EXPOSED

ANNUAL REPORT 2019

CONTENT

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

SUMMARY

In 2019, the EXPOSED Aquaculture Operations research centre had a successful midway evaluation and is now planning for the final centre period with increased 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.

Especially in Norway, there is a strong innovation drive in the aquaculture industry, and extensive investments are done. New farm concepts and novel opportunities for production in the coastal areas also requires authorities and the industry to review current legislation and governing practices. 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. The centre is frequently contacted by foreign governments, industry and researchers to support similar developments abroad.

2019 started with a panel of four international experts evaluating the achievements of the centre so far. For EXPOSED, the feedback was positive, and both the process of preparing for the evaluation and the feedback from the panel has been useful to outline the coming centre period.

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.

Several demonstrator projects were initiated in 2019, with the goal of exploring the potential of several technologies in exposed aquaculture operations, such as decision support systems and the use of robotic arms to compensate for the relative motions of vessels and cages.

The first PhD candidates have now successfully defended their thesis. They will become a valuable contribution to industrial and academic future work for the aquaculture industry.

sfi Centre for Research-based Innovation
The Research Council of Norway

[1] https://www.forskningsradet.no/om-forskningsradet/programmer/sfi/

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 2019. 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

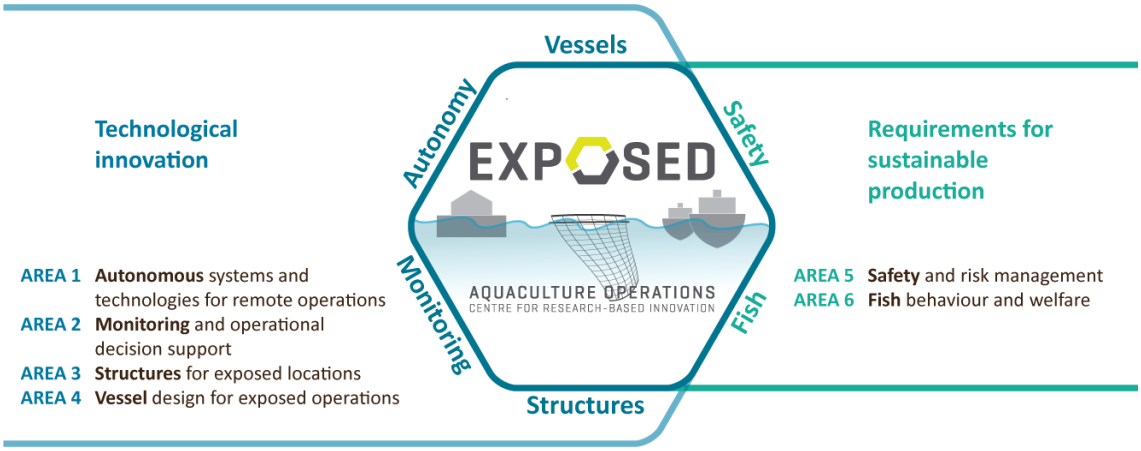
- Enable safe and profitable operations at exposed fish farming sites to increase sustainable seafood production.
- Develop new technologies to underpin Norway's global leading position in aquaculture and maritime competence and technology.
- Help develop new technologies related to the concepts found 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.*

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. Seven projects (P12 – P18) were active in 2019, in addition to 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 2019, and are presented in more detail below (p. 15).

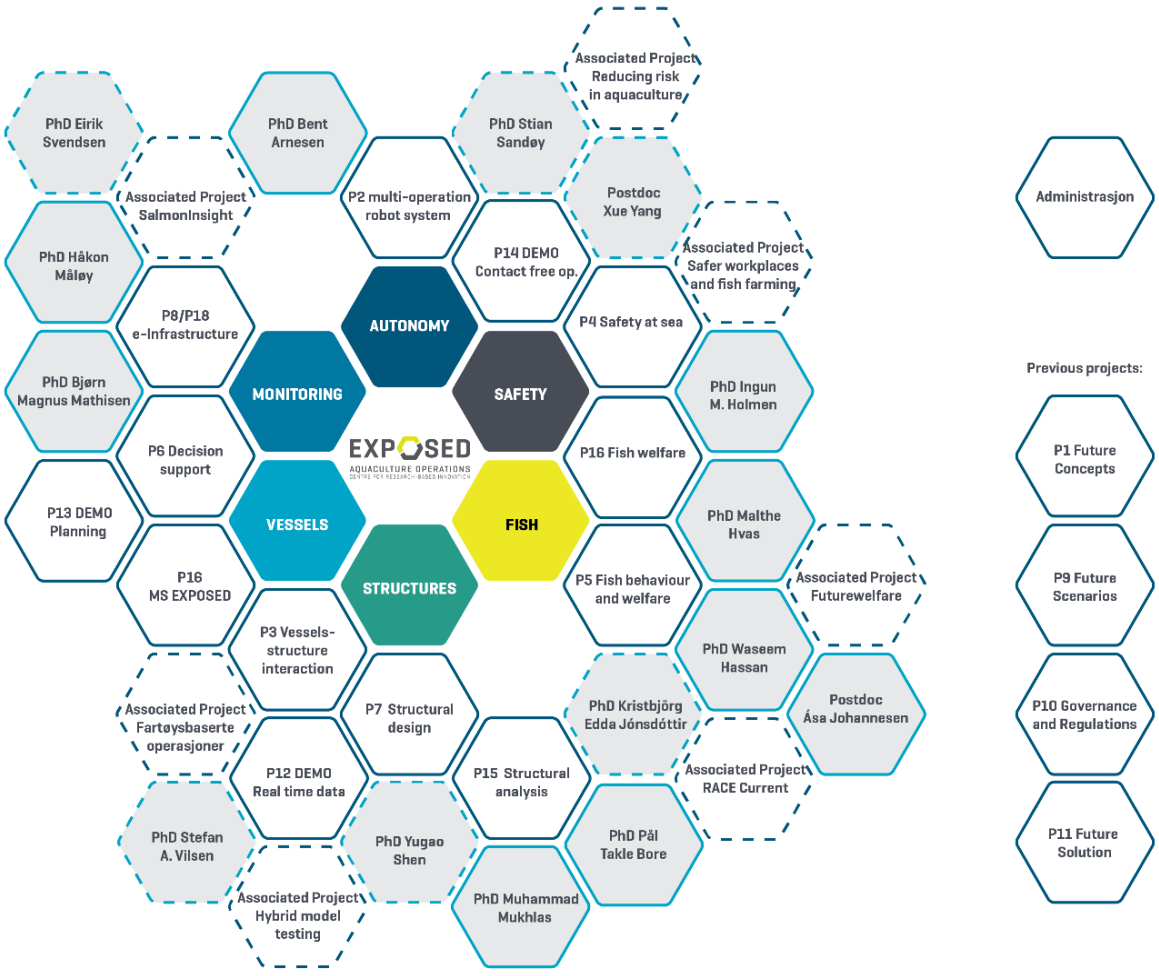


Figure 1 Activities are organised in projects, combining research areas, partners and methods. PhDs and postdocs will take part in the project teams. A selection of associated projects and PhDs are indicated with dashed strokes.

*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 companies or research partners. 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
FASTWELL - Optimising Feed Withdrawal for Safeguarding Fish Welfare,	2019-2022. Researcher project HAVBRUK2, RCN	Institute of Marine Research	Project P16

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
Alf Jostein Skjærvik (Chairman)	SalMar
Noralf Rønningen	Aqualine (ScaleAQ)
Bjørn Egil Asbjørnslett	NTNU
Hanne Digre	SINTEF Ocean
Berit Floor Lund	Kongsberg Subsea
Ole Folkedal	Institute of Marine Research
Svein Jarle Midtøy	Lerow
Kjell Emil Naas (Observer)	The Research Council of Norway

Figure 3 EXPOSED Day in October 2019.

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
Heidi Moe Føre **SINTEF Ocean**	Area 3 Project P15
Ørjan Selvik SINTEF Ocean	Area 4 Project P17
Ingunn M. Holmen SINTEF Ocean	Area 5 Project P4
Ole Folkedal Institute of Marine Research	Area 6 Project P16
Jan Tore Fagertun SINTEF Ocean	Area 2 Project P11 and P18
Leif Magne Sunde SINTEF Ocean	Aquaculture operations
Carina Norvik SINTEF Ocean	Scientific coordinator 2019
Kaja Haug SINTEF Ocean	Scientific coordinator 2020

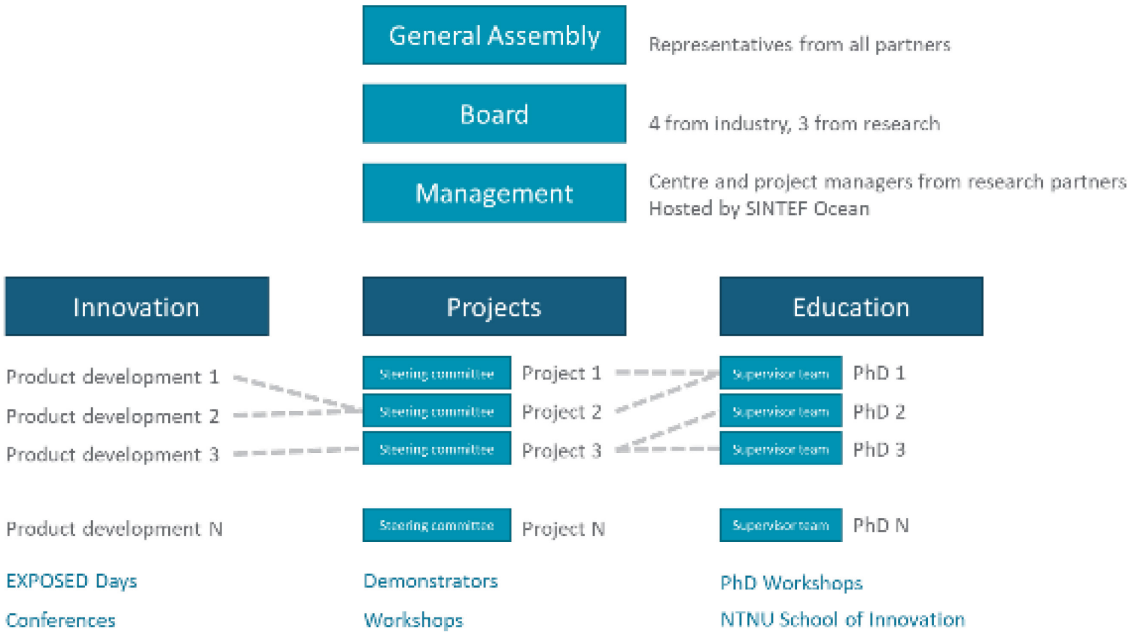


Figure 4 Organisational structure of EXPOSED

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. 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 Exposed Days, April 2019.

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. Experiments at new farms in Norway and in the Faroe Islands is 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 (ScaleAQ) 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.	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 Leading 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
Safetec An innovative partner within safety management. Creates value within the framework of safety. Enters the Centre in March 2020.	Safety management and risk analysis

Safetec is a new partner in the EXPOSED Centre

It is a pleasure welcoming Safetec to the EXPOSED centre - an innovative and multidisciplinary company working with safety management, support and risk-based decision-making support.

"We believe that the centre and its partners will benefit from Safetec's long and professional experience within risk analyses, emergency preparedness, technical safety and human and organizational factors from different industries," says Xue Yang in Safetec. Safetec can also assist the aquaculture industry with a cost effective and sustainable management responding to the governmental expectations, she adds.

Safetec's experience from project and research work within safety management brings a strong and relevant knowledge into the centre. They can contribute to developing methods and knowledge that can be used in a holistic safety management, both on traditional aquaculture farms inshore, and on developing concepts offshore. Safetec's focus will be risk analyses and emergency preparedness to optimize design and safe management within HES, escapes, fish health and fish welfare at the farms.

With this, Safetec will contribute in the Research Area 5: *Safety and risk management* in the EXPOSED Centre, especially within:

- Developing methods for risk analyses and barrier management for safety design and management.
- Developing methods for better and more efficient emergency preparedness

The Centre Director Hans Bjelland is happy to welcome Safetec into the EXPOSED Centre, and says: "We see that Safetec will complement the centre with knowledge and make us capable of taking care of important issues for the aquaculture industry. They will challenge us and help us develop towards an even safer aquaculture industry."

SCIENTIFIC ACTIVITIES AND RESULTS

Seven projects have been finalised in 2019, covering fundamental research, industrial 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.

P12 DEMO Real-time condition monitoring and operation support

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Stefan Vilsen, SO	**SINTEF Ocean, Kongsberg Maritime, Kongsberg Seatex, Aqualine, MOWI, DNV GL**	**Q1 2019 – Q4 2019**	**Industrial**

The main aim of this project was to develop and demonstrate methods for integrating sensor data with simulation models of exposed aquaculture for monitoring and operation support.

Fish farming at exposed locations is demanding with respect to both structural integrity, personnel safety during operations and fish welfare. Operations on fish farms are often performed with lacking or no prior information of the waves and current at the specific site, and how this affects the fish farm.

Large volumes of data are gathered from fish farms while usage of data is limited. The underlying idea behind this project was to demonstrate increased value of sensor data through integration with a numerical model of the fish farm (digital twin), giving a holistic representation of structures and environment during operations.

The project objectives were to develop the fundamental tools needed to couple sensor data and simulation models and a demonstrational prototype of use in operational planning.

Main results

- A simulation model (digital twin) of SINTEF ACE Rataran was developed in FhSim and used as base of the studies.
- The effect of sensor placement was studied using statistical methods to determine how to intelligently place sensors where most information is obtained.
- A current velocity estimator using net displacement sensors to determine current direction and magnitude was developed and implemented.

Innovation potential

- Remote monitoring of structural loading and environmental condition.
- Better data for decision support during operations.

P13 DEMO Operational planning

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Eivind Lona, SO	**Anteo, MOWI, NTNU IMT, SINTEF Ocean**	**Q1 2019 – Q4 2019**	**Industrial**

The aim of this project was to develop and 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.

The objective of P13 is to improve operability and safety in operations at exposed fish farms. The aim is to develop methods for improving operational planning of aquaculture operations performed by service vessels. This will be achieved by the following secondary goals:

a) Establish methods for capturing qualitative operational data.

A better understanding and categorisation of limiting operational factors for service vessel operations is essential for this project. Development of improved methods for capturing qualitative operational data from aquaculture operations will be performed using vessel AIS combined with a geofence around relevant aquaculture farms. When the service vessels arrive and later leave a location, the idea is to send a notification to the vessel and ask for details of their mission with respect to planned vs. actual limiting operational factors.

Service vessels participating in the study needs to be equipped with AIS and preferably wind sensors. Wind, wave and current monitoring is required at the aquaculture farms used in the study

b) Specification of operational planning methodology. Define parameters and objective operational indicators that could be used for decision support.

The decision basis for planning and execution of current service vessel operations needs to be better understood, e.g. which weather forecast sources are used, which sensors or other weather data are used, what are the typical limiting operational factors used in planning of operations. An interview guide has been created in order to assist in collecting information from various vessel representatives.

c) Development of user interface prototype.

Anteo will develop a user interface that will demonstrate assignment of work tasks to service vessels. This will be based on established operational factors combined with weather forecasts and available weather data.

Main results

The project did not manage to capture any data during 2019 due to lack of available weather monitoring systems at relevant exposed aquaculture farms. A certain amount of data is needed for development of the user interface. The project work will continue in 2020.

Innovation potential

- Use of use established operational limits combined with automated data acquisition as a tool for operational planning and decision support for service vessels in the aquaculture industry.
- Long term expected results - capture qualitative operational data for different types of vessels and operations and use this in combination with real-time sensors and forecasts as decision support for fleet management.
- Short term expected results - demonstrate methodology in a user interface prototype.

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

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Martin Gutsch, SO	**SINTEF Ocean, SINTEF Digital, MacGregor, Kongsberg Seatex, Kongsberg Maritime, AQS, Lerow, Salmar, Cermaq**	**Q1 2019 – Q4 2019**	**Industrial**

The main objective of the project was to demonstrate in simulations how service vessels can operate in different weather conditions when performing aquaculture operations without having contact with the facilities, except for the intended use and contact between the vessel's manipulator arm and the facility. In the initial phase, the feasibility of contact free operations was demonstrated by simulations for a range of weather scenarios.

Harsher environmental conditions at more exposed fish farming locations require new solutions regarding vessel navigation when doing aquaculture operations in close proximity to the fish cages. The vessel handling at increased wave heights, wind, and current conditions will make direct interaction between vessel and cage structure more difficult and hazardous for the crew and the structural integrity of the facility. New contact-free solutions, replacing the crew from the hazardous working area on the fish cage, shall contribute to increase operability and safety within aquaculture operations.

The feasibility of contact free operations in different weather scenarios was analysed by time domain simulations using a typical fish-farm service vessel (of 25.5m length) close to a fish farm. During the operations, the vessel's position was maintained by a dynamic positioning (DP) system. Relative motions between the mounting position of the manipulator arm on the vessel's main deck and a selected point on the circular collar of the fish farm were extracted and used as input for the motion compensation algorithm of the manipulator arm. Statistical analysis was performed indicating the operational envelope of the system of vessel and manipulator arm for different weather conditions.

In the next phase, the required sensors and instrumentation for performing a selected set of work tasks will be investigated.

In the long term, the project shall establish a test environment where it will be possible to train machine learning algorithms to perform work tasks with the manipulator arm operating in an automated mode.

Main results

- The motion response relative to the fish cage was analysed for significant wave heights of 0.5 m, 1.5 m and 2.5 m.
- The motion compensation algorithm for the manipulator arm was developed and applied based on the relative motion data from the vessel response analysis.
- A simple visualization of the moving vessel, operating close to the fish farm, was made available.

Innovation potential

- Contactless operations between vessels and cages.
- Flexible operations with reduced risk of injury to humans, fish and structures.
- Increased weather window for performing operations.
- Establishment of a test environment to develop and train algorithms for new operational tasks in a safe environment.

P15 Structural analysis of fish farms

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Heidi Moe Føre, SO	Aqualine, Salmar, AQS, LEROW, Kongsberg SEATEX, SINTEF Ocean, DNVGL, NTNU	**Q1 2019 – Q4 2019**	**Fundamental**

This project aimed to contribute with new knowledge, which can be used to develop improved load models and analysis methods for fish farms. This work is based on the previous Exposed-project P7 (Structural design of reliable offshore aquaculture structures)

Fish farming at more exposed sites require robust and reliable structures which facilitate safe and efficient production.

There is a need for more refined and precise load models and analysis methods. In this project we choose to focus on nets for fish farming, as they are the main source of loads acting on a conventional fish farm, and will have a large impact on total loads on new designs utilizing netting for containment of fish. Formulas for estimation of drag loads on nets were established about 30 years ago, and there is a need to adjust these according to current and new net materials, and more precise solidity measurements.

To establish drag loads on nets, towing tank tests with net panels have been performed. Several Raschel knitted PA6 multifilament nets with solidities varying from low to high (0.15 – 0.32) were tested. Loads acting on the netting and the flow velocity reduction through the netting were measured for a variation of towing velocities (up to 2 m/s) and net panel inclinations to the incident water flow. Current and new methods for determining netting solidity were investigated and compared.

P15 is completed with independent results. Further work on loads on aquaculture netting will be continued in Research Area 3 in 2020.

Main results

- A review of previously published data from experiments on net panels; focusing on drag forces, variation in velocity and netting solidity.
- Dataset from towing tests of net panels with Raschel knitted PA6 multifilament netting yielding updated drag- and lift force values, and measurements of flow velocity reduction through the panels.
- For a flow velocity of 1 m/s, drag forces on Raschel knitted PA6 multifilament nets are close to proportional to netting solidity for all solidities tested (up to 0.32). Drag loads found are only to a limited degree dependent on Reynolds number for typical design conditions.
- Drag forces on high solidity nets are lower than predicted by previously established formulas.
- The velocity reduction factor, i.e. the reduced flow velocity behind a net panel, decreased in general as a linear function of solidity for flow perpendicular to the panel. Compared to previous published material, these data showed higher velocity reduction.

Innovation potential

- Improved accuracy for drag force calculations on medium to high solidity aquaculture nets with Raschel-knitted netting.

P16 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 2019**	**Fundamental**

The aim of P16 is 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 waves has been achieved,and novel research infrastructure and observation tools for fish behaviour and physiology has been made and evaluated..

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 of both constructions and fish.

Numerous experiments with salmon and cleaner fish in P16 have resulted in journal publications showing 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, as surveyed in a study based on current data from exposed farms in Norway, communicated in a report ordered by the Directory of Fisheries, and in a submitted review addressing biological criteria for exposed salmon farming. Field observation is particularly demanding in exposed farming, and new tools, including a long distance communication system for individual fish tag data (the Internet of fish), and novel tag parameters, such as swimming speed have been developed and verified. Ongoing work in this field focus on building and verifying a technical and biological standard for individual fish welfare monitoring for use in exposed farms, including heart beat and tail beat frequency, and development of analytical methods and tools (e.g. deep learning) for understanding fish behaviour as recorded by echosounders. Monitoring of fish behaviour and welfare at an exposed farm at the Faroe Islands, in collaboration with international partner Fiskaaling, has over the last year provided valuable field data and knowledge on salmon coping strategies towards both current and waves.

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, ploidy, starvation, 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.
- Detailed field data of fish behaviour and welfare from an exposed farm.

Innovation potential

- Addressing the biological needs in innovations 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.

P17 MS Exposed – Service vessel for exposed operations

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ørjan Selvik, SO	**Marin Design, Møre Maritime, AQS, Lerow, Aqualine, MOWI, Kongsberg Maritime Merchant Marine, Kongsberg Seatex, MacGregor, NTNU IMT, SINTEF**	**Q1 2019 – Q4 2019**	**Industrial/ Fundamental**

Service vessels are a central and frequently used resource in aquaculture operations. The aim of 'MS Exposed' is to develop a holistic methodology for design of service vessels. The method will combine vessel design, work deck equipment and operational safety for exposed aquaculture. A secondary objective was to design 'MS Exposed', a service vessel which implement R&D knowledge from EXPOSED.

There is a considerable potential for innovative vessel designs for exposed aquaculture operations by combining design and safety barrier thinking. By establishing a library for operations, equipment and resources needed, new vessels can be defined from predefined modules based on tested hull designs. This will speed up the design process and ensure that the new vessels support the operations they will perform. On a longer term, this will provide several well-documented service vessel designs for exposed aquaculture production units.

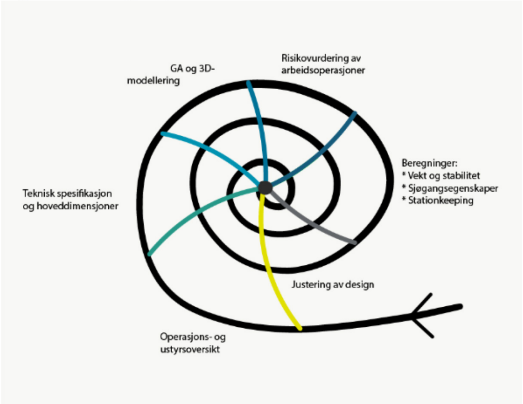
Short term results will be increased knowledge about aquaculture operations and its implications for vessel design. Safety thinking will be included in the design process, by integrating safety barriers and performing risk assessments.

Understanding and categorizing the different vessel classes are conducted to map the variety of operations that the different vessels performs. An overview of operations, equipment and vessel functions is important in order to understand which vessel and which equipment that is needed for the different aquaculture operations.

A holistic design methodology for the aquaculture solutions is developed. The design spiral consists of the following elements:

- Overview of operations and equipment
- Technical specifications and main dimensions
- GA and 3D-modelling
- Risk assessment of operations
- Calculations
- Operability calculations

Figure 6 Design spiral



Main results

- Service vessels are categorized according to function
- Operational overview summarizing equipment, operations and vessel category
- Design methodology developed

Innovation potential

- An improved and holistic design methodology for the next generation service vessels which combines vessel design, work deck equipment and operational safety.
- Increased knowledge of aquaculture operations and their influence on vessel design
- A methodology that will result in well documented service vessel designs for use in exposed aquaculture

P18 EXPOSED e-Infrastructure

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Jan Tore Fagertun, SO	**Aqualine AS, Cermaq, MOWI, SalMar, Kongsberg Seatex**	**Q3 2015 – Q4 2019**	**Industrial**

The aim of the P18 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 oceanographic, meteorological, response and water quality measurements create a platform for the development of methods, systems and solutions.

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 reduce the uncertainty 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 and numerical simulations.

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.

The work is continued in Research Area 2 under work package H1 in 2020.

Main results

- Long time series of data from 5 locations, 3 vessels, 2 fish farm net cages and 2 feed barges.
- 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 methods, systems for use at fish farms and seaweed cultivation facilities in exposed localities.
- Data to support software development,validation of numerical simulations 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.

A collaboration with the research organisation Fiskaaling in the Faroe Islands has so far resulted in a mutual post doc. project that started in 2018 between Fiskaaling, EXPOSED and the associated project FutureWelfare .

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:

- NASF 2019, Bergen, Norway
- AquaNor 2019, Trondheim, Norway

The centre director and researchers have chaired sessions relevant to aquaculture technology and exposed fish farming:

- OMAE 2019, Glasgow, Scotland
- Open Ocean Symposium, Nelson, New Zealand
- EAS 2019, Berlin, Germany

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).

The host institution, SINTEF Ocean, and the partner DNV GL have become partners in the newly started Blue Economy Cooperative Research Centre in Australia.

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

Martin Slagstad - PHD candidate profile
Advanced and Rational analysis of steel fish farms in exposed waters

Martin has a MSc from NTNU in addition to 5 years of working experience as a structural engineer in the oil and gas industry. He is currently undertaking a PhD at the department for marine technology at NTNU AMOS. The PhD research will be on design methods for the structural strength of fish farms in exposed areas. Both advanced as well as simplified methods will be considered.

Design methods for traditional fish farms have existed for many years and have given a satisfactory level of safety. With the current desire to move to more exposed locations new types of structures are being created and being placed in environments from which we have little experience. The goal of Martin's PhD work is to contribute to the development of robust design methods for fish farms at exposed locations.

Professor Jørgen Amdahl at the department of marine technology at NTNU AMOS is Martin's supervisor. Associate Professor David Kristiansen at the department of marine technology at NTNU will be a co-supervisor.

Muhammad Muklas - PHD candidate profile
Closed Aquaculture Cage in Waves and Current

Mukhlas received his MSc in Marine Technology from NTNU. In October 2018, he started his position as a PhD candidate at the Department of Marine Technology, NTNU. His PhD research is affiliated to research area 3, structures for exposed locations.

Main motivation of his PhD topic is to gain more physical understanding of hydrodynamics of closed flexible cages (CFC), which is of paramount importance for the safety and reliability of the structures and fish welfare. CFC is a unique ocean structure with complex hydrodynamic interaction between environmental loads, deformable body, and internal water motion. Mukhlas will investigate various hydrodynamic problems of CFC in waves and current with a combination of scaled physical model and numerical methods.

Mukhlas' work is supervised by Professor Pål Furset Lader, and co-supervised by Professor Trygve Kristiansen, Associate Professor David Kristiansen and Professor Bjørn Egil Asbjørnslett at Department of Marine Technology, NTNU.

Congratulations to our PHD-students that have defended their thesis!

During the years of the EXPOSED Centre, we are proud to say that four PHD-students have defended their thesis. In 2018, Yugao Shen finished his thesis "*Operational limits for floating-collar fish farms in waves and current, without and with well-boat presence*". In 2019, we had two PHD-students that delivered: Stefan Vilsen with his thesis "*Method for Real-Time Hybrid Model Testing of Ocean Structures Case Study on Slender Marine Systems*" and Malte Hvas with his thesis "*Physiology and welfare of Atlantic salmon and cleaner fish in exposed aquaculture*". And on top of that, Bent Haugaløkken have defended his thesis in January 2020, "*Autonomous Technology for IMR Operations in the Norwegian Aquaculture*". Congratulations!

Yugao Shen

Stefan Vilsen

Malte Hvas

Bent Haugaløkken

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 7 Exposed days in April 2019.

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.

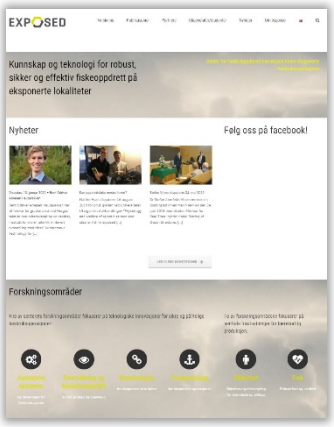


Figure 8 The EXPOSED web page

In 2018 the EXPOSED catalogue, an internal, living document which purpose is to increase the accessibility of the knowledge generated 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 9 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

2015

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2017

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Faltinsen, O.M. and Shen, Y., 2018. Wave and current effects on floating fish farms. *Journal of Marine Science and Application*, *17*(3), pp.284-296.

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2019

Hvas M. 2019 Physiology and welfare of Atlantic salmon and cleaner fish in exposed aquaculture. Doctoral thesis at University of Bergen. ISBN 9788230845271

Vilsen S.A. 2019 Method for Real-Time Hybrid Model Testing of Ocean Structures Case Study on Slender Marine Systems. Doctoral thesis at NTNU, 2018:166. ISBN 978-82-326-3930-4 2019

2020

Haugaløkken, BOA. 2020 Autonomous Technology for IMR Operations in the Norwegian Aquaculture. Doctoral thesis at NTNU, 2020:9

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
Jan Tore Fagertun	SINTEF Ocean	Aquaculture structures, field measurements and e-infrastructure
Andrei Tsarao	SINTEF Ocean	Aquaculture structures
Stefan Vilsen	SINTEF Ocean	Aquaculture structures
Carina Norvik	SINTEF Ocean	Aquaculture structures
Ørjan Selvik	SINTEF Ocean	Vessel design
Martin Gutsch	SINTEF Ocean	Marine operations
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
Bjørn Egil Asbjørnslett	NTNU, Department of Marine Technology	Marine operations and systems
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
Martin Føre	NTNU, Department of Engineering Cybernetics	Telemetry and biological modelling
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
Martin Slagstad	Norwegian	Q4 2019 – Q4 2022	M	Advanced and Rational analysis of steel fish farms in exposed waters

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
Malthe Hvas	Danish	Q3 2019 – Q4 2022	M	Physiology and behaviour of salmon in strong water currents

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

Name	Sex (M/F)	Period	Affiliation	Topic
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
Runar Stemland	M	2017	Department of Marine Technology, NTNU	Assessment of Service Vessel Operability In Exposed Aquaculture - An exploratory approach combining vessel response and discrete-event simulation
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 Bredahl 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

Name	Sex (M/F)	Period	Affiliation	Topic
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.

Figure 10 EXPOSED Days in April 2019.

STATEMENT OF ACCOUNTS

Name		Funding	Cost
The Research Council	12 093	(52%)	-
The Host Institution (SINTEF Ocean)	1 387	(6%)	6 810
Research Partners*	3 034	(13%)	10 155
Enterprise partners**	6 711	(29%)	6261
Public partners	-	-	-
Equipment	-	-	-
Total	**23 225**		**23 225**

(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 · Safetec Nordic

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