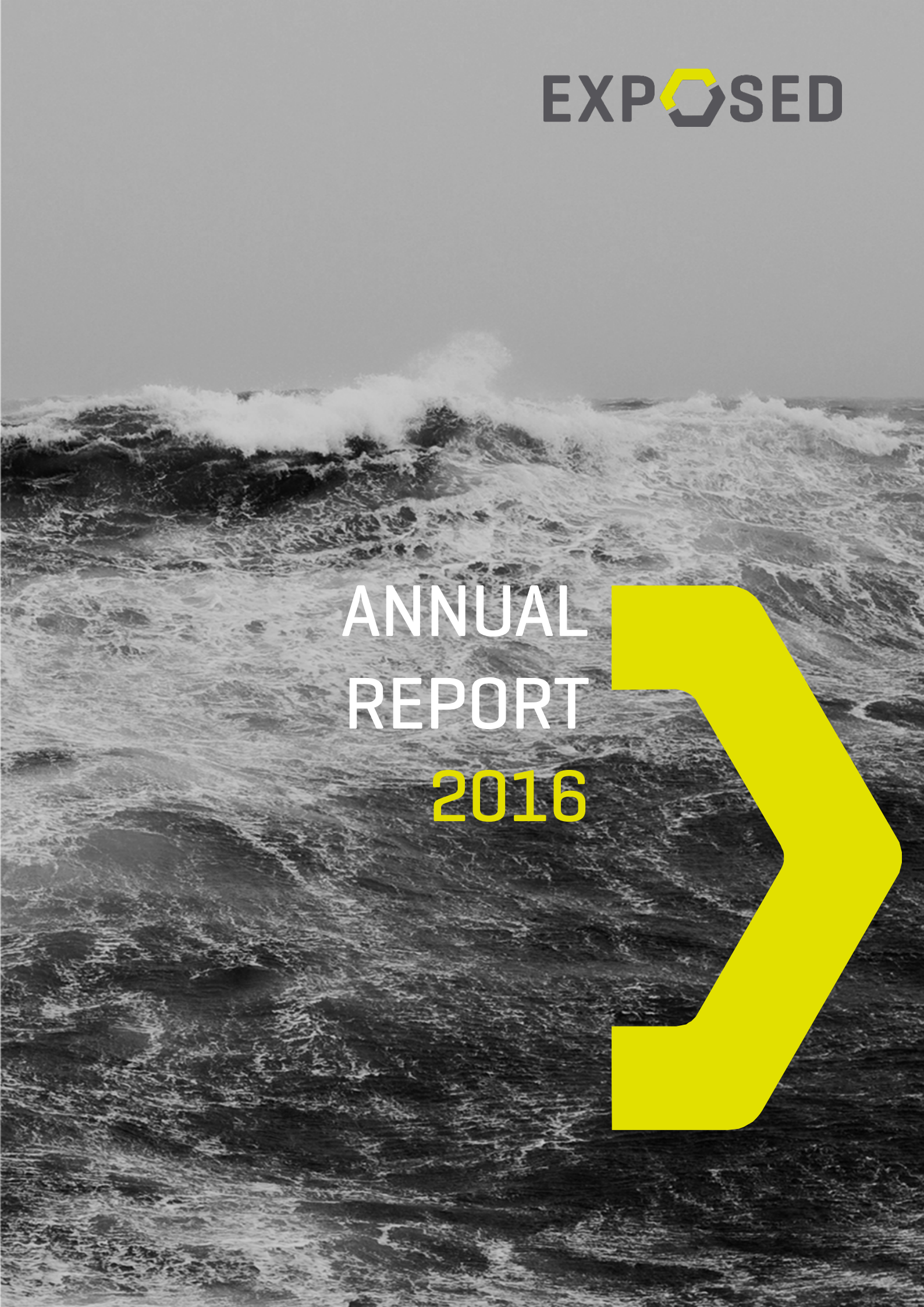
EXPOSED
ANNUAL
REPORT
2016

CONTENT

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

SUMMARY

Significant parts of the Norwegian coast are today unavailable to industrial fish farming due to ***remoteness and exposure*** *to harsh wind, wave, current and ice conditions. Regular as well as infrequent* ***operations*** *are challenging.*

The Exposed Aquaculture Operations Centre (EXPOSED) draws upon Norway's strong position in the aquaculture, maritime and offshore sectors to enable ***safe and sustainable seafood production*** *in exposed coastal and ocean areas.*

EXPOSED is a Centre for Research based Innovation (SFI), a funding scheme administered by the Norwegian Research Council's Division for Innovation[1]. A SFI has the main objective to enhance the capability of the business sector to innovate by focusing on long-term research based on creating close alliances between research-intensive enterprises and prominent research groups. The EXPOSED Centre brings together global leading salmon farmers, key service and technology providers, SINTEF Ocean and other strong research groups, including AMOS (the Norwegian Centre of Excellence for Autonomous Marine Operations and Systems).

The centre initiated its activities in 2015, and in 2016, there was full project activity. Eight projects have started, covering fundamental research and applied studies, innovation activities, establishment of research infrastructure and recruitment of six PhD candidates. In addition, several associated projects carry out additional activities and involve supplementary candidates.

To support cross-disciplinary innovation and good communication within the centre, the centre arranged a two-day EXPOSED Days during spring and a one-day EXPOSED Day during autumn. In addition, more targeted events are arranged and upcoming within projects, cross projects and among students, such as PhD/post-doc workshops.

There is a significant industrial, as well as political interest in EXPOSED and its objectives in 2016. This interest is driven by:

- An ambition to increase salmon production, given that key environmental and wellbeing challenges are addressed
- Increasing salmon prices
- Low oil prices and suppliers to the oil & gas sector looking for other industries
- Industrial and political will to adapt competence and capacity from other industries to seafood
- A new opportunity for farmers to apply for development concessions regime that drives innovation towards technological concepts for more exposed farming
- A potential for technology export and competing on global markets

The topic of exposed farming also raises significant interest internationally. The centre's research areas have been presented in various national and international forums to support future collaboration with other stakeholders.

Four new partners were accepted as new members of the consortium in 2016: DNV GL, Kongsberg Maritime Merchant Marine, Kongsberg Maritime Offshore and MacGregor Norway.

sfi 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 to industrial fish farming due to remoteness and exposure to harsh wind, wave and current conditions. The EXPOSED aquaculture operations 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.

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.

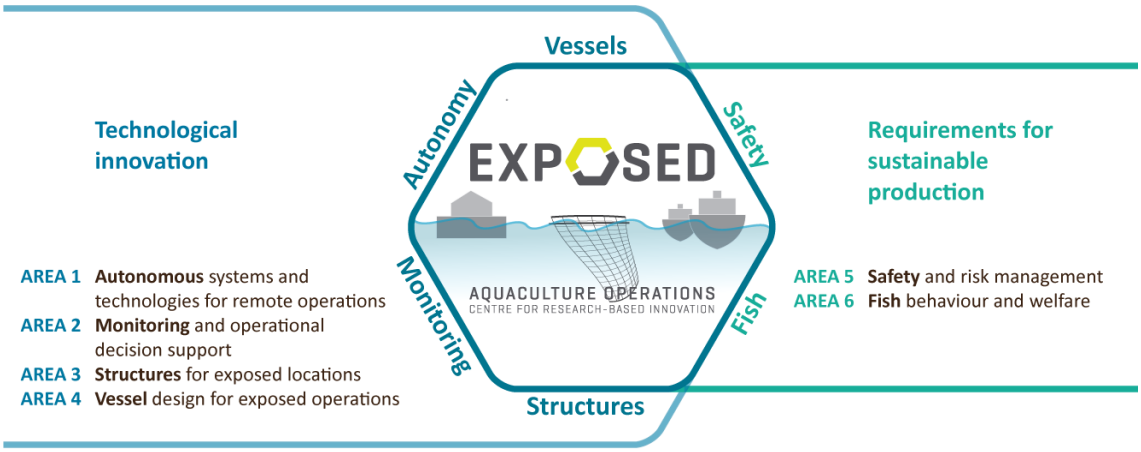
Research objectives

- 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 11 PhD candidates, 4 post-docs and 30 MSc candidates.

EXPOSED brings together global leading salmon farmers, key service and technology providers, SINTEF Ocean and other strong research groups, including AMOS (the Norwegian Centre of Excellence for Autonomous Marine Operations and Systems).

RESEARCH STRATEGY AND PLAN

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



Four of these 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. Flexible and rigid systems, active regulation, and new concepts will be studied.

- ### 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.*

Eight projects (P1 – P8) were active in 2016, covering fundamental research, applied studies, innovation activities, establishment of research infrastructure, and recruitment of six PhD candidates. In addition, several associated projects carry out additional activities and involve supplementary candidates. The project P1 was finalised in 2016, while two new projects, P9 and P10 will commence in 2017. The projects are further presented under *Scientific activities and results* (p. 13).

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

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

These may involve one or more of the centre partners, and potentially others. They may vary between researcher based projects (e.g. funded by the Norwegian Research Council or EU) or more innovation-driven projects. The centre will seek to establish agreements within these projects to allow mutual benefits and synergies between EXPOSED and associated projects.

There is also an identified potential in collaboration with other research centres and groups. There are already common activities and shared PhD-students with NTNU AMOS (the Norwegian Centre of Excellence for Autonomous Marine Operations and Systems). Together with the two other maritime centres, SFI Move (Centre for research and innovation for demanding marine operations) and SFI Smart Maritime (Centre for improved energy efficiency and reduced harmful emissions from the maritime sector) the four centres currently collaborate on PhD-education. There are also potential for future collaboration with SFI CtrlAqua (Centre of Research-based Innovation in Closed-Containment Aquaculture).

A selection of associated projects are listed below. Some of these will also be presented along with the results under *Scientific activities and results* (p. 13).

Associated projects	Duration, project type and funding source	Host institution	Relevant EXPOSED-activity
Reducing risk in aquaculture – improving operational efficiency, safety and sustainability	2016-2019 Research based in HAVBRUK2	NTNU Department of Marine Technology	Project P2 and P4
Safer operations and workplaces in fish farming	2016-2018 Research based in HAVBRUK2	SINTEF Ocean	Project P4
SEATONOMY	2013-2016 Strategic research project of the SINTEF Group	SINTEF Digital	Project P2
BEHAVEGENES - Behavioural and genomic characteristics of selected farmed salmon families related to robustness, welfare and performance	2014-2017 Research based in HAVBRUK	Institute of Marine Research	Project P5
ECHOFEEDING - Echo sounder technology for appetite-led-feeding and welfare-monitoring of caged salmon	2017-2020 Research based in HAVBRUK2	Institute of Marine Research	Project P5
Furturewelfare - Environmental requirements and welfare indicators for new cage farming locations and systems	2017-2021 Research based in HAVBRUK	SINTEF Ocean	Project P5
LAKSIT - Technologies for new datatypes and information describing the states of salmonids in commercial cages	2016-2017 The Norwegian Seafood Research Fund FHF	SINTEF Ocean	Project P5
HYBRID - Real-time hybrid model testing for extreme marine environments	2016-2019 Knowledge-Building Project for Industry in MAROFF	SINTEF Ocean	Project P3 and P7

ORGANISATION

Organisational structure

Organisation and implementation of the centre are 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 2016, the following people where members of the board:

Member of Centre Board	Affiliation
Arne Rinnan (Chairman)	Kongsberg Seatex
Noralf Rønningen	Aqualine
Harald Ellingsen, replaced by **Bjørn Egil Asbjørnslett** in June	NTNU
Arne Fredheim	SINTEF Ocean
Olai Einen	Cermaq
Ove Løfsnes	AQS
Frode Oppedal	Institute of Marine Research
Kjell Emil Naas (Observer)	The Research Council of Norway

Figure 2 EXPOSED Day 3. November 2016.

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 Area 2 Project P1, P9 and P10
Esten Ingar Grøtli SINTEF ICT	Area 1 Project P2
David Kristiansen SINTEF Ocean	Area 3 Project P7
Dariusz Eirik Fathi SINTEF Ocean	Area 4 Project P3
Ingunn M. Holmen SINTEF Ocean	Area 5 Project P4
Frode Oppedal replaced by **Ole Folkedal** Institute of Marine Research	Area 6 Project P5
Gunnar Senneset SINTEF Ocean	Project P6 and P8
Leif Magne Sunde SINTEF Ocean	Aquaculture operations
Ingrid Schjølberg NTNU	NTNU representative

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 two yearly 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.

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

Research facilities

The centre has access to an extensive research infrastructure through its research partners:

- A full-scale Aquaculture Engineering test site (ACE) at SalMar locations in Mid-Norway and exposed Marine Harvest and Cermaq locations in West and North Norway for both technological and biological studies. Technical e-infrastructure integrating the ACE aquaculture research sites with SINTEF Sealab SSO, enables secure access for project partners.
- Ocean Basin (80 x 50 x 10 m), Ship Towing Tank (260 x 10.5 m), Marine Cybernetics Laboratory (40 x 6.45 x 1.5 m) and Marine structures laboratory at SINTEF Ocean/NTNU.
- Flume tank (21 x 8 m) at SINTEF Ocean
- Applied Underwater Robotics Laboratory (ROVs and AUV), RV Gunnerus and Unmanned Aerial Vehicles Laboratory at NTNU.
- IMR experimental farms at Solheim and Austevoll and at IMR's land-based facilities in Matre to conduct scaled-down biological trials.
- Extensive hydrodynamic and structural testing laboratories through international partners.

Figure 3 Testing of aquaculture structures in the Ocean Basin at Tyholt in Trondheim.

Partners

Four new partners were accepted by the General Assembly to become new members of the consortium in 2016. These were **DNV GL**, **Kongsberg Maritime Merchant Marine**, **Kongsberg Maritime Offshore** and **MacGregor Norway**. They are expected to complement and further strengthen the innovation potential of the centre. **Kongsberg Maritime Merchant Marine** and **Kongsberg Maritime Offshore** have since 1 January 2017 merged into **Kongsberg Maritime**.

	Industry partners	Contribution/Role
marineharvest	**Marine Harvest** World's largest salmon and trout fish farmer. Runs large operations in Norway, Scotland, Canada and Chile.	End user of technology and solutions
cermaq	**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	**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	**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	**Aqualine** Major international supplier of equipment and complete fish farms.	Technology/solution provider
møre maritime	**Møre Maritime** Provides maritime consulting, engineering and 3D modelling.	Technology/solution provider
REINERTSEN	**ÅF Reinertsen** A leading provider of engineering, procurement, construction and installation to the oil companies, as well as the aquaculture sector.	Technology/solution provider
Anteo	**Anteo** Operates and develops technical solutions and decision support systems for fish farming companies.	Technology/solution provider
ARGUS	**Argus Remote Systems** Performs research, development and manufacturer of electrical ROVs.	Technology/solution provider
LERØW AS	**Lerow** Service provider for inspection and cleaning of net cages and moorings by advanced use of ROV.	Service provider
AQS	**AQS** Service provider for inspection, maintenance and a range of operations, including delousing.	Service provider
marin design as	**Marin Design** Provides vessel design and maritime consulting.	Technology/solution provider
DNV·GL	**DNV GL** is a leading classification society and certification body, and a recognized advisor to a wide range of industries.	Certification, classification and advisory
MACGREGOR	**MacGregor Norway** A maritime leading provider of solutions and services for handling systems to the offshore, fishery, research and mooring segments.	Technology/solution provider

The centre host **SINTEF Fisheries and Aquaculture** and the research partner, the Norwegian Marine Technology Research Institute (**MARINTEK**) merged into **SINTEF Ocean** 1 January 2017. The department for environmental technology in SINTEF Materials and Chemistry is also transferred to the new company. SINTEF Ocean has 340 employees and will become an integrated part of SINTEF, owned by strong and motivated industry players.

SINTEF ICT has changed its name to **SINTEF Digital**.

Research partners	AREA
SINTEF Ocean (SO) SINTEF Ocean conducts research and innovation related to 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) The department carries out research within the field of marine technology, and is the largest in its field in the western world. 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) The department 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) The department 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) is Norway's largest centre of marine science. The main task is to provide advice to Norwegian authorities on aquaculture and the ecosystems.	6

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

AMOS

SINTEF

NTNU
Norwegian University of Science and Technology

SCIENTIFIC ACTIVITIES AND RESULTS

After the initial year of 2015, there was full project activity in 2016. Eight projects were started, covering fundamental research and applied studies, innovation activities, establishment of research infrastructure and recruitment of six PhD candidates.

P1 Future concepts

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Hans Bjelland, SO	**All**	**Q2 2015 – Q2 2016**	**Fundamental**

This project has explored the areas of opportunity and future concepts for exposed aquaculture operations. This has been a centre-wide activity involving all partners and research areas and serves as a foundation for future research and collaboration.

Future Concepts report

All research areas have contributed to the internal report "Future Concepts" that documents the state of knowledge and discusses the innovation potential of salmon farming at more exposed sites. The levels of exposure at current Norwegian farms have been studied. Within each research area, possible technologies and strategies for exposed aquaculture have been evaluated. Parts of the results have been published in Bjelland et al. 2016 (p. 37).

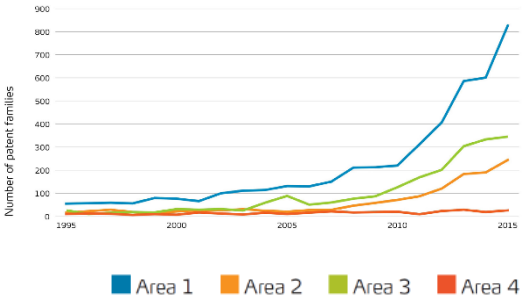
Figure 4 (a) Internal report documenting the state of knowledge and discussing the innovation potential of salmon farming at more exposed sites (b) Patent landscaping report.

Patent landscape analysis

Through a collaboration between the Norwegian Industrial Property Office and the Research Council of Norway, an analysis of the existing patent data within marine aquaculture and fish farming have been conducted. The resulting report[2] focuses on the EXPOSED research areas 1 - 4.

- Which countries patent within aquaculture and marine technology and their focus
- The most significant organisations in the various geographical areas

The Norwegian based patent applications in the dataset, revolve mostly around structural solutions (see Area 3 in Figure 6). In this technical field, Norwegian applicants are gaining a strong position, but in areas such as autonomous systems, monitoring systems and vessel design, Norwegian based intellectual property rights owners are lacking presence.



[2] https://www.patentstyret.no/om-oss/nyheter/nfd-vil-ha-bedre-resultater-av-fou-satsinger/

Figure 5 Historical patenting development for each patent data subset.

Area 1	Area 2	Area 3	Area 4
Area of technology			
Autonomous systems and technologies for remote operations	Monitoring and operational decision support	Structures for exposed locations	Vessel design for exposed operations
Technical content			
▪ Autononmous operating arms ▪ Feeding systems ▪ Fish pen cleaning systems ▪ ROV's ▪ Automated ▪ Dead fish removal ▪ inspection ▪ Maintenace ▪ Repair routines	▪ Oxygen monitor instruments ▪ Camera technology ▪ Sonars ▪ Hydroacoustics	▪ Floating fish cages ▪ Submersible fish cages ▪ Onshore breeding cages ▪ Flexible strucutres ▪ Structural components ▪ Net cages	▪ Service vessels ▪ Maintenance ships ▪ Cranes, specially adapted for ships ▪ Fish carriers
Number of patent documents in data subsets			
11832	4544	5551	2579
Number of patent families in data subsets			
5507	1715	2464	952

Figure 6 An overview of the different data subsets used in this report.

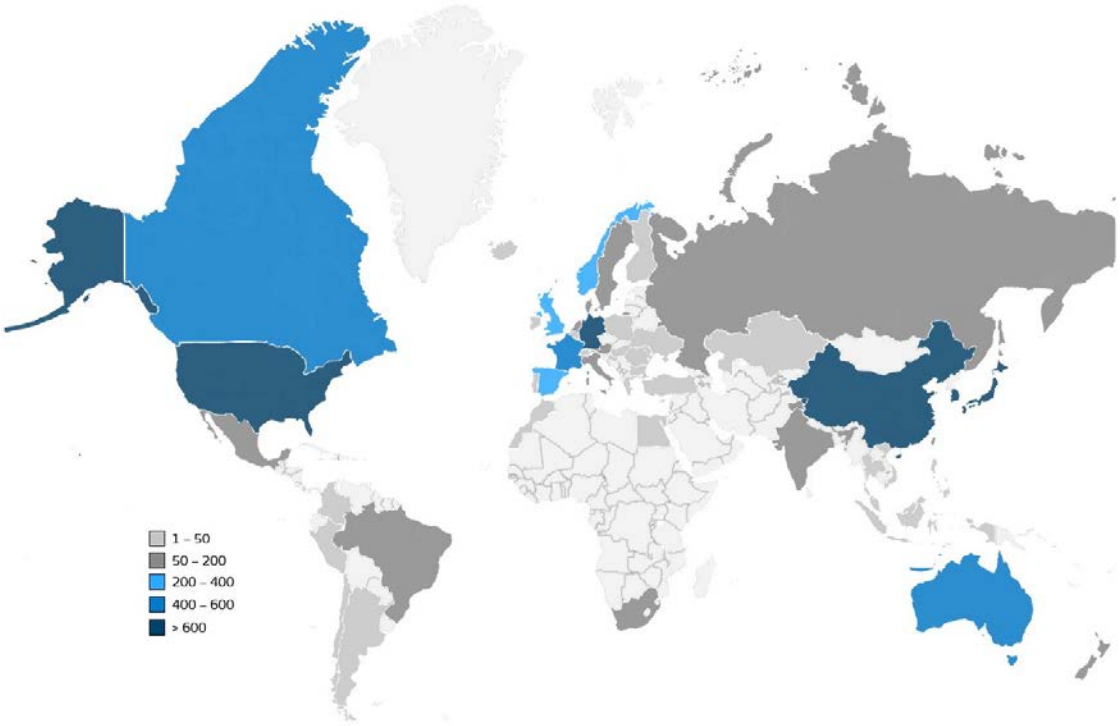


Figure 7 Global distribution of filed applications counted in patent families. The numbers are based on the whole patent dataset. This map merely discloses where patent applications are being filed and does not disclose the ownership of the patent applications.

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

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Esten I Grøtli, SD	**SINTEF F&A, SINTEF ICT, NTNU IMT, Argus, Lerow, Kongsberg Maritime Subsea, Kongsberg Seatex, AQS, Marine Design, Møre Maritime**	**Q2 2015 – Q2 2019**	**Industrial**

This project aims to develop and demonstrate technologies for an underwater vehicle fitted with various tools to perform frequent operations at exposed sites, including cage integrity inspection and net cleaning.

Study of concepts: ROV launch and recovery

Today, launch and recovery of ROV are performed with cranes from a service vessel. For high wave states the relative motion between the crane and the floating ROV, makes the operation dangerous and difficult. The small weather window for the existing crane based launch- and recovery systems is the single most limiting factor for utilizing ROV's in high wave states. In this study, different concepts for launch and recovery were investigated and evaluated based on factors such as functionality, safety, ease of use, complexity and costs.

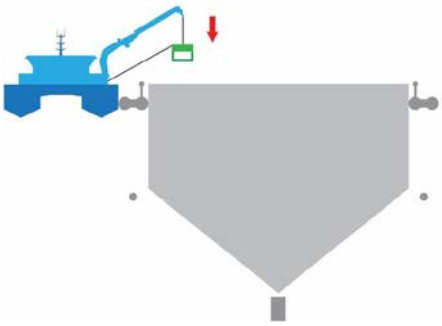


Figure 8 Concepts for actively controlled tugger winch which stabilize ROV pendulum movement.

Autonomous functionalities for net-cage inspection

One of the main goals of this project is to reduce the dependency on a human operator when inspecting the net cage. An important stepping-stone toward autonomous cage integrity inspection is the ability for the vehicle to determine its position and orientation relative to the net. Towards this end an algorithm for automatic tracking and following of ropes inside the cage using a camera is developed. The provided information will complement the information from other sensors on the vehicle and make it possible to accurately determine its net-relative motion.

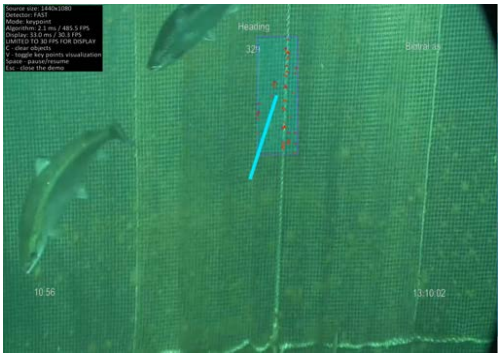


Figure 9 Automatic tracking of fish cage rope in camera pictures

Design of autonomous net-cage inspection operation

The Autonomous Job Analysis (AJA) is a new method for design and analysis of autonomous operations. To ease the application of AJA, a graphical tool called the AJA canvas has been developed. It contains the categories treated in the AJA method on a single page -*the canvas*. Each category is supported with questions to ask during the design of the operation, as well as example answers. The canvas was successfully used to decide how an autonomous net-cage inspection operation should be carried out. This is an example of a result from the associated project Seatonomy.

SEATONOMY

2013-2016 Strategic research project of the SINTEF Group

Host and partners: SINTEF ICT, MARINTEK, SINTEF Fisheries and aquaculture (both currently SINTEF Ocean)

Project manager: Esten Ingar Grøtli, SD

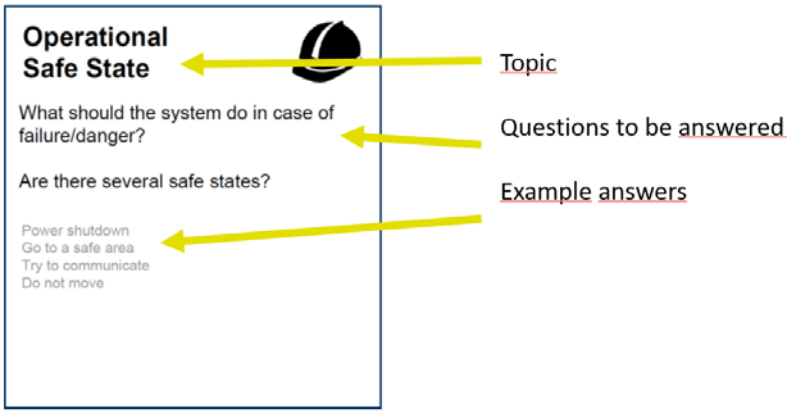


Figure 10 "Operational safe state" is one of the categories of the AJA canvas.

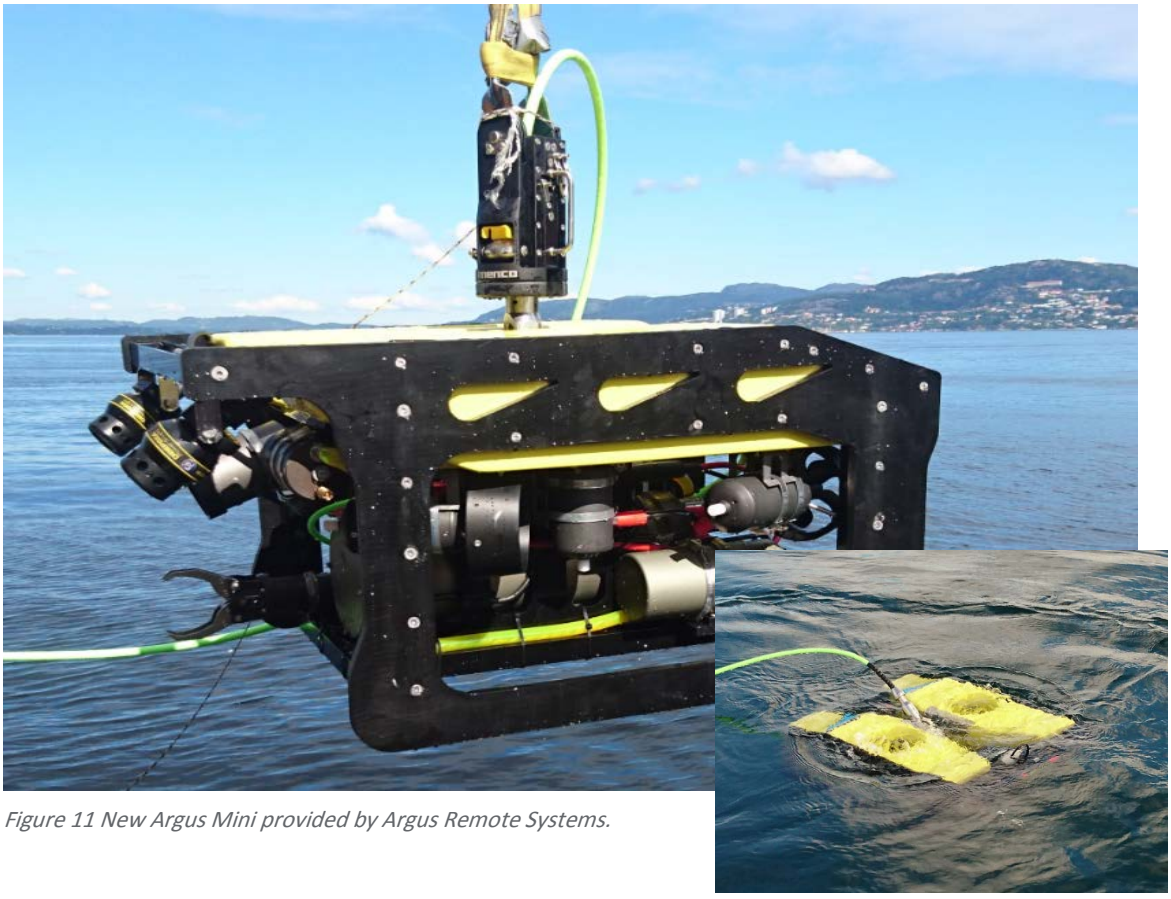


Figure 11 New Argus Mini provided by Argus Remote Systems.

P3 Vessels-Structures Interaction

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Dariusz Eirik Fathi, SO	**MARINTEK, SINTEF F&A, NTNU IMT, Møre Maritime, Marin Design, AQS, Aqualine, Kongsberg Seatex, Kongsberg Maritime, Cermaq, MacGregor, DNV GL**	**Q4 2015 – Q4 2019**	**Industrial**

This project aims to investigate new design concepts for vessels and structure interfaces for increased reliability of exposed aquaculture operations both related to equipment, crew and fish welfare. It is expected that larger vessels will impose new requirements on the design of the floating collar and mooring system, which means that the interaction between the flexible collar and the rigid ship side will be important. Focus on the actual operations will be important in order to reduce risk and increase safety and operability.

Identification of challenges

Three cooperative workshops were conducted in order to identify and document challenges related to exposed aquaculture operations.

During spring (March/April 2016), two HAZID workshops were conducted in cooperation with Project P4. The goal was to identify challenges with today's aquaculture operations involving vessels-structures interactions and through this work get an overview of risks and dangers. This insight will be used to develop knowledge and technology for improved safety, availability, maintenance and operation of exposed aquaculture installations.

In June, a workshop on Launch- and Recovery Systems (LARS)/Underwater docking was conducted in cooperation with Project P2. Remotely Operated Vehicles (ROVs) are an important tool in aquaculture operations to increase situation awareness, for documentation and to carry out interventions. There are challenges related to launch- and recovery at the cages with today's technologies. Wave induced motions may lead to large uncontrolled pendulum motions if the ROV is launched with a crane. Different solutions were discussed during the workshop.

Vessel design concepts

During 2016, the designers (Møre Maritime and Marin Design) have been developing two vessel concepts as part of P3. Møre Maritime has developed a 25m Service Catamaran (MACHOCAT 25) with diesel-electric propulsion and the first vessel is to be launched Q2 2017.

Marin Design is working on a large combination feed carrier enabling distribution of bulk and bags in the same silos as well as a separate rooms for bags. Effort has been put into efficient loading and offloading systems as well as giving the vessel a green profile. The vessel will offload through a robot arm while maintaining position at the feed barge by using dynamic positioning (DP).

Figure 12 Illustration of MACHOCAT 25.

Figure 13 Illustration of Marin Design's combination feed carrier.

Simulation of aquaculture operations using SIMA

During Summer 2016, a summer job on "Simulation of aquaculture operations using SIMA" was conducted at SINTEF Ocean. Student Mona Tufte investigated the applicability of the workbench SIMA for simulation of various aquaculture operations. SIMA is a tool developed at SINTEF Ocean (previously MARINTEK), which is extensively used for simulation of marine operations in the oil and gas industry as well as offshore wind. A note describing the findings was part of the delivery as well as example cases for SIMA. The examples include a feed carrier at a feed barge, both moored and on DP, as well as DP operation at a cage.

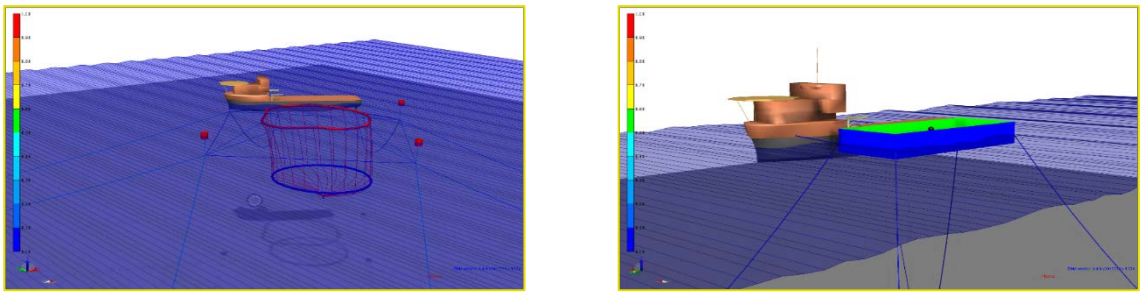


Figure 14 Example cases of simulation of aquaculture operations using SIMA.

Figure 15 AQS Loke will be monitored with Kongsberg Seatex's MRUs to study vessel motion during operations.

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 FH, DNV GL, MacGregor, Kongsberg Maritime, Møre Maritime, Marine Design**	**Q2 2015 – Q2 2019**	**Fundamental**

There is a significant potential for increased safety in fish farming operations by implementing systematic risk management. Risk management deals with identifying, analysing, assessing and controlling occupational risk and major accident risks, through development of mitigating measures. The project aims to develop good practices for safety and risk management during both complex and daily work operations at fish farms, as well as to suggest safety measures (barriers) to be implemented.

Previous work

The fish farming industry is the second most risk-exposed workplace in Norway. A study conducted within a previous project, Sustainfarmex, showed that today's farms already operate at the safety limit of available technology and management systems. Adverse weather conditions, suboptimal human-technology interaction and a number of organizational aspects are known risk factors.

Previous research based on interviews with fish farm workers, has identified that aquaculture operations are especially hazardous with regard to occupational risk in general and escape of fish. These are operations involving work on the net cage or the sinker tube; chemical delousing operations with tarpaulins; and well boat operations in the fish farm. These operations involve extensive use of cranes and the first two also the use of workboats and service vessels. In addition, the success of many operations is dependent on the competence and abilities of individuals.

The status of risk assessments in Norwegian fish farming

The fish farming industry is characterised by operations that are vulnerable to changing weather, wind and currents, and face challenges when it comes to safety for fish and personnel. Previous research and accident analyses suggest a lack of understanding of risk factors during aquaculture operations. The objective of the paper Holmen et al. 2017 (p. 37) is primarily to describe the status for risk assessments practices in the Norwegian fish farming industry according to the regulatory requirements. To improve the safety level at workplaces, the operators need to be aware of the safety challenges in their working environment. A practical approach to risk assessments based on preliminary hazard analysis is presented. This approach has been developed in cooperation with the aquaculture industry and has been evaluated in a series of workshops involving several operators with good results.

Interviews were conducted with managers and HSEQ personnel in six Norwegian aquaculture companies regarding practices for risk assessments. Informants from both fish farming companies, in-house service vessels and subcontracting service providers were included. The purpose of the interviews and fieldwork was to assess the risk assessment practices, and how the knowledge on hazards and risk mitigating measures are utilised in the daily work on board.

Four workshops were arranged in December 2015, March and April 2016, with managers, fish farmers and service vessel operators. Some of the interview objects were also participants in one or two of the workshops. Providers of aquaculture technology were invited to the latter two, to explore the potential for integrating risk-reducing measures, or safety barriers, in the design of technology concepts. Risk assessments for several service vessel operations were performed. The operations were identified to be of high risk based on current analyses of causalities in occupational accidents and fish escapes, in addition to the participants' own experiences. Table 1 presents the work operations that were risk assessed, and the number of participants and their expertise.

Table 1 Description of workshops. Work operations for risk assessments, number and category of participants are shown

Workshop no.	1	2	3	4
Participants*	MFS	MFS	MFST	MFST
No. of participants	20	17	12	13
↓Operations				
Cleaning of floaters	X			
Tightening of moorings	X			
Set and fasten anchors in seabed	X	X		
Swim fish between net cages		X		
Mount nets in cages		X		
Lift coupling plates	X	X		
Preparations for fish transfer			X	
Maintenance operations			X	
Lifting sinker tube				X
Removal of old moorings				X

*Participant categories: Managers (M), fish farmers (F), service vessel crew (S), technology providers (T).

The study shows that the quality of risk assessments in the Norwegian aquaculture sector may vary considerably both between companies and different geographical locations within companies. In some cases risk assessments are performed at manager level only, and safe job analyses prior to complex operations are not the standard procedure. Furthermore, the fish farming industry has to report to five different regulatory authorities, covering fish welfare, fish farm technical standard, occupational safety, vessel design and food safety. This might result in a fragmented risk management system within the companies. A general industry standard for risk assessments of fish farm operations is lacking.

ONS DAG 7. DESEMBER 2016 FISKERIBLADET FISKAREN

fiskeribladetfiskaren.no fbfi.no

Regelrett risiko?

NEDGANG: Hyppigheten av både arbeidsulykker og antall rømte oppdrettsfisk har gått ned de siste årene. Skal vi fortsette den gode trenden, må vi ha et koordinert regelverk, understreker forskere. ILL.FOTO: MIKE HENDERSON

Fragmenterte regelverk kan føre til at fiskevelferd prioriteres over de ansattes sikkerhet.

BIOMENING

INGUNN MARIE HOLMEN OG INGRID BOUWER UTNE

Holmen er seniorforsker ved Sintef Fiskeri og havbruk og Utne er professor ved NTNU Institutt for marin teknikk.

Biomarin gjestespalte

Fiskeribladet Fiskaren vil ukentlig ha en gjesteskribent knyttet opp mot det biomarine stoffområdet.

Følgende institusjoner bidrar til spalten: FHF, Sjømat Norge, Marelife, Maring, Nifes, Nofima, Norges Sjømatråd, Rubin, Universitetet i Bergen, Haukeland Universitetssjukehus, Sintef og Universitetet i Tromsø.

Pålagte risikovurderinger kan dermed bli en øvelse i å fylle tall i et skjema framfor å gjøre en reell vurdering av risiko for de ansatte

Figure 16 A feature article in Fiskeribladet Fiskaren 6. December 2016 describing the challenges of risk management with different regulatory authorities.

Safer operations and workplaces in fish farming (associated project)

The objective of the project is to provide knowledge about the current situation regarding health, safety and work environment for production site workers in the Norwegian aquaculture industry.

The focus is put on how to reduce risks in marine operations by building safety barriers into procedures, systems and technology. The aim is thus to reduce the probability for and the consequences of operational and human errors.

An interdisciplinary approach is applied to achieve the goals of the project. The characteristics of the fish farmers' work environment, the workers' role in the value chain and how organizational factors influence the safety performance at the fish farms are studied. This forms the basis for the development of design principles which can be used by manufacturers to build safety barriers into the products, and by fish farming companies in the process of testing and evaluating new equipment or work procedures. The theoretical perspectives are based on the understanding that technical, human and organizational factors should be seen as complementary safety indicators.

In 2016, two surveys regarding workers perceptions of their work environment and the companies work with safety at the management level have been conducted. Interviews, observations and measurements of work load will take place in 2017.

The project is funded by the Norwegian Research council (Havbruk2 programme) and is a collaboration between SINTEF Ocean (host institution), SINTEF Technology and Society, Dept. for Health Research and NTNU Social Research, Studio Apertura.

International experts will participate as scientific advisors and four master students have been recruited to the project so far. An industry reference group has been established to ensure industry relevance and communication with key users.

Safer operations and workplaces in **fish farming**

2016-2018 Research based in HAVBRUK2

Host and partners: SINTEF Ocean, SINTEF Technology and Society, NTNU Samfunnsforskning

Project manager: Hans V. Bjelland, SO

P5 Fish behaviour and welfare

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ole Oppedal, IMR	**IMR, NTNU ITK, SINTEF Ocean, Cermaq, SALMAR, Marine Harvest, Kongsberg Maritime Subsea, Aqualine, AQS, Lerow**	**Q2 2015 – Q2 2019**	**Fundamental**

Success in aquaculture operations depends on knowledge of fish physiological and behavioural limitations and opportunities, both for individual fish and the vast group sizes of farmed salmon. In exposed farming, water current strength and waves are main concerns, and the coping ability and strategies in farmed salmon is largely unknown.

Current tolerance

In P5, novel methodology for investigating current tolerance in individual and groups of salmon has been successfully implemented. A large swim tunnel system for swimming of large individual fish and fish groups (Remen et al., 2016)(p. 37)(Figure 17), and an experimental push cage system for testing of current tolerance in commercially relevant group sizes (Hvas et al., 2017a)(Figure 18) are designed, tested and documented. Using the large swim tunnel, the critical swimming speed (Ucrit) for salmon at different sizes are described (Remen et al., 2016). Moreover, effects of temperature on salmon metabolism and Ucrit revealed that salmon maintain a relatively high scope for activity at extreme temperatures (23°C) and are more vulnerable at the lower end of the temperature spectrum (3°C) the farmed salmon are exposed to (Hvas et al., 2017b)(p. 37).

Currently, work is being conducted on the effect of amoebic gill disease (AGD) on Ucrit, and the temperature dependent Ucrit of cleaner fish is soon to be tested. While Ucrit is a standard for describing the absolute swimming capacity in a short time perspective (stepwise increment of current speed in 30 min intervals), which is ideal for comparing different parameters that affect fish metabolism, testing over a longer time span and in farming relevant group sizes are necessary. A test of sustained swimming capacity showed that salmon can endure swimming for 4 hours at 80% of Ucrit (Hvas and Oppedal, submitted February 2017)(p. 37). Using the experimental push cage (a sea cage fixated to a ship) the critical swimming speed in a group of 3000 large salmon (3 kg) was estimated above the levels of similar sized fish as recorded in swim tunnels, suggesting that fish may benefit from schooling behaviour (Hvas et al., 2017b)(p. 37). NTNU is developing individual tags for recording of salmon behaviour, where individual swimming speed and spatial positioning are key parameters. Individually tagged fish will be tested both in the large swim tunnel and in sea cages. Monitoring of heart rate and blood parameters of fish in the large swim tunnel and push cage will be included in future trials.

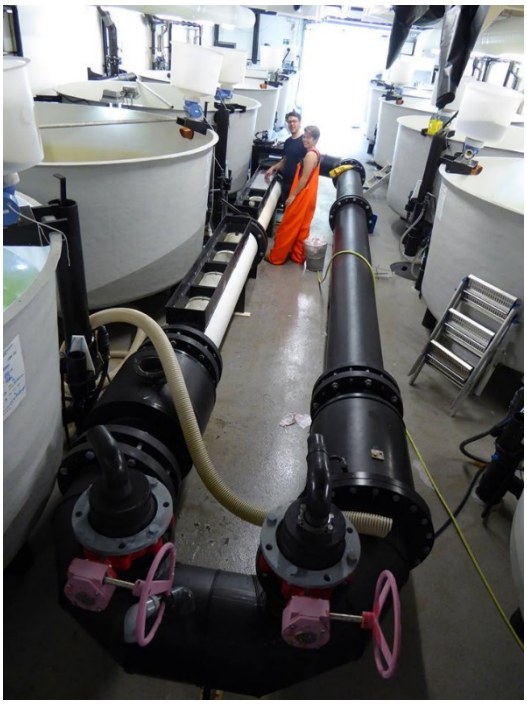


Figure 17 A large swim tunnel system for swimming of large individual fish and fish groups.

The systematic approach of developing research tools and facilities, and describing the fundamentals of salmon physiology and behaviour towards exposed aquaculture has provided a strong fundament for future testing of specific exposed operations. This includes crowding of fish, and detailed testing of how well fish cope with current patterns based on recorded data for potential exposed farming sites. The results from P5 interacts with the other projects in the SFI, and are especially important for construction design and strategic production management.

Figure 18 An experimental push cage system for testing of current tolerance in commercially relevant group sizes.

BEHAVEGENES (associated project)

The main aim of the BEHAVEGENES project is to advance our understanding of the concept of robustness in farmed fish so that robustness traits can be implemented in on-going breeding regimes. We want to determine why some farmed salmon are more robust and perform better than others, and to determine if these performance related traits are heritable, and if we can find genomic markers for these. The consortium holds excellent technical facilities and a large number of selected salmon families, as well an ongoing production of double haploids and cloned fish groups. We utilize a set of novel methods developed by the project consortium, including newly developed technology to collect frequent estimates of individual size and spatial position in tanks and cages and an automatic profiling system that collects and processes water quality data.

Behavioural traits such as swimming depth is confirmed as heritable, and links to heritable fish growth pattern are found. Most relevant for exposed farming is a trial where we investigate the effects of freshwater rearing environment on fish behavior, environmental utilization and performance throughout the production cycle. In this, clonal lines of salmon were given a regime of physical exercise by daily alternations of water current velocity over a 7 month period. Physical exercise resulted in better growth than in control fish, but the Ucrit tested three months post smoltification and end of the exercise regime was not found different from that of the control, suggesting no long-term effects of early exercise on swimming capacity.

BEHAVEGENES - Behavioural and genomic characteristics of selected farmed salmon families related to robustness, welfare and performance.

2014-2017 Research based in HAVBRUK

Host and partners: Institute of Marine Research, Uni. Uppsala, Norwegian Uni. of Life Sciences, Akvaforsk Genetics Centre AS, Benchmark SalmoBreed AS, Marine Harvest

Project manager: Ole Folkedal, IMR

LAKSIT (associated project)

"Technologies for new datatypes and information describing the states of salmonids in commercial cages" (LAKSIT) is a research project funded by The Norwegian Seafood Research Fund FHF (FHF project number 901184), that features a collaboration between SINTEF Ocean and NTNU. The primary aim of LAKSIT is to develop and field-test new technological solutions for automatically monitoring of the states of Atlantic salmon in commercial cages, with a particular focus on studying fish responses to delousing procedures. Two technical solutions were developed in the project: an acoustic telemetry system where individual fish were equipped with transmitter tags registering the swimming activity (tail beats, orientation changes) and depth dynamics of the fish, and a computer vision system computing swimming speeds and skin condition indicators based on high-resolution stereo video streams. The field tests in LAKSIT were conducted in full-scale at SINTEF ACE, and aimed at identifying differences and trends in fish states before, during and after crowding/delousing procedures.

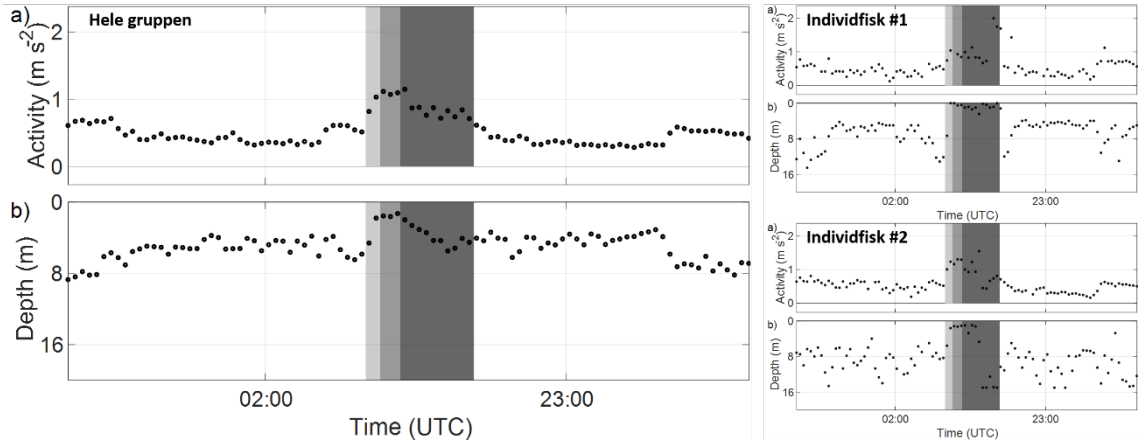


Figure 19 Data from the fish group and two individual fish during delicing. Black circles represent mean/10 min for a) activity and b) depth. Light grey background represent first phase of raising the net wall (7 m), medium grey second phase (1 m), while dark grey represents the final phase, with crowding, delicing and transfer to new cage.

Both systems were able to produce data on salmon states in a commercial cage setting, with the telemetry system catching trends in activity and depth movement, and the computer vision system detecting wounds and computing swimming speeds. Furthermore, the telemetry system was operational during the crowding/delousing procedures, and hence was able to produce a continuous dataset throughout the entire experimental period. In LAKSIT, these data series are currently being analysed to identify changes in states or trends in these that may be ascribed to crowding/delousing operations.

Although these technologies were primarily developed to study delousing procedures, their outputs are also relevant for studying fish responses against exposed conditions. For example, fish activity levels and swimming speeds have been highlighted as central topics in P5, and storm conditions and large waves may influence depth movements. Furthermore, the PhD-candidate in P5 who will develop new acoustic telemetry systems for monitoring fish at exposed sites may benefit directly from the experiences on using telemetry made in LAKSIT. The potential for using the knowledge, technologies and methods developed in LAKSIT as research tools in EXPOSED is therefore considerable.

LAKSIT - Technologies for new datatypes and information describing the states of salmonids in commercial cages

2016-2017 The Norwegian Seafood Research Fund (FHF)

Host and partners: SINTEF Ocean and NTNU ITK

Project manager: Martin Føre, SO

ECHOFEEDING (associated project)

Waste feed is a huge economic cost and source of environmental impact in salmon sea-cage farming. Appetite monitoring and feed control is key to reducing waste feed and optimizing fish growth for maximum profits. However, visual-based techniques in current use are labour-intensive, imprecise and prone to overfeeding, and becoming increasingly inadequate in larger modern cages of different designs. In this project, we will explore the technology application of an ECHOFEEDING system to autonomously monitor fish appetite and control feeding. The technology uses an echo sounder transducers to monitor fish and calculate their biomass in the feeding area of a cage. When feeding is performed, it is pre-programmed to continue or stop feeding based on the amount of fish biomass levels in the feeding area. In this way, fish appetite is measured in real-time and dictates feed quantities at each meal. In contrast to visual-based appetite monitoring, the technology of ECHOFEEDING does not require continuous visual observation and can objectively quantify fish appetite. Intensive feeding over shorter intervals is a prerequisite for ECHOFEEDING, as an unambiguous feeding response is required. This naturally attracts the salmon to the surface where the pellets arrive, and is thus a highly relevant feeding method in high current environments to secure minimal drift/sinking distance of pellets.

ECHOFEEDING - Echo sounder technology for appetite-led-feeding and welfare-monitoring of caged salmon

2017-2020 Research based in HAVBRUK2

Host and partners: Institute of Marine Research, Uni. Melbourne, Uni. Bergen, Lindem Data Acquisition AS.

Project manager: Ole Folkedal, IMR

Future Welfare (associated project)

The Future Welfare project will address key knowledge gaps related to the behaviour and welfare of farmed salmon introduced by the rapid and recent development of an array of new farming systems and locations. These new farming systems attempt to reduce long-standing and intractable environmental problems such as salmon lice infestations and the escape of farmed fish. However, new knowledge is required to assess how these new farm types impact the behaviour and welfare of salmon. Future Welfare will first develop fundamental knowledge on production environments, fish behaviour and welfare in new farming systems and locations using three case studies of existing and planned technologies (exposed traditional cages, lice-barrier skirt and snorkel cages, and submerged cages). We will generate knowledge of the adaptive capacity of fish within these new farming systems, and how this can be facilitated or encouraged for production and welfare benefit. Using results from each case study, we will adapt an existing standardized welfare assessment method to incorporate new welfare indicators and create a welfare assessment method suited for new farming systems. Finally, we will build a predictive biophysical model that integrates cage environments and fish behaviours to predict how new faming systems will affect fish behaviours and welfare. The predictive model will be made freely available to cage developers so that outcomes for fish can become central to technological design processes.

Future Welfare - Environmental requirements and welfare indicators for new cage farming locations and systems.

2017-2021 Research based in HAVBRUK

Host and partners: SINTEF Ocean, Institute of Marine Research, University in Bergen, University of Melbourne, Fiskaaling

Project manager: Pascal Klebert, SO

P6 Decision support systems

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Gunnar Senneset, SO	**NTNU IDI, Anteo, Kongsberg Maritime, DNV GL**	**Q3 2015 – Q4 2017 (Phase 1)**	**Industrial**

Management and operation of modern aquaculture sites requires monitoring of biomass, environment and complex infrastructures to ensure efficient and safe production. The acquired data are used as a basis for operational decisions. As the industry is moving towards more exposed sites, it is highly likely that the need for monitoring and decision support systems will increase. Limited access for personnel in periods of rough weather will also require the possibility for remote operation of site equipment. Autonomous systems will also be increasingly important, both for resolving critical situations and for increasing the production efficiency.

Decision support tools for exposed aquaculture operations will require data from both new types of sensors as well as those currently used in the industry. As there is a wide range of methods and tools in the AI (Artificial Intelligence) and ML (Machine Learning) fields, it can also be expected that a combination of methods will be necessary to cover the main challenges regarding management and operation at exposed aquaculture sites.

In the first phase of the project, the main goal is to identify challenges and the requirements for decision support systems for exposed operations. This includes the need for new types of sensors and other sources of information. The SFI Exposed report 'Future concepts' (reference) will be used as a starting point, supplemented with more detailed mapping and analysis in co-operation with the relevant partners. Testing of new types of sensors and challenges regarding integration of data from different sources will also be addressed.

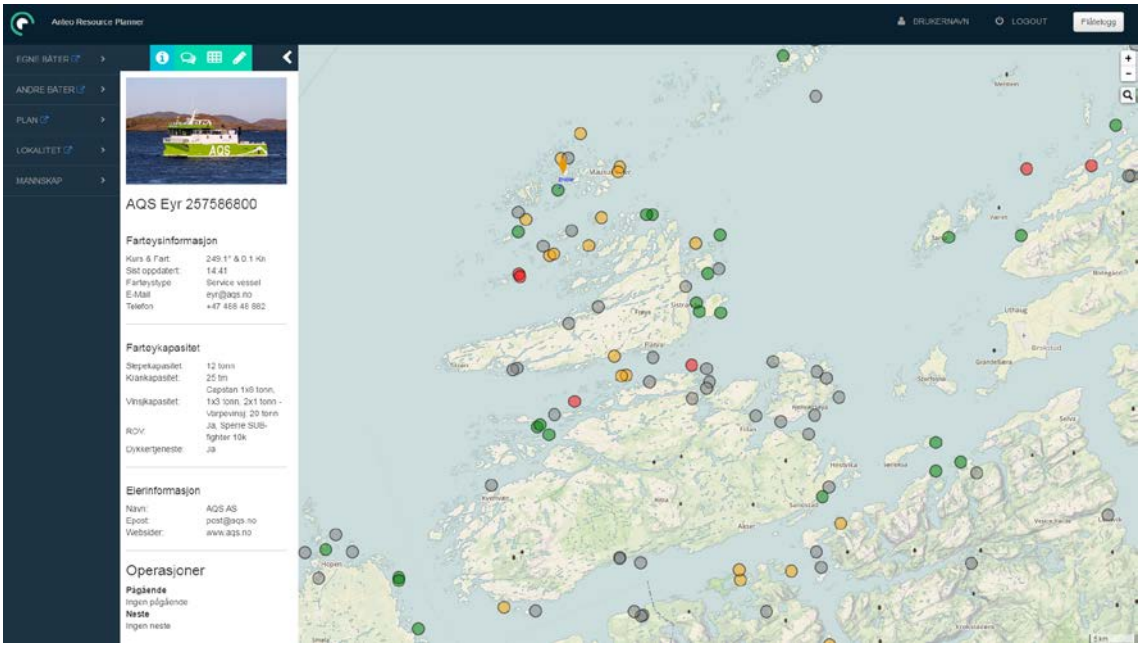


Figure 20 The Anteo Resource Planner is an example of a decision support system for the aquaculture industry utilising data from several sources and systems.

P7 Structural design of reliable offshore aquaculture structures

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

This project aims to contribute with new knowledge on the physical behaviour of fish farm structures during operation at exposed locations. It will develop knowledge-based design criteria for main components of aquaculture structures for exposed locations.

Fish farming at exposed locations require robust and reliable structures that facilitate sustainable, safe and efficient production. The cages, mooring systems and feed barges that is used by the industry today is capable of operating at the sites in present use, but how will they perform when waves and current increases beyond the current level? As wave and current exposure increases, the forces on, and the response of, the structures increases and changes. Performance of the structural components under increased exposure must be evaluated relative to the behaviour of the complete system. An essential premise for design of reliable aquaculture structures for an exposed location is an adequate description of the physical environment and corresponding representative design conditions.

The project is divided into four work packages (WP's):

1. Description of exposure
2. Numerical and physical modelling
3. Identification of critical problem areas
4. Research-based design criteria

WP 1 focuses on how to obtain reliable quantitative descriptions of the physical environment on exposed locations for use in design and dimensioning of fish farms. In WP 2, focus is to extend and improve the knowledge on numerical and physical modelling of fish-farm structures. WP 3 will seek to identify possible critical problem areas associated with moving production to more exposed locations based on the output from WP 1 and WP 2. The acquired knowledge from the previous work packages will be compiled in WP 4 and suggestions to research-based design criteria for exposed fish farm structures will be formulated. A PhD candidate has been employed to study and will aim towards development of knowledge-based technical requirements for the main components of fish farms for exposed locations.

In the first year of the project period, focus has been on the description of wave and current exposure at Norwegian fish-farm sites. A screening of wind-wave exposure for all Norwegian salmon sites was performed by means of fetch analysis of all sites in The Aquaculture Register provided by the Norwegian Directorate of Fisheries. The analysis was performed using digital maps and hindcast wind data from ERA-interim reanalysis available from the European Centre for Medium-Range Weather Forecasts. This is considered as the state-of-the-art engineering method for prediction of wind-wave exposure in coastal waters and is also the recommended approach by the Norwegian standard NS 9415, a technical standard for design of floating fish farms. The screening showed that the 17 % most exposed sites is characterized by significant wave height with 50 years return period of 1.5 m or above (See Figure 21). There were also a large variation of exposure in the different counties with Sør-Trønderlag beeing by far the county with the most exposed sites (See Figure 22). The fetch analysis was summarized in a technical paper (Lader et al. 2017)(p. 37).

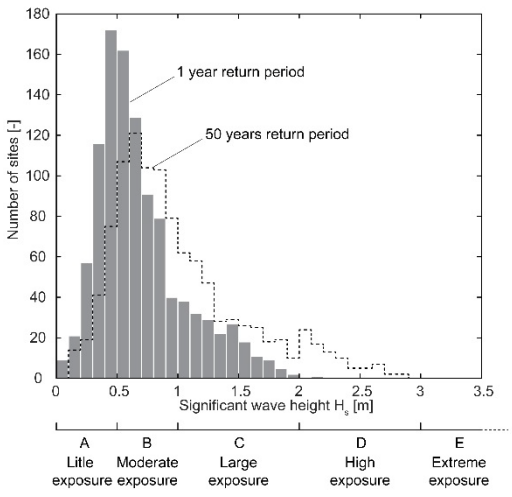


Figure 21 Distribution of $H_{s\ 1\ year}$ and $H_{s\ 50\ year}$ (significant wave height with 1 and 50 years return period) for all 1070 Norwegian salmon sites. The Hs classification (bottom of the figure) is taken from Norwegian Standard NS 9415.

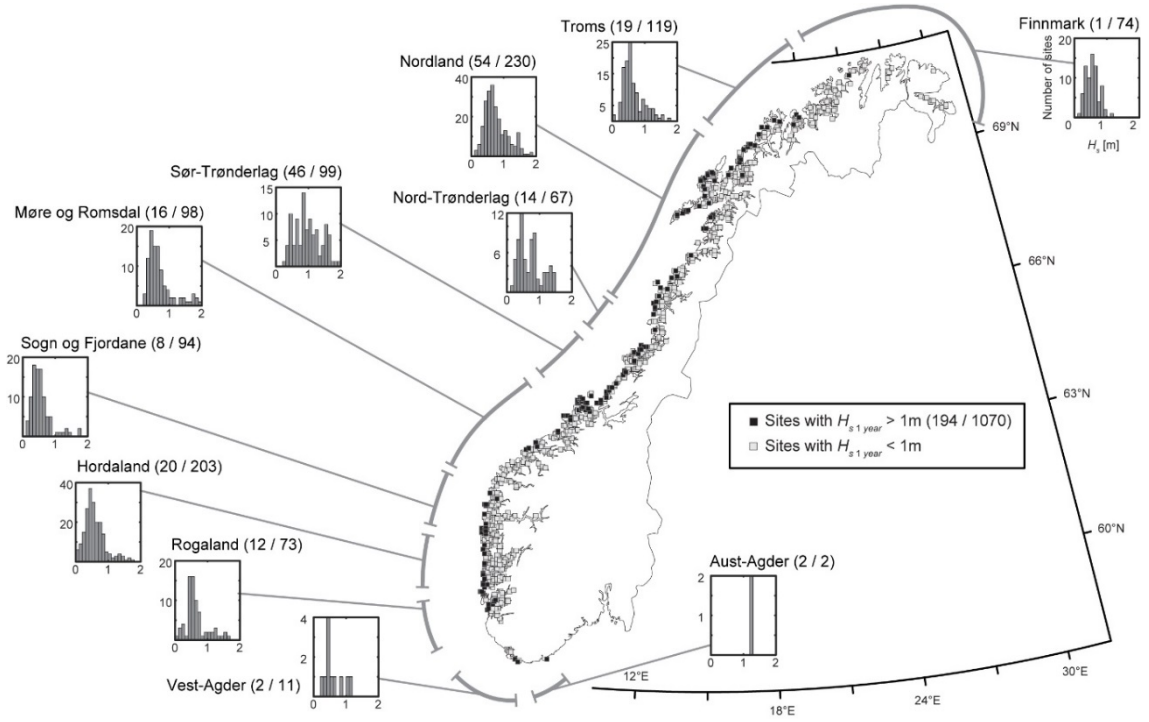


Figure 22 The distribution of $H_{s\ 1\ year}$ in each of the Norwegian counties. The numbers in the parenthesis show the number of sites with $H_{s\ 1\ year}$ larger than 1m together with the total number of sites in the area. In the map, sites with $H_{s\ 1\ year}$ > 1m are shown as black filled squares, while the less exposed sites are shown as white squares.

As part of the EXPOSED project P8, two oceanographic buoys by Fugro OCEANOR were installed in February/March 2016 at two different exposed sites in central Norway. The buoys are equipped with sensors to measure current velocity profile, directional waves and wind. A number of additional quantities such as temperature and salinity are also measured. In the present project, field measurement data from of the wave- and current condition at these sites were analysed. Different statistical approaches adopted from offshore engineering were used to give estimates of the design wave height and current speed with probability level corresponding to 10 years and 50 years return period. It was found that the different approaches gave large variations of the estimates and that methods adopted from offshore engineering are not directly applicable for exposed coastal waters. It was also demonstrated that one month measurement data, as suggested in NS 9415, is not sufficient to obtain reliable estimates of the dimensioning conditions at the sites. Two similar but different analyses were documented in two technical papers (Bore et al. 2017 and Kristiansen et al. 2017)(p. 37) to be presented at the OMAE 2017 conference in Trondheim.

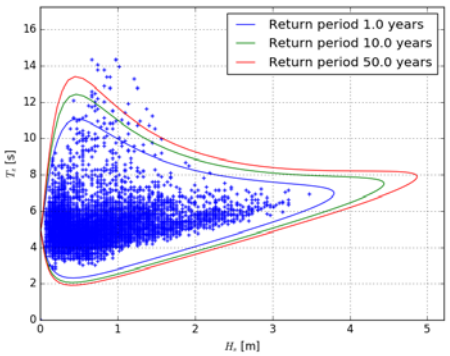


Figure 23 Scatter diagram of significant wave heights and wave peak periods at an exposed aquaculture site from field measurements in the time period February to December 2016. Estimated contour lines shows that the applied method adopted from offshore engineering is not directly applicable for exposed coastal waters.

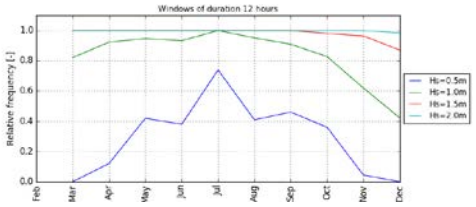


Figure 24 Relative frequency of continuous time periods of duration more than 12 hrs with significant wave height below various limits at an exposed aquaculture site from February to December 2016.

Further work on environment description for exposed aquaculture operations include sensitivity study of the duration of the measurement period on the estimates of the design wave and current conditions, statistical analysis of current speed data for coastal waters with strong tidal component, suggestion of best practice for environment description in design of aquaculture structures for exposed locations.

Hybrid model testing (associated project)

"Real-time hybrid model testing for extreme marine environments" (Hybrid) is a KPN project funded by the MAROFF programme including two research partners (SINTEF Ocean and NTNU AMOS) and three industry partners (Statoil, SalMar and ABB) who provide an aggregated cash contribution corresponding to 20% of the total budget of 20 MNOK. The overall aim of the project is to develop Real-Time Hybrid Model Testing (or "hybrid testing") methods for extreme marine environments. Hybrid testing is a testing method in which the physical system under study is partitioned into two (or more) subsystems: a physical subsystem tested experimentally in model-scale, connected in real-time with a numerical subsystem, simulated on a computer. The two parts interact with each other using a network of sensors and actuators. Methods and principles developed in the project will be demonstrated through practical experiments studying slender systems (e.g. fish cages, risers), offshore wind turbines and marine machinery.

Hybrid testing methods will enable experiments that are otherwise difficult to realise because:

- the limitations on the physical size or characteristics of testing facilities do not allow a full model of the system to be accommodated,
- the conflict in scaling between different subsystems hinders the use of conventional model testing, or
- the focus of the test is the performance of a single module in a complex operation involving many different physical systems

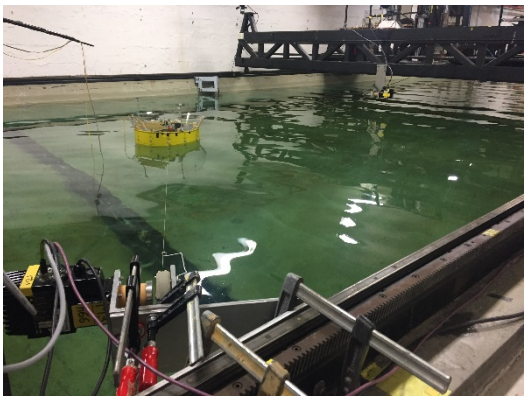


Figure 25 Hybrid model testing.

These are also challenges that may arise in experiments aimed at investigating exposed aquaculture operations. In addition, the effects of the extreme environmental conditions encountered at exposed fish farming sites may be difficult to recreate in laboratories using conventional model tests. The methods developed in the Hybrid project are therefore relevant for future research in Exposed, illustrating the synergy between the projects.

HYBRID - Real-time hybrid model testing for extreme marine environments

2016-2019 Knowledge-Building Project for Industry in MAROFF

Host and partners: SINTEF Ocean, NTNU, Statoil, SalMar and ABB

Project manager: Vegard Aksnes, SO

P8 EXPOSED e-Infrastructure

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Gunnar Senneset, SO	**Cermaq Norway AS, Marine Harvest Norway AS, SalMar Farming AS, Aqualine AS, Kongsberg Seatex**	**Q3 2015 – Q4 2017 (Phase 1)**	**Industrial**

Industrial scale field experiments will constitute an important basis for developing new knowledge and technology for operations at exposed sites. Cost effective implementation and documentation of such experiments require flexible and reliable e-Infrastructure. Exposed sites operated by Cermaq Norway AS, Marine Harvest Norway AS and SalMar Farming AS are being used for field experiments.

In addition to e-Infrastructure solutions for field experiments at existing exposed sites, there is a need for new reference data series for projects within several of the research areas in EXPOSED:

- Looking further ahead: All three fish farming companies are considering 'next generation sites', and detailed data on wind, waves and currents are needed to provide design criteria for equipment and operations on such sites.
- Operational constraints: What are the limits for safe operations on todays exposed sites with respect to absolute and relative movements (accelerations, roll/pitch/yaw) on installations and vessels

One of the focus areas for this project in 2016 has been the long-term data series from two oceanographic buoys deployed early in the year. The locations were chosen to represent possible 'next-generation' sites.

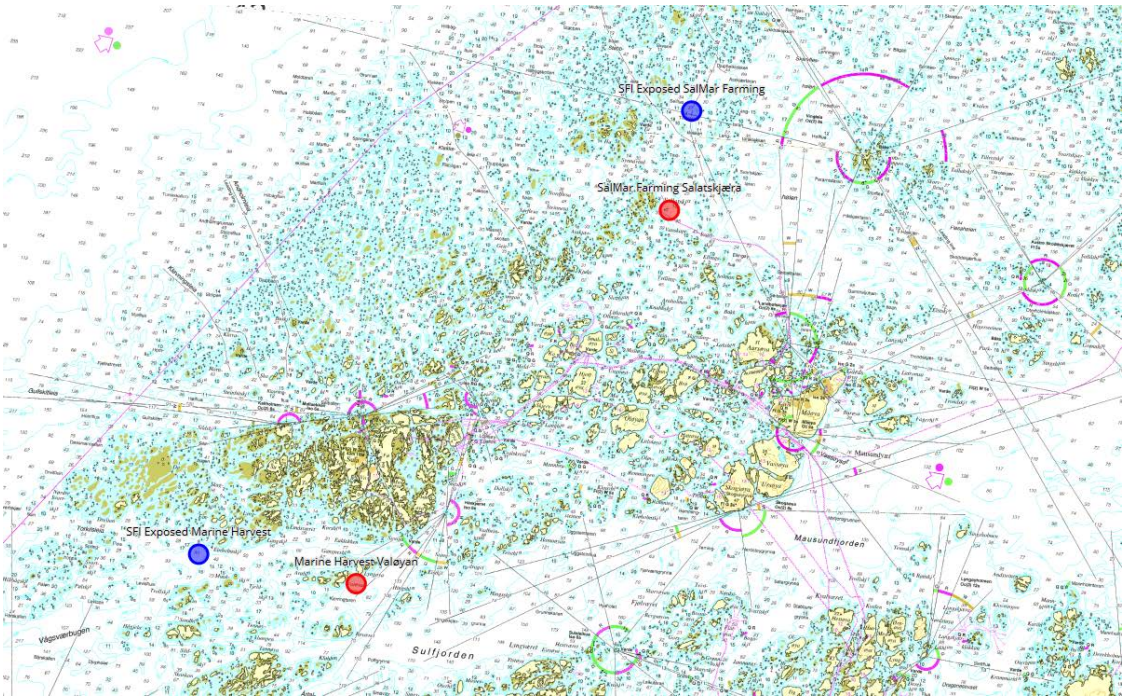


Figure 26 'Next-generation' sites (blue dots) and the current sites of Valøyan (Marine Harvest) and Salatskjæra (SalMar Farming) (red dots).

Figure 26 also shows the aquaculture sites Valøyan (Marine Harvest) and Salatskjæra (SalMar Farming). These sites have been used for testing e-Infrastructure and basic sensor equipment until the fish was harvested and the fallowing period started late autumn 2016.

Data series from the buoys have been used by other projects in the SFI and by students. The

Figure 27 shows maximum waves at the Marine Harvest buoy approaching 6 meters during gale force conditions late December 2016. Buoy data are available for projects partners through a web interface. Aggregated and recent graphs of the environmental conditions at the sites are published at the external web page:

http://exposedaquaculture.no/boyedata/.

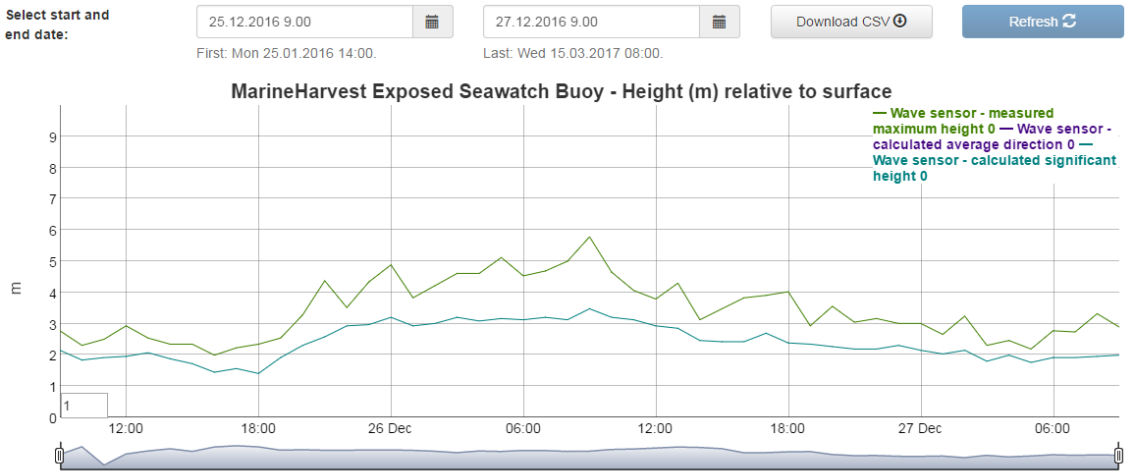


Figure 27 Web interface for internal access to data.

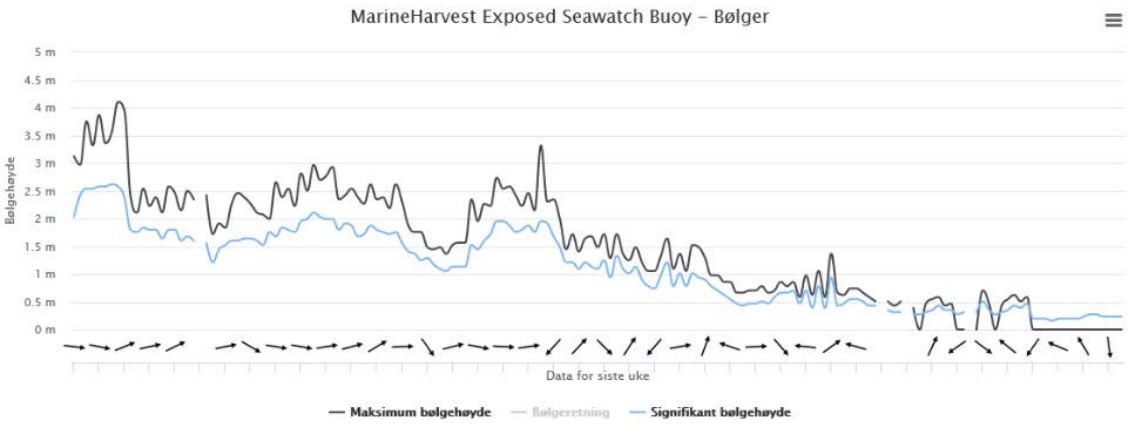


Figure 28 Aggregated and recent graphs of the environmental conditions at the sites are published at the external web page: [http://exposedaquaculture.no/boyedata/.](http://exposedaquaculture.no/boyedata/)

Figure 29 Oceanographic buoy.

P9 Future Scenarios

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Hans Bjelland, SO	**NTNU IMT**	**Q1 2017 – Q4 2017**	**Fundamental**

The pace of innovation is currently very high in the aquaculture industry. The potential for development licenses, low oil prices, high salmon prices, and a huge demand for production increase have led to many development projects, with a potential for significant investments in the years to come. In addition to the larger structures and concepts supported by the development licenses, a range of other technologies are under development, such as treatment units and closed and semi-closed systems. There is, therefore, a large uncertainty in which technological concepts that will be accepted, financed, and ultimately succeed in operation, and how the future aquaculture industry will be. There is a need to ensure that the activities of EXPOSED are adapted to the future concepts and industry structure.

This project, starting in 2017, will explore the use of scenario methods to assess possible future scenarios for the technological concepts and structure of the aquaculture industry.

P10 Governance and regulations

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Hans Bjelland, SO	**DNV GL**	**Q1 2017 – Q4 2017**	**Fundamental**

An efficient governance and regulation of the industry will be key to fulfilling the ambitions of EXPOSED to enable robust, safe and efficient fish farming at exposed locations. The challenges with current exposed farming operations and the new technology concepts under development highlight the needs to assess how governance and regulations could adapt.

This project, starting in 2017, will study the governance and regulations of the Norwegian aquaculture industry, with focus on production at exposed locations. With its broad scope, EXPOSED is expected to provide knowledge and input that will be highly valuable to future revisions of governance and regulations.

The project will:

- Identify how EXPOSED can contribute to the future revision of regulations and standards.
- Provide a platform for dialogue among EXPOSED partners, authorities and other stakeholders.
- Coordinate activities and document results in EXPOSED and associated projects that have relevance to these objectives.
- Communicate results from relevant EXPOSED and associated projects to authorities and other stakeholders and get advice on future activities.
- Assess potential frameworks for governance and regulations in a future aquaculture industry.
- Assess applicability of existing industry and public standards.

INTERNATIONAL COOPERATION

The topic of exposed farming raises significant interest internationally.

The research areas of the centre have been presented in various international forums to support future collaboration with other stakeholders:

- European Safety and Reliability (ESREL) 2016, September, Glasgow
- Arctic Frontiers 2016, January, Tromsø
- Oceanology International, March, London
- Aquaculture Europe (EAS) 2016, September, Edinburgh
- Offshore Aquaculture 2016, December, Antwerpen
- Ny-Ålesund Symposium, September, Spitsbergen

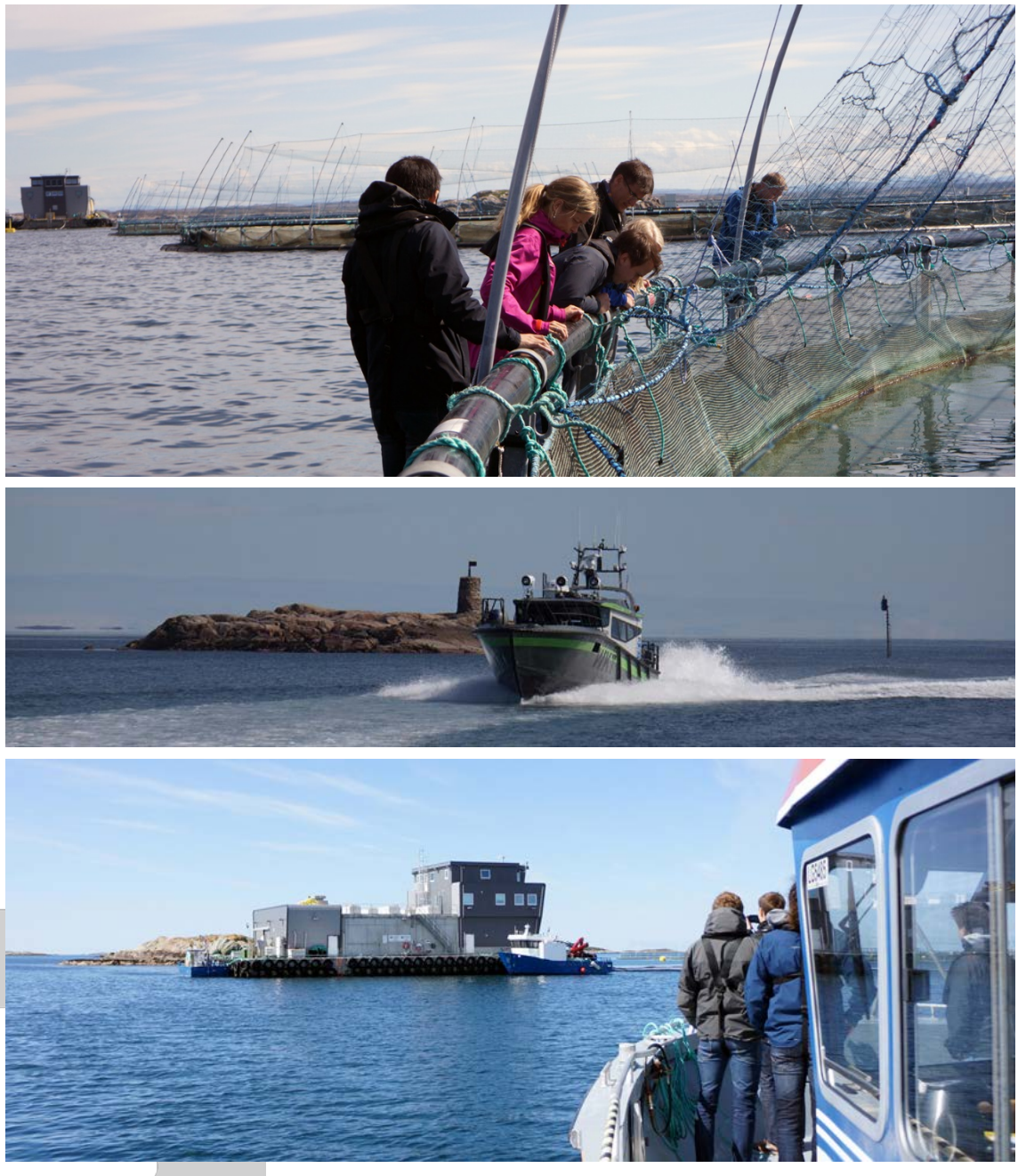


Figure 30 PhDs, researchers and farmers at workshop at fish farm close to Frøya.

RECRUITMENT

Six PhDs are now hired and funded by EXPOSED, in addition to several PhDs and postdocs that 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 have been given centre status for several leading research environments within ocean space technology. In the coming years hundreds of phd's will perform excellent research 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

Malthe Hvas (PhD) - Physiology and behaviour of salmon in strong water currents

Malthe Hvas holds a MSc in biology from Aarhus University in Denmark. During his studies he has been working with acid-base physiology, nitrite toxicology and the effect of temperature on oxygen consumption in the striped catfish (Pangasianodon hypophthalmus), a tropical facultative air-breathing fish of great socioeconomic importance in Vietnamese aquaculture.

His primary task within SFI EXPOSED at The Institute of Marine Research will be to define peak water current thresholds that secure acceptable welfare in farmed Atlantic salmon. For this purpose a large swim tunnel system has been developed at The Institute of Marine Research, which for the first time gives the opportunity to asses swimming performance in groups of Atlantic salmon during various conditions such as different temperatures, hypoxia and stress.

Furthermore, he will also investigate swimming capabilities in commercial facilities and in experimental push cages.

Bent Arnesen (PhD) - Remotely controlled and automated underwater vehicles

Bent holds a master degree in Marine Cybernetics from NTNU. His Master thesis is about experimental testing of underwater path-following for a Videoray Pro 4 ROV (Remotely Operated Vehicle).

Within SFI EXPOSED he will develop systems for remotely controlled and automated underwater vehicles. This includes the use of ROVs for inspecting fish net or cage conditions as well as verifying the safety of using such systems in the industry.

Stian Sandøy (PhD) - Navigation of autonomous subsea vehicles

Stian is 24 years old and holds a Masters degree in Engineering and ICT, specialised within Marine Technology.

In his master thesis, he has worked with navigation algorithms related to a self-developed low-cost ROV. Alongside his studies, Stian worked with development of ROV's guidance, navigation and control (GNC)-systems at Blueye Robotics.

The PhD will focus on navigation of autonomous subsea vehicles aiming towards exposed aquaculture. The plan is to look more closely at the usage of range measurements found through acoustics. To help understanding the problem, a simulator will be developed and used in implementation in a small scale model. Later, the aim is to do tests in large scale facilities. This should contribute in increased usage of autonomous subsea vehicles within aquaculture.

Stian is funded by the associated project «Reducing risk in aquaculture», managed by IMT NTNU and funded by the Norwegian Research Council.

Other PhDs and postdocs

Three of the PhDs have already been presented in the Annual report of 2015. In addition, Waseem Hassan and Kristbjörg Edda Jónsdóttir will be presented at a later stage.

Waseem has started his PhD with the objective to develop new technological solutions based on acoustic telemetry for extracting real-time in-situ individual based data and knowledge on fish behaviour in full-scale aquaculture sea cages. He and his project will be presented more in full at a later stage.

Kristbjörg Edda Jónsdóttir has started on a project to establish new theoretical and empirical knowledge related to the dynamics of water flow and turbulence inside large-scale aquaculture sea cages.

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 will serve as a meeting place for innovation, presentation of results, and exchange of ideas and creation of new projects.

Main communication channels with the public is through:

- A web-page (http://exposedaquaculture.no/) has been established to present information about the centre to both internal and external target groups.
- A Norwegian facebook-page (https://www.facebook.com/eksponert) is used to share relevant news.
- Participation and presentation at international (see above) 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.

Figure 32 EXPOSED Days in May 2016.

Figure 31 The EXPOSED web page

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

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

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.). Revised paper submission to J. Exp. Biol. January 2017.

Hvas, M., Oppedal, O. (submitted 2017) High sustained swimming capacity in Atlantic salmon *Salmo salar.* submitted February 2017.

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.

Conference papers

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

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.

Holmen IM, Utne IB, & Haugen S (2016) Organisational safety indicators in aquaculture – a preliminary study. ESREL

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 2017 ISBN 9781138029972. p.1809-1816.

Kristiansen D, Aksnes V, Su B, Lader P and Bjelland HV (2017) *Environmental description in the design of fish farms at exposed locations*. Accepted as 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*. Accepted at The 36th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2017.

Utne IB, Schjølberg I, Holmen IM (2015). Reducing risk to aquaculture workers by autonomous systems and operations. In: Safety and Reliability of Complex Engineered Systems. Edited by: L Podofillini, B Sudret, B Stojadinovic, E Zio, Wolfgang Kröger. European Safety and Reliability Conference (ESREL) 2015, CRC Press, Switzerland, 2015.

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
Andreas M. Lien	SINTEF Ocean	Vessel design and aquaculture operations
Leif Magne Sunde	SINTEF Ocean	Aquaculture operations
Per Rundtop	SINTEF Ocean	Autonomous systems
Pål Lader	SINTEF Ocean	Aquaculture structures
Heidi Moe Føre	SINTEF Ocean	Material science
Arne Fredheim	SINTEF Ocean	Aquaculture structures
Gunnar Senneset	SINTEF Ocean	Field measurements and infrastructure
Martin Føre	SINTEF Ocean	Telemetry and biological modelling
Dariusz Fathi	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
Jørgen Amdal	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
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	Norway	Q3 2015 - Q3 2019	M	Monitoring and operational decision support.
Pål Takle Bore	Norway	Q1 2015 - Q3 2018	M	Intelligent Aquaculture Structures
Ingunn Marie Holmen	Norway	Q1 2016 - Q4 2019	F	Safety and risk management
Bent Arnesen	Norway	Q3 2016 - Q3 2019	M	Remotely controlled and automated underwater vehicles
Malthe Hvas	Denmark	Q2 2016 - Q2 2019	M	Navigation of autonomous subsea vehicles
Waseem Hassan	Pakistan	Q4 2016 - Q4 2020	M	Acoustic fish telemetry for real-time fish performance monitoring in aquaculture

PhD students working on projects with financial support from other sources

Name	Nationality	Period	Sex (M/F)	Funding	Topic
Kristbjörg Edda Jónsdóttir	Norway	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	Norway	Q3 2016 - Q3 2019	M	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability. Funded by Havbruk2 in the Norwegian Research Council	Sensor fusion for autonomoous underwater inspection of aquaculture structures
Yugao Shen	China	Q3 2013 - Q3 2016		NTNU AMOS - Centre for Autonomous Marine Operations and Systems	Limiting operational conditions for a well boat
Stefan A. Vilsen	Denmark	Q1 2014 - Q1 2018		NTNU AMOS - Centre for Autonomous Marine Operations and Systems	Hybrid model testing of marine systems

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

Name	Nationality	Period	Sex (M/F)	Funding	Topic
Eirin Marie Skjøndal Bar	Norway	Q4 2016 - Q4 2016	F	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability	Environmental risk assessment in aquaculture
Xue Yang	China	Q2 2017 - Q1 2019	F	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability	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			

STATEMENT OF ACCOUNTS

Name	Funding		Cost
The Research Council	9 009	(39 %)	-
The Host Institution* (SINTEF Fisheries and aquaculture)	2 177	(9 %)	6 657
Research Partners**	2 859	(12 %)	8 438
Enterprise partners***	8 995	(39 %)	7 944
Public partners	-	-	-
Equipment	-	-	-
Total	**23 040**		**23 040**

(All figures in 1000 NOK)

* Partner names as registered in 2016. Host Institution in 2016 was still SINTEF Fisheries and aquaculture

** MARINTEK, IMR, SINTEF ICT, NTNU IMT, NTNU IDI, NTNU ITK

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

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