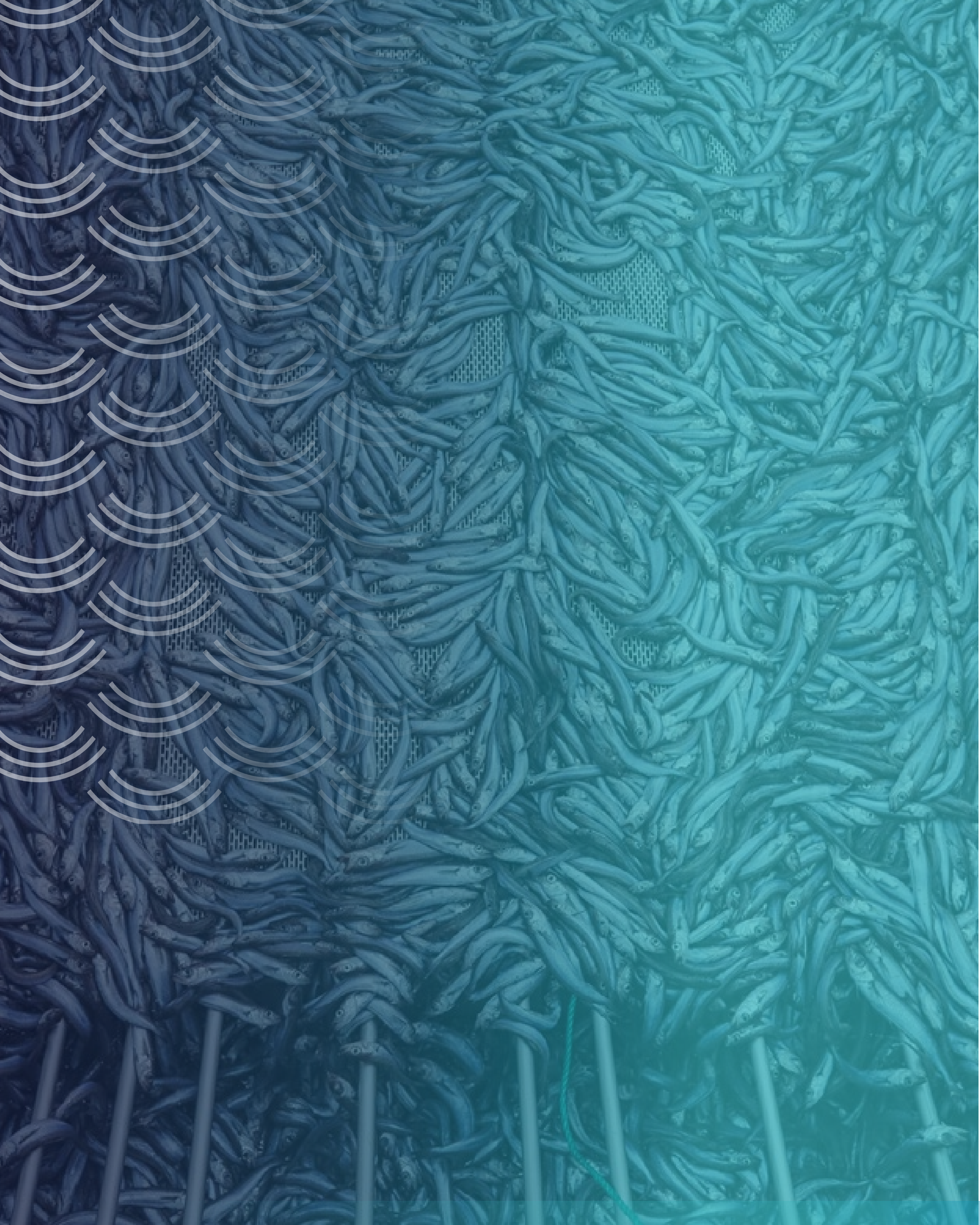
CRIMAC

Annual report 2022



Contents

Summary

Nils Olav Handegard

CENTRE DIRECTOR

Our centre has been operational for three years and during that time we have established our way of operating. The achievements so far range from developments in acoustic signal processing to applications in close cooperation with our user partners. In this report you will find more information about some of these achievements.

We are exploring how to exploit different acoustic signal processing methods with use cases covering our four pillars. This includes experiments, standardized data processing, and calibration standards. We are also working on optical systems. This is relevant both for fisheries applications and marine science. Machine learning methods are developing rapidly, and we have established ourselves in the forefront for using these techniques on acoustic data.

I find the interaction between the method developments and the application of the methods highly motivating. Working closely with the industry and user partners accelerates the transition from idea to implementation Still, this is a challenging aspect and work package 6 are working well to glue the users and the research activities together. This way we can keep track of changing needs from our user partners.

We have had several master students associated with the centre. The biology and mathematics PhD students are well integrated in the centre, but we are still seeking PhD students in physics. Our international collaborations are also increasing, and we have had several visiting PhD and master students.

The main point of contact is the Monday meeting series that is open for all partners in the centre. We have also continued to use one-off workshops to address specific topics in the centre and for establishing collaboration with other centres and projects. The annual meeting was organized by Scantrol and I would like to express my gratitude to them for hosting and organizing the meeting. We also had the first site visit from the research council and the feedback was positive.

We are very much looking forward to the continuation.

BOARD

2022 was the year when the artificial intelligence (AI) chatbot, ChatGPT, was launched to the public and soon became the fastest growing consumer internet app of all time and has now reached 100 million users in the beginning of 2023. This has raised public attention of AI considerably and has fuelled relevant discussions on possibilities, limitations, and consequences. In CRIMAC, AI plays a central role through WP4 "Machine Learning and Species Categorization Methods Applied to Fisheries Acoustics and Ground Truthing Data". Good progress has been made in this work package in addressing the special challenges related to applying AI for the types of applications and data which are relevant for CRIMAC. Significant progress has also been made on the other parts of the data processing pipeline such as data collection, pre-processing, and data infrastructure. We are all looking forward to seeing the entire data pipeline being implemented in applications relevant for the user partners in CRIMAC.

In 2022, the Research Council of Norway (RCN) performed the first of their regular site visits to the CRIMAC centre. The centre was presented by the Institute of Marine Research (IMR) as the host institution and selected projects were presented by representatives from the work package leaders, user partners, and Ph.D. students. The general feedback from the Research Council was very positive and the board would like to thank RCN, IMR, and all other participants for arranging and contributing to a positive and constructive site visit.

The annual gathering was in 2022 hosted by Scantrol in Bergen, and it was the first time where members of the International Scientific Advisory Committee (ISAC) were able to participate in-person. Work package leaders and students presented state-of-the-art and new achievements and user partners expressed needs and expectations which all formed the basis for productive discussions. The board would like to thank Scantrol and all other participants who contributed to create a very successful meeting.

The operational framework for CRIMAC is now in place and generally seems to be working well but we will continue to adjust as needed. The new role of WP6 "Extracting Gains for Science and Industry" provides an important forum for linking the activities in CRIMAC with the expectations from the user partners. Continuous recruitment and integration of new and existing students still requires special focus since this is essential to the success of CRIMAC. The board would like to use the opportunity to thank all participants in CRIMAC for a productive 2022 and we are very much looking forward to continuing the journey.

Vision and objectives

VISION

Sustainable, healthy food production and clean energy production for a growing population are important global goals. Important elements to achieve these goals are technology development and know how, and CRIMAC will contribute to these by obtaining accurate underwater observations of gas, fish, nekton, and other targets.

Underwater observations are challenging both due to the additional spatial dimension compared to terrestrial systems and the unfavourable optical properties of the water. To overcome this, advanced underwater acoustic systems offer both range, observation volumes and resolution for descriptive and quantitative observations of the ocean interior. A game-changer, both for research and the fishing industry, occurred recently with the introduction of commercially available scientific broad band echo sounders and sonars. It represents an expansion of the current multifrequency methods both in the frequency domain and in the time domain, enabling improved acoustic classification of targets and increased resolution.

CRIMAC will contribute to the understanding the new echo spectra, how to process them and how to utilize them in a range of different sectors relevant to Norway and internationally. Improved quantification and classification of targets and mixtures may prevent unwanted bycatch and suboptimal fish size for the fishing industry, provide information on key parameters for modern aquaculture farms, indicating size, density, growth and animal welfare, improved identification of gas releases in the ocean floor relevant for, e.g., CO2 sequestration for the energy sector, and monitor key features like abundance and distribution of key species in a changing marine ecosystem.

OBJECTIVES

The primary objective of the SFI is to advance the frontiers in fisheries acoustic methodology and associated optical methods, and to apply such methods to 1) surveys for marine organisms, 2) fisheries, 3) aquaculture and 4) the energy sector.

This will be achieved via the following secondary objectives:

1. Improve automatic interpretation of (wideband) fisheries acoustics, including sizing of targets (fish and bubbles), target identification and increased spatial resolution.

2. Aid the target classification of fish and zooplankton by experimental measurements of known target and backscatter modelling.

3. Collect reference data for machine learning projects on research vessels and in the commercial fishery with similar, calibrated instrumentation.

4. Develop better verification methods using optical systems and dropped probes and working-drones.

5. Develop automated classification systems based on modern machine learning methods.

6. Work with the user partners to apply the techniques and instruments developed in 1) to 4), in scientific surveys, for sizing and species classification in fisheries, for sizing, growth and behavioural measurements in aquaculture, and improved gas and bubble detection systems for the energy sector.

RESEARCH PLAN

The research plan is updated annually and follows the work package structure. A selection of current tasks from the plan are reported under the "scientific activities" chapter.

Organisation

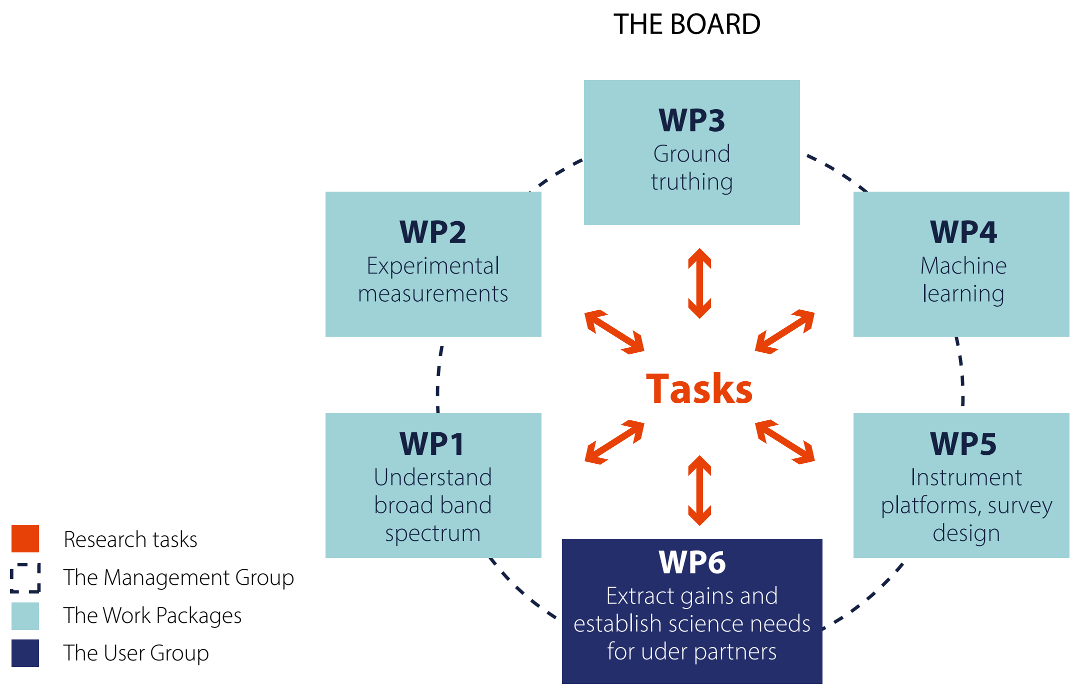


Figure 1. Relationships between work packages. The science WPs (1-5) will cover the different scientific fields and maintain the overview of state of the art within each field. The management group will set up research tasks to deliver methods and knowledge. The tasks may be fundamental science projects as well as projects that facilitates the implementation and uptake by the industry. The feasibility of the methods and the needs from the user partners industry will be assessed by WP6.

ORGANISATIONAL STRUCTURE

The research tasks and scientific methods are structured into work packages (Figure 1) which follow five research frontiers (WP1-5), plus a work package (WP6) that keeps track of the user needs and facilitate uptake of the methods by the user partners. The remaining work package (WP0) coordinates and manages the centre and outlines the governing structure of the project in more detail.

Centre leader and project coordinator

Nils Olav Handegard is appointed centre leader. Turid Loddengaard is appointed project coordinator and will assist the centre leader in administrative matters.

Work Package leaders

Each of the work packages (WP) have a WP manager appointed by the Board. Each work package leader is responsible for maintaining an overview of state of the art within the field the WP is covering. Geir Pedersen (IMR), Tonje Nesse Forland (IMR), Maria Tenningen (IMR), Nils Olav Handegard (IMR) and Espen Johnsen (IMR) are leading WP1-5. WP6 is led by Tonny Algrøy (KM) representing the user partners.

The Management Group (MG)

The MG will be responsible for the day-to-day operation of the Centre. The MG consists of the WP leaders and centre leader, the leader of the Marin Ecosystem Acoustics research group at IMR, and one representative from NORCE (Inge Eliassen), NR (Ingrid Utseth) and UoB (Audun Oppedal Pedersen) to ensure at least one representative for each science partner. A major responsibility of the MG will be to develop annual work plans with budgets and oversee the activities. The MG could also start new activities to respond to new developments within the field.

Tasks

The centre will establish a set of dynamic tasks that is associated to a work package. The WP leader is responsible for the tasks, and a task leader will be assigned to each task. Personnel from several partners will ideally be involved in each task, and part of the work should ideally be carried out while staying at the centre. Each task reports briefly to the MG on the weekly update meetings.

CRIMAC – THE BOARD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Lars Nonboe Andersen, Kongsberg Maritime


Board member
Puben Patel, CODELAB


Board member
Per W. Lie, Lie-Gruppen


Board member
Pål Cato Reite, EROS AS


Board member
Øyvind Frette, UiB


Board member
Helge Hammersland, Scantrol/ Scantrol Deep Vision


Board member
Annette F. Stephansen, Norce


Board member
Anne-Sofie Utne, SalMar


Board member
Line Eikvil, NR


Board member /observer
Lars H Andersen, NFR


Board member
Frode Vikebø, HI


Centre leader
Nils Olav Handegard, HI


Secretary
Turid S. Loddengard, HI

The board

The Board will approve the appointment of the Centre director and project managers and will be responsible for decisions on annual work plans and budget. All partners will be represented on the Board, chaired by the partner contributing most economically (Kongsberg Maritime).

The International scientific advisory committee (ISAC)

The committee will consist of three persons and is appointed by the board. The ISAC will provide a report to the board at the annual meeting to assist the board in terms of the scientific performance of the centre. The ISAC members are Dr William Karp (USA), acoustics and survey implementation expert, Director, Dr. Paul Winger (Canada), trawling and fisheries expert and professor Laura Uusitalo (Finland), expert in Machine Learning and Artificial intelligence.

Host institution, location, and facilities

IMR will serve as the host institution. IMR will provide the necessary administrative support systems for the Centre. IMR will provide office space to the Centre, including offices for industry partners and visitors from the international cooperating research institutes.

Meeting schedules

There will be a weekly update meeting for everyone working actively on a task, and the task leader will be responsible for providing a brief update. A bi-monthly MG meeting will be held, but the meeting frequency may be higher during the development of the annual plans etc. There will be an annual "fag-samling". There will be 1-2 board meetings a year.

RESEARCH PARTNERS

The Institute of Marine Research (IMR)

The Institute of Marine Research is one of the largest marine research institutes in Europe with approximately one thousand employees. Our main activities are monitoring, research, and advice for the marine

environment. IMR's head office is in Bergen. We also have a department in Tromsø and research stations in Matre, Austevoll and Flødevigen. In addition, we operate a fleet of research vessels. These vessels are an important tool for collecting acoustic data and will be central to CRIMAC. IMR has a strong track record for innovation and method development within the field of fisheries acoustics. This includes the first scientific publication utilizing underwater acoustics on fish distributions, the development of the echo integrator commonly used worldwide in acoustic trawl surveys, and experimentally establishing the basic acoustic linearity principle. IMR has worked extensively with scientific multibeam sonars and echosounders in cooperation with KM and IFREMER. IMR has been a driving force for international cooperation within the field, e.g., by hosting the ICES fisheries acoustics symposium several times and through significant contributions to the development of acoustic methods trough several ICES Cooperative Research Reports. CRIMAC will support the continuation of this effort.

NORCE

NORCE is an independent research institute with around 750 employees that undertakes research for both the public and the private sector. NORCE has a long tradition for cooperation with IMR, UiB and KM within the topic of SFI CRIMAC, due to a strong competence within acoustics and data science.

NORCE has been a key contributor for the development and implementation of acoustic methods in postprocessing systems, and the effect of nonlinear loss in fisheries acoustics. Together with IMR, NORCE has developed the software LSSS which is used by several hundred researchers for better to monitor and analyse fish resources. NORCE will contribute to broadband spectrum modelling, develop methods/use machine learning for broadband noise removal and automatic categorization of backscatter. They will also be involved in training and education of researchers and PhD students.

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>
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The Norwegian computing Center (NR)

The Norwegian Computing Center (NR) conducts research and is one of Europe's largest environments within statistical modelling and machine learning. We carry out research assignments for Norwegian and international business, the public sector and within national and international research programs, with a vision to contribute with research that is used and seen.

We have more than 30 years of experience in developing image analysis methods for automatic analysis and extraction of information from various types of image data. Our strategy is also to contribute with specialist expertise in image analysis to other research environments in Norway.

CRIMAC fits very well with this strategy where we work with image analysis based on artificial intelligence to extract information about the occurrence of fish and fish species from fishing acoustics.

The work in CRIMAC builds on collaboration that was started with the Institute of Marine Research in this field several years ago. We also have a long-term collaboration related to statistical modelling for stock estimation. Through CRIMAC, we look forward to a further strengthening of this successful collaboration.

The University of Bergen (UoB)

The University of Bergen is a world leading university in marine science and technology. UoB participates in CRIMAC with three departments: the Department of Biological Sciences, the Department of Physics and Technology, and the Department of Mathematics.

The Department of Biological Sciences contributes with (i) supervision and education of 2 PhD candidates (one financed by UoB, and one financed by the Research Council of Norway), and (ii) supervision and education of master candidates; all in the field of "Ground truthing methods" of which organisms and targets that generate broadband acoustic backscatter. The Department of Physics and Technology contributes with (i) supervision and education of 2 PhD candidates (one financed by UoB, and one financed by the Research Council of Norway), and (ii) supervision and education of master candidates; all in the field of fisheries acoustics. The Department of Mathematics contributes with (i) supervision and education supervision of one PhD candidate (financed by the Research Council of Norway), and (ii) supervision and education of master candidates in dynamic modelling and machine learning.

UoB has a long history on close collaboration with the Institute of Marine Research (IMR) and other centre partners. The master and PhD candidates are supervised in a collaboration between UoB, IMR, and relevant centre partners.

INDUSTRY PARTNERS

Kongsberg Maritime (KM)

Kongsberg Maritime is a Norwegian based technology company with a diversified portfolio of products and services that spans applications from the deepest oceans to the space. With over 7 300 employees and an installation base of more than 30 000 vessels worldwide the company is positioned in both traditional and new ocean-based industries.

Sustainable development of the oceans and its resources have been an integrated part of KM's strategies for many decades already, through the commercial fishery and marine research sector. The main reason for KM's participation in SFI CRIMAC is to further improve our offerings to these sectors as well as to bring this competence into other marine industries such as offshore energy production and aquaculture.

The KM contribution to the CRIMAC centre is mainly focused on wideband acoustics and sensors for catch monitoring, and how products in these areas can be improved through the introduction of new digital infrastructure for machine learning and seamless data flow. This applies to both vessels as well as alternative sensor platforms such as marine drones and stationary observatories.

SFI CRIMAC is a natural development of a research and scientific based collaboration with centre partners such as the Institute of Marine Research and the industrial partners which we believe will continue to believe innovative solutions to both marine industry and ocean management. Through CRIMAC KM wishes to position as highly relevant supplier of scientific based products and solutions for users of the coastal and ocean areas

Scantrol and Scantrol Deep Vision

Scantrol AS and Scantrol Deep Vision AS are located in Bergen, Norway. Scantrol has delivered control systems to trawls and cranes all over the world for more than three decades and has an extensive experience with developing technology for the marine research and trawl fisheries markets.

Scantrol was a partner in the CRISP Centre for Research-based Innovation (SFI) led by the Institute of Marine Research in Bergen. The Deep Vision trawl camera and sorting technology was developed in this centre and led to the spin-off company Scantrol

Deep Vision. Today, the technology is commercialized for marine research and used to sample fish from images in the trawl without bringing any catch onboard. The technology is being further developed into a catch identification and sorting device for commercial trawlers.

In CRIMAC, the companies will leverage the force of collaboration between leading scientific institutions and private companies to bring the successful technology even further. Deep Vision will both complement and support the interpretation of acoustic data.

Liegruppen

Liegruppen, located in Øygarden outside the city of Bergen has been in the fishing industry for more than 120 years. Liegruppen has throughout its history always had a strong focus on development and innovation in fisheries as well as in vessel construction.

Today the company are operating 2 purse seiners/pelagic trawlers. One of them – MS Libas is the world's most environmentally friendly fishing vessel. In addition, Liegruppen have one more "green" vessel under construction. MS Libas, delivered in march 2021 is the first purse seiner/pelagic trawl vessel using primary LNG when sailing, saving the environment for significant CO_2 and NOX-emission. MS Libas is also constructed and well equipped for doing scientific research. It is planned to use MS Libas in the CRIMAC-project.

Liegruppens role in the CRIMAC project is to test acoustic sonars and echo sounders in fishery. Improved quality of such instruments will make the fisheries more efficient and sustainable.

Liegruppen fishery are employing about 50 fishermen/crew in addition to 7 persons in the office.

Eros AS

EROS AS is a fishing company based in Fosnavaag with a history going back to 1917. Todays «Eros» is the seventh vessel carrying the same name. The vessel is a 77 metre modern pelagic trawler/purse seiner fishing for Herring, Mackerel, Capelin and Blue Whiting in the North Atlantic, Norwegian Sea, North Sea and Barents Sea.

«Eros» is equipped with a drop keel and echo sounders/sonars for doing scientific research and has over the last 15 years been employed both by the Norwegian Marine Institute and the Greenland Nature Institute on a number of research trips. The vessel has an experienced crew with more than 20 years fishing experience. Eros AS is also operating the pelagic trawler «Herøyfjord» and is involved in the white fish business being the majority shareholder of the factory trawler «Ramoen» producing fresh frozen fillets of Cod, Haddock and Saithe for the Norwegian and International markets.

Our obligation to the consortium is to test acoustic sonars and echo sounders in a real fishery and in specific surveys when hired as a research survey by CRIMAC. Improved quality in such instruments will make the fisheries more efficient as it put the industry in a better position with respect to selecting the correct fish species, estimation of the biomass, size of the fish and movement of the fish prior to shooting the fishing gear.

Salmar ASA

On November 22, Norway Royal Salmon ASA was merged into Salmar. Participation in CRIMAC has been transferred to Salmar ASA. Salmar ASA is a Norwegian aquaculture company listed on the Oslo Euronext. Our product is Atlantic salmon, and we have aquaculture activities in Norway, Scotland,

and the Westfjords of Iceland. Salmar is the world's second-largest producer of Atlantic salmon. In 2022, Salmar delivered 193,700 tons of salmon.

Salmar is continuously working to improve their biological results, including the development of new production technology, to address challenges related to our environmental footprint and location challenges. Through our subsidiaries Arctic Offshore Farming (AOF) and Salmar Aker Ocean (SAO), new production technologies are being developed, which are suitable for more exposed sea areas and for offshore aquaculture.

There is a lot happening in instrumentation for monitoring the aquaculture environment and fish. Having good observations and measurements of the environment, fish growth, behavior, and health status provides better decision-making support. This is a desired development for scaling up offshore aquaculture units and for submerged farming, such as in AOF.

New instruments and methods developed in the CRIMAC program may be suitable for salmon and trout farming, and our interest is to test this in commercial/full-scale aquaculture units in Salmar, especially instrumentation that can contribute to success in exposed aquaculture and offshore aquaculture.

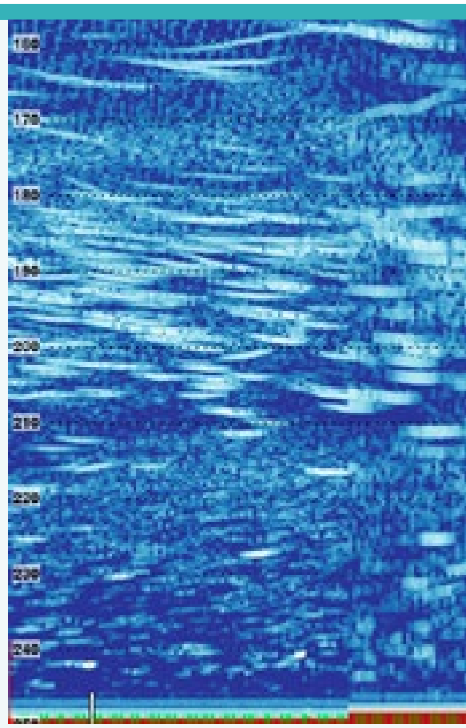
We are proud to be a partner in the CRIMAC program.

For more information about the company, please visit www.salmar.no.

CodeLab

CodeLab AS was established in 2013 and is located in Bergen, Norway. CodeLab is a technology company focusing on Business development, software development and signal processing. They have broad experience taking a concept from idea to product. Some of the developed products are Subsea Active acoustic leak detection system, deployed on Troll B. Fare evasion detection system tested in cooperation with Delhi Metro Rail Corporation and Metropolitano de Lisboa. System for counting people in passing cars deployed at Halhjem ferry pier and MF Nesvik. Health diagnosis system to decrease diagnosis time and improve diagnosis precision for chronical diseases as COPD, Asthma, Migraine, Heart failure, Diabetes and Osteoporosis. We have long time experience in real time data processing, acoustic wide band processing, and machine learning. We also have an ambition to develop software solutions for the fishing industry and aquaculture, using algorithms developed by the research partners on data both from optical and acoustic sensors of particular relevance to CRIMAC. We deliver both independent products and libraries that can be interfaced into, e.g. Kongsberg software

Scientific activities and results



WP1

WP1 UNDERSTAND THE BROADBAND ECHO SPECTRUM FOR CLASSIFICATION

Scientific questions: *What are and how do the various parts of marine organisms contribute to broadband backscatter, and how can we improve the amount of information extracted from the acoustic signal?*

WP1 focuses on understanding how the complex broadband frequency responses from marine organisms are generated and how to enhance the amount of information which can be extracted from marine backscatter. Knowledge of the broadband backscatter contributes to the development of methods for automatic classification of marine targets. Further development of broadband acoustic signals and processing will enhance the amount of information available for classification. Numerical modelling of backscatter and in situ and ex situ measurements from individual and groups of marine organisms carried out in WP2 forms the basis for understanding the broadband response.

Fundamentals of broadband echosounding

To utilize the added information contained within broadband signals, beyond our current capabilities, an in depth understanding of broadband acoustics and signal processing is needed (Figure 2). A detailed description of current processing in commercial broadband echosounders was developed in 2022 and verified, and an accompanying Python code was developed and shared publicly (https://github.com/CRIMAC-WP4-Machine-learning/CRIMAC-Raw-To-Svf-TSf). This serves as a basis for common understanding of today's signal processing and as a starting point for further developing broadband signal processing in fisheries and marine environmental acoustics.

Echosounder settings for the collection of high-quality broadband acoustic data

Collecting high-quality broad-banded echosounder data is more challenging than collecting traditional narrowband data. Acoustic "cross-talk", i.e. interference between transducers, being a particular chal-

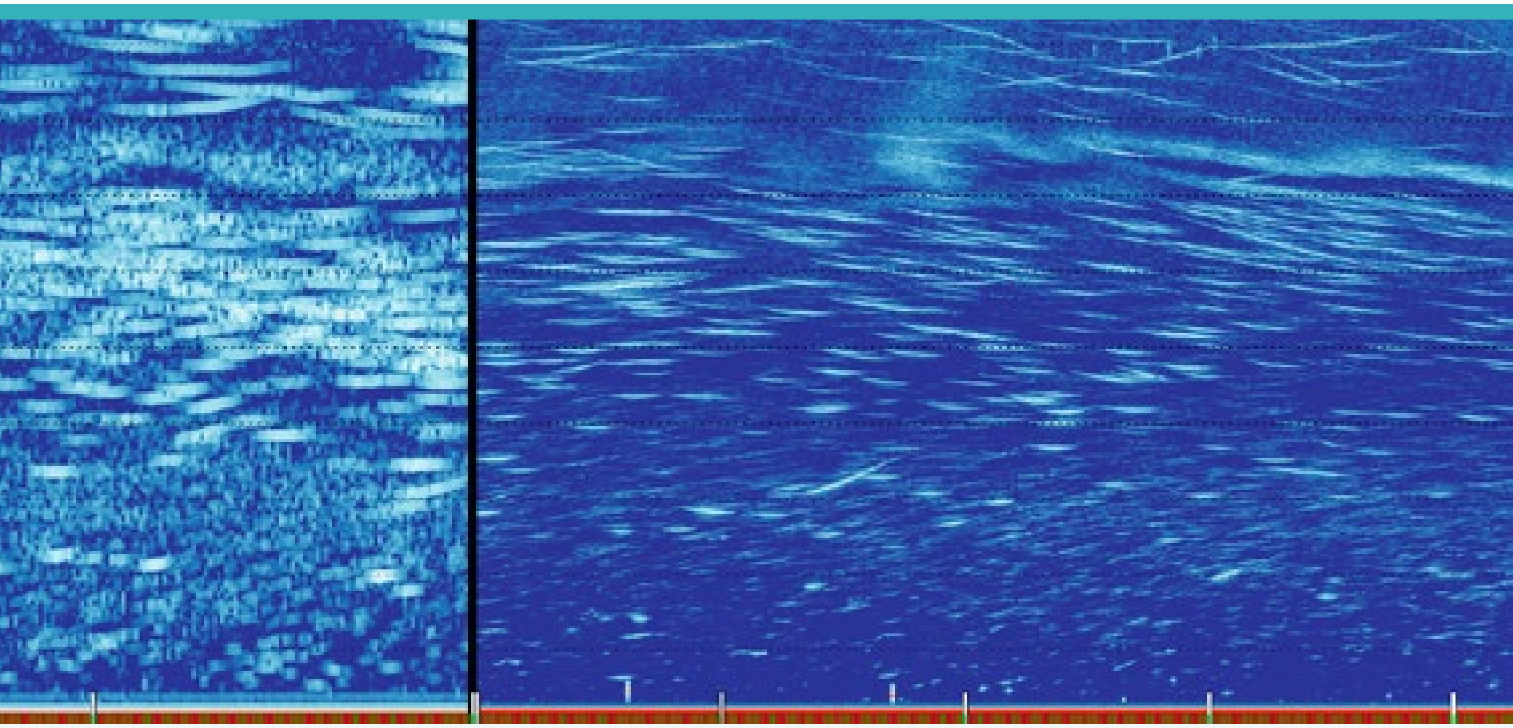


Figure 2. Echosounder data (echogram) from the Lofoten Vesterålen Ocean Observatory illustrating the improved resolution with broadband signals (FM) over conventional narrowband signals (CW). The same aggregation of marine organisms was observed first with CW before switching to FM.

lenge. Without consistent settings and high-quality data, it is not possible to utilize and further explore the added value of broadband in marine acoustics. Research and development prior to CRIMAC and within the centre were summarized to produce recommended echosounder settings for simultaneous data collection with multiple transducers. The recommendations cover all available standard broadband transducers (18-333 kHz), and includes recommendations for bandwidth, tapering, pulse duration, and power. The recommendations cover two data collection scenarios; data collected by surface vessels in a routine survey setting (Figure 3) and short-range data collection by submerged platforms.

Kanal	Tr. type	Puls-form	Bånd-bredde, kHz	Taper	Puls-varighet, ms	Effekt, W
18-CW	ES18	CW	-	Fast	1.024	800
38-FM	ES38-7	FM-Up	34-45	Fast	2.048	400
38-CW	ES38-7	CW	-	Fast	1.024	400
70-FM	ES70-7C	FM-Up	50-85	Fast	2.048	225
120-FM	ES120-7C	FM-Up	95-165	Fast	4.096	100
200-FM	ES200-7C	FM-Up	170-260	Fast	4.096	105
333-FM	ES333-7C	FM-Up	280-380	Fast	4.096	40

Figure 3. Standardized CRIMAC settings for broadband echosounder data collection for surface vessels.

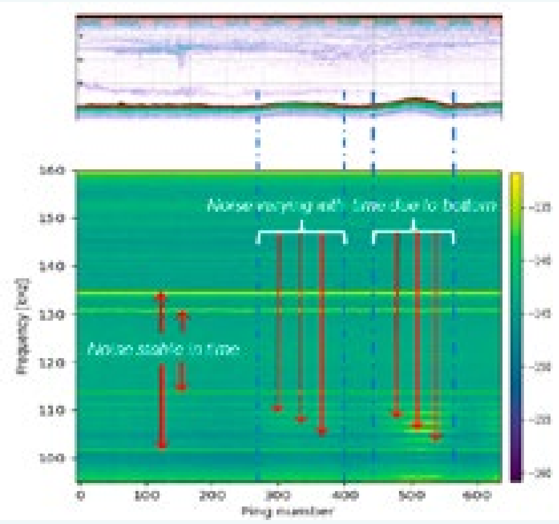


Figure 4. Narrowband noise in a broadband signal.

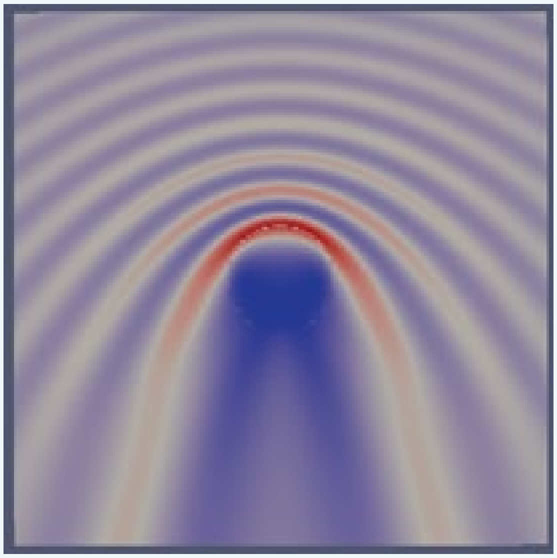


Figure 5. Acoustic nearfield modelling of scattering using the Boundary Element Method (BEM) with Fast Multipole performed on a conventional laptop..

Estimation and removal of noise in broadband echosounders

Broadband data are susceptible to noise. At higher frequencies noise from external sources or other instruments are a challenge. At lower frequencies noise caused by bottom backscattered ship-noise is a challenge. Higher frequency narrowband noise in a broadband signal is typically stationary, i.e., it does not change as a function of time, whereas noise caused by, e.g. bottom reflections tend to vary with time. The noise identification and removal is improved stepwise by first selecting segments of the data well suited for noise extraction (Figure 4), and then apply appropriate filters, such as notch filters. This efficiently remove temporal spike-noise and ambient echo integration noise.

Methodology for numerical modelling of acoustic backscattering by individuals and aggregations

The ability to accurately model backscattering from marine organisms is important for data interpretation, for gaining deeper insight into the mechanisms of acoustic scattering, and for generation of simulated data for training classifiers. Under this task we further develop methods for modelling broadband backscattering by individuals and aggregations and perform modelling to support work in other WPs. Efficient numerical methods for calculating backscatter over a range of frequencies and incidence angles are of particular importance, and initial trials with new and efficient methods were performed in 2022 (Figure 5). These methods will be further developed in 2023.

WP2

WP2 EXPERIMENTAL MEASUREMENTS OF BACKSCATTER

Scientific questions: *What are the broadband frequency responses of marine organisms and other scatterers?*

This WP is developing methods for controlled measurements of broadband backscatter from a wide range of marine organisms and other scatterers. Important categories of organisms and targets are fish, gas bubbles, fish larvae, krill, copepods, and jellyfish. Existing knowledge about these organisms has been reviewed and are used to prioritize our efforts. Experimental measurements will occur in the large tanks and net pen mesocosms at IMR's Austevoll and Matre research facilities and at-sea from vessels using hull-mounted echo sounders and close-range probing systems.

Calibration

Calibration spheres with known acoustic properties are used to calibrate echosounders. The spheres are suspended within the acoustic beam and the gain of the received signal is estimated and used to adjust the signal to fit the known signatures of the spheres. A challenge with this approach is that the frequency spectrum of the calibration spheres has several deep minima which must be excluded. A solution is to use two or more spheres with minima at different frequencies to cover the frequency range. A Master thesis from 2022 combined theory and measurements to find which combination of spheres that could be used for each echosounder, taking the signal to noise ratio and efficient calibration time into account. Occasionally we obtain inconsistent results using different spheres (Figure 6), and further work to address these discrepancies is ongoing.

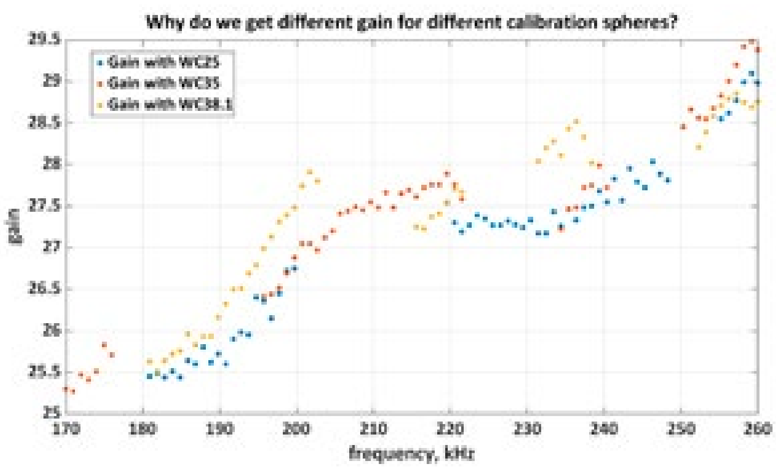


Figure 6. The measured calibration gain for a transducer should be identical for different calibration spheres, but this example shows gaps in the gain, in particular located close to the deep minima of the spheres.

Echo sounder monitoring of deflated swim bladder

Submerged net-pens in aquaculture are used to prevent sea-lice infestation on salmon close to the surface. Submerged pens force the fish below the layer where the sea lice are located, but can have fish welfare implications. When the fish are submerged, the amount of air in the swimbladder can be used as a welfare measure. Two master students investigated how early swimbladder deflation could be detected by echo sounders when the salmon was deprived from access to surface (Figure 7). It took about 7-10 days before a decrease in target strength was seen. The volume backscattering coefficient, Sv, decreased after about two weeks. The frequency spectrum of the fish also changed, and the ratio between Sv or TS from low to high frequencies could be used as an early detection of fish welfare problems in the netpens.

Resolving adjacent targets by broad band signals and interaction between the targets

In dense fish registrations the echoes for adjacent target may interact. Theoretical simulations and experiments were conducted to investigate how close two targets can be without affecting the frequency spectrum of each other. An echo sounder probe with 5 echo sounders was lowered a few meters below the surface from a crane on a vessel (Figure 8). Two pulse durations, 2 ms and 4 ms was used for broad band signals. The backscatter from two tungsten carbide spheres with different distances between them were measured. The results show that the frequency spectrums were affected when the targets were close. This needs to be accounted for when using broad banded echosounder observations in dense fish registration.

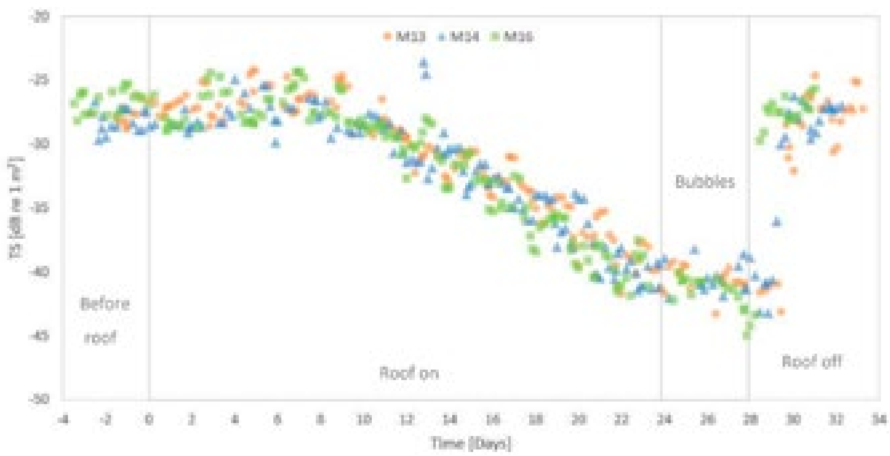
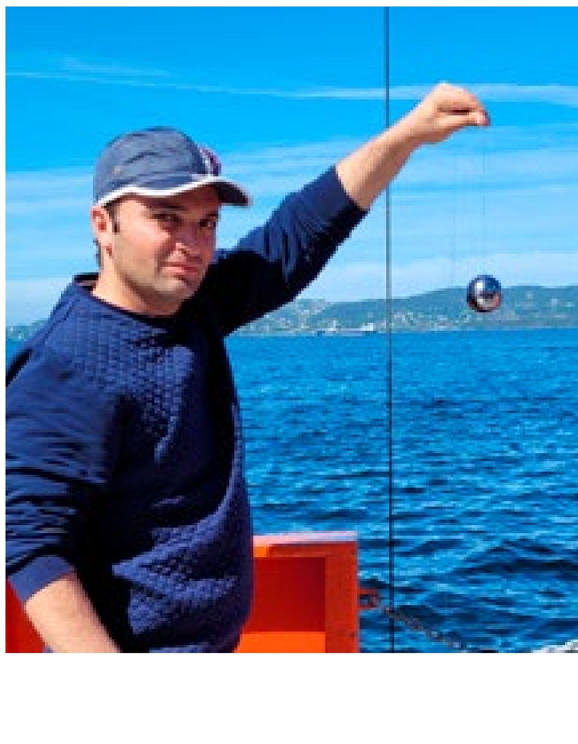


Figure 7. The target strength of individual fish depends on swimbladder inflation. Measured target strength from salmon in a net pen before, during and after the surface was closed with a netting roof. Lack of access to the surface deprived the fish from access to air for filling their swimbladders. Measurements in three different net pens showed the same trend (one colour for each net pen).



New research facility for net pen experiments

IMR has built a new marine research facility that includes 16 12x12 m^2 net pens at the Austevoll research station (Figure 9). This allows us to efficiently perform echosounder measurements on a range of species. CRIMAC has been involved in the planning of the facility to ensure that it is fit for our purpose, including all the needs for cables, housing, network, cranes and poles for suspension of equipment. We have collaborated with SFI Smart Ocean who is developing methods to monitor the environmental parameters close to the research facility.

Figure 9. The new marine research facility at Austevoll where we will do controlled measurements on different fish species, starting with salmon.

Figure 8. An acoustic probe with 5 echo sounders was used to do experimental measurements on calibration spheres at Sandvikflaket just outside Bergen. Backscatter from two calibration spheres positioned above each other with different separation distance.

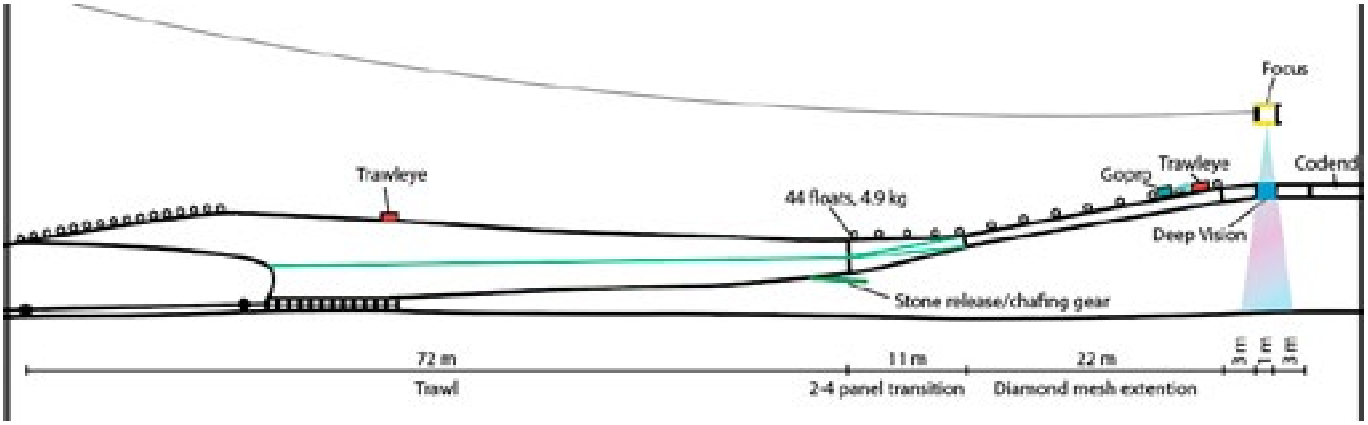


Figure 10. Working with the trawl to get the optical system above the sand cloud.

WP3

WP3 **GROUND TRUTHING METHODS**

Scientific questions: *What are the organisms and targets that generate broadband backscatter?*

This WP will develop and implement techniques for identifying and measuring the sources of broadband backscatter detected in WP2 using optical verification tools, such as stereo cameras and high-resolution optic imaging systems. The WP will also evaluate and further develop sampling methods for acoustic surveys. This year we have focused on improved video-trawling methods and sampling methods for future autonomous acoustic surveys (MSc project in WP5). The work requires biological understanding of fish reactions to sampling gears and will also include development and implementation of improved communication channels, data integration onboard, and data processing. Video-trawling as a sampling tool in scientific surveys that provides improved temporal and spatial resolution of the catch process. It also supports less invasive sampling when trawling with an open cod end releasing the fish compared to traditional trawl sampling. The WP cooperates closely with the industry partners and aims to identify applications to commercial fisheries (see user story about Scantrol Deep Vision camera system for commercial fisheries).

Image-based methods in trawls near bottom

Clear images from in-trawl camera systems are necessary for using optical methods in bottom trawls, both for commercial and scientific purposes. In this task the height of the trawl generated sediment cloud and its effect on image quality was measured in the Barents Sea fishing grounds. The sediment cloud was measured to be 4-5 m high using an echosounder on a towed underwater vehicle. Image clarity improved significantly as the camera system was lifted from 4 to 11 m above the seabed (Figure 10). A commercial bottom trawl was then modified by increasing extension length and adding floats to keep the camera system above the sediment cloud.

Trawl cameras in scientific surveys: from data collection to processed and visualized data

The aim of this task is to implement Scantrol deep vision (DV) camera system to the IMR ecosystem survey in Nordic Sea (IESNS) over a three-year period. The purpose of the image data is to support the scrutinizing of the acoustic data. A deck unit was

Figure 11.CRIMAC PhD student Taraneh Westergerling and Egil Frøyen from IMR use image data from the Scantrol Deep Vision in-trawl camera system to help scrutinizing acoustic data in the LSSS software. The image is from the IMR Ecosystem survey in the May 2022. (Image credit Vaneeda Allken)

developed by Scantrol for efficient and user-friendly download, processing, and transfer of data. The processing includes species identification algorithm previously developed by Allken et al (2021). It now takes about 2 hours from DV comes on deck until images and species distributions are available in the Large Scale Survey system (LSSS), which is the standard tool at IMR for processing acoustic data (Figure 11).

Automated image analyses methods for mesopelagic species

Mesopelagic species have important roles in the ecosystems and may support a large commercial fishery in the future. In this task a machine learning model is being developed to automate the identification and estimation of the distribution of different mesopelagic species, such as benthosema, maurolicus, and krill (Figure 12). A preliminary model trained on a limited dataset has been built but needs to be further refined using more annotated images from the species of interest. The data has been collected from different surveys and is now being annotated.

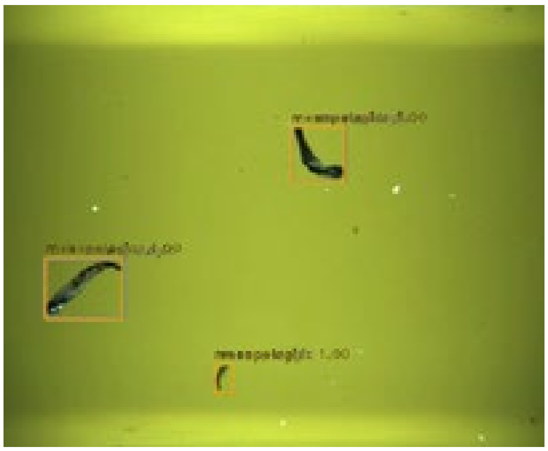


Figure 12. Developing automated imaging methods for in trawl camera systems.

WP4

WP4 MACHINE LEARNING AND SPECIES CATEGORIZATION METHODS APPLIED TO FISHERIES ACOUSTICS AND GROUND TRUTHING DATA

Scientific questions: *Can machine learning techniques reliably and accurately categorize acoustic backscatter?*

This WP will apply machine learning tools on large volumes of acoustic data, with a focus on categorizing acoustic backscatter. This includes supervised methods, using a combination of historical labels, experimental data, and ground truthing information (WP3) as well as semi-supervised and unsupervised methods to extract classes that are not the target species. This will be particularly relevant for gas seep detection, plankton layers and other non-labelled categories. Classes also includes bottom detections and samples dominated by noise. By clustering historical data and comparing the classes with the classes derived using broad band data, we expect to see an improvement in acoustic target classification.

Preparing data for machine learning

Datasets from major IMR acoustic surveys, both multifrequency and broadband, are being prepared for efficient access for modern machine learning libraries. We have been experimenting with a range of different methods and settled on the methods developed for model data through the https://pangeo.io/ project. We combine local data storage with a S3 object storage service and convert our data to the cloud friendly Zarr format (Figure 13). This allows us to easily access and subset large amounts of archived data through the xarray library in Python. We are in the process of working up several historical datasets and preparing them for machine learning.

Figure 13. The technologies used for presenting and accessing large amounts of archived acoustical data. We store the data in an object storage system (S3 buckets) in the self-documented zarr format. This allows direct connection through python using the xarray library.

Optimizing and operationalization ML model on Sand Eel

The Machine Learning model (U-Net) developed by the Norwegian Computing Centre has been adapted to IMRs standard data models and can be used to train and predict on historical data. The predictions are saved using the same format, making it easy to compare the model predictions and the manual annotations. By packaging the code in a docker container, the model can be integrated with the Blue Insight system developed by Kongsberg Maritime (see user story below). The model is also integrated

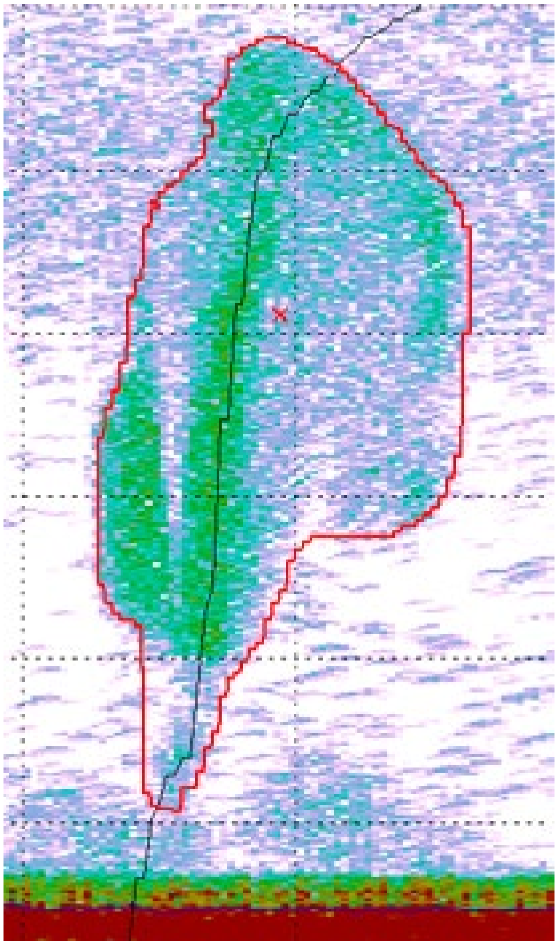


Figure 14. The U-Net algorithm running within LSSS for predicting Sand eel schools.

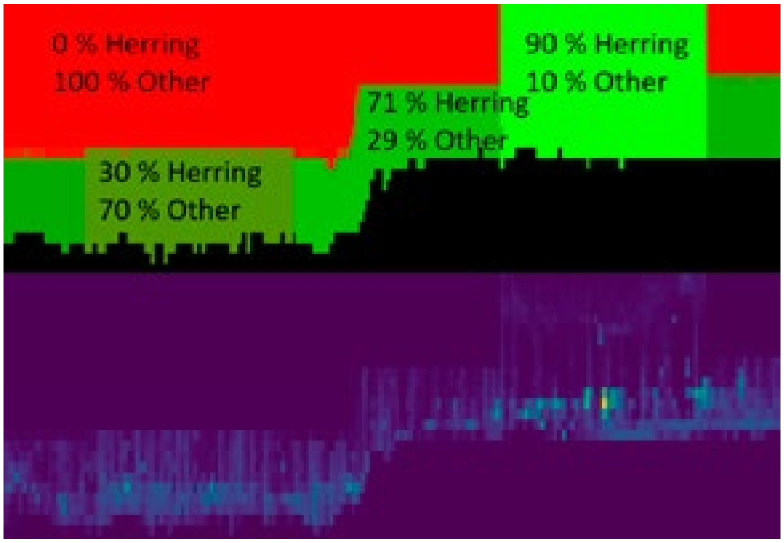


Figure 15. For the spring spawning herring survey, annotations are given as the portion of total acoustic energy from Herring in each layer.

with the Large Scale Survey System (LSSS) used by IMR for their standard surveys (Figure 14).

Weakly supervised learning on acoustic data

The current deep learning approach for acoustic target classification relies on being trained on pixel-wise annotations of fish schools in the acoustic data. However, in cases where the fish are distributed in layers as opposed to denser schools, such annotations will not be available. Instead, annotations are given as weak labels in the form of acoustic energy per fish category for layers.

In this task we are using the integrated backscatter by acoustic category over the integration distance used in the survey, typically 0.1 or 1.0 nautical mile (Figure 15), instead of pixel-based annotations for training. With data from the spring spawning herring survey, we train a model that combines segmentation and regression to predict the distance-integrated backscatter. This task is carried out in collaboration with the Visual Intelligence SFI.

Adding auxiliary data to DL ATC models

Adding auxiliary information such as sample depth, time of day and trawl information may assist the existing U-Net algorithm in classifying the acoustic data. Currently, such data are not directly available through the gridded samples used as input to the deep learning network. Different strategies for including depth and time information have been developed and tested (Figure 16), and the results of these experiments were published in 2022. The paper also includes various strategies for pre-processing the data for deep learning networks.

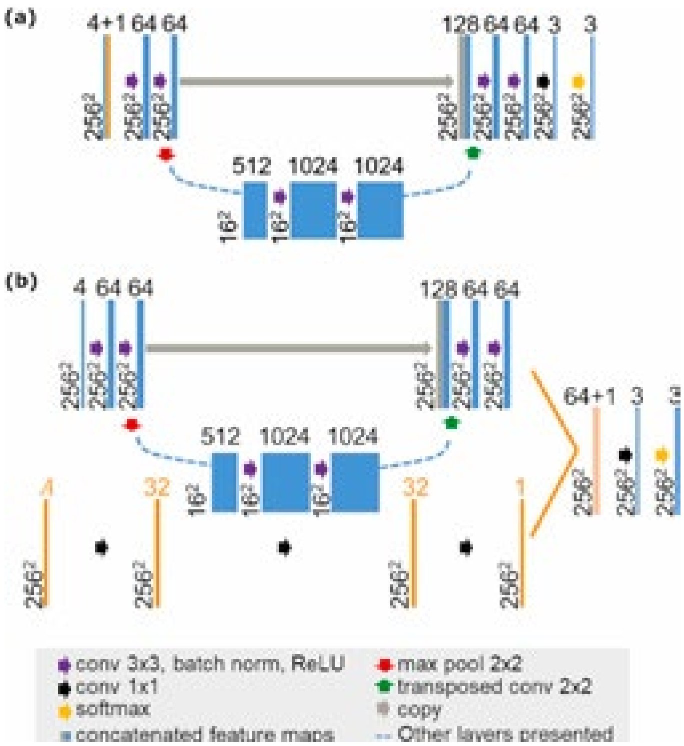


Figure 16. Two approaches were tested for adding auxiliary information to the Network architecture: (a) An "early" auxiliary model where the original U-Net model was modified such that the auxiliary data was simply concatenated to the multi-frequency input data, and (b) a "late" auxiliary model where the extracted features from the auxiliary data tensor were concatenated to the penultimate layer of the original model. Figure 2 from Ordonez et al (2022) (CC-BY 4.0).

WP5

WP5 **IMPROVING PRECISION BY AUTONOMOUS PLATFORMS AND SURVEY AND EXPERIMENTAL DESIGN**

Scientific questions: *How to utilize acoustic sensors on autonomous platforms, assess uncertainty and utilize the effect of behaviour on acoustic backscatter?*

WP5 is responsible to establish methods for utilizing autonomous or remotely operated platforms as an efficient way for deploying acoustic sensors. The platforms can either be run stand-alone or in conjunction with ships. They can also be used in a range of different applications, including scouting vessels for fishing operations and to augment research vessel based acoustic surveys. Different approaches to utilize these platforms will be explored, including various static and adaptive survey designs. How the uncertainty in automated acoustic target classification propagates to the use cases will be addressed, and WP5 will use survey time series from a range of IMR surveys to test the impact of automating target classification.

Towards a multi-platform armada strategy for ecosystem based marine surveys

Traditional fisheries independent surveys for fish stock abundance are developed around research vessels, either working alone or as part of an in-

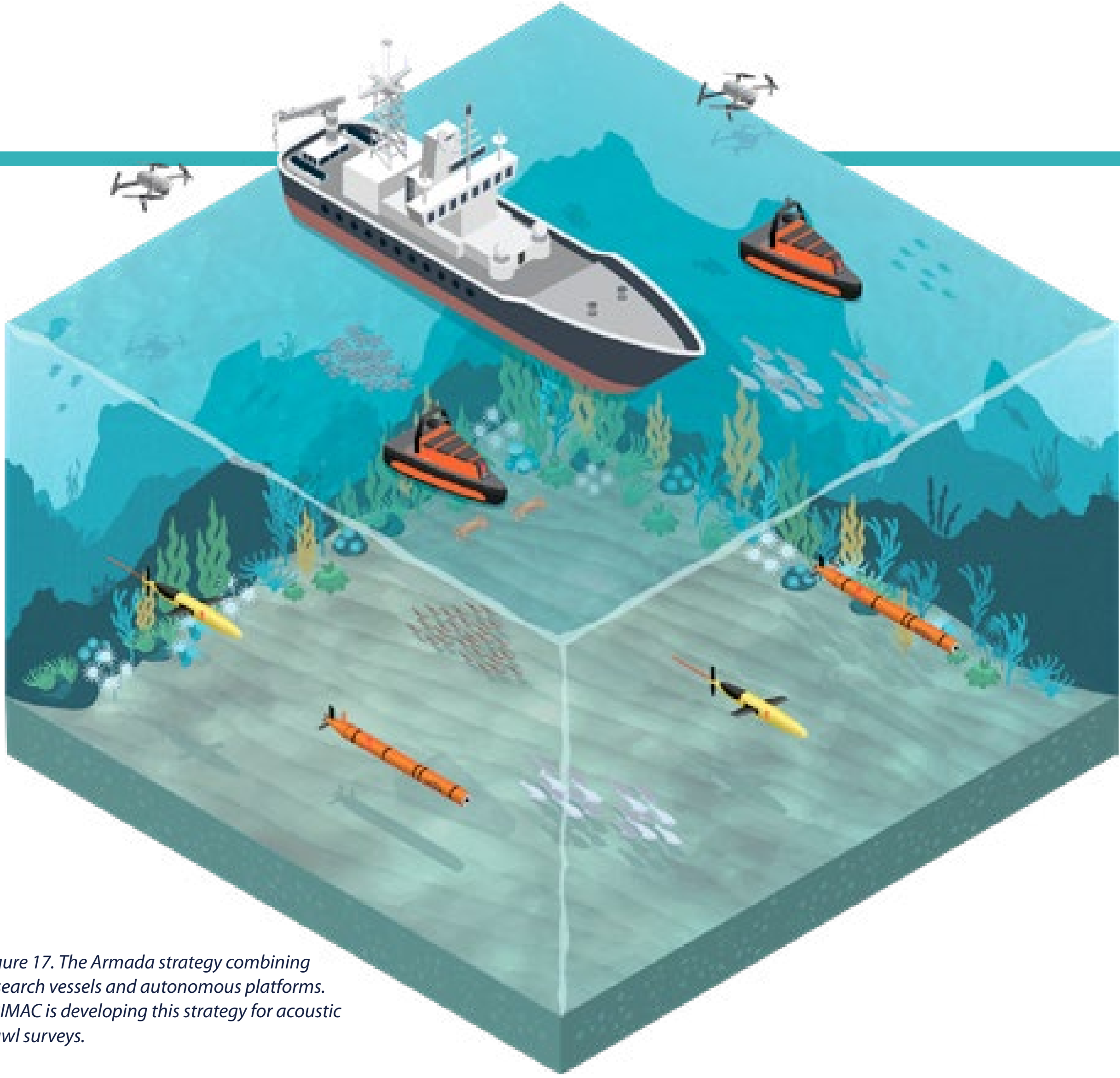


Figure 17. The Armada strategy combining research vessels and autonomous platforms. CRIMAC is developing this strategy for acoustic trawl surveys.

tegrated survey with multiple vessels covering a planned survey area. We are working on a strategy to utilize autonomous platforms to make data collection more efficient. In the foreseeable future, research vessels will still play an important part. This includes taking physical samples for species, age and other population parameters, and to operate the unmanned platforms to ensure efficient and safe operations. We have coined this approach the "Armada strategy" (Figure 17), and we are working on the principles for optimal sharing of workload between the different platforms.

Using saildrones to monitor the sand eel fishing grounds

Echosounder data from two Saildrones monitoring the sandeel fishing grounds in the North Sea from May through July 2019 (Figure 18). The data were analysed with respect to the spatiotemporal dynamics of sandeel schools by our PhD student Sakura Komiyama. For these data, only the frequencies 38 and 200 kHz were present, preventing the use of conventional acoustic classification by frequency response. Instead, a classifier based on acoustic backscatter, shape of the school and distance from the bottom was developed to automatically detect sandeel schools. Based on the measured distance from

Figure 18. Survey track of the two Saildrones surveying the sandeel fishing grounds from May through July 2019.

the bottom, a two-mode vertical distribution model was developed where a sandeel school is either in resting mode close to the bottom or in feeding mode midwater. The sandeel schools were observed to change behaviour from feeding strongly in the morning and in the evening early May, to feeding strongly also midday late May and early June.

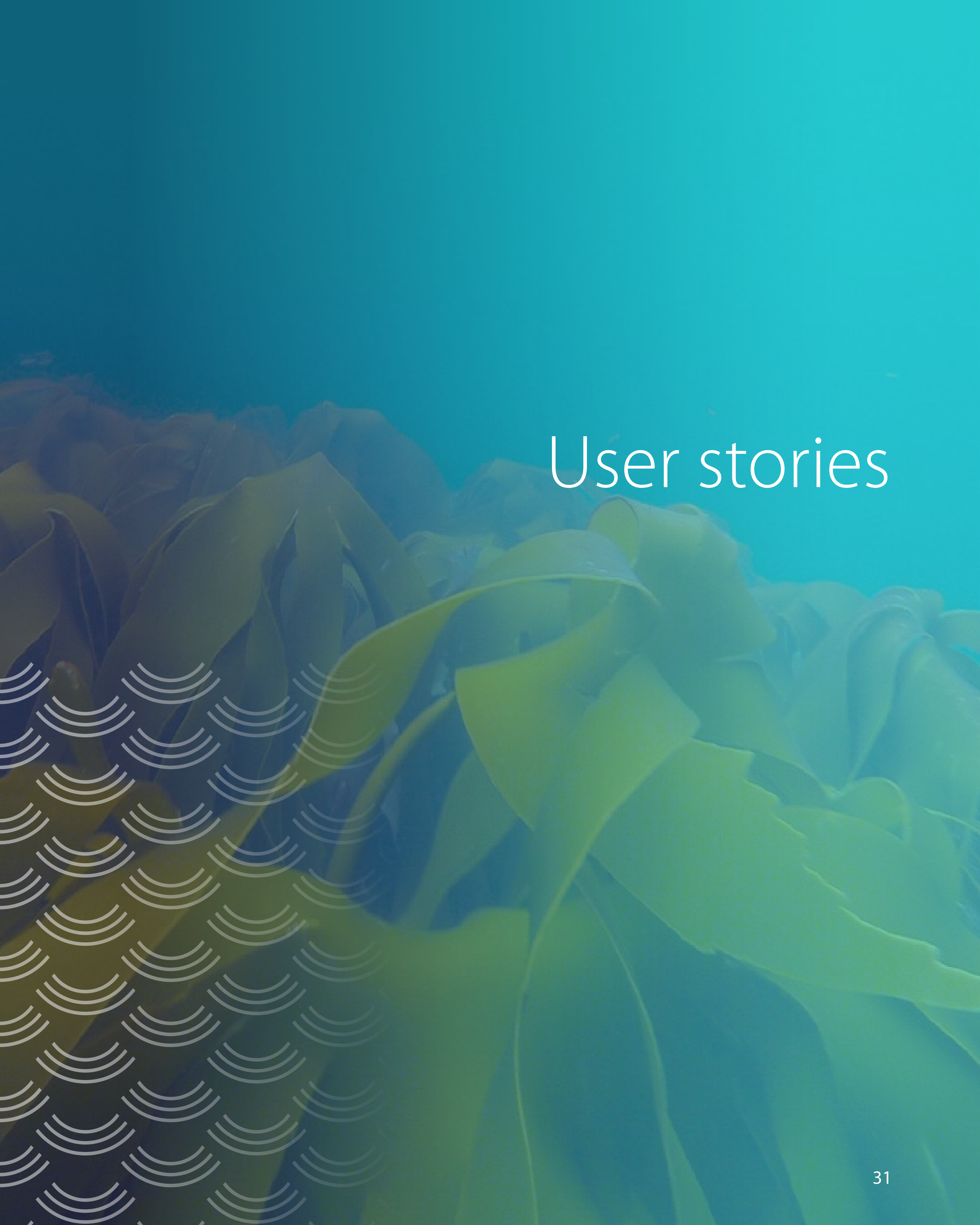
WP6

WP6 **AND EXTRACTING GAINS FOR SCIENCE AND INDUSTRY**

The overall goal of WP6 is to link the ongoing research and development in the CRIMAC SFI with the needs of the centre user partners. The consortium spans both scientific and industrial end users as well as suppliers, ensuring that quantified gains would cover both new methods as well as the commercialization of solutions from the centre. The goal of the SFI is to foster innovation and value creation. CRIMAC has identified four key sectors to target, on which the success of this work package will be measured:

- Science & Management
- Commercial Fishery
- Aquaculture
- Marine Energy

The stories below highlight some examples of relevance for this work.



User stories

Figure 19. The brand-new prototype of the commercial version of Deep Vision.

USER STORY: DEEP VISION HARVESTING CONTROL TESTED FOR COMMERCIAL FISHING VESSELS

In CRISP SFI, Deep Vision was developed into an eco-friendly fish sampling tool that record species, size, and location of fish from trawl images without the need for catching the fish. Through CRIMAC, machine learning algorithms was developed to identify and count fish entering the net. Today the system is operational on IMR's research vessels as well as in South Korea.

Under the CRIMAC SFI, we have further developed this technology into a brand-new product for commercial trawlers. Deep Vision will make fishing more sustainable and efficient by identifying the catch in the trawl by help of the new CamSounder. From a subsea "photo studio" attached to the trawl in the research version of the system, Deep Vision for fisheries has been developed into a much smaller unit that attaches directly to the trawl net and contains both a stereo-camera and an echosounder (Figure 19). This will make it possible to identify valuable fish and release undersized fish or bycatch. Deep Vision's ambition is to change the way we harvest our ocean's resources.

The requirements and needs from the industry guide the developments of solutions and algorithms for Deep Vision. In 2023, "Ramoen" will use Deep Vision to collect images of redfish for automated identification. In addition, Deep Vision can be used to collect data from the commercial fleet and use it for research purposes. This can dramatically increase the amount and quality of data used to map and understand our fisheries resources.

USER STORY: APPLICATIONS OF SCIENTIFIC SPLIT-BEAM BROADBAND ECHOSOUNDERS FOR THE ENERGY SECTOR

Signals from broadband echosounders contain not only information on marine organisms but also, if present, information on gas bubbles, oil droplets, and other particles suspended in the water column. This makes broadband echosounders a valuable tool for the energy sector, with several applications including environmental monitoring and detection of gas seeps.

Widespread use of broadband echosounders within the energy sector hinges on many of the same factors as in abundance estimation, aquaculture, and fisheries. These factors include data pipelines with automated processing, appropriate algorithm usage, and providing actionable information from the vast amounts of acoustic data. A dedicated activity in CRIMAC started in 2022 to investigate energy-related applications, focusing on automated quantification of gas seep emissions as well as investigating the potential for using split-beam broadband echosounders to better understand the oceans.

In collaboration with the Lofoten-Vesterålen Ocean Observatory (LoVe) project, we mapped an area with known natural gas seepage during the November CRIMAC survey (Figure 20). A new combined split-beam echosounder/Acoustic Doppler Current Profiler (ADCP) installed on G.O Sars was also used to collect information. Quantification of bubble seeps requires both calibrated backscatter and information about currents in the area. With the new combined echosounder/ADCP, backscatter and current flow rates are available simultaneously from a single instrument. To quantify the flow rate of seeps, we need to combine measurements with physical models in real-time, a solution that is possible through containerized algorithms that can be deployed in new data management and processing tools such as the Blue Insight.

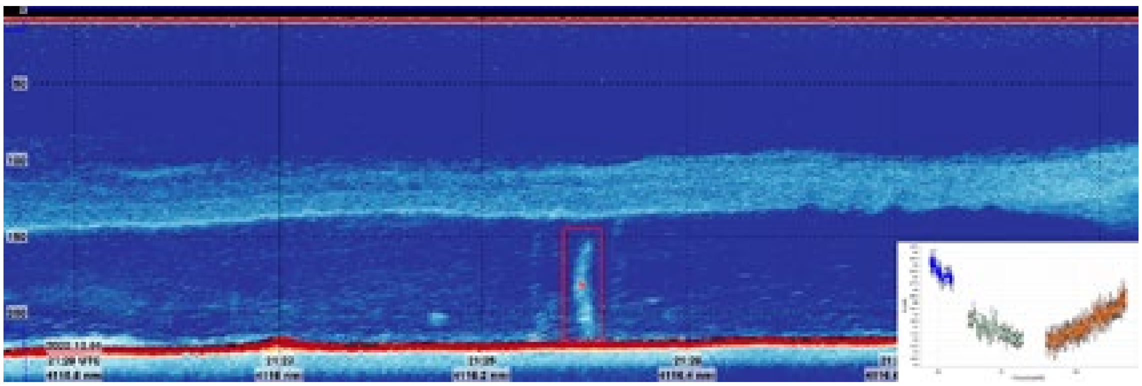
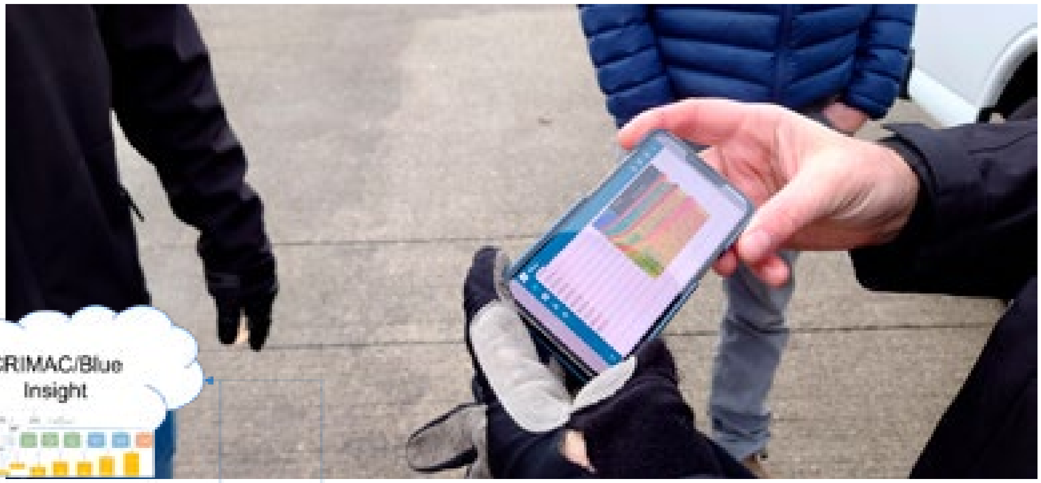


Figure 20. Broadband echogram showing backscattering by a small natural seep of methane (red box) near Node 7 of the Lofoten Vesterålen Ocean Observatory. The broadband frequency response of the seep is also shown (lower right inset). The seep consists of a few small single bubbles rising from the seafloor at a depth of 220 meters, clearly observed in the broadband data.



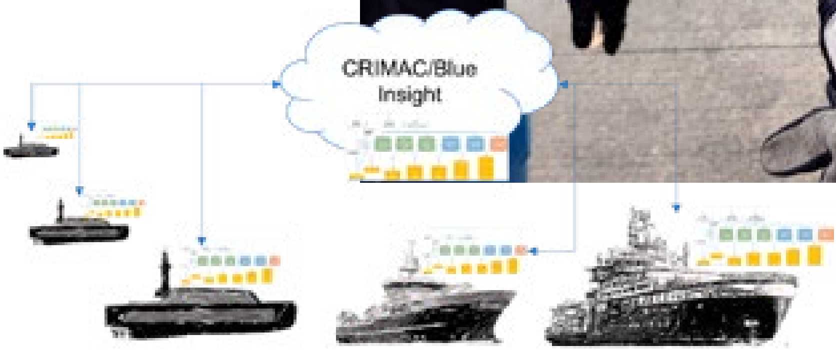


Figure 21. Remote operation of an EK80 echo sounder through the Blue Insight platform.

Figure 22. CRIMAC processing pipelines running on multiple platforms.

USER STORY: BLUE INSIGHT ON THE EDGE: LEVERAGING CRIMAC PROCESSING ON AUTONOMOUS PLATFORMS

Kongsberg maritime is developing autonomous platforms for maritime surveillance, either equipped with their own sensors- or third-party sensors. The traditional approach depends on human-operated desktop applications, but several use-cases requires remote operation of the software and the data processing algorithms. Remote operations can be used to generate and transmit decimated information through limited band withs as well as operating the instruments. Running the algorithms on the platforms is called edge computing, and the Blue Insight platform is being developed to support this.

A prototype of the system has been operational this summer, and several new Blue Insight capabilities have been developed in direct cooperation with CRIMAC. With new deployments models, such as the armada concept, where part of a survey operation is performed with one or more uncrewed vessels, it is important to be able to remotely manage the settings of the echosounders and to ensure data quality. Remote EK80 capability was added to the Blue Insight platform to control the echosounder from a web or mobile interface (Figure 21), and a subscription service to receive decimated data was developed.

Automated classification of fish using modern machine learning methods have been developed in CRIMAC, and, during a summer project in 2022, KM deployed the CRIMAC data processing pipeline in the Blue Insight framework (Figure 22) and were able to run multiple processing pipelines in parallel on the KM Sounder platform. The containerized processing steps allowed multiple workflows to be tested.

The development of the Blue Insight platform in collaboration with CRIMAC has helped KM design their edge environment. Further work on the environment includes automated updates of software and automated deployment of data processing pipelines, facilitating large scale edge deployment of automated data processing across a range of sensors and platforms. To improve pipeline portability Kongsberg is investigating using Docker with Kubernetes as the orchestration system. This helps automating software deployment, portability, and scaling and management of workloads. Since the CRIMAC pipeline is supporting both real-time and historical data processing, it is important that the portability aspects are covered.

Cooperation

INTERNATIONAL COOPERATION

- Alaska Fisheries Science Centre, NOAA, Seattle, USA
- Northwest Fisheries Science Centre, NOAA, Seattle, USA
- Woods Hole Oceanographic Institution, Woods Hole, US
- Florida International University, Miami, USA
- Memorial University of Newfoundland, Saint Johns, Canada
- AZTI, Spain
- Imperial College, London, UK
- Ifremer, Nantes, France
- Wageningen University & Research, Wageningen, Netherlands
- Thünen Institute, Bremerhaven, DE
- Aqualyd Limited, Nelson, New Zealand

PhD candidates

Ahmet Pala

Sakura Komiyama

E. H. Taraneh Westergerling

RECRUITMENT

Recruiting PhD students are an ongoing process. We have successfully hired 3 within biology and mathematics. Two PhD positions in physics were advertised in 2021 and again in 2022 without finding suitable candidates. These positions are planned to contribute with important work in WP1 and WP2. The search for candidates continues, and the centre and vacancies are promoted in relevant fora such as ICES and the Scandinavian physical acoustics community. We are also active in attracting master students by promoting the centre in undergraduate courses at UiB and by proposing CRIMAC-associated projects to students that are starting on their master programme within biology, mathematics, or physics. We have participated in student events at University of Bergen and The Arctic University of Tromsø.

Ahmet Pala has a master's degree in Industrial Engineering on machine learning and is currently continuing his Ph.D. in Applied Mathematics at UiB. Ahmet also holds a bachelor's degree in Naval Architecture and Marine Engineering. In his studies, he mostly focused on the applications of machine learning in the marine field. He is included in the work package 4 of the CRIMAC Project and aims to apply machine learning/deep learning methods on acoustic data and analyze the uncertainty.

Sakura Komiyama received her second master's degree in biology and currently works for the CRIMAC project as a PhD research fellow. She has also worked for the sandeel project at IMR for few months before starting her PhD programme. Her overarching interests are fish behaviour and species interaction within marine ecosystems, observing through up-to-date instruments such as broadband echosounders and unmanned surface vehicles.

E. H. Taraneh Westergerling is a PhD Research Fellow at the Department of Biological Sciences of the University of Bergen. She completed an international Master's program in Marine Biological Resources (IMBRSea) in 2021 with a thesis focused on the Deep Vision in-trawl camera system. Her topic of research breaches the fields of fish capture technology and fisheries acoustics. Her PhD in CRIMAC's work package 3 under the supervision of Maria Tenningen.

Appendices

Publications

An up-to-date list of publications can be found here: ***https://crima.no/ publikasjoner***

Peer reviewed publications

Allken, V., Rosen, S., Handegard, N. O., and Malde, K. 2021a. A real-world dataset and data simulation algorithm for automated fish species identification. Geoscience Data Journal, 8: 199–209.

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Handegard, Nils Olav. 2022. Deep learning models for fisheries acoustic target classification. Scandinavian Symposium on Physical Acoustics

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Khodabandeloo, Babak; Pedersen, Geir; Forland, Tonje Nesse; Korneliussen, Rolf; et. al. 2023. Resolving and characterizing nearby targets by means of broadband acoustics. Scandinavian Symposium on Physical Acoustics

Korneliussen, Rolf; Heggelund, Yngve; Eliassen, Inge Kristian. 2023. Estimation and removal of acoustic broadband noise. Scandinavian Symposium on Physical Acoustics

Ona, Egil. 2021. Echo sounder developments during my scientific life,- from EK38 to EK80, some significant steps. ICES WGFAST and ICES-FAO WGFTFB

Ona, Egil; Zhang, Guosong; Handegard, Nils Olav; Berg, Sverre; et. al. 2021. Direct measurements of the migration speed of spawning herring. ICES WGFAST and ICES-FAO WGFTFB

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Annual accounts 2022

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Havforskningsinstituttet

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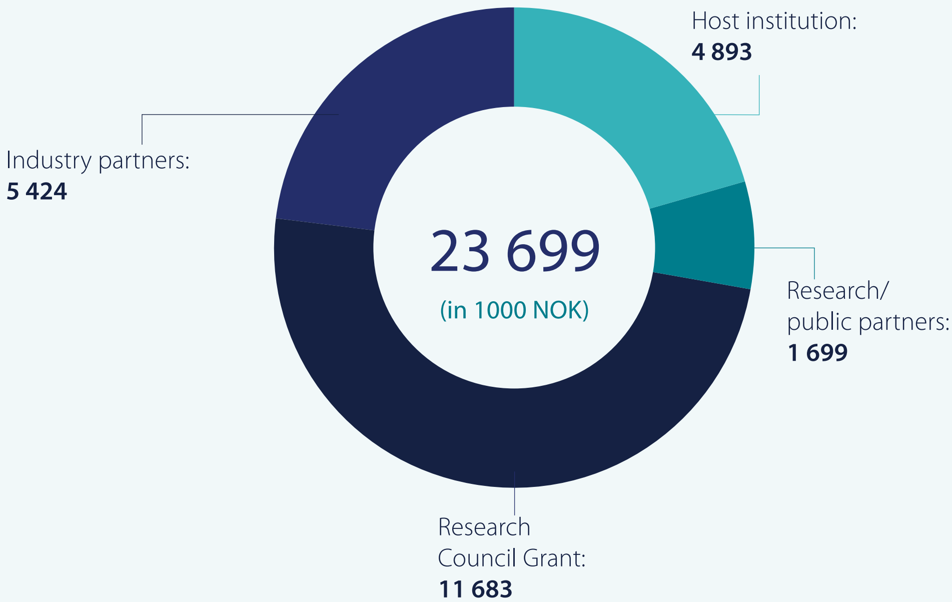
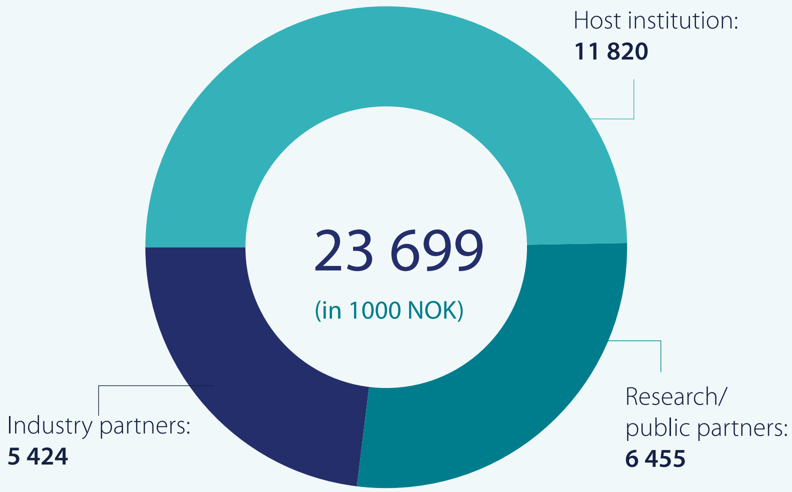
Universitetet I Bergen, Norce,
Norsk Regnesentral

Industry partners:
Kongsberg Maritime, Scantrol,
Scantrol Deep Vision, Lie Gruppen,
EROS, CodeLab, Salmar ASA*





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