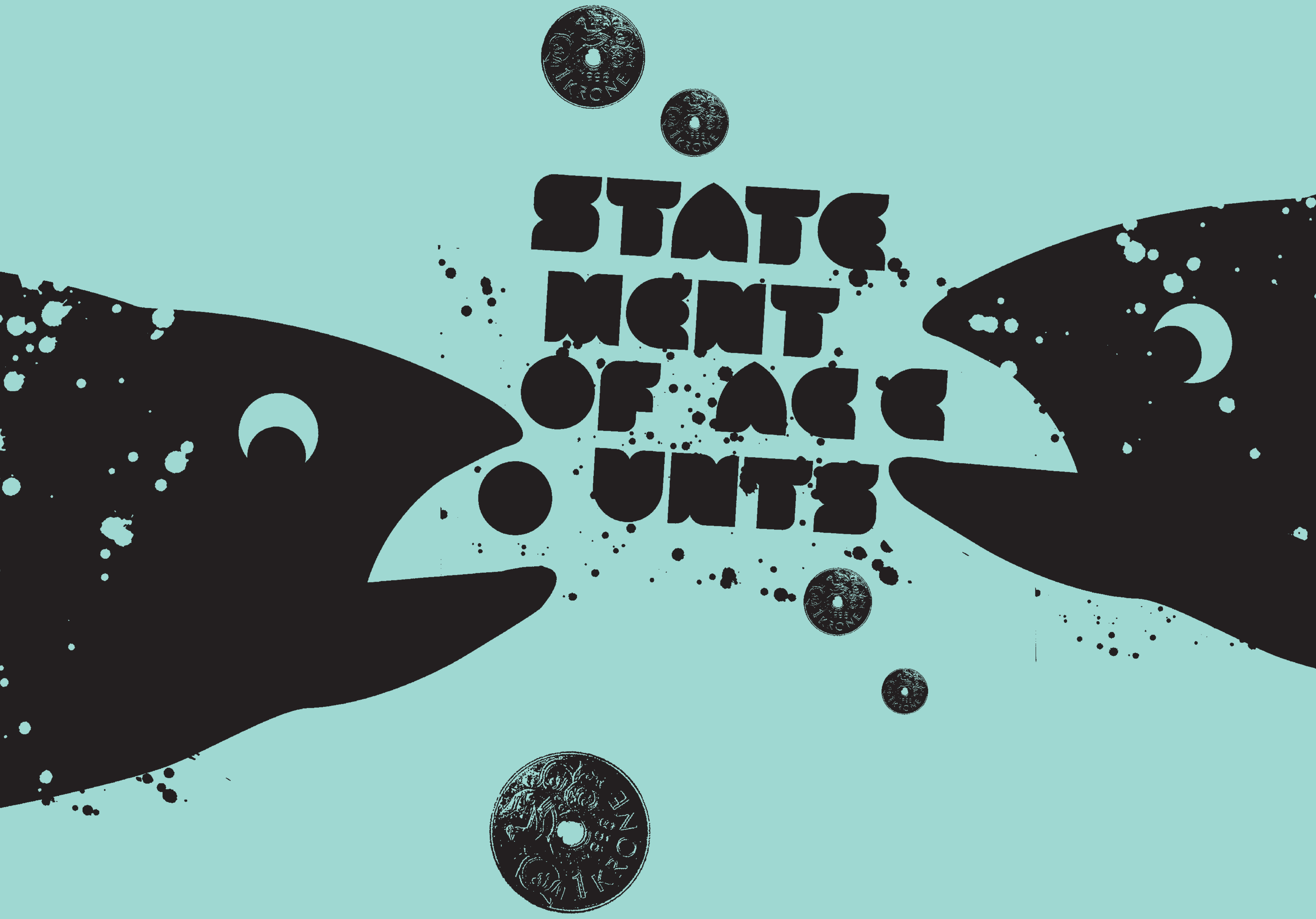
SVEIN OVE RABBEN - 47

Education:
Electrician

Company/Institution:
Egersund Net AS

Place of residence: Bergen
Place of birth: Austevoll
Nationality: Norwegian

Leisure activities:
There is very little spare time ☺,
Fishing and family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Statement of Accounts 2009

Funding	2009	2008	2007
The Research Council	12 453	9 934	5 709
The Host Institution	1 770	1 325	481
Research Partners	2 665	3 002	860
Enterprise Partners	4 603	4 925	3 774
Public Partners	0	0	0
Total	**21 491**	**19 186**	**10 824**

Costs	2009	2008	2007
The Host Institution	8 507	5 460	3 049
Research Partners	6 012	6 460	2 982
Enterprise Partners	6 900	7 136	4 694
Public Partners	0	0	0
Equipment	72	130	99
Total	**21 491**	**19 186**	**10 824**

(All figures in 1000 NOK)


PUBLICATIONS AND DISSEMINATION

Publications and Dissemination

Peer-reviewed journal articles

Aquaculture technology - structures

DETAILS	YEAR	TITLE	SOURCE
Jensen Ø, Wroldsen AS, Lader PL, Fredheim A, Heide M	2007	Finite element analysis of tensegrity structures in offshore aquaculture installations.	Aquacultural Engineering 36: 272-284
Lader P, Olsen A, Jensen A, Sveen JK, Fredheim A, Enerhaug B	2007	Experimental investigation of the interaction between waves and net structures - Damping mechanism.	Aquacultural Engineering 37(2): 100-114 1
Lader PF, Jensen A, Sveen JK, Fredheim A, Enerhaug B, Fredriksson D	2007	Experimental investigation of wave forces on net structures.	Applied Ocean Research 29(3): 112-127 1

Aquaculture technology - nets

DETAILS	YEAR	TITLE	SOURCE
Lader PL, Dempster T, Fredheim A, Jensen Ø	2008	Current induced net deformations in full-scale sea-cages for Atlantic salmon *(Salmo salar).*	Aquacultural Engineering 38: 52-65
Moe H, Fredheim A, Hopperstad OS	2010	Structural analysis of aquaculture net cages in current.	Journal of Fluids and Structures (in press)
Moe H, Hopperstad OS, Olsen A, Jensen Ø, Fredheim A	2009	Temporary-creep and post-creep properties of aquaculture netting materials.	Ocean Engineering 36: 992-1002
Moe H, Olsen A, Hopperstad OS, Jensen Ø, Fredheim A	2007	Tensile properties for netting materials used in aquaculture net cages.	Aquacultural Engineering 37(2): 252–265 1

Biofouling

DETAILS	YEAR	TITLE	SOURCE
Guenther J, Carl C, Sunde LM	2009	The effects of colour and copper on the settlement of the hydroid *Ectopleura larynx* on aquaculture nets in Norway.	Aquaculture 292: 252-255
Guenther J, Wright AD, Burns K, de Nys R	2009	Chemical antifouling defences of tropical sea stars: Effects of the natural products hexadecanoic acid, cholesterol, lathosterol and sitosterol.	Marine Ecology Progress Series 385: 137-149
Guenther J, Misimi E, Sunde LM	2010	The development of biofounling, particularly the hydroid *Ectopleura larynx*, on commercial salmon cage nets in Mid-Noway	Aquaculture 300: 120-127

Submerged sea-cages

DETAILS	YEAR	TITLE	SOURCE
Dempster T, Juell JE, Fosseidengen JE, Fredheim A, Lader P	2008	Behaviour and growth of Atlantic salmon (*Salmo salar*) subjected to short-term submergence in commercial scale sea-cages.	Aquaculture 276: 103-111
Dempster T, Korsoen Ø, Oppedal F, Folkedal O, Juell JE	2009	Submergence of Atlantic salmon (*Salmo salar*) in commercial scale sea-cages: a potential short-term solution to poor surface conditions.	Aquaculture 288: 254-263
Korsøen Ø, Dempster T, Fjelldal PG, Oppedal F, Kristiansen TS	2009	Long-term culture of Atlantic salmon (*Salmo salar* L.) in submerged cages during winter affects behaviour, growth and condition.	Aquaculture 296: 373-381

Fish behaviour

DETAILS	YEAR	TITLE	SOURCE
Føre M, Dempster T, Alfredsen J-A, Johansen V, Johansen D	2009	Modelling of Atlantic salmon (*Salmo salar*) behaviour in aquaculture sea-cages: a Lagrangian approach.	Aquaculture 288: 196-204
Johansson D, Ruohonen K, Kiessling A, Oppedal F, Stiansen J-E, Kelly M, Juell J-E	2006	Effect of environmental factors on swimming depth preferences of Atlantic salmon (*Salmo salar* L.) and temporal and spatial variations in oxygen levels in sea cages at a fjord site.	Aquaculture 254: 594-605
Johansson D, Ruohonen K, Juell J-E, Oppedal F	2009	Swimming depth and thermal history of individual Atlantic salmon (*Salmo salar* L.) in production cages under different ambient temperature conditions.	Aquaculture 290: 296-303

Aquaculture-Environment Interactions

DETAILS	YEAR	TITLE	SOURCE
Moe H, Dempster T, Sunde L M, Winther W, Fredheim A	2007	Technological solutions and operational measures to prevent escapes of Atlantic Cod (*Gadus morhua*) from sea-cages	Aquaculture Research 38: 91-99
Dempster T, Sanchez-Jerez P, Uglem I, Bjørn P-A	2010	Species-specific patterns of aggregation of wild fish around fish farms	Estuarine, Coastal and Shelf Science 86(2): 271-275
Dempster T, Uglem I, Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere J, Nilsen R, Bjørn PA	2009	Coastal salmon farms attract large and persistent aggregations of wild fish: an ecosystem effect.	Marine Ecology Progress Series 385: 1-14
McClimans TA, Handå A, Fredheim A, Lien E, Reitan KI	2010	Controlled artificial upwelling in a fjord to stimulate non-toxic algae	Aquaculture Engineering 42: 140-147
Sanchez-Jerez P, Fernandez-Jover D, Bayle-Sempere J, Valle C, Dempster T, Tuya F, Juanes F	2008	Interactions between bluefish *Pomatomus saltatrix* (L.) and coastal sea-cage farms in the Mediterranean Sea.	Aquaculture 282: 61-67
Uglem I, Dempster T, Bjørn P-A, Sanchez-Jerez P, Økland F	2009	High connectivity of salmon farms revealed by aggregation, residence and repeated movements of wild fish among farms.	Marine Ecology Progress Series 384: 251-260

Peer-reviewed book chapters

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

Peer-reviewed international conference papers.

DETAILS	YEAR	TITLE	SOURCE
Gansel LC, McClimans TA, Myrhaug D	2010	Average flow inside and around fish cages without and with fouling in a uniform flow.	Proceedings of the 29th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2010, Shanghai, China, June
Gansel LC, McClimans TA, Myrhaug D	2009	Flow around the free bottom of fish cages in a uniform flow with and without fouling.	Proceedings of the 28th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2009, Hawaii, USA, June

Non-reviewed journal articles

DETAILS	YEAR	TITLE	SOURCE
Aure J, Oppedal F, Vigen J	2009	Hva bestemmer vannutskifting og oksygenforhold i oppdrettsmerder?	Kyst og Havbruk 2009, Fisken og Havet, særnummer 2-2009, 169-171.
Dempster T	2009	Prevent Escape - Assessing the causes and developing measures to prevent the escape of fish from sea-cage aquaculture.	Aquaculture Europe 34(2): 23
Dempster T, Holmer M	2009	Introducing the new multidisciplinary journal Aquaculture Environment Interactions	Aquaculture Environment Interactions 1 i-ii
Dempster T, Moe H, Fredheim A, Sanchez-Jerez P	2007	Escape of Marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention.	CIESM workshop Monograph no. 32.
Fredheim A, Dempster T	2009	Centre for Research-based Innovation in Aquaculture Technology (CREATE).	Aquaculture Europe 34(2): 6-13
Juell JE, Nilsson J, Olsen RE, Fridell F, Kvamme BO, and 5 others	2007	Dyrevelferd i akvakultur og fiskeri et nytt fagområde i rask vekst.	Kyst og Havbruksrapporten, Fisken og Havet, Særnummer 2, 20

DETAILS	YEAR	TITLE	SOURCE
Korsøen Ø, Dempster T, Oppedal F, Folkedal O, Kristiansen T	2008	Nedsenkede merder – en del av fremtidens lakseoppdrett?	Kyst og Havbruk 2008
Kristiansen TS, Johansson D, Oppedal F, Juell J-E	2007	Hvordan har oppdrettsfisken det i merdene.	Kyst og Havbruk 2007, Fisken og Havet, Særnummer 2, 2007: 151-154.
Moe H, Sunde LM, Winther U	2009	Effekter og tiltak – rømt fisk. Valg av not til oppdrettstorsk.	Kyst og Havbruk 2009, Fisken og havet, særnummer 2-2009, ISSN 08020620: 148-150
Oppedal F, Vigen J	2009	Oksygenforhold under avlusing.	Norsk Fiskeoppdrett 6a: 74-76

National and International Conference Presentations

DETAILS	YEAR	TITLE	SOURCE
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 2008, Kobe, Japan, July
Dempster, T, Korsøen, Ø, Oppedal, F, Juell, J-E, Fredheim, A, Lader, P	2009	Can salmon tolerate submergence in commercial scale sea-cages?	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Fredheim A	2009	Research and industry working together.	1ST INTERNATIONAL SEMINAR ABOUT R+D+I IN AQUACULTURE 2009, Puerto de Santa Maria, Cádiz, Spain, April
Fredheim A	2009	Technological challenges and opportunities in meeting future industry requirements.	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Fredheim A	2007	How to prevent escapes	Evaluation of genetic impact of aquaculture activities on native populations - A European network (GENIMPACT), 2007, Thessaloniki, Greece, April
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
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
Føre M, Alfredsen JA	2009	A software tool for interpretation of fish telemetry data from fish farms	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Føre M, Dempster T, Alfredsen JA	2007	Modelling of fish behaviour in sea-cages.	Aquaculture Europe Conference 2007, Istanbul, Turkey, May
Føre M, Dempster T, Alfredsen JA	2008	Matematisk modellering av fiskeatferd i merd.	Havbruk 2008, Tromsø, Norway, April

DETAILS	YEAR	TITLE	SOURCE
Gansel LC, McClimans TA, Myrhaug D	2009	Flow patterns in and around fish cages: the effects of biofouling on the flow in and around net pens and the resulting forces.	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Gansel LC, McClimans TA, Myrhaug D	2009	Flow patterns in and around fish cages: their importance for fish welfare, environmental pollution and integrated multi-trophic aquaculture.	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Gansel LC, McClimans TA, Myrhaug D	2008	Virkning av fiskemerder på lokale strømforhold.	Havbruk 2008, Tromsø, Norway, April
Gansel LC, McClimans TA, Myrhaug D	2010	Betydning av notmotstand, begroing og fiskeadferd for strømning i og rundt fiskemerder.	Havbruk 2010, Trondheim, April
Gansel LC, McClimans TA, Myrhaug D	2008	The effect of fish cages on ambient currents.	Proceedings of the the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE) 2008, Portugal, June
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 2008, Kobe, Japan, July
Guenther J, Carl C, Sunde LM	2009	The growth of the hydroid *Ectopleura larynx* on nets in relation to fish farming practices in Norway.	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Guenther J, Carl C, Sunde LM	2009	Aggressive hydroider – en ny utfordring? (Oral presentation by LM Sunde)	Productivity Conference, Kristiansund, Norway, 28-29 October 2009
Harendza A, Visscher J, Gansel L , Pettersen B	2008	PIV on inclined cylinder shaped fish cages in a current and the resulting flow field.	Proceedings of the the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE) 2008, Portugal, June
Korsøen Ø, Dempster T, Fosseidengen JE, Fernö A, Kristiansen TS	2009	Safe decompression procedures during lifting of submerged caged Atlantic cod, *Gadus morhua*	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Korsøen Ø, Oppedal F, Folkedal O, Dempster T, Kristiansen TS	2008	Nedsenking av stor laks. Dypt, mørkt, og over en lengre periode.	Havbruk 2008, Tromsø, Norway, April
Kristiansen, TS	2009	Sea cage farms- localization, management and fish welfare.	Aquaculture Med. 2009, Verona Fiera, Italy, October
Kristiansen, TS	2009	IMR Health and welfare research. Current focus areas.	Open Seminar on Sustainable Aquaculture. AquaNor 2009, Trondheim, Norway. August 20.2009
Kristiansen, TS	2009	Sterk strøm gir dødelighet. Hvorfor?	Torskenettverksmøte 2009, Bergen, Norway, February
Kyujin S, Klebert P, Fredheim A Engineering 2009, Honolulu, USA, June	2009	Numerical investigation of the flow through and around a net cage.	ASME 28th International Conference on Ocean, Offshore and Arctic

National and International Conference Presentations

DETAILS	YEAR	TITLE	SOURCE
Oehme M, Aas TS, Sørensen M, He G, Lygren I, and 4 others	2009	Technical feed quality in pneumatic feed conveying systems.	ResirkForumNor 2009, Trondheim, Norway, January
Oehme M, Aas TS, Sørensen M, He G, Åsgård T	2009	Feed Ingredients, technical feed quality and pellet breakage in pneumatic conveying systems.	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Oppedal F, Vigen J, Remen M, Bailey J	2008	Salmon in sea cages affect the water flow.	Aquaculture Europe Conference 2008, Krakow, Poland, September
Oppedal F, Vigen J, Remen M, Bailey J	2008	Vannstrøm gjennom en laksemerd.	Havbruk 2008, Tromsø, Norway, April
Remen M, Olsen RE, Oppedal F	2009	Stressrespons og habituering til fluktuerende hypoksi hos laks i sjøvann.	Frisk Fisk Conference 2009, Bergen, Norway, January
Remen M, Oppedal F, Olsen RE	2009	Habituation and acclimation of Atlantic salmon Salmo salar L. subjected to fluctuating hypoxia.	Aquaculture Europe Conference 2009, Trondheim, Norway, August
Vigen J, Remen M, Bailey J, Oppedal F	2008	Oxygen variation within a sea-cage.	Aquaculture Europe Conference 2008, Krakow, Poland, September (Poster)
Vigen J, Remen M, Bailey J, Oppedal F	2008	Oksygenvariasjon innenfor en merd.	Havbruk 2008, Tromsø, Norway, April (Poster)
Aas TS, Terjesen BF, Sigholt T, Hillestad M, Holm J, and 6 others	2009	Physical properties affect the nutritional value of fish feeds, a challenge when testing new feed ingredients.	Aquaculture Europe Conference 2009, Trondheim, Norway, August

Theses

DETAILS	YEAR	TITLE	SOURCE
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.	Diploma 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, Norway.

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