
EXPOSED
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CONTENT

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EXPOSED
AQUACULTURE OPERATIONS
CENTRE FOR RESEARCH-BASED INNOVATION
exposedaquaculture.no

SUMMARY

*Approaching its **midway** milestone, the EXPOSED Centre is increasing its focus on turning knowledge into innovations.*

EXPOSED is a Centre for Research based Innovation (SFI) and is funded by the Research Council of Norway's Division for Innovation[1]. The main objective of EXPOSED is to enhance the capability of the business sector to innovate by focusing on long-term research through creating close alliances between research-intensive enterprises and prominent research groups. The EXPOSED Centre brings together global salmon farmers, key service and technology providers, and leading research groups to develop knowledge and technology for robust, safe and efficient fish farming at exposed locations.

At present, there is a strong innovation drive in the aquaculture industry, and extensive investments are done. The centre and its partners are valued contributors to this development, through their role as partners in R&D projects, in scientific and industrial fora, and in the public debate.

In the second half of the its lifetime, the centre aims to increase its focus on turning knowledge into innovations for the industry partners and aquaculture industry.

Some of the main research achievements of the EXPOSED centre to this date are:

- Environmental descriptions of coastal sites, to improve precision and relevance of the basis for design and operations planning.
- Salmon and cleaner fish swimming capacity, which is important to assess new locations and new farming technology.
- Navigation/localization of ROV/AUVs, relative to nets and flexible structures enables more precise and autonomous operations.
- Machine vision-based hole detection and integrity control used to improve inspection operations.
- Modelling of aquaculture systems, including vessel-structure interaction, as a future tool to study the systems, inform design and monitor conditions.
- Methods to analyse and predict operational limits, supporting technology development in design decisions and operational planning. Working environment and competence requirements to improve procedures and inform design and technology development.

Centre for Research-based Innovation
The Research Council of Norway

[1] http://www.forskningsradet.no/prognett-sfi/Forside/1224067021121

VISION AND OBJECTIVES

*EXPOSED will develop knowledge and technology for **robust**, **safe** and **efficient** fish farming at exposed locations.*

Significant parts of the Norwegian coast are today unavailable for industrial fish farming due to remoteness and exposure to harsh wind, wave and current conditions. The EXPOSED Centre will take advantage of Norway's strong position in the aquaculture, maritime and offshore sectors to enable safe and sustainable seafood production in exposed coastal and ocean areas. Technological innovations, such as more autonomous systems, offshore structures and vessels are needed to sustain farm production under all conditions and enable more robust, safe, controlled and continuous operations.

EXPOSED brings together global leading salmon farmers, key service and technology providers, and leading research groups as SINTEF, the Institute of Marine Research and the Norwegian University of Science and Technology (NTNU), including AMOS (the Norwegian Centre of Excellence for Autonomous Marine Operations and Systems).

The centre's objectives were reviewed as part of the midway evaluations in 2018. The vision and main objective for the EXPOSED centre remains unchanged. There has been a significant increase in the industrial and political interest in the EXPOSED centre and its research and innovation activities since its launch. This interest, partly driven by the development permits, has caused changes in the innovation area of exposed aquaculture and therefore a new industry objective has been added. An additional industry objective has also been added to support the industry partners in their innovation processes.

The increased interest has also manifested among students, allowing the centre to recruit many MSc candidates as well as find well qualified PhD students. To adapt to this trend, the centre has adjusted the second research objective and increased the ambition on recruitment of PhD candidates, post-docs and MSc candidates associated with EXPOSED.

Main objective

To develop knowledge and technologies for EXPOSED aquaculture operations, enabling a sustainable expansion of the fish farming industry.

Industry objectives

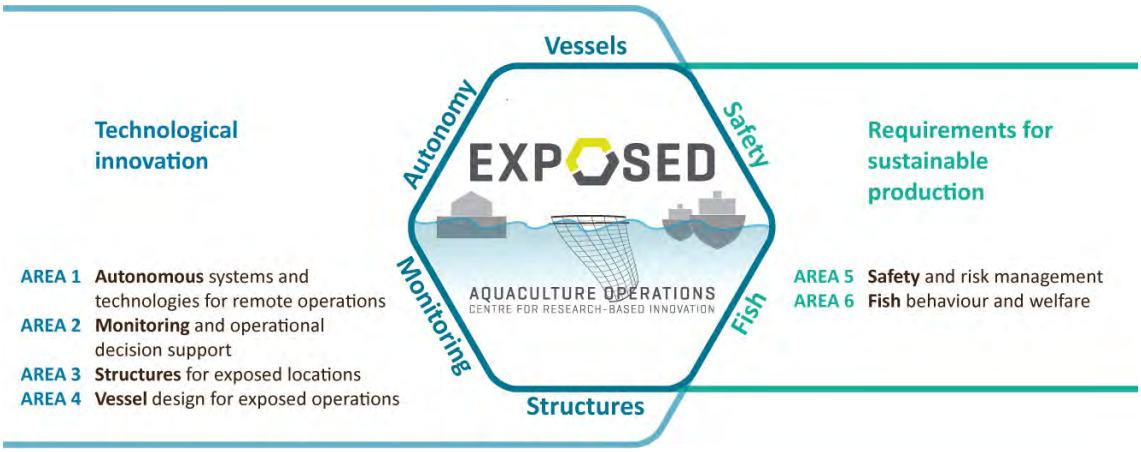
- Enable safe and profitable operations at exposed fish farming sites to increase sustainable seafood production.
- Develop new technologies to underpin Norway's global leading position in aquaculture and maritime competence and technology.
- Help develop new technologies related to the concepts found in the development permits.
- Support innovation processes at the industry partners through access to the relevant researchers.

Research objectives

- Conduct fundamental and applied research into key knowledge gaps related to exposed aquaculture operations by combining research fields from the aquaculture, maritime and offshore sectors.
- Build knowledge and competence capacity through educating at least 20 PhD candidates, 5 post-docs and 70 MSc candidates.

RESEARCH STRATEGY AND PLAN

*EXPOSED has identified six core **research areas** to address the challenges described.*



Four of the research areas focus on technological innovations for safe and reliable aquaculture operations:

Area 1: Autonomous systems and technologies for remote operations

Daily routine work and periodical operations must become less dependent on close human intervention.

Area 2: Monitoring and operational decision support

Severe weather conditions and remoteness impede access and increase the need for robust monitoring of structures, systems and fish welfare to assess system state and support operational decisions.

Area 3: Structures for exposed locations

Aquaculture structures need to be operational at exposed sites with respect to sea load response, personnel safety and fish welfare.

Area 4: Vessel design for exposed operations

Vessels, on-board equipment and logistical solutions must be designed to enable safe and efficient operations in exposed areas.

Two research areas focus on key requirements for sustainable production:

Area 5: Safety and risk management

Exposed operations require improved risk management strategies and systems.

Area 6: Fish behaviour and welfare

The technologies and new operational solutions must ensure fish performance and welfare in exposed condition.

*Activities in EXPOSED are organised in **projects**, combining research areas, partners and methods.*

Seven projects (P2 – P8) were active in 2018, covering fundamental research, applied studies, innovation activities, including nine PhD candidates and one post.doc researcher. In addition, several associated projects carry out relevant research activities and involve additional candidates. All seven projects were concluded in 2018, and are presented in more detail under (p. 15).

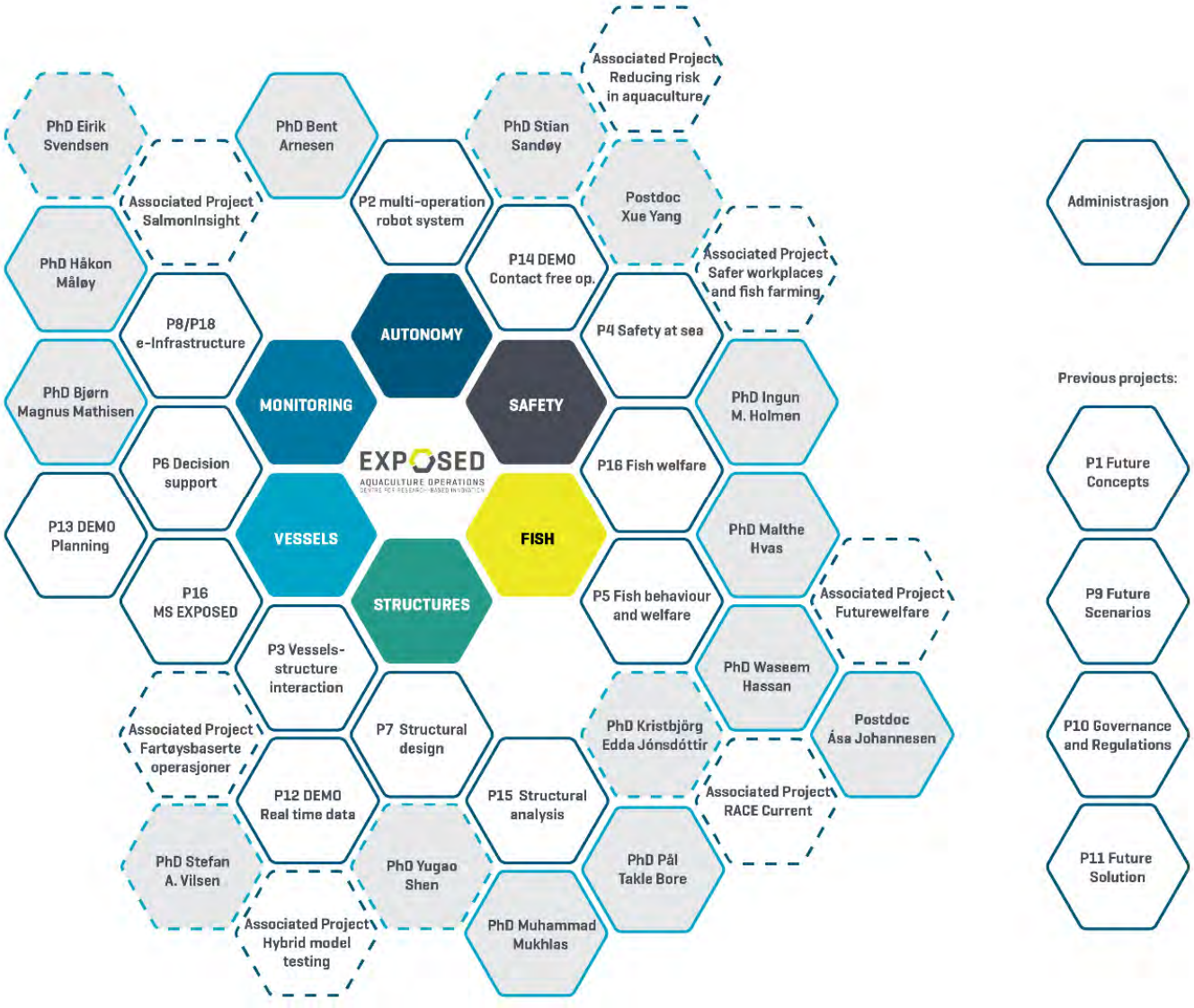


Figure 1 Activities are organised in projects, combining research areas, partners and methods. PhDs and postdocs will take part in the project teams. A selection of associated projects and PhDs are indicated with dashed strokes.

As a part of the midway evaluation, the Centre management team decided that future projects should be of shorter length to help them become more adjustable to changes and needs from the industry. Eight new projects are planned for the coming year, many of which will build on the results of finalised projects in or associated with the centre. The new projects cover fundamental research, more industrial research, as well as an increased focus on developing demonstrators to promote future innovations. The new projects are:

P11 Future solutions for exposed fish farming

Holistic design is demanding, with many considerations weighed against each other. P11 intends to use case studies of existing technologies, and technologies developed as part of development licences, to identify benefits and improvement potential among the available concepts.

P12 DEMO Real-time condition monitoring and operation support

The aim of this project is to develop technology and methods for the condition monitoring of aquaculture installations as a tool in operational planning, analysis and the monitoring of fish welfare and constructional integrity, and for maintenance scheduling.

P13 DEMO Operational planning

The project will demonstrate use of historical and real time data, knowledge on operational limits and identified risks in a user interface as a methodology for operational planning and risk management of aquaculture operations performed or assisted by service vessels.

P14 DEMO Contact-free operations using a vessel-mounted robot arm

The main aim of this project is to use simulations to demonstrate how service vessels under different weather conditions can carry out operations without contact with fish farm installations, with exception of intended applications and contact between installations and the vessel's robot arm.

P15 Structural analysis of fish farms

The project will contribute to greater precision in structural analysis of fish farms by developing new load models and analytical methods. In the long-term, this has the potential to reduce risk of structural damage and fish escapes, promote development of optimized structures and safe working platforms for personnel.

P16 Fish behaviour and welfare in exposed aquaculture operations

The aim of the project is to provide fundamental understanding of fish coping ability towards exposed farming conditions and develop welfare indicators and tools for monitoring salmon in exposed farms. The project is a continuation of P5.

P17 MS Exposed – Service vessels for exposed aquaculture operations

Service vessels are a much used resource during aquaculture operations. The aim of the project "MS Exposed" is to develop an integrated design methodology for service vessels that links vessel design, deck equipment and operational safety, for use in exposed areas. Two design concepts for future service vessels will be developed.

P18 e-Infrastructure and data capturing

The aim of the P8 project is to capture monitoring data from exposed farms and to construct a robust database for the development of new infrastructure systems, operational planning, and as a basis for drafting requirement specifications for vessels and installations used in exposed localities. The project is a continuation of P8.

To further support research and innovation, the EXPOSED centre aims to initiate or encourage ***associated projects****, in addition to the centre-funded projects.*

Associated projects typically involve one or more of the centre partners, but also other They may vary between researcher projects, e.g. funded by the Research Council of Norway (RCN) or EU, or more innovation-driven projects. The centre will establish agreements with these projects to allow mutual benefits and synergies.

There is also an identified potential in collaboration with other SFI research centres and groups. EXPOSED has common activities and shared PhD-students with NTNU AMOS, and collaborates with two other maritime centres for research-based innovation, SFI Move (Centre for demanding marine operations) and SFI Smart Maritime (Centre for improved energy efficiency and reduced harmful emissions from the maritime sector) on PhD-training. There is also potential for increased collaboration with SFI CtrlAqua (Centre for Closed-Containment Aquaculture) in the coming years.

Figure 2 Photo by Marius Dahle Olsen.

Associated projects	Duration, project type and funding source	Host institution	Relevant current EXPOSED-activity
Reducing risk in aquaculture – improving operational efficiency, safety and sustainability	2016-2019 Researcher project HAVBRUK2, RCN	NTNU IMT	Project P12, P13, P14 and P17
Safer operations and workplaces in fish farming	2016-2018 Researcher project HAVBRUK2, RCN	SINTEF Ocean	Project P17
SEATONOMY	2013-2016 (finished) Strategic research project of the SINTEF Group	SINTEF Digital	Project P14
RACE Current – Farm scale currents, in and between cages	2015-2018 Strategic research project of the SINTEF Ocean	SINTEF Ocean	Project P16 and P7
BEHAVEGENES - Behavioural and genomic characteristics of selected farmed salmon families related to robustness, welfare and performance	2014-2017 Researcher project HAVBRUK, RCN	Institute of Marine Research	Project P16
ECHOFEEDING - Echo sounder technology for appetite-led-feeding and welfare-monitoring of caged salmon	2017-2020 Researcher project HAVBRUK2, RCN	Institute of Marine Research	Project P16
FurtureWelfare - Environmental requirements and welfare indicators for new cage farming locations and systems	2017-2021 Researcher project, HAVBRUK2, RCN	SINTEF Ocean	Project P16
LAKSIT - Technologies for new datatypes and information describing the states of salmonids in commercial cages	2016-2017 Researcher project, The Norwegian Seafood Research Fund (FHF)	SINTEF Ocean	Project P16
HYBRID - Real-time hybrid model testing for extreme marine environments	2016-2019 Knowledge-Building Project for Industry MAROFF, RCN	SINTEF Ocean	Project P12 and P15
SalmonInsight - Unveiling links between salmon physiology and online monitored behaviour	2018-2022 Researcher project HAVBRUK2, RCN	SINTEF Ocean	Project P16
Industriell forskning på fartøysbaserte operasjoner for eksponert havbruk	2018-2020 Innovation project MAROFF, RCN	Lerow	Project P12 and P15

ORGANISATION

Organisational structure

Organisation and implementation of the centre is governed by a **consortium agreement**, describing the obligations and rights of the partners, as well as roles and responsibilities of the different parts of the organisation. The **General Assembly**, with representation from all partners, elects the **Centre Board** of seven members among the centre partners. The board is the operative decision-making body for the execution of the centre. In 2018, the members of the board were:

Member of Centre Board	Affiliation
Arne Rinnan (Chairman)	Kongsberg Seatex
Noralf Rønningen	Aqualine
Bjørn Egil Asbjørnslett	NTNU
Arne Fredheim	SINTEF Ocean
Olai Einen	Cermaq
Stein Are Ystmark	AQS
Frode Oppedal	Institute of Marine Research
Kjell Emil Naas (Observer)	The Research Council of Norway

Figure 3 EXPOSED Days in April 2018.

The **Centre Director**, Hans Bjelland manages the Centre on behalf of the Host institution, SINTEF Ocean, and reports to the Centre Board. Together with the **Management Group**, the Centre Director manages centre activities related to **projects**, **education** and **innovation**. The Management Group consists of Research Managers for the six core research areas, Project Managers, and a NTNU representative:

Member of Management Group	Role and responsibility
Hans V. Bjelland SINTEF Ocean	Centre Director
Esten Ingar Grøtli SINTEF Digital	Area 1 Project P2
David Kristiansen SINTEF Ocean	Area 3 Project P7
Ørjan Selvik SINTEF Ocean	Area 4 Project P3
Ingunn M. Holmen SINTEF Ocean	Area 5 Project P4
Ole Folkedal Institute of Marine Research	Area 6 Project P5
Jan Tore Fagertun SINTEF Ocean	Area 2 Project P6 and P8
Leif Magne Sunde SINTEF Ocean	Aquaculture operations
Carina Norvik SINTEF Ocean	Scientific coordinator

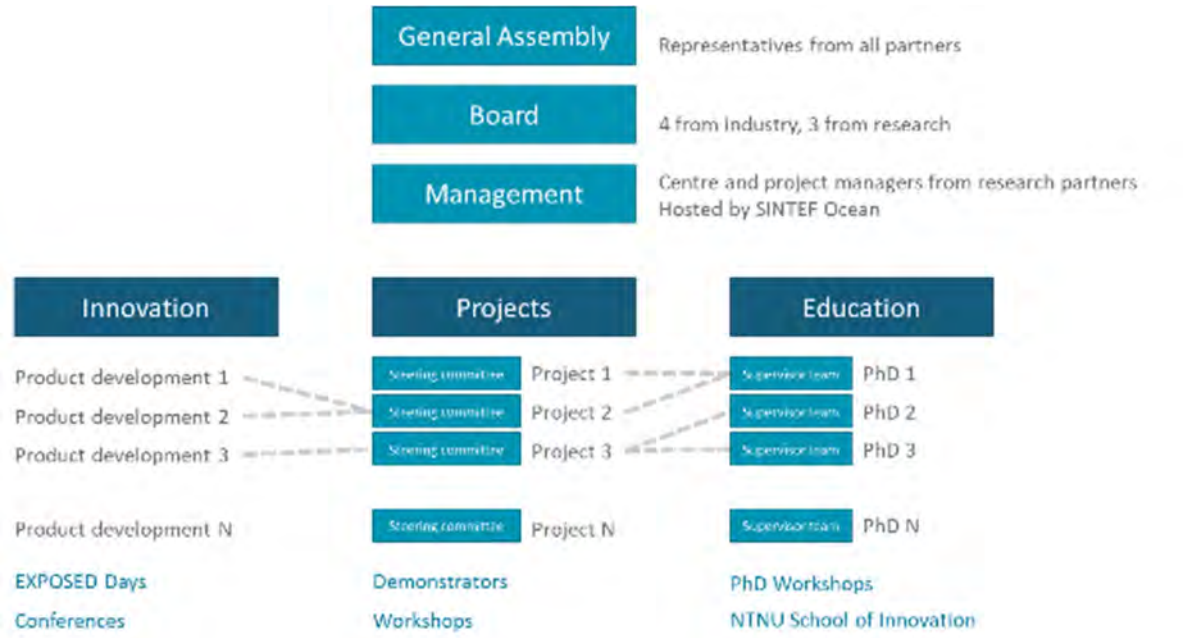


Figure 4 Organisational structure of EXPOSED

Projects are set up with a **Project Manager** and a **Steering Committee**. The project leader has the responsibility for carrying out the project, while the Steering Committee has the responsibility to follow up on the progress and objectives. The Steering Committee is managed by one of the industrial partners.

Education is primarily maintained through the three NTNU departments; Marine Technology, Computer and Information Science, and Engineering Cybernetics. In addition, PhD and MSc candidates are educated at the University of Bergen through a collaboration with the Institute of Marine Research. PhD and post.doc candidates are associated with related projects. Several other NTNU departments have been involved in MSc and Bachelor student activities related to the centre.

Innovation is supported through arranging a yearly two-day EXPOSED Day during spring, a one-day EXPOSED Day during autumn, and PhD/post-doc workshops. The EXPOSED Days serve as a meeting place for innovation, presentation of results, exchange of ideas and creation of new projects. Further partner involvement and cross-disciplinary interaction takes place in the individual projects. As part of planning the next phase of the EXPOSED centre, an Innovation Day for the user partners facilitated by the design firm Halogen was held in autumn 2018. Moving forward EXPOSED wishes to further support innovation by helping to identify and following up innovation processes led by industry partners, as well as connecting them with relevant research projects and researchers.

Figure 5 Innovation Day, September 19th 2018.

The centre host, SINTEF Ocean, is located in Trondheim, and serves as a hub for centre activities. Several activities are also carried out in other parts of Norway, where partners and field sites are located.

Research facilities

The centre has access to an extensive research infrastructure hosted by both research and industry partners:

- **Full scale industrial fish farms with various exposure levels**, including the Aquaculture Engineering test site (SINTEF ACE) at SalMar locations in Mid-Norway, and more exposed farms operated by Marine Harvest, Cermaq and SalMar. The farms are equipped with measurement buoys and other instrumentation, all integrated with a technical e-infrastructure to a central and secure data access point for project partners. Onward, experiments at new farms in Norway and in the Faroe Islands will be added to the activities, giving access to even more exposed sites.
- **Vessel motion monitoring** through the two service providers and vessel operators Lerow and AQS has been used to study operational limits.
- **Scaled down biological trials** on swimming capacity under varying conditions have been conducted at IMR's land- and sea-based facilities in Matre, including two swim tunnels and a push cage.
- **Hydrodynamic laboratories** with a large variety of sizes and capabilities in Trondheim and Hirtshals, Denmark are available, and will be a resource for future centre financed activities.
- **Various simulation tools** developed by the research partners have been used to model the aquaculture systems and to study the dynamics and interactions of structures and vessels, as well as developing guidance systems for the ROV/AUV-solutions.

Research partners	AREA
SINTEF Ocean (SO) Conducts research and innovation related to the ocean space for national and international industries. Our ambition is to continue Norway's leading position in marine technology and biomarine research.	All
SINTEF Digital [SD] Provides research-based expertise, services and products ranging from robotics, microtechnology, communication and software technology, computational software, information systems and security and safety.	1, 2
NTNU Department of Marine Technology (IMT) Carries out research within the field of marine technology. IMT hosts the Centre for Autonomous Marine Operations and Systems (AMOS), a Norwegian Centre of Excellence. AMOS will have a key role within the EXPOSED centre.	1, 3, 4, 5
NTNU Department of Computer and Information Science (IDI) Conducts research in fields of computer and information science, covering hardware related research, intelligent systems and social implications of information systems.	1, 2
NTNU Department of Engineering Cybernetics (ITK) Conducts research on various fields associated with control theory, including mathematical modelling and simulation, autonomy, optimisation and automatic control. Together with IMT, ITK plays a major role in the Centre for Autonomous Marine Operations and Systems (AMOS).	1, 2, 6
The Institute of Marine Research (IMR) Norway's largest centre of marine science. The main task is to provide advice to Norwegian authorities on aquaculture and the ecosystems.	6

SINTEF NTNU Norwegian University of Science and Technology HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH AMOS

Partners

EXPOSED brings together global leading salmon farmers, key service and technology providers, and leading research groups.

	Industry partners	Contribution/Role
	Marine Harvest World's largest salmon and trout fish farmer. Runs large operations in Norway, Scotland, Canada and Chile. Changed company name to **Mowi** 1.1.2019.	End user of technology and solutions
	Cermaq World's third largest salmon and trout fish farmer with operations in harsh environments especially in the northern parts of Norway.	End user of technology and solutions
	SalMar World's fourth largest salmon and trout fish farmer. Operates large fish farms in particular at exposed locations in mid Norway.	End user of technology and solutions
	Kongsberg Seatex, Kongsberg Maritime Subsea and Kongsberg Maritime Supplier of technology and systems to the global maritime and offshore sector. Provides knowledge of and systems for communication, control, navigation, decision support, AUV etc.	Technology/solution provider
	Aqualine Major international supplier of equipment and complete fish farms.	Technology/solution provider
	Møre Maritime Provides maritime consulting, engineering and 3D modelling.	Technology/solution provider
	ÅF A leading engineering and design company within the fields of energy, industry, infrastructure and digital solutions. ÅF Engineering focus on engineering customized robust and sustainable solutions, both on land and in sea.	Technology/solution provider
	Anteo Operates and develops technical solutions and decision support systems for fish farming companies.	Technology/solution provider
	Argus Remote Systems Performs research, development and manufacturer of electrical ROVs.	Technology/solution provider
	Lerow Service provider for inspection and cleaning of net cages and moorings by advanced use of ROV.	Service provider
	AQS Service provider for inspection, maintenance and a range of operations, including delousing.	Service provider
	Marin Design Provides vessel design and maritime consulting.	Technology/solution provider
	DNV GL eading classification society and certification body, and a recognized advisor to a wide range of industries.	Certification, classification and advisory
	MacGregor Norway A maritime leading provider of solutions and services for handling systems to the offshore, fishery, research and mooring segments.	Technology/solution provider

SCIENTIFIC ACTIVITIES AND RESULTS

Seven projects have been finalised in 2018, covering fundamental research, applied studies, industrial activities, establishment of research infrastructure, and nine PhD candidates and one post.doc researcher.

A short description of the finalised projects, as well as their main results and innovation potential is presented here.

P2 In-cage multi-operation robot system for inspection and intervention

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Esten I Grøtli, SD	**SINTEF Ocean, SINTEF Digital, NTNU IMT, Argus, Lerow, Kongsberg Maritime Subsea, Kongsberg Seatex, AQS, Marine Design, Møre Maritime**	**Q2 2015 – Q4 2018**	**Industrial/ Fundamental**

The aim of this project was to develop and demonstrate the autonomous functionality of a robotic underwater vehicle equipped with the tools required to carry out frequent operations on aquaculture facilities in exposed areas.

The frequent and full inspection of nets is a key task carried out at modern fish farm facilities and will probably become increasingly important if this type of production system is to be used in more exposed localities.

Inspections are carried out to monitor the integrity of net pens and prevent escapes. It is assumed that the use of improved technology will enable more effective and less expensive inspections than current manual approaches employing divers. The use of divers will also be more restricted at exposed localities due to weather conditions.

Net pens are flexible structures with variable geometries, and this places strict requirements on vehicle navigation and control systems in terms of completing comprehensive inspections and the prevention of collisions.

The use of machine vision for inspections is challenging due to variable light conditions, fouling and turbid water.

This project has focused on addressing some of the basic challenges faced by an autonomous inspection system.

Main results

- A laser-assisted camera system for the lightweight positioning of AUVs/ROVs.
- Algorithms for model-based and data-driven detection methods for holes in nets.
- Algorithms for net-relative positioning.
- A conceptual study of the ROV-LARS system.
- Autonomous Job Analysis – design tool for autonomous operations.

Innovation potential

- Use of an ROV equipped with autonomous functions for inspection, maintenance and repair in current net pen systems:
  - Hole detection in nets.
  - Hardware/software to enable effective positioning relative to nets and other objects.
  - Net pen condition assessments.

P3 Vessels-structures interaction

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ørjan Selvik, SO	**SINTEF Ocean, NTNU IMT, Møre Maritime, Marin Design, AQS, Aqualine, Kongsberg Seatex, Kongsberg Maritime, Cermaq, MacGregor, DNV GL**	**Q2 2015 – Q4 2018**	**Industrial/ Fundamental**

Aquaculture operations in exposed localities will place new demands on vessels and equipment in terms of safe operations, efficient operability and profitability. The interactions between installations and support vessels will be a key factor during operations.

The project has been studying new vessel design concepts and the interface with aquaculture installations with the aim of enhancing operational reliability in exposed localities. It is anticipated that the use of larger vessels will demand new requirements for the design of floating collars and mooring systems. Assuming that current net pen technologies will be adapted for use in exposed localities, the interaction between flexible collars and vessel hulls will be an important factor. A focus on real operational settings will be key to risk mitigation and increased levels of safety, operability and profitability.

The project started with a study aimed at identifying the challenges we face in exposed localities in relation to vessels, installations, crews and the fish. There was also separate work packages linked to vessel design (new designs and systems), operations in exposed localities (application of new technology and new procedures), and feasibility studies.

The project combines expertise from several fields of research linked to the SFI EXPOSED project.

Main results

- Demonstrator for simulation of feeding barge operations for efficient evaluation and comparison of different vessels and development of new vessel concepts.
- Design follow-up and simulation of new vessel concepts.
- New knowledge regarding forces between vessels and fish cage with the workbench SIMA.

Innovation potential

- Fish carrier simulations will not only provide additional knowledge on the optimum size, composition and capacity of the vessel fleet, but also effective assessments of new vessel concepts. The opportunity to simulate how a given logistical solution will perform over a period (such as one year).
- Increased understanding of vessel-installation interactions will contribute towards the development of vessels, equipment and methodologies used in exposed localities.
- Increased understanding of vessel response and operational limits will enable the adaptation of vessel designs and equipment to operational conditions, and thus increase operational efficiency. Increased understanding will also enable safer operations within a greater range of weather conditions.

P4 Safety at sea – risk management and best operational practices

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ingunn M Holmen, SO	**SalMar, Cermaq, Marine Harvest, Anteo, Aqualine, AQS, Lerow, NTNU IMT, SINTEF Ocean, DNV GL, MacGregor, Kongsberg Maritime, Møre Maritime, Marine Design**	**Q2 2015 – Q4 2018**	**Fundamental**

The aim of this project was to improve operational safety on aquaculture installations in exposed locations. An overall ambition is to develop integrated risk management systems for material assets, fish welfare, the external environment, escapes and HSE issues.

The project activities have focused on conditions that are significant for operational safety in the aquaculture sector. These include service operations hazards, risk assessments, training and competence requirements. The results are of both short and long-term value to the industry; knowledge that the industry can implement immediately, and measures needed for safe operations at more exposed locations using new fish farm concepts.

Initial studies demonstrated that the levels of standardisation between companies and vessels is low when it comes to design, installed equipment and work procedures. Standardisation may be invoked as a safety initiative. Standardised, best practice operations within the industry also make it safer to transfer personnel between sites when assistance is needed. Today this could be a risk factor in itself if the extra personnel are not familiar with the local routines.

The fish farming companies require higher levels of technical expertise than before due to advances in technology. They currently report that, in some cases, operations must be adjusted to the personnel available. This was the background for two workshops aimed at developing recommendations preparing recommendations for competence requirements for personnel at fish farms and service vessels.

Operational planning is increasingly important to ensure that the necessary resources and personnel are available when needed. Effective risk assessment procedures and Safe Job Analyses also contribute to a common understanding among the workers of potential operational hazards, and which measures that need to be implemented in order to reduce operational risk levels.

Main results

- Established an overview of the regulatory requirements as well as the current practice for risk assessments in the aquaculture industry.
- Identified hazards in critical aquaculture operations.
- Competence requirements for personnel.
- Recommendations for best practice in aquaculture operations.

Innovation potential

- The results provide new knowledge about risk factors linked to aquaculture operations, and a platform for the development of safety barriers in a holistic risk perspective.

P5 Fish behaviour and welfare

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ole Folkedal, IMR	**IMR, NTNU ITK, SINTEF Ocean, Cermaq, SALMAR, Marine Harvest, Kongsberg Maritime Subsea, Aqualine, AQS, Lerow**	**Q2 2015 – Q2 2018**	**Fundamental**

The aim of P5 was to investigate the biological limitations and opportunities in exposed farming. In this work, fundamental knowledge of fish physiology and behaviour towards coping with water current velocity and novel observation tools for such has been gained.

Successful fish farming depends on matching the farming environment with the species' biological needs, and not exceed the adaptive capacity of the fish. Farming under exposed conditions requires fundamental knowledge on how and how well fish cope with strong water currents and waves.

Exposed conditions require higher energy expenditure for the fish than at conventional sheltered farming sites. Additional challenges such as disease and stress linked to operations such as delousing will further increase the load. Moreover, weather conditions may raise welfare issues linked to interruptions in feeding and supervision.

Numerous experiments with salmon and cleaner fish in P5 have acquired knowledge about how and how much fundamental parameters as fish size, water environment and disease influence swimming capacity, metabolism and behaviour. This represents a strong biological fundament in planning of sites, production strategies and development of novel technology and operational solutions. Field observation is particularly demanding in exposed farming, and new tools and parameters have been developed for measuring relevant behavioural parameters such as swimming speed in individual fish tags.

Main results

- Tolerance limits for water-current velocity in individual fish and groups, and fundamental understanding of physiology and behaviour of salmon and cleaner fish related to fish size, temperature, oxygen, salinity, stress and AGD.
- A welfare-based fundament towards current velocity for site use and selection under today's rearing practice.
- New research infrastructure – large swim tunnel/respirometer and push cage.
- New communication system for fish tags (Internet of Fish).
- Swimming speed as a parameter in fish tags.

Innovation potential

- Addressing the biological needs in innovation of farming strategy, design and construction, and operational procedures.
- Welfare indicators (including fish tags) as observation tools for use in development and verification of exposed farming operations.

P7 Structural design of reliable offshore aquaculture structures

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
David Kristiansen, SO	**Aqualine, AQS, DNV GL, ÅF Engineering, LEROW, Kongsberg Seatex, SalMar, NTNU IMT**	**Q1 2016 – Q4 2018**	**Industrial**

This project aimed to contribute with new knowledge on the physical behaviour of fish farm structures during operation at exposed locations. This project also addressed the development of knowledge and methodologies used in the design and analysis of reliable aquaculture structures for use in exposed localities.

Fish farming in exposed locations requires robust and reliable structures to support sustainable, safe and efficient production. This project uses current, conventional fish farm systems as its starting point and examines the challenges linked to the adaptation of net cages, mooring systems and feed barges for use in more exposed settings.

The study is looking into the various phases of today's design processes and methods, focusing on an assessment of uncertainties and how these propagate through the design process. This includes a review of the methods used to describe environmental conditions at given localities, design condition estimates, methods for the calculation of loads and main component response, and a coupled analysis approach for the entire fish farm.

The project aims to develop new knowledge on critical problems linked to greater exposure and to devise methods for the design, simulation and analysis of fish farms at exposed sites. The aim is to contribute to the development of reliable fish farm structures and other aquaculture facilities for operation in exposed areas.

Main results

- A review of methods for describing environmental conditions in coastal areas, including an analysis of wave exposure using stroke length analysis, buoy data analysis, etc. Directional dependency is key.
- Focus on wave and current measurements, and uncertainty linked to the estimation of design conditions based on extreme value statistics.
- Simulation of current fields from Trøndelag coastal waters (acquired during the period 2012 to 2016) using SINMOD software to produce long-term statistics.
- Development of an integrated computational model for the real-time simulation of net cage structures.
- Mooring analysis of an entire net cage farm facility exposed to currents and variable sea conditions.

Innovation potential

- Improved method for describing environmental parameters during the design of aquaculture structures.

P8 EXPOSED e-Infrastructure

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Jan Tore Fagertun, SO	**Aqualine AS, Cermaq Norway AS, Marine Harvest Norway AS, SalMar Farming AS, Kongsberg Seatex**	**Q3 2015 – Q4 2018**	**Industrial**

The aim of the P8 project was to construct a robust database for the development of new infrastructure systems, operational planning, and as a basis for drafting requirement specifications for vessels and installations used in exposed localities.

Fish farming in exposed localities requires robust and reliable installations that provide a setting for safe operations and sustainable, efficient production. Data from meteorological, motion and water quality measurements create a platform for the development of new systems.

Long-term measurement series for waves, currents and wind was used to produce sound statistical data relating to extreme and operational conditions. Long-term measurement series raise the quality of extreme value statistics.

These statistics can be applied in the preparation of design requirements for new technologies and requirement specifications for vessels and installations used in everyday operations. Measurement series can also be applied in health, environmental and safety assessments for personnel assigned to work on future fish farms in exposed localities.

Such series can also be used in software development and for the validation of laboratory experiments.

Other measurements of parameters such as water temperature, salinity, oxygen concentrations, etc., can be used in production planning, and as such provide key supportive data for economic analyses carried out by the operator. Water quality measurements can also be used in assessments of fish health and welfare, and in risk assessments of fouling and the transmission of disease and parasites, etc.

Motion response measurements for installations and vessels linked to fish farm facilities were also made.

Main results

- Measurement data from buoys, installations and vessels.
- Construction of a measurement infrastructure for *ad hoc* measurements (plug and play).
- Water quality measurements at exposed localities.
- Logging of operational constraints at two localities.

Innovation potential

- Data to support the development of new systems for use at fish farms and seaweed cultivation facilities in exposed localities.
- Data to support software development/validation of software and laboratory experiments.
- Data to support laboratory calibration.

INTERNATIONAL COOPERATION

The topic of exposed farming raises significant interest internationally.

The potential of exposed fish farming and the research of the EXPOSED centre receives attention from several countries, including Scotland, the Faroe Islands, Chile, Australia, China, South Korea and Japan.

In June, a workshop with the research organisation Fiskaaling from the Faroe Islands was held in Trondheim to discuss potential collaboration and research on fish welfare, structural integrity and environmental measurements. This has so far resulted in a mutual post doc. project that started in 2018 between Fiskaaling, EXPOSED and the associated project FutureWelfare .

In 2018, the EXPOSED centre has contributed to two international reports:

- An OECD report planned to feed into a future OECD-publication on "Rethinking Innovation for a Sustainable Ocean Economy".
- A report on "Occupational health and safety in Norwegian aquaculture" as an input to the Food and Agricultural Organization of the United Nations (FAO) report on the global position on aquaculture/fish farming occupational health and safety.

Other ongoing projects with international partners and funding include Echofeeding (Echo sounder technology for appetite-led-feeding and welfare-monitoring of caged salmon), FlexAqua (Aquaculture operations with reliable flexible shielding technologies for prevention of infestation in offshore and Coastal areas) and SalmonInsight (Unveiling links between salmon physiology and online monitored behaviour).

A collaboration with Memorial University, St. John's, NL, Canada has been established on competency within occupational health and safety (OHS).

Several specific invites to present the centre and research activities and results at international conferences has been received, and the centre director and researchers have chaired sessions relevant to aquaculture technology and exposed fish farming:

- AquaForum at AquaSur 2018, Puerto Montt, Chile
- Oceanology International, 2018, London, UK
- North Atlantic Seafood Forum 2018, Bergen, Norway
- OMAE 2018, Madrid, Spain
- AQUA 2018 (EAS and WAS), Montepellier, France
- Support High Energy Mariculture Conf. 2018, Corfu, Greece
- IFISH5 2018, St. Johns, Canada

Researchers in EXPOSED have been invited to take part in a new ICES (International Council for the Exploration of the Sea) working group on Open Ocean Aquaculture (WGOOA).

RECRUITMENT

Eight PhDs are funded by EXPOSED, and several PhDs and postdocs are involved in associated projects.

They are invited to common activities, such as two aquaculture workshops in collaboration with NTNU AMOS. To further promote collaboration, knowledge sharing and industrial insight, EXPOSED has also partnered with other maritime research centres in a joint initiative to increase awareness and competence on innovation among PhDs and researchers.

NTNU School of innovation

Norway is a "centre of gravity" within ocean space technology. Together with international and national companies and research partners, NTNU and SINTEF host several leading research centres within ocean space technology. In the coming years hundreds of PhDs will be conducted at these centres. The challenge is to also excel in creating new products and solutions. In order to overcome this challenge, researchers will also need competence within innovation and entrepreneurship.

The main goals of the NTNU School of innovation are therefore to

1. Create a culture for innovation
2. Strengthen the awareness and competence on innovation
3. Contribute to increased commercialization of research results

Hans Tobias Slette (PhD) Methods and models for marine system design of vessels and vessel operations in exposed aquaculture

Hans Tobias has a MSc from NTNU and is undertaking his PhD at the department of marine technology. His PhD research is mainly affiliated to research area 4, Vessel design for exposed operations.

Increased knowledge will contribute to the development of more robust vessels and optimized logistics. In turn, this leads to increased operability and production at exposed facilities without compromising safety. The mission of research area 4 is four-fold.

Point 1: Study and develop new designs for all three vessel types, yielding acceptable seaworthiness, structure interaction and equipment for operations at exposed locations.

Point 2: Analyse the behaviour of floating objects and the relative motion between vessel and structure using simulation models and analytical software.

Point 3: Develop a simulation model for exposed aquaculture enabling analysis of critical operations. Then, the goodness of fit for a vessel

design can be evaluated with respect to its intended role in the system.

Point 4: New logistical solutions accounting for changes in vessel designs and fleet operations. Important aspects include onshore and offshore

storage and the logistics of personnel and equipment.

Hans Tobias will connect these points in a simulation model representing a complete aquaculture system. This allows for evaluation of the complete system performance and how it's affected by changes in operations and system composition

Hans Tobias is supervised by professor Bjørn Egil Asbjørnslett, and co-supervised by professor Stein Ove Erikstad and professor Pål Lader at the Department of Marine Technology, NTNU.

Håkon Måløy (PhD) Recognizing Ecological Behaviour Patterns with Deep Learning

Håkon has a MSc in Data Science from NTNU and is taking a PhD at the department of computer science, NTNU. The PhD research will be in the cross-section between research area 2 and 6. A central topic is how monitoring and operational decision support can be used to recognise fish behaviour and welfare. Håkon will analyze sensor data from within breeding cages with data-driven methods and machine learning, to uncover co-relations between external environmental factors and the behavioral patterns in salmon.

Previous experiments during his master using similar methods have resulted in promising results. The access to more and better sensor data will make it possible to test and evaluate candidate approaches in lab. The most promising approaches is planned to be tested in large scale, operational environments.

Professor Keith L. Dowing at NTNU, Department of Computer Science is Håkon's supervisor, while associate professor Kerstin Bach, NTNU, Department of Computer Science, and Ekrem Misimi senior research scientist from SINTEF Ocean are co-supervising.

Eirik Svendsen (PhD) Technological Solutions for Real-Time Observation of Physiological and Behavioural Dynamics in Farmed Fish

Eirik is a senior scientist at SINTEF Ocean and now also a PhD candidate at NTNU. With his background from engineering cybernetics Eirik has worked with numerous projects connected to fish behaviour and welfare in his 5 years at SINTEF Ocean. Eirik's PhD is funded by the associate project SalmonInsight, a four-year research project funded by the Research Council of Norway. The project includes SINTEF Ocean, NINA, NTNU department of Engineering Cybernetics and the Institute for Biology at the University of Gothenburg and the Swedish University of Agricultural Sciences. The project's main purpose is to develop new knowledge about how physiology and stress in farmed salmon manifest themselves in observable behavioural expressions.

SalmonInsight focuses on production of atlantic salmon and will, for industrial production of this

species, answer this challenge by investigating new technologies for observation of behavioural expressions, and correlate the results with salmon physiology and stress levels, and from that derive an evaluation of welfare.

The project and Eirik will through testing and evaluation of candidate technologies in laboratory scale on living salmon, select the most promising solutions for use in full scale. The technologies expected to have the greatest potential for application in full scale production will thereafter be tested in an operational environment.

Collected data will be analysed and seen in context with traditional measurements for stress in salmon.

The PhD is supervised by associate professor Jo Arve Alfredsen, Department of Engineering Cybernetics, and co-supervised by associate professor Martin Føre, Department of Engineering Cybernetics and professor Rolf Eirik Olsen, Department of Biology, all from NTNU.

Figure 6 Test facility at Frøya, Norway

Figure 7 Icing on structures can be a challenge

COMMUNICATION AND DISSEMINATION ACTIVITIES

As a Centre for Research based Innovation, EXPOSED has a responsibility to disseminate research results to the public, as well as a need for effective communication internally between partners and activities.

To support cross-disciplinary innovation and good communication within the centre, the centre has arranged a two-day EXPOSED Days in the spring and a one-day EXPOSED Day in the autumn. Such events will be arranged yearly, in addition to PhD/post-doc workshops and more targeted project related meetings. The EXPOSED Days serve as a meeting place for innovation, presentation of results, and exchange of ideas and creation of new projects.

Figure 8 Exposed days in May 2017.

Main communication channels with the public is through:

- A Norwegian facebook-page (https://www.facebook.com/eksponert) is used to share relevant news.
- Participation and presentation at international and national conferences and other fora. The centre has been invited to present at a number of national events.
- Scientific, trade and popular science articles published in relevant channels (See below).
- A web-page (http://exposedaquaculture.no/) has been established to present information about the centre to both internal and external target groups.

Figure 9 The EXPOSED web page

In 2018 the EXPOSED catalogue, an internal, living document which purpose is to increase the accessibility of the knowledge generated through the research activities to the industry partners in order to promote future value creation was created. The catalogue gives an overview over the work done, and links to relevant articles, memos, associated projects and personnel. The catalogue also links to relevant documents on the internal document sharing web hotel.

Figure 10 EXPOSED-catalogue.

PUBLICATIONS

EXPOSED strives to register all dissemination activities in the Current Research Information System in Norway (CRIStin). Please see https://www.cristin.no/app/projects/show.jsf?id=536331. Scientific papers are listed below.

Journal papers

2016

Bui S, Dempster TD, Remen M, Oppedal F (2016), *Effect of ectoparasite infestation density and life-history stages on the swimming performance of Atlantic salmon Salmo salar*. Aquaculture Environment Interactions 2016 (1869-215X) Vol. 8, s. 387-395

Remen M, Solstorm F, Bui S, Klebert P, Vågseth T, Solstorm D, Hvas M, Oppedal F (2016), *Critical swimming speed in groups of Atlantic salmon Salmo salar.* Aquaculture Environment Interactions 2016: Volume 8, pages 659-664.

Rundtop P, Frank K (2016*), Experimental evaluation of hydroacoustic instruments for ROV navigation along aquaculture net pens.* Aquacultural Engineering 2016; Volume 74.

2017

Hvas M, Folkedal O, Imsland A, Oppedal F (2017b), *The effect of thermal acclimation on aerobic scope and critical swimming speed in Atlantic salmon* (*Salmo salar* L.). J. Exp. Biol. 220, 2757-2764.

Hvas M, Oppedal O. (2017c), *Sustained swimming capacity of Atlantic salmon.* Aquacult. Env. Interact. 9, 361-369.

Hvas M, Karlsbakk E, Mæhle S, Wright D, Oppedal F (2017d), *The gill parasite Paramoeba perurans compromises aerobic scope, swimming capacity and ion balance in Atlantic salmon.* Conservation Physiology 5. 10.1093/conphys/cox066

Hvas M, Folkedal O, Solstorm D, Vågseth T, Fosse JO, Gansel LC, Oppedal F (*2017a), Assessing swimming capacity and schooling behaviour in farmed Atlantic salmon Salmo salar with experimental push-cages,* Aquaculture, Volume 473, 20 April 2017, Pages 423-429

Mathisen B M, Aamodt A, Langseth H (2017), *Data driven case base construction for prediction of success of marine operations*. CEUR Workshop Proceedings 2017; Volum 2028. s. 104-113

2018

Haugaløkken, Bent Oddvar Arnesen; Jørgensen, Erlend Kvinge; Schjølberg, Ingrid (2018b), *Experimental Validation of End-Effector Stabilization for Underwater Vehicle-Manipulator Systems in Subsea Operations*. Robotics and Autonomous Systems; Volum 109. s. 1-12

Holmen, Ingunn Marie; Utne, Ingrid Bouwer; Haugen, Stein (2018) Risk assessments in the Norwegian aquaculture industry: Status and improved practice. *Aquacultural Engineering* 2018; Volum 83. s. 65-75

Hvas, Malthe; Folkedal, Ole; Imsland, Albert; Oppedal, Frode (2018), *Metabolic rates, swimming capabilities, thermal niche and stress response of the lumpfish, cyclopterus lumpus*. Biology Open 2018; Volum 7:bio036079.(9) s. 1-9

Hvas, Malthe; Nilsen, Tom Ole; Oppedal, Frode (2018), *Oxygen Uptake and Osmotic Balance of Atlantic Salmon in Relation to Exercise and Salinity Acclimation*. Frontiers in Marine Science 2018; Volum 5. s.1-11

Conference papers

2016

Bjelland H, Føre M, Lader P, Kristiansen D, Holmen IM, Fredheim A, Grøtli EI, Fathi DE, Oppedal F, Utne IB, Schjølberg I (2016), *Exposed aquaculture in Norway- Technologies for robust operations in rough conditions.* Proceedings from OCEANS' 15 MTS/IEEE, Washington, USA, 19-22 October 2015.

2017

Arnesen BO, Lekkas AM and Schjølberg I (2017), *3D path following and tracking for an inspection class ROV,* In: Proc. of the 36th International Conference on Ocean, Offshore & Arctic Engineering (OMAE17), June 25-50, 2017, Trondheim, Norway.

Bore PT & Amdahl J (2017), *Determination of environmental conditions relevant for the ultimate limit state at an exposed aquaculture location*. In proceedings of the 36th Offshore Mechanics and Arctic Engineering Conference, OMAE2017-61413, June 25-50, 2017, Trondheim, Norway.

Bore PT, Amdahl J, Kristiansen D, (2017), *Modelling of Hydrodynamic Loads on Aquaculture Net Cages By a Modified Morison Model.* 7th International Conference on Computational Methods in Marine Engineering, At Nantes, France

Grøtli EI, Bjerkeng M, Rundtop P, Vagia M, Haugli FB, Transeth AA (2017), *Canvas as a design tool for autonomous operations: With application to net inspection of a sea based fish farm using an underwater vehicle*, OCEANS, Aberdeen, UK

Holmen IM, Utne IB, Haugen S (2017*), Organisational safety indicators in aquaculture – a preliminary study. Risk, Reliability and Safety: Innovating Theory and Practice:* Proceedings of ESREL 2016 (Glasgow, Scotland, 25-29 September 2016). CRC Press.

Holmen IM, Utne IB, Haugen S, Ratvik I (2017), *The status of risk assessments in Norwegian fish farming.* In: Safety & Reliability, Theory and Applications. CRC Press.

Kristiansen D, Aksnes V, Su B, Lader P and Bjelland HV (2017), *Environmental description in the design of fish farms at exposed locations*. In proceedings of the 36th Offshore Mechanics and Arctic Engineering Conference, OMAE2017-61531, June 25-50, 2017, Trondheim, Norway.

Lader P, Kristiansen D Kristiansen, Alver M, Bjelland HV & Myrhaug D (2017), *Classification of aquaculture locations in Norway with respect to wind wave exposure*. In: The 36th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2017.

Mathisen BM, Aamodt A, Langseth H (2017), *Data driven case base construction for prediction of success of marine operations.* ICCBR-17 Workshop on Workshop on Case-based Reasoning and Deep Learning - CBRDL 2017; 2017-06-26 - 2017-06-26, NTNU

2018

Fredheim, Arne; Reve, Torger (2018), *Future Prospects of Marine Aquaculture*. OCEANS 2018 MTS/IEEE Charleston. IEEE conference proceedings 2018 ISBN 978-1-5386-4814-8.

Haugaløkken, Bent Oddvar Arnesen; Sandøy, Stian Skaalvik; Schjølberg, Ingrid; Alfredsen, Jo Arve; Utne, Ingrid Bouwer (2018a), *Probabilistic Localization and Mapping of Flexible Underwater Structures using Octomap*. 2018 European Control Conference (ECC). IEEE 2018 ISBN 978-3-9524-2698-2. s. 268-275

PERSONNEL

Key Researchers	Institution	Main research area
Hans V. Bjelland	SINTEF Ocean	Decision support systems and aquaculture operations
David Kristiansen	SINTEF Ocean	Aquaculture structures
Ingunn Marie Holmen	SINTEF Ocean	Safety and risk management
Trine Thorvaldsen	SINTEF Ocean	Safety and risk management
Leif Magne Sunde	SINTEF Ocean	Aquaculture operations
Heidi Moe Føre	SINTEF Ocean	Material science
Per Christian Endresen	SINTEF Ocean	Aquaculture structures
Gunnar Senneset	SINTEF Ocean	Field measurements and infrastructure
Martin Føre	SINTEF Ocean	Telemetry and biological modelling
Jan Tore Fargertun	SINTEF Ocean	Aquaculture structures
Andrei Tsarao	SINTEF Ocean	Aquaculture structures
Stefan Vilsen	SINTEF Ocean	Aquaculture structures
Carina Norvik	SINTEF Ocean	Aquaculture structures
Dariusz Fathi	SINTEF Ocean	Vessel design
Ørjan Selvik	SINTEF Ocean	Vessel design
Vegard Ø. Aksnes	SINTEF Ocean	Aquaculture structures
Frode Oppedal	Institute of marine research	Fish behaviour and welfare
Ole Folkedal	Institute of marine research	Fish behaviour and welfare
Esten Ingar Grøtli	SINTEF Digital	Autonomous systems
Trine Kirkhus	SINTEF Digital	Optical Measurement Systems and Data Analysis
Pål Lader	NTNU, Department of Marine Technology	Aquaculture structures
Jørgen Amdal	NTNU, Department of Marine Technology	Marine structures
Trygve Kristiansen	NTNU, Department of Marine Technology	Marine structures
Ingrid B. Utne	NTNU, Department of Marine Technology	System safety engineering, risk assessment, and maintenance management of marine systems
Stein Haugen	NTNU, Department of Marine Technology	Risk monitoring and analysis
Agnar Aamodt	NTNU, Department of Computer and Information Science	Intelligent systems and decision support
Kerstin Bach	NTNU, Department of Computer and Information Science	Intelligent systems and decision support
Helge Langseth	NTNU, Department of Computer and Information Science	Intelligent systems and decision support
Jo Arve Alfredsen	NTNU, Department of Engineering Cybernetics	Telemetry and biological modelling

PhD students with financial support from the Centre budget

Name	Nationality	Period	Sex (M/F)	Topic
Bjørn Magnus Mathisen	Norwegian	Q3 2015 - Q3 2019	M	Monitoring and operational decision support.
Pål Takle Bore	Norwegian	Q1 2015 - Q3 2018	M	Intelligent Aquaculture Structures
Ingunn Marie Holmen	Norwegian	Q1 2016 - Q4 2019	F	Safety and risk management
Bent Arnesen	Norwegian	Q3 2016 - Q3 2019	M	Remotely controlled and automated underwater vehicles
Malthe Hvas	Danish	Q2 2016 - Q2 2019	M	Physiology and behaviour of salmon in strong water currents
Waseem Hassan	Pakistani	Q4 2016 - Q4 2020	M	Acoustic fish telemetry for real-time fish performance monitoring in aquaculture
Håkon Måløy	Norwegian	Q2 2018 - Q2 2022	M	Recognizing ecological behaviour patterns with deep learning
Hans Tobias Slette	Norwegian	Q3 2018 - Q3 2021	M	Methods and models for marine system design of vessels and vessel operations in exposed aquaculture
Muhammad Mukhlas	Indonesian	Q4 2018 – Q4 2022	M	Closed Cage Aquaculture Structures in Waves and Currents

PhD students working on projects with financial support from other sources

Name	Nationality	Period	Sex (M/F)	Funding	Topic
Kristbjörg Edda Jónsdóttir	Norwegian	Q3 2016 - Q3 2019	F	Strategic research project of SINTEF Ocean	Dynamics of water flow and turbulence in large-scale aquaculture sea cages
Stian Sandøy	Norwegian	Q3 2016 - Q3 2019	M	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability. HAVBRUK2, RCN	Sensor fusion for autonomous underwater inspection of aquaculture structures
Yugao Shen	Chinese	Q3 2013 - Q3 2016	M	NTNU AMOS - Centre for Autonomous Marine Operations and Systems	Limiting operational conditions for a well boat
Stefan A. Vilsen	Danish	Q1 2014 - Q1 2018	M	NTNU AMOS - Centre for Autonomous Marine Operations and Systems	Hybrid model testing of marine systems
Eirik Svendsen	Norwegian	Q3 2018 - Q3 2022	M	SalmonInsight. HAVBRUK2, RCN	Links between salmon physiology and online monitored behaviour

Postdoc. researchers with financial support from the Centre budget

Name	Nationality	Period	Sex (M/F)	Topic
Ása Johannesen	Faroese	Q3 2018 - Q3 2020	F	Fish behaviour and welfare in waves

Postdoc. researchers working on projects with financial support from other sources

Name	Nationality	Period	Sex (M/F)	Funding	Topic
Xue Yang	Chinese	Q2 2017 - Q1 2019	F	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability HAVBRUK2, RCN	Operational risk assessment

Master students

Name	Sex (M/F)	Period	Affiliation	Topic
Lene Erdal	F	Q1-2 2016	Industrial Economics and Technology Management, NTNU	Shared Value Creation in an Industry Context - Assessing How Governmental Policies Can Contribute to Increased Corporate Sustainability in the Norwegian Aquaculture Industry
Marianne Wethe Koch	F			
Fredrik Lindahl Roppestad	M	Q1-2 2016	Department of Computer Science, NTNU	Decision support for predictive maintenance of exposed aquaculture structures
Niklas Bae Pedersen	M			
Helene Nordtvedt	F	Q2 2016	Department of Production and Quality Engineering, NTNU	Development of a Risk Model for Fish Farming Operations
Alexander Wallem Berge	M	Q1-2 2017	Department of Marine Technology, NTNU	Fleet Scheduling of Service Vessels used in a more exposed Norwegian Aquaculture Industry
Henrik Theodor Ramm	M			
Marius Gyberg Haugland	M	Q1-2 2017	Department of Marine Technology, NTNU	Use of Clusters in a Route Generation Heuristic for Distribution of Fish Feed
Sondre Thygesen	M			
Simen Aleksander Haaland	M	Q1-2 2017	Department of Marine Technology, NTNU	Semi-closed containment systems in Atlantic salmon production Comparative analysis of production Strategies
Jens Kristian Hole	M	Q1-2 2017	Department of Marine Technology, NTNU	Risikobasert design av fartøy og merde for eksponert havbruk
Hanne Hornsletten	F	Q2-3 2017	Department of Marine Technology, NTNU	Optimization Model Aimed for the Aquaculture Industry for Fleet Composition and Routing of Wellboats
Henrik Håkonsen	M	Q1-2 2017	Department of Marine Technology	Emergency Preparedness and Response in Aquaculture
Marte Tuverud Kamphuse	F	Q1-2 2017	Department of Marine Technology, NTNU	Modeling of Seaborne Transport of Fresh Salmon. Inventory Routing with Continuous Time Formulation for a Perishable Product

Runar Stemland	M	Q1-2 2017	Department of Marine Technology, NTNU	Assessment of Service Vessel Operability In Exposed Aquaculture. An exploratory approach combining vessel response and discrete-event simulation
Arne Jacob Eide	M	Q1-2 2017	Department of Marine Technology, NTNU	Analysis of Ocean Farming's Steel Cage Concept Subjected to Environmental Loads
Lars Sunde Gjengseth	M	Q1-2 2017	Department of Marine Technology, NTNU	Rational analysis of Nordlaks' "Havfarm" aquastructure concept for exposed waters
Nikolai Hanevik	M	Q1-2 2017	Department of Marine Technology, NTNU	Analysis of Ocean Farming's Steel Cage Concept in Very Exposed Waters
Vegard Holen	M	Q1-2 2017	Department of Marine Technology, NTNU	Ultimate Limit State Analysis of Havfarm
Ole-Johan Nekstad	M	Q2-3 2017	Department of Marine Technology, NTNU	Modularization of Aquaculture Service Vessels - An Approach for the Implementation of Operational Flexibility
Erik Andreas Næstvold	M	Q1-2 2017	Department of Marine Technology, NTNU	Simuleringsmodell som beslutningsstøtte for valg av tiltak mot lakselus på lokalitetsnivå
Adrian Stenvik	M	Q1-2 2017	Department of Marine Technology, NTNU	Fleet Size and Mix in the Norwegian Aquaculture Sector. A stochastic fleet renewal problem with an uncertain future
Vetle Skavraker Evju	M	Q1-2 2017	Department of Marine Technology, NTNU	Competitiveness in construction of offshore fish farms Assessment of cost and strategic aspects
Ronja Eide Lilienthal	F	Q1-2 2017	Department of Marine Technology, NTNU	Discrete-Event Simulation of a Multimodal Downstream Supply Chain for Future Norwegian Aquaculture
Ragni Rørtveit	F			
Odin Dybsland	M	Q1-2 2017	Department of Marine Technology	Risikostyringsverktøy for oppdrettsnæringen
Solveig Sæbø	F	Q1-2 2017	Faculty for science and technology, UiT	Integrering av ytre miljørisiko i HMS-arbeidet - En casestudie av et fiskeoppdrettselskap
David Williams	M	Q3 2016 – Q2 2017	Department of Marine Technology, NTNU	Extreme loads on a feeding barge
Yuyang Zang	F	Q1-2 2018	Department of Marine Technology, NTNU	Experimental and Numerical Investigations of Global Motions and Slamming Loads on an Aquaculture Feed Barge
Øyvind Haug Lund	M	Q1-2 2018	Department of Marine Technology, NTNU	Evaluation and Comparison of Operability and Operational Limits of Service Vessel Designs in Exposed Aquaculture
Trym Sogge Sjøberg	M			
Gøran Bredal Woll	M	Q1-2 2018	Department of Technology and Safety, UiT	Sertifiserer de seg sikrere? - En casestudie av frivillige miljøsertifiseringers innvirkning på sikkerhetsstyringen i oppdrettsnæringen
Loenard O. Cheri	M	Q3 2017 – Q1 2018	Department of Physics, UiO	Net-relative localization algorithm for fish cage inspection operation
Erling Nilsen	M	Q3 2017 – Q3 2018	University of Agder	Effect of ploidy on oxygen uptake and swimming performance in the lower end of the thermal niche of Atlantic salmon.
J.W. Yuen	M	2018	University of Melbourne, Australia	Effect of temperature on metabolic scope and swimming capacity in the ballan wrasse (Labrus bergylta).

Figure 11 EXPOSED Days in April 2018.

STATEMENT OF ACCOUNTS

Name	Funding		Cost
The Research Council	13 169	(48 %)	-
The Host Institution (SINTEF Ocean)	1 236	(4 %)	8 681
Research Partners*	3 325	(12%)	9 491
Enterprise partners**	9 797	(36 %)	9 347
Public partners	-	-	-
Equipment	-	-	-
Total	**27 527**		**27 527**

(All figures in 1000 NOK)

* IMR, SINTEF Digital, NTNU IMT, NTNU IDI, NTNU ITK

** Marine Harvest, Cermaq, SalMar, Kongsberg Seatex, Kongsberg Maritime Subsea, Kongsberg Maritime, Aqualine, Møre Maritime, ÅF, Anteo, Argus Remote Systems, Lerow, AQS, Marine Design, DNV GL and MacGregor Norway

sfi Centre for Research-based Innovation

The Research Council of Norway

EXPOSED

AQUACULTURE OPERATIONS

CENTRE FOR RESEARCH-BASED INNOVATION

SINTEF Ocean · Mowi · Cermaq Norway · SalMar Farming · Kongsberg Maritime
Kongsberg Seatex · Aqualine · Marine Design · Lerow · ÅF Engineering · Møre Maritime
Argus Remote Systems · DNV GL · SINTEF Digital · Institute of Marine Research
Anteo · Norwegian University of Science and Technology · AQS · MacGregor Norway

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