CRIMAC

Annual report 2024


HAVFORSKNINGS
INSTITUTTET

Contents

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Summary

Nils Olav Handegard

CENTRE DIRECTOR

In 2024, the centre reached a significant milestone with its mid-term evaluation. This process offered an opportunity to review our progress to date, gather feedback from international experts on our work, and reflect on plans for the final phase of the centre's lifespan. It also prompted us to consider the future legacy and continuation of CRIMAC's efforts beyond the centre's formal duration. We received very positive feedback from the reviewers, which is highly motivating when starting the last term of the centre.

We are continuing to make progress in methods to process broad band echosounder data and imaging systems. Products and services resulting from collaborations with our user partners are emerging, and we used 2024 to further elaborate on the plans for how CRIMAC can contribute to these processes among the user partners. This resulted in concrete plans for how CRIMAC will contribute to the implementation of USVs at IMR, how we can address by catch of undersized herring in the fisheries and how we can help the aquaculture partner to process large amounts of acoustic data.

The training of the next generation of researchers is important both for the field and for the centre, and The PhD and master students constitute an important component of CRIMAC. During the mid-term evaluation, we received positive feedback from the students, particularly regarding the freedom they have to explore their own ideas and take charge of their future scientific directions. We are proud to have established a supportive working environment for our students. Like last year, we have highlighted the student projects, and you can read more about them in this report.

We are continuing to arrange workshops for topics relevant to the centre. Last year we arranged a large workshop on data processing methods for large volumes of plankton and fisheries-acoustics data. We have also started to write up summaries from the workshops and publish them in the primary literature. This further strengthen the impact of the workshops including the international visibility of the centre.

We are also continuing our bi-weekly Monday meeting series, which is open to all partners within the centre. In 2024, the Norwegian Computing Centre hosted the annual meeting, giving the partners an overview of what they are working on beyond the topics in CRIMAC, and I would like to extend my gratitude for hosting and coordinating the event.

Finally, I would like to thank everyone that makes the centre work, and to the Norwegian research council for providing this unique opportunity to move our field forward. Without the effort from everyone involved there would be no centre. We are halfway, we have accomplished a lot, and there is time and funding to take this even further. It will be very interesting to see how far we can take this.

CRIMAC BOARD

As we reach the midpoint of SFI CRIMAC, we have achieved significant theoretical advancements and developed several key elements. In the second half of CRIMAC, we will continue to advance basic theory and create new essential components, while also increasing our focus on the applications within ocean ecosystem management, sustainable fisheries, aquaculture, and energy production.

The relevance of CRIMAC continues to grow, particularly considering the heightened emphasis on sustainable and efficient operations. The recent strategic review of the Institute of Marine Research (IMR) by Deloitte underscored this importance. One of the primary recommendations from the review is the "Comprehensive digitalization of IMR and increased utilization of new technology and data." This recommendation aligns closely with the objectives of CRIMAC. The innovations developed within CRIMAC will be essential for IMR to implement these recommendations in their daily operations. A significant milestone will be the sprat survey in the Hardangerfjord in 2025, where IMR plans to incorporate several CRIMAC innovations into their survey methodology. We are all enthusiastic about contributing to this important development.

Norway's leadership in marine resource management, sustainable fisheries, and aquaculture has also garnered strong international interest in the results and innovations generated by CRIMAC. This interest is evident in the high level of international participation in the workshops organized by CRIMAC. These workshops facilitate valuable discussions and knowledge sharing with the global community and support the dissemination of CRIMAC's results and innovations internationally. We will continue strengthening both national and international partnerships.

As we continue to navigate the challenges and opportunities in marine research, we remain committed to our vision of creating a sustainable and prosperous future for our oceans. We extend our sincere gratitude to all our partners, researchers, students, and supporters for their unwavering commitment and contributions to CRIMAC's success.

Thank you for being part of this remarkable journey. Together, we can make a lasting impact on sustainable and efficient ocean ecosystem management, fisheries, aquaculture, and energy production.

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 knowledge, and CRIMAC contributes 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 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 of the echo spectra, how to process them and how to utilize them in a range of different sectors. 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

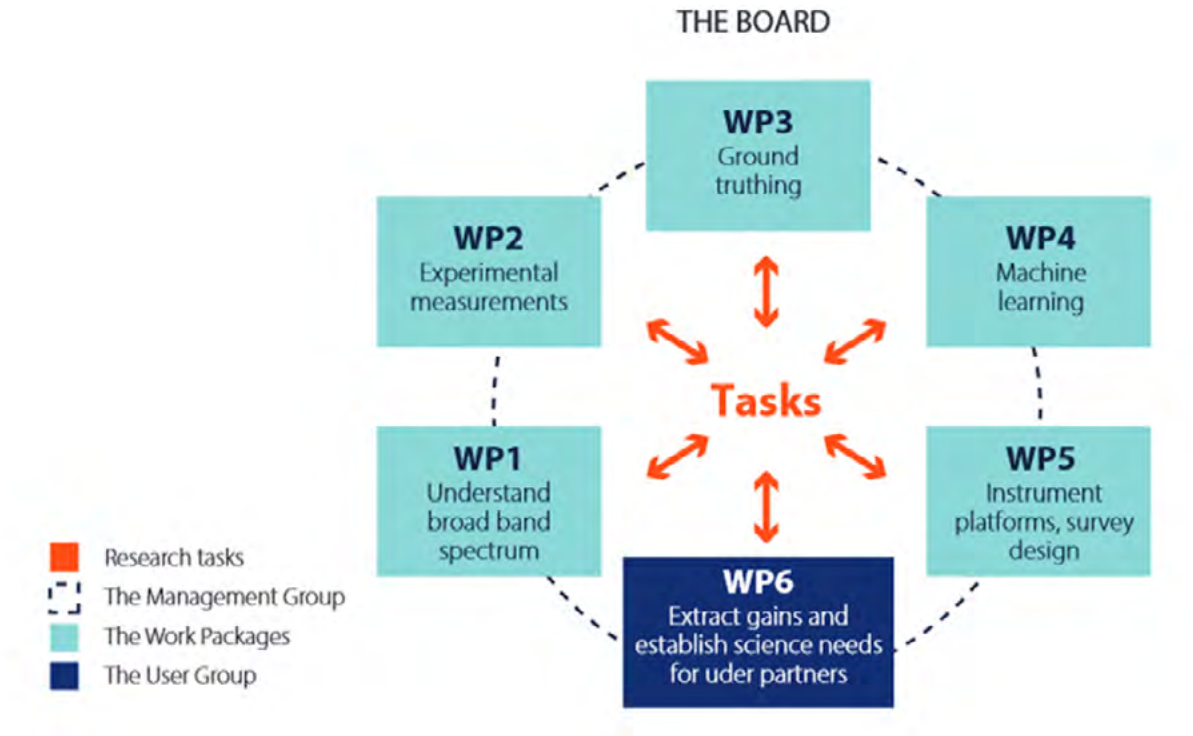


Figure 1. Relationships between work packages. The science WPs (1-5) will cover the different scientific fields and maintain the overview of state of the art within each field. The management group will set up research tasks to deliver methods and knowledge. The tasks may be fundamental science projects 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), Ketil Malde (IMR) and Arne Johannes Holmin (IMR) is 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 UiB (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.

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 will be 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 Pierre Petitgas (France), 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 bi-weekly update meeting for everyone working actively on a task, and the task leader will be responsible for providing a brief update. MG meetings will be held when necessary. There will be an annual "fagsamling", and there will be 2 board meetings a year.

PARTNERS

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.

Figure 2. NORCE.

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.

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.

Figure 4. University of Bergen.

The University of Bergen (UiB)

The University of Bergen is a world leading university in marine science and technology. UiB 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 oversees the supervision and education of two PhD candidates (one funded by UiB and the other by the Research Council of Norway), as well as the supervision and education of master's candidates, all focusing on "Ground truthing methods" related to organisms and targets that produce broadband acoustic backscatter. The Department of Physics and Technology is involved in supervising and educating two PhD candidates (one funded by UiB and the other by the Research Council of Norway), as well as master's candidates, within fisheries acoustics. The Department of Mathematics is supervising and educating one PhD candidate (funded by the Research Council of Norway) and master's candidates in machine learning for acoustic target classification.

UiB has established a longstanding collaboration with the Institute of Marine Research (IMR) and other relevant centre partners. The supervision and education of master's and PhD candidates are conducted through a collaborative effort between UiB, IMR, and other centre partners.

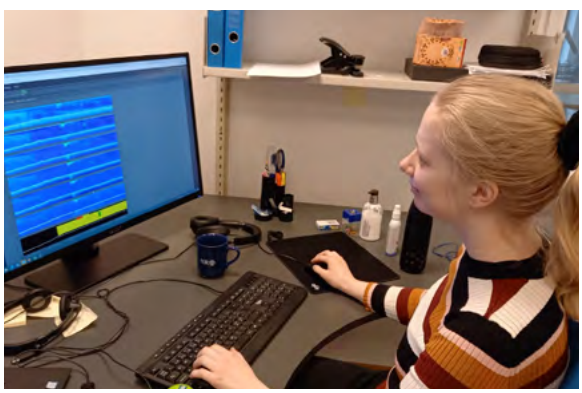


Figure 3. Ingrid Utseth (NR) working on acoustic target classification problems.

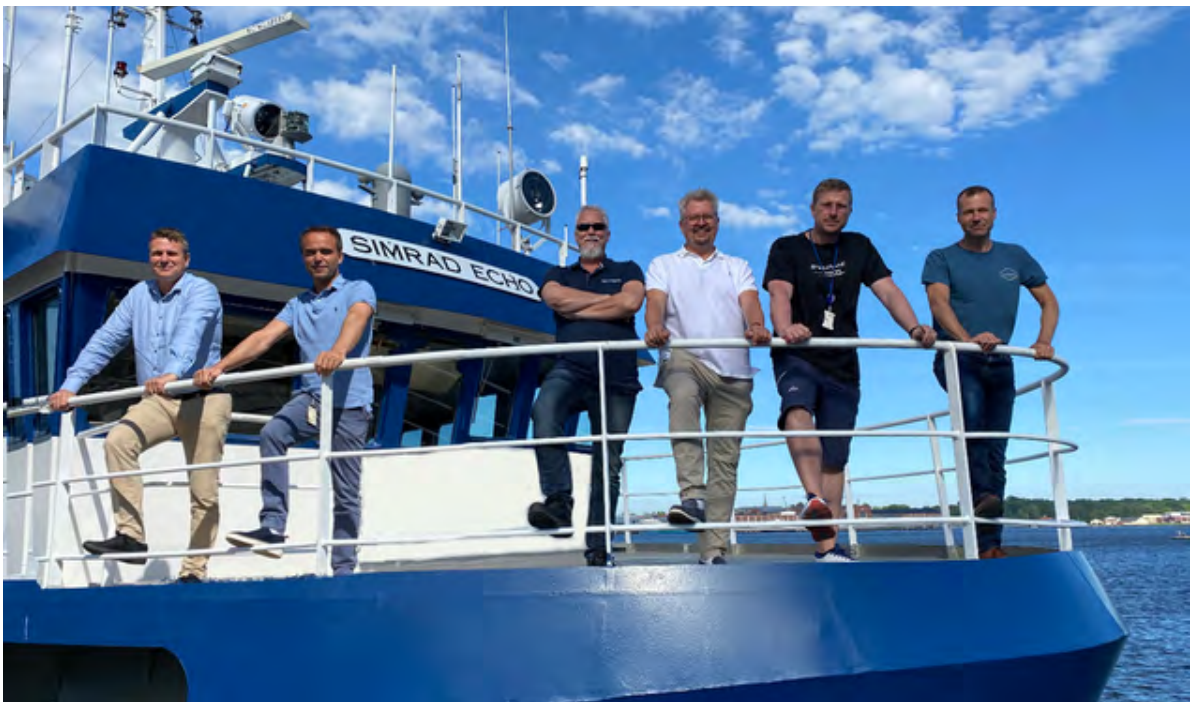


Figure 5. Kongsberg Discovery.

INDUSTRY PARTNERS

Kongsberg Discovery (KD)

Kongsberg Discovery specializes in cutting-edge technology that provides vital insights and key data about life in the oceans and ecosystem conditions. From shallow water wind farms to the deepest oceans, we offer a comprehensive range of systems optimized for ultimate ocean mapping and subsea positioning accuracy, enhancing operational efficiency.

Sustainable development of the oceans and their resources is an integrated part of KD's strategies, through the commercial fishery and marine research sector. The main reason for KD'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 KD contribution to the CRIMAC centre is mainly focused on wideband acoustics, 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 KD wishes to position as highly relevant supplier of scientific based products and solutions for users of the coastal and ocean areas

Figure 6. Scantrol Deep Vision AS.

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 3 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 CO2 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.

Figure 7. MS Libas from Liegruppen.

Liegruppen fishery are employing about 50 fishers/ 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.

Figure 8. MS Eros.

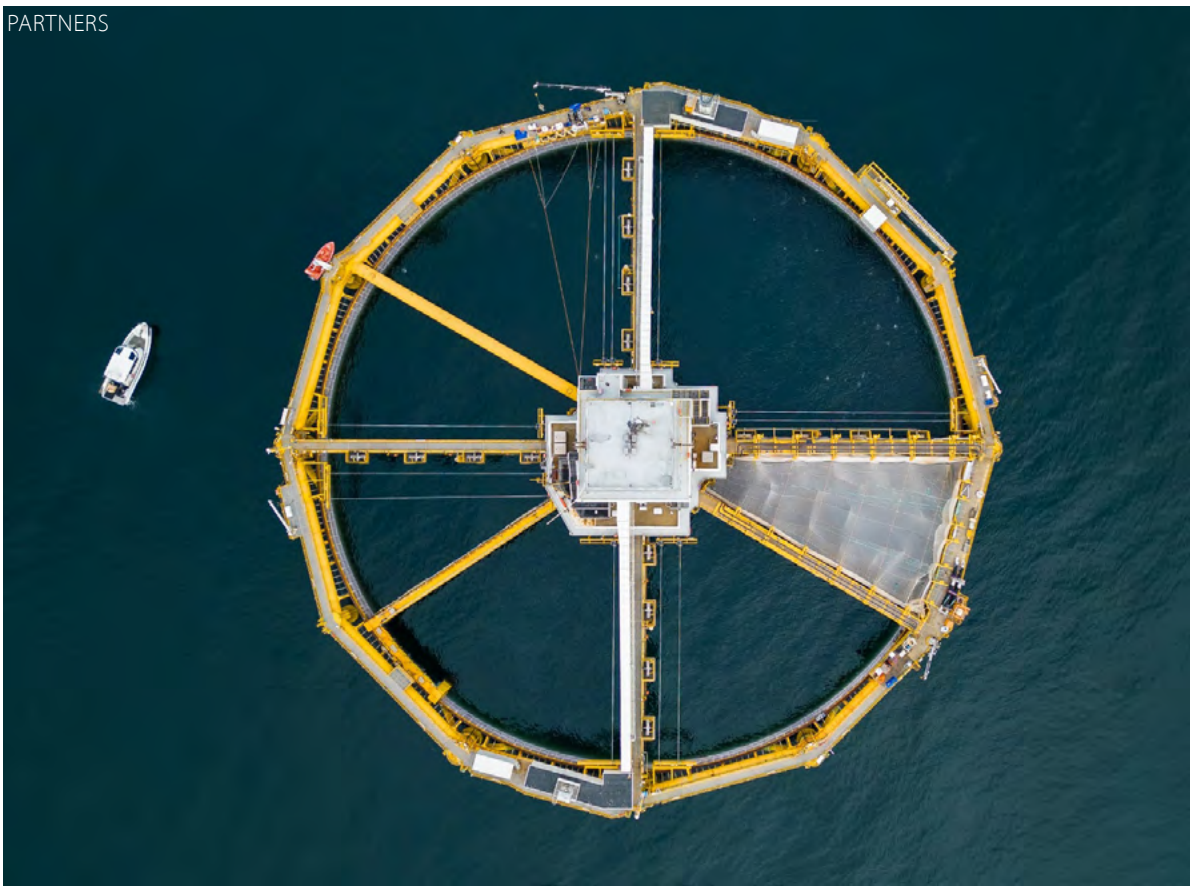


Figure 9. Salmar Aker Ocean's Ocean Farm.

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 Ocean Farming (OF), organized under SalMar Aker Ocean (SAO), two 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, behaviour, 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.

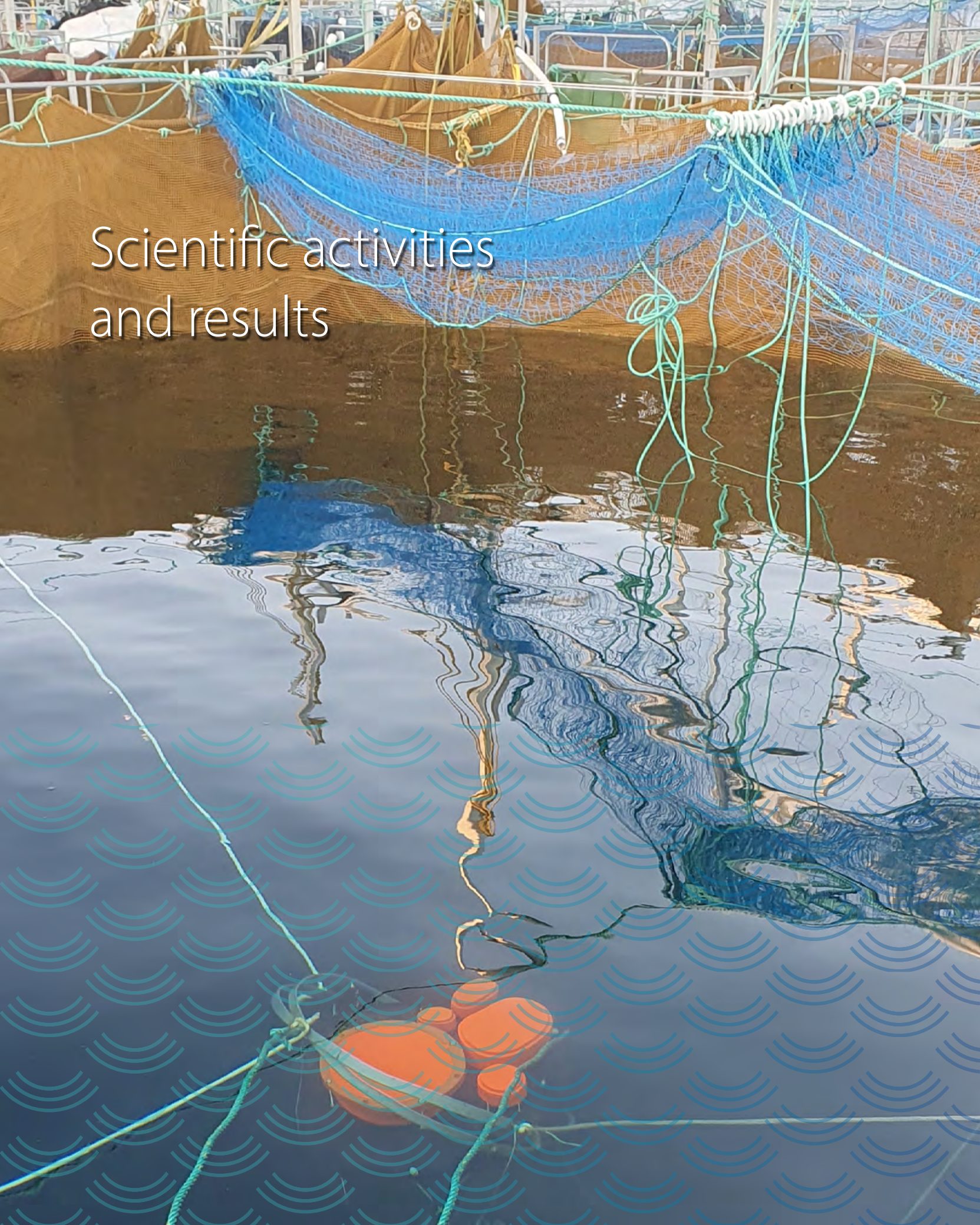
New instruments and methods developed in the CRIMAC program may be suitable for salmon and trout farming, and our interest is to test this in commercial/full-scale aquaculture units in Salmar, especially instrumentation that can contribute to success in exposed aquaculture and offshore aquaculture.

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

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.

Acoustic modelling of backscattering by fish

Backscattering models are a key element in fisheries acoustics, enabling the interpretation and conversion of acoustic data into biological information. Many marine organisms, or their primary reflective structures (e.g., swim bladders), have elongated shapes. The prolate spheroid, a volume obtained by rotating an ellipse around its major axis, is an attractive geometry for modelling such objects. It is one of the few geometries with an analytical scattering solution.

However, this solution is not only computationally demanding but also requires handling numerical overflow and underflow, as well as high-precision arithmetic, to address ill-posed systems of equations—particularly at higher frequencies where the wavelength is small compared to the objects size. These challenges have historically limited the validity of existing solutions to low frequencies.

Approximate solutions have been proposed to overcome the difficulties associated with the exact solution.

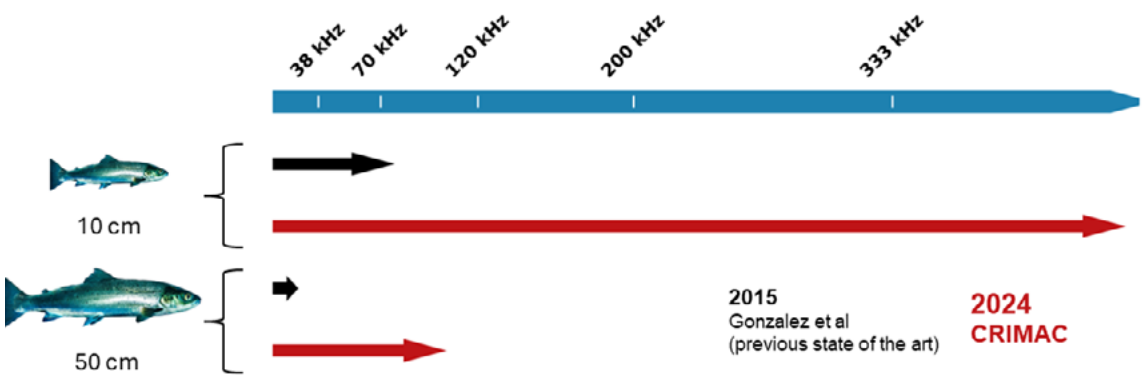


Figure 10. Validity (fish size and frequency) of the new spheroid model vs previous state of the art for swimbladders with size corresponding to 10 and 50 cm fish length (salmon photo Erling Svensen/ Havforskningsinstituttet).

However, they are only reliable for near-broadside incidence or applicable only to very weakly scattering objects (impedance contrasts < 0.2%). These limitations restrict the practical applicability of existing models.

In CRIMAC, we have addressed several of these issues and provide a stable solution for gas- and liquid-filled prolate spheroids over a much wider range of values and for all incident angles.The validity of the models can be quantified by the parameter $h_s(=\pi f d/c_s)$, where $f[Hz]$ is frequency, $d[m]$ is focal length, and c_s $[m/s]$ is the sound speed of prolate spheroid. Gonzalez et al., (2016) provided a solution valid up to $h_s = 24$. We have extended this limit to 173 and 230 for gas- and liquid-filled prolate spheroids, respectively. This corresponds to frequencies of $f = 73c_s/d$ for liquid-filled and $f = 55c_s/d$ for gas-filled targets.

As part of this effort, we have developed an open-source code, which is freely available at https://github.com/CRIMAC-WP4-Machine-learning/Prol_Spheroid_herring The optimized version can be found in the "vectorized" branch.

Platform-dependent broadband frequency response

Extracting detailed information from broadband acoustic signals, particularly regarding fish size, species, and behaviour, is an area of particular focus within CRIMAC. As part of this research, a series of experiments were conducted to examine how the avoidance behaviour of Norwegian spring-spawning herring, triggered by approaching vessels, influences the broadband signal. The study also investigated whether the differing responses to a traditional research vessel and a small uncrewed survey vehicle affect the broadband signal.

The findings indicate that by monitoring backscattering at high frequencies, it is possible to detect avoidance reactions that impact the signal and potentially estimates of abundance. Additionally, the study highlights the importance of exercising caution when training automatic classification algorithms on data obtained from traditional vessels, as this may introduce bias when applied to other, smaller platforms.

The results of the research are presented in a paper published 2024 in the ICES Journal of Marine Science.

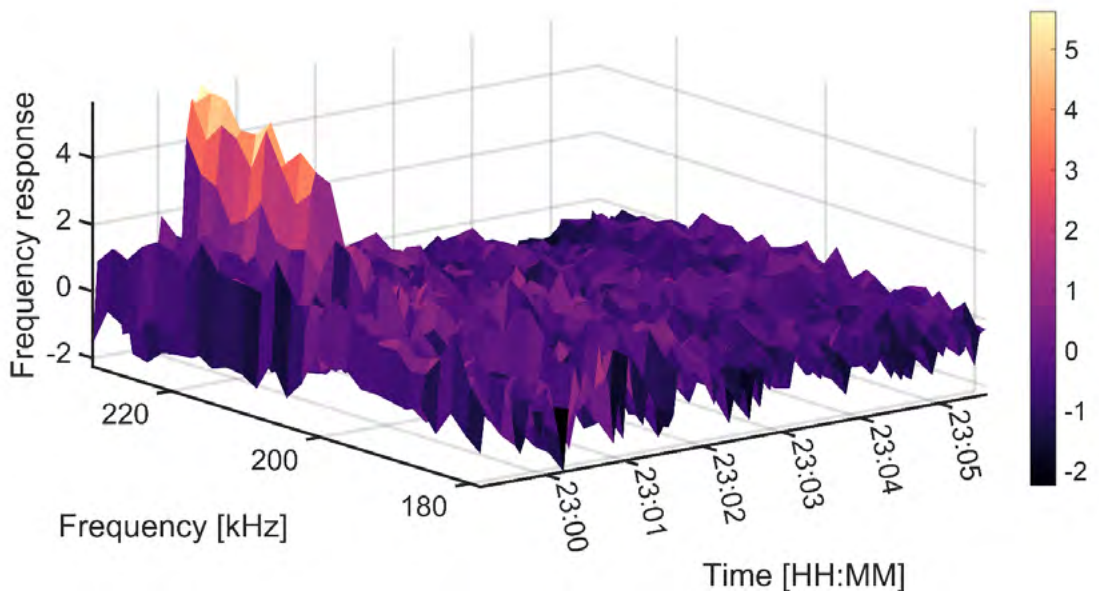


Figure 11. Time evolution of broadband backscatter from herring, the peak between 23:00 and 23:01 indicate an avoidance reaction (diving) to a research vessel.

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 large tanks and net pen mesocosms at IMR's Austevoll and Matre research facilities, at-sea from vessels using hull-mounted echo sounders, offshore wind farms instrumented with acoustics and close-range probing systems.

Testing the new Kongsberg Discovery 18 kHz frequency broadband transducer (ES18-11mk2)

The ability to use the EK80 broadband echosounder at lower frequencies than those available with current transducers is highly desirable, particularly for the characterization of mesopelagic fishes.

Kongsberg Discovery has developed a new version of their 18 kHz scientific echosounder transducer (ES18-11mk2), and parts of the 2024 CRIMAC survey were dedicated to testing this new transducer. An ES18-11mk2 was installed in the drop keel of GO Sars prior to the survey, replacing the old 18 kHz transducer. The EK80/18kHz system was extensively tested and verified during this survey. The transducer was also used to collect new broadband data on mesopelagic layers in Osterfjorden complemented with Deep Vision in-trawl camera data and automated image analysis algorithms (see WP3 for more information).

The new EK80/18kHz system performed well with both narrowband and broadband pulses. The narrowband performance was better, less ringing, than the previous versions of the 18 kHz transducer when comparing data from the CRIMAC 2024 survey with data from earlier surveys using the old system.

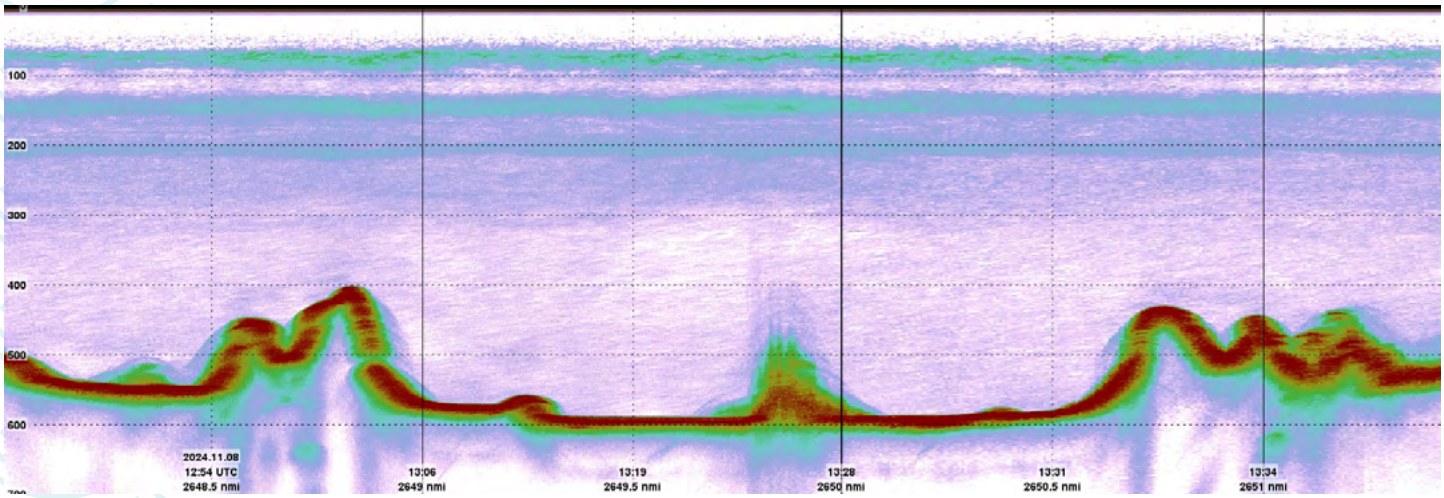


Figure 12. Broadband measurements of mesopelagic layers in Osterfjorden using the new 18 kHz transducer (ES18-11mk2).

Figure 13: Victor and Isabel from the University of Valencia measuring speed of sound in salmon flesh at Matre research station.

Test dataset for broadband data processing

We have published a test dataset for FM which can be used for development and testing of data processing methods. New algorithms for processing broadband echosounder data are being developed, and test datasets are of high utility when developing and demonstrating new algorithms. This can serve as a resource and a common data set for benchmarking and testing within the fisheries acoustics community. The test data include subsets of files from experiments, where broadband echosounders have been deployed covering a wide range of applications. The acoustic targets include fish, with and without swim bladder, larger zooplankton, and calibration spheres. The data sets contain a collection of data files from the Simrad EK80 system, including associated metadata and calibration data. The data set represents an openly available collection of broadband echosounder data sets for testing, developing, and showcasing new data processing methods on broadband acoustic data. Here is the link to the datasets: http://metadata.nmdc.no/metadata-api/landingpage/f0bdafac077ee736926b57c422221f27

Measurements on speed of sound in salmon flesh, and x ray of several sizes as input to modelling cooperation with University of Valencia

Víctor Espinosa Roselló and Isabel Pérez Arjona from the University of Valencia visited the CRIMAC centre. They are interested in modelling the backscatter from fish and have developed a model based on the method of fundamental solutions. They brought equipment for measuring the density and speed of sound in fish flesh. In addition, x-ray of salmon with different sizes was obtained. Isabel's model will be adapted to salmon and used to simulate the backscatter from salmon for the size groups we have measured in CRIMAC and compare to measurements.

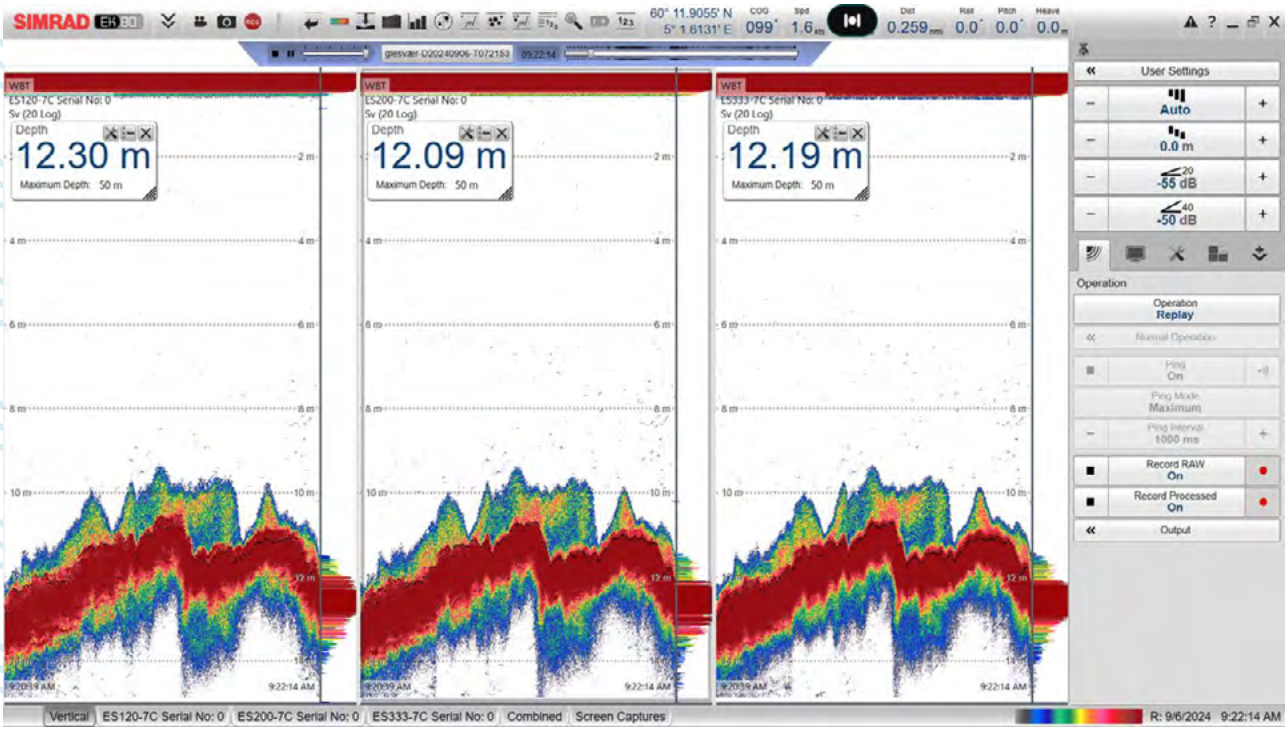


Figure 14: Echogram showing the bottom in red and visible kelp in green, orange and blue over the bottom for 120 kHz (left), 200 kHz (centre) and 333 kHz (right).

Broadband measurements on Kelp

Kelp forests are among the most productive and ecologically significant marine ecosystems. These underwater forests provide habitat and food for diverse marine species, support fisheries, and act as natural coastal barriers against erosion and storm surges. Kelp also plays a crucial role in carbon sequestration, helping to mitigate climate change by absorbing CO_2 from the atmosphere.

However, kelp forests worldwide are declining due to climate change, ocean warming, pollution, and overgrazing by sea urchins in the absence of natural predators. Monitoring the kelp forests are important. Traditional monitoring methods, such as diver surveys and satellite imagery, can be costly, time-consuming, and limited by water clarity. Acoustic echo sounders offer a promising alternative for kelp monitoring. Acoustic echo sounders offer a promising alternative for kelp monitoring. A little experiment was made with three EK80 echo sounders (120, 200 and 333 kHz) to test if it is possible to separate the three categories, kelp, bottom and air. Preliminary results show that the separation of the categories are possible both for CW and FM signals. It may also be possible to separate different kelp species based on different Sv(f) and height.

WP3

Ground truthing methods

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

WP3 develops and implement techniques for identifying and measuring the sources of broadband backscatter using mainly optical verification tools, such as stereo camera systems. The WP also evaluates and further develops sampling methods for acoustic surveys. We are especially focussing on developing in-trawl camera systems that can improve the temporal and spatial resolution of trawl samples. When combined with open codend, it is also a less invasive sampling method. The WP cooperates closely with the industry partners and aims to identify applications to commercial fisheries.

Improved algorithm to detect, identify and count mesopelagic species in trawl images

Mesopelagic organisms form extensive deep scattering layers between 200 and 1000 m depth and are therefore commonly detected with echosounders. However, extracting species and length composition from acoustics alone is challenging. We have automated the detection of seven common mesopelagic groups in the Norwegian Sea and West-Norwegian fjords: barracudina (Arctozenus risso), lanternfishes (dominated by Benthosema glaciale), silvery lightfish (Maurolicus muelleri), krill (dominated by Meganyctiphanes norvegica), pelagic shrimps (Pasiphaea spp., Eusergestes antarcticus), gelatinous zooplankton (e.g. Periphylla periphylla, Aurelia aurita), and squids (e.g. Gonatus spp.). In addition, we aim to identify the optimal image resolution to detect small objects and to compare the detection rates of different species under white versus red light.

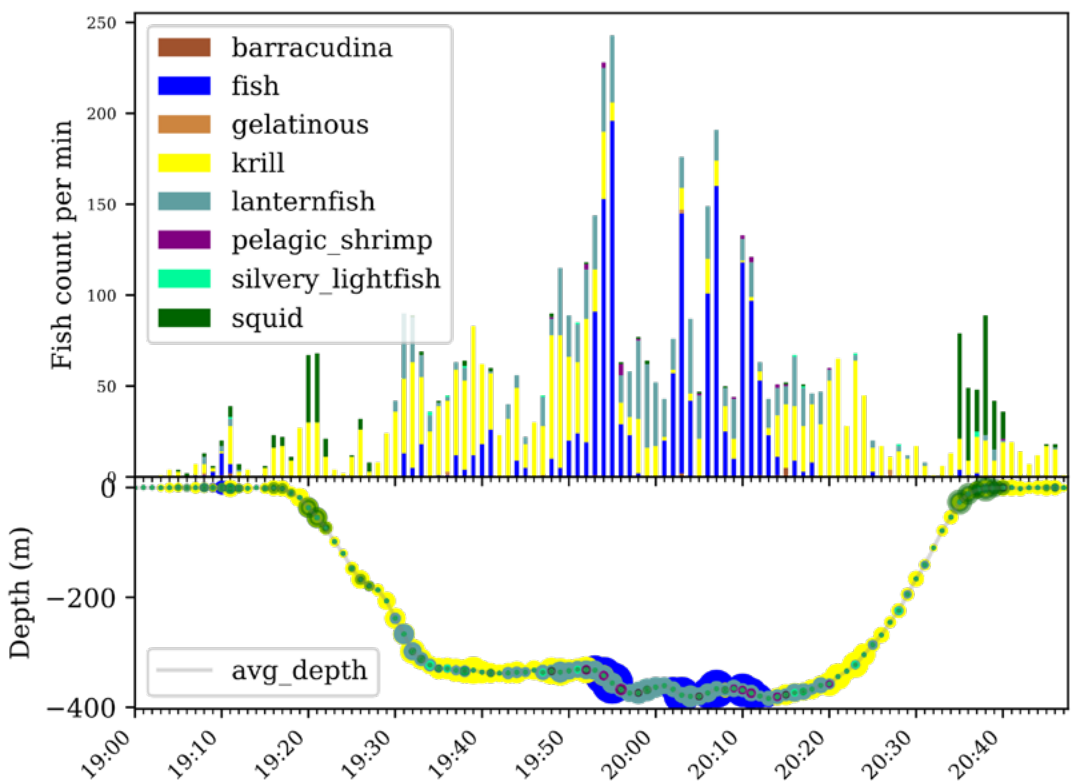


Figure 15. Information about mesopelagic species entering the trawl based on in-trawl images and machine learning algorithms for automatic species detection and count.

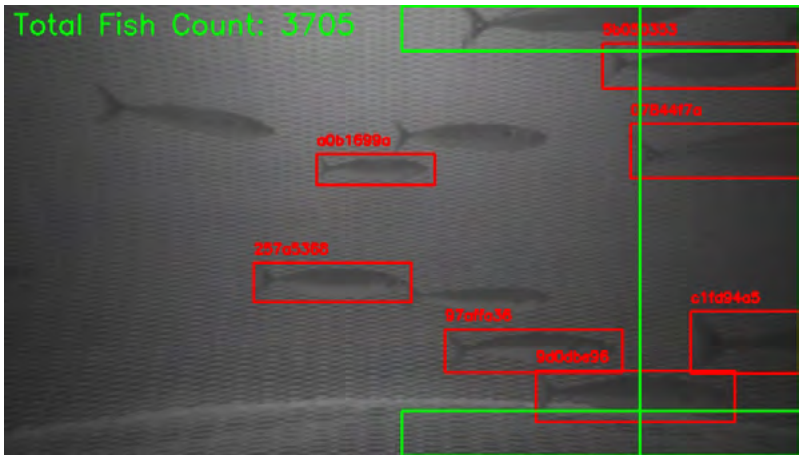


Figure 16. Automated tracking of mackerel imaged with an in-trawl camera system.

Mackerel swept area survey: Can sampling be improved with in-trawl camera systems?

The international Ecosystem Summer Survey in the Nordic Seas (IESSNS) is an important survey for monitoring of the distribution and changes in abundance by age of mackerel using surface swept area trawling. Only a small fraction of the caught fish in large catches is needed for biological sampling and is a waste of valuable resources when a high number of fish is discarded. Using trawl camera systems to accurately measure density, species and length distributions is likely to improve the accuracy of the survey. Combining it with closing and opening cod-end devices for random sub-sampling of adequate number of individuals for biological sampling will in addition significantly reduce the discarding of fish. In the summer 2024 data were collected with a stereo camera system (Mohn Technology AS) attached to the trawl on board MS "Vendla". Preliminary results on manual (MSc project Adrian Røsland) and automated machine learning based counting, length measuring and studying the behaviour of mackerel in the trawl are promising.

Methods to obtain clear images in demersal survey trawls using sediment suppression sheet

A challenge with using cameras in demersal trawls is poor visibility due to sediment swirled up by the trawl ground gear. DTU Aqua in Denmark have developed a method where a sediment suppression sheet is attached behind the ground gear for improved image clarity (Sokolova et al., 2022). In the November CRIMAC cruise we tested this method on the IMR Campelen 1800 demersal survey trawl on board GO Sars. The main objective was to optimise the setup of Campelen trawl with camera and sediment suppression sheet. The preliminary results indicate that the sediment suppression sheet effectively reduced the sediment plume and improved visibility in the trawl cameras. There were no clear indications of effects on trawl geometry or catch efficiency from the sediment suppression sheet. However, a more detailed data analyses is required before any conclusions can be made.

Figure 17. Adrian Røsland and Jostein Saltskår are attaching the sediment suppression sheet in the trawl. The aim was to improve image clarity by reducing the interference from sediment swirled up by the ground gear.

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.

KoronaScript

The KORONA library provides a large set of functions to process and manipulate echo sounder data. In response to needs from the CRIMAC project, it has been extended with new functionality for broadband processing and output formats. KORONA is normally run as a graphical application, either from the LSSS application, or using its own interface for configuring the processing pipeline. For automation (in particular, the data processing pipeline described below), a programmatic interface accessible from Python is needed. To these ends, we have designed and implemented a Python package, KoronaScript, that implements an API to the various KORONA modules (Figure 18).

https://github.com/CRIMAC-WP4-Machine-learning/CRIMAC-KoronaScript

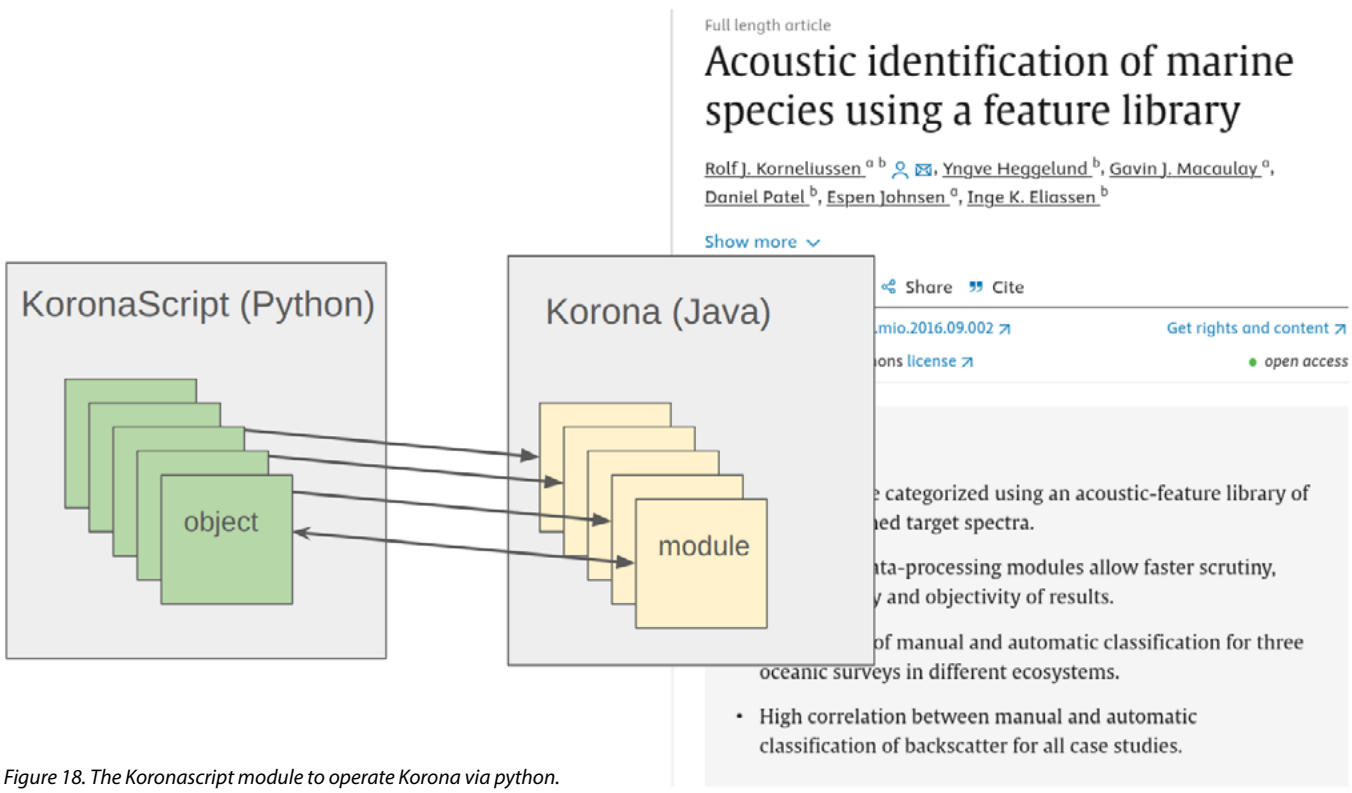


Figure 18. The Koronascript module to operate Korona via python.

Data processing pipeline

Broadband measurements result in large amounts of data where the acoustic broad band signals include information in the frequency domain which is not straightforward to interpret due to the complexity of the backscatter of moving objects like fish. For this reason, efficient signal processing methods are needed to adapt the data to a format, like NetCDF, which can serve as input to algorithms using artificial intelligence.

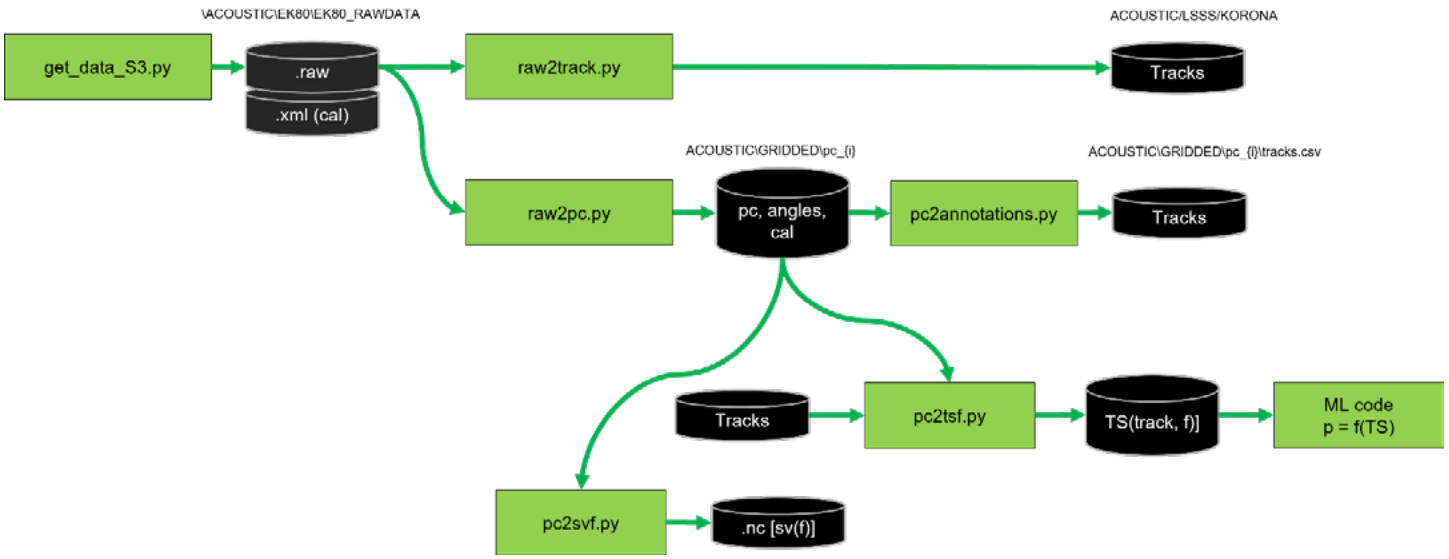


Figure 19: FM data processing pipeline from raw data to pulse compressed NetCDF format which can serve as input to AI algorithms.

Foundation models for acoustic classification

Where semi-supervised methods leverage unlabelled data in conjunction with scarcer labelled data, unsupervised and self-supervised methods aim to derive a representation directly from unlabelled data. Most existing methods are targeted to image data, and adapting these methods to acoustic data can be challenging. We have developed a novel method inspired by DINO (Pala et al., 2024)acoustic signals are sent into the water and the strength of the reflection, so-called backscatter, is recorded. The collected data are typically annotated manually, a process that is both labor-intensive and time-consuming, to support acoustic target classification (ATC, and shown that it can accurately identify clusters of acoustic signal that in turn can me matched to specific species. We are currently exploring a different approach, based on masked auto-encoders (MAE).

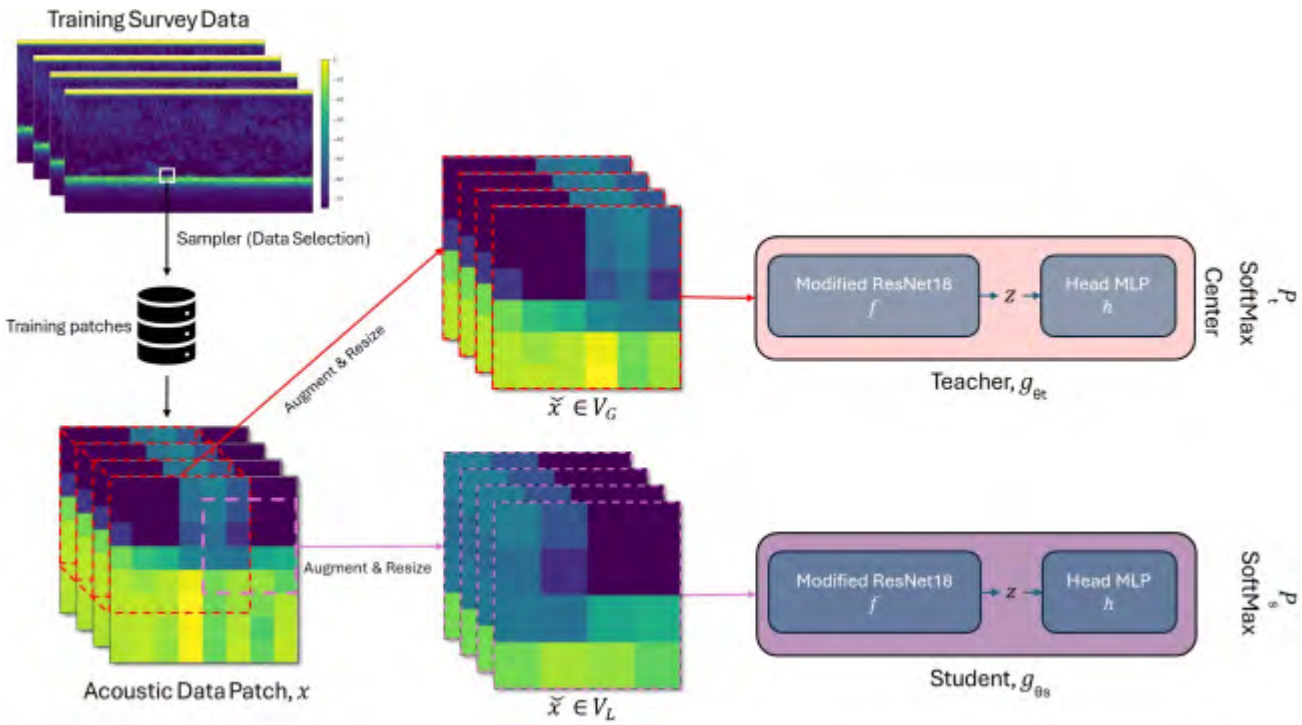


Figure 20. The illustration shows the self-supervised learning model for acoustic data as a 2D grid, with the x-axis for ping time and the y-axis for depth. Acoustic data patches are first extracted from training survey data using a predefined sampling scheme. For each patch, two global and eight local views are created, forming sets VG and VL . Pairs of views are selected, with one pair assigned to the teacher network and the other to the student network. The teacher network receives only global views, while the student network can receive all views, ensuring alignment in their outputs (Pala et al., 2024, CC-BY 4.0).

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 are being 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.

Joint sprat survey in Hardangerfjorden with research vessel and remotely operated USV

The coastal spart survey is conducted each year in the fjords Hardangerfjorden, Sognefjorden, Nordfjord and Trondheimsfjorden. In 2024 the research vessel Prinsesse Ingrid Alexandra was accompanied by the USV Frigg, remotely operated from the Remote Operation Centre ROC (Figure 21) in Nykirkekaien in Bergen. During the survey different methods for retrieving acoustic and other data from the USV were tested, laying the grounds for live monitoring and analysis of the echosounder data from USVs which can be used to identify locations for trawling by the research vessel in future surveys.

Figure 21. Live monitoring and operation of the USV Frigg from the remote operating centre at in Nykirkekaien in Bergen.

Silent uncrewed surface vehicles reveal the diurnal vertical distribution of lesser sandeel

The paper by Sakura Komiyama, Arne Johannes Holmin, Geir Pedersen and Espen Johnsen was accepted late 2024 and published early 2025, and shows an analysis of the vertical distribution of lesser sandeel observed by two Saildrones with little disturbance to the fish. The results provide insight to changes in behaviour of sandeel during the day and during the feeding season (Figure 22), and the relationship between the sandeel and zooplankton diurnal vertical distribution (Figure 23). The paper also shows a considerably deeper vertical distribution of sandeel observed by the fishing FV Eros that conducted the biological sampling in the survey, compared to the data from the Saildrones (Figure 24).

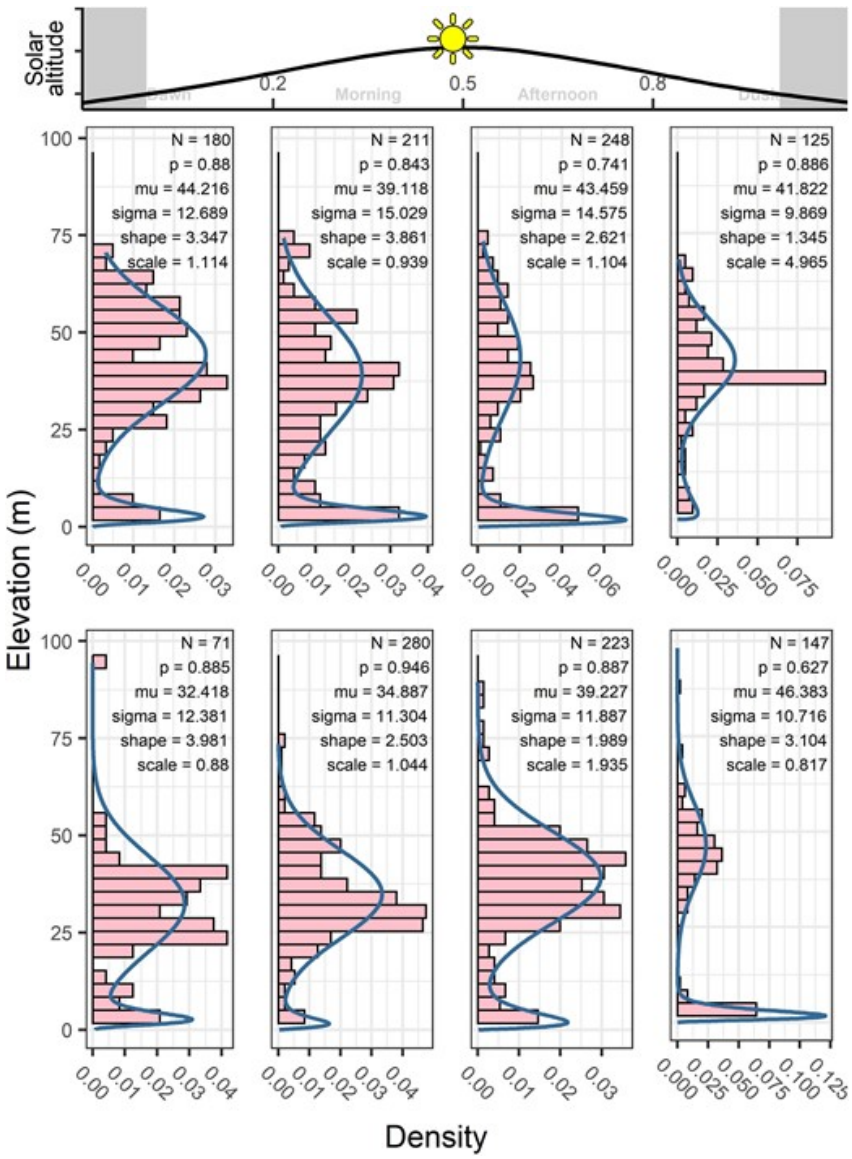


Figure 22. Vertical distribution of sandeel observed by Saildrone in May (upper panel) and Juni (lower panel) shown by time of day (dawn, morning, afternoon and dusk) (Komiyama et al., 2024, CC-BY 4.0).

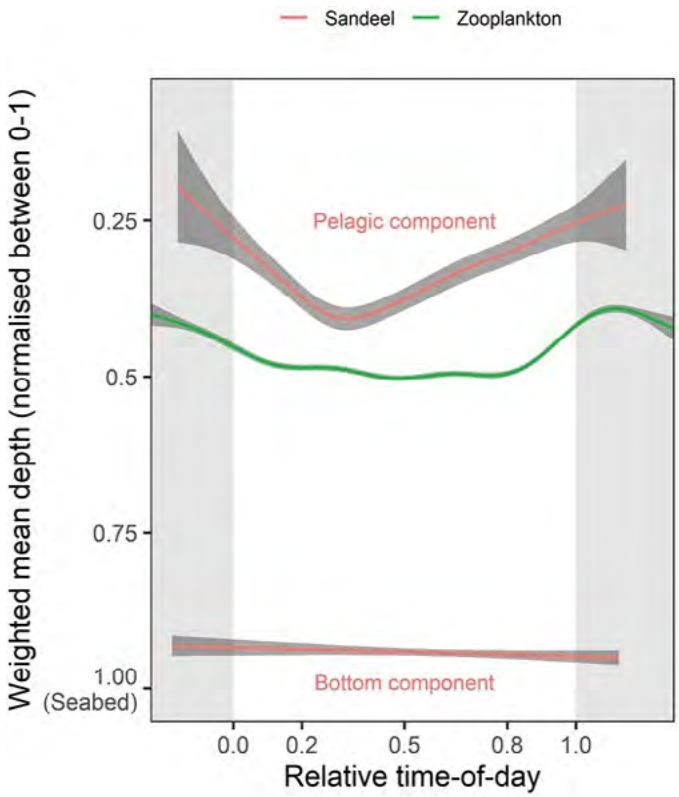


Figure 23. Location of the pelagic and bottom component of the vertical distribution of sandeel by time of day compared to the mass center of the plankton vertical distribution (green) (Komiyama et al., 2024, CC-BY 4.0).

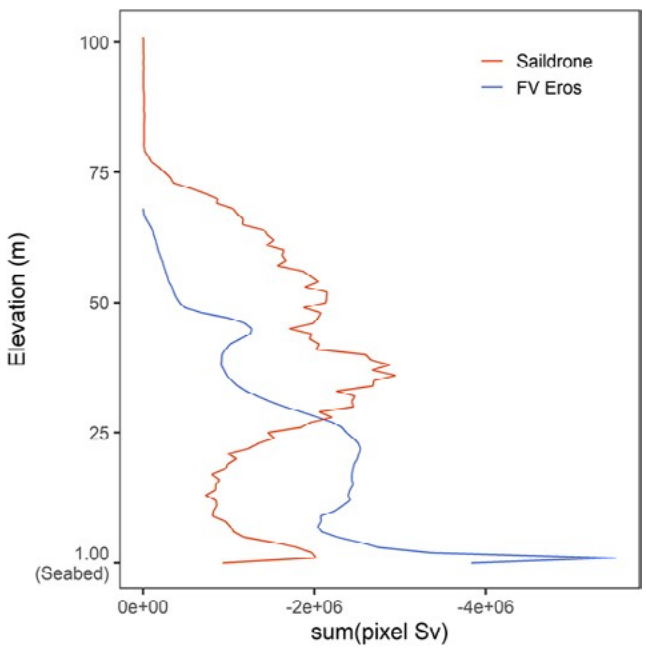


Figure 24. Vertical distribution of sandeel observed by Saildrone in orange versus FV Eros in blue (Komiyama et al., 2024, CC-BY 4.0).

USV paper summary

Uncrewed surface vehicles (USVs) can potentially replace or enhance acoustic data collection from traditional research vessels (RVs), offering expanded spatial and temporal coverage while reducing costs and carbon emissions. CRIMAC has provided a review of the objectives, system needs, infrastructure, and legal requirements for using USVs in ecological experiments, acoustic-trawl surveys, and long-term monitoring. Sail-driven USVs, though slower, can operate for months continuously, while motorized USVs can match RV speeds, allowing for combined surveys with synchronized USV and RV transects. Critical considerations for USVs include design, noise reduction, communication infrastructure, onboard data processing, and legal compliance. Although this technology is advancing, further development and institutional support are needed for USVs with echosounders to become standard tools in the global network of autonomous ocean observation platforms.

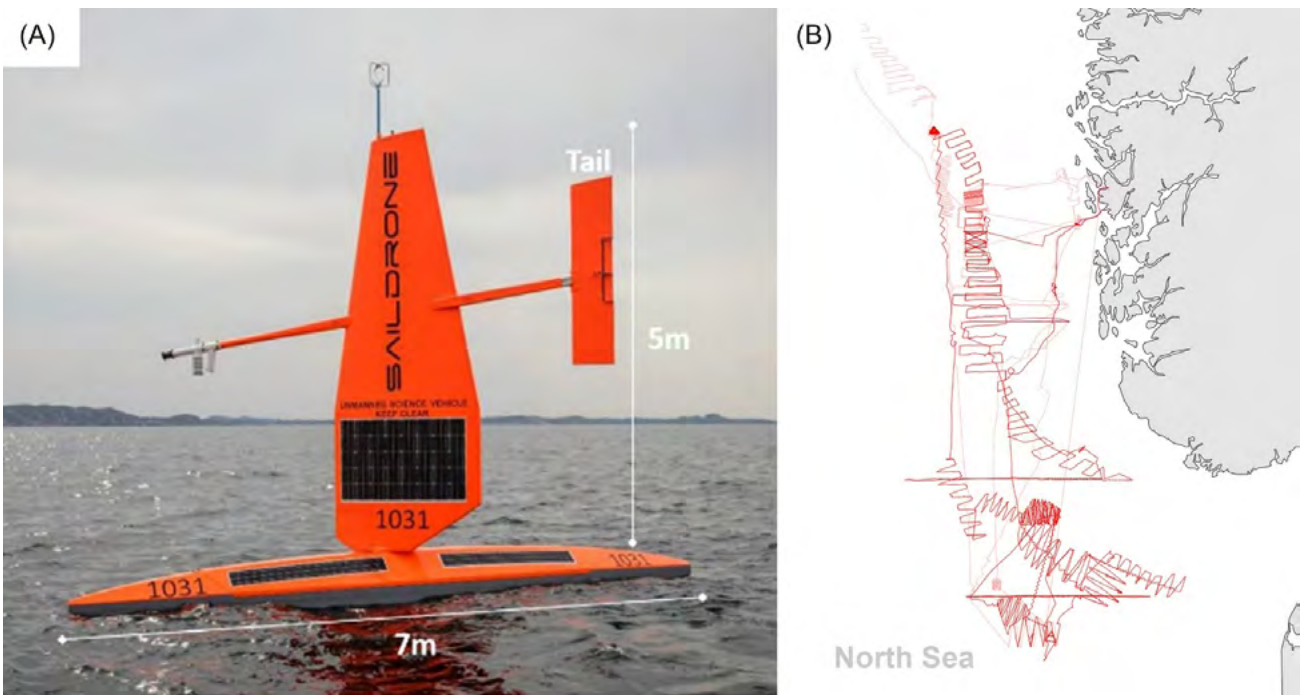


Figure 25. A Saildrone Explorer (A) was utilized to investigate the schooling behavior and spatial and temporal distributions of lesser sandeel along its track lines in the northeastern North Sea (B) (Handegard et al., 2024, CC-BY 4.0)

User stories

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 user stories below highlight examples of the links between the science and user partners in CRIMAC.

User story: Kongsberg Discovery Blue Insight infrastructure

Kongsberg Discovery are developing a new cloud-based software product for ocean data. The first official product launch is planned for spring 2025, and several of the CRIMAC related innovations are intended to be built into products in 2025 and beyond. This is a key product that will allow methods developed in CRIMAC to be deployed for users in the thematic areas that we are working in.

Relevant use cases for BI supported by CRIMAC are listed below. First is the implementation of the CRIMAC automated data pipeline and remote functionality for Sounder USV and IMR research vessel during Sand Eel and Sprat survey 2025. This includes compression, transfer and decompression of data, acoustic target classification on edge, and data quality. The second BI use case is the implementation of data quality control functionality in Blue Insight for various type of echo-sounder users.

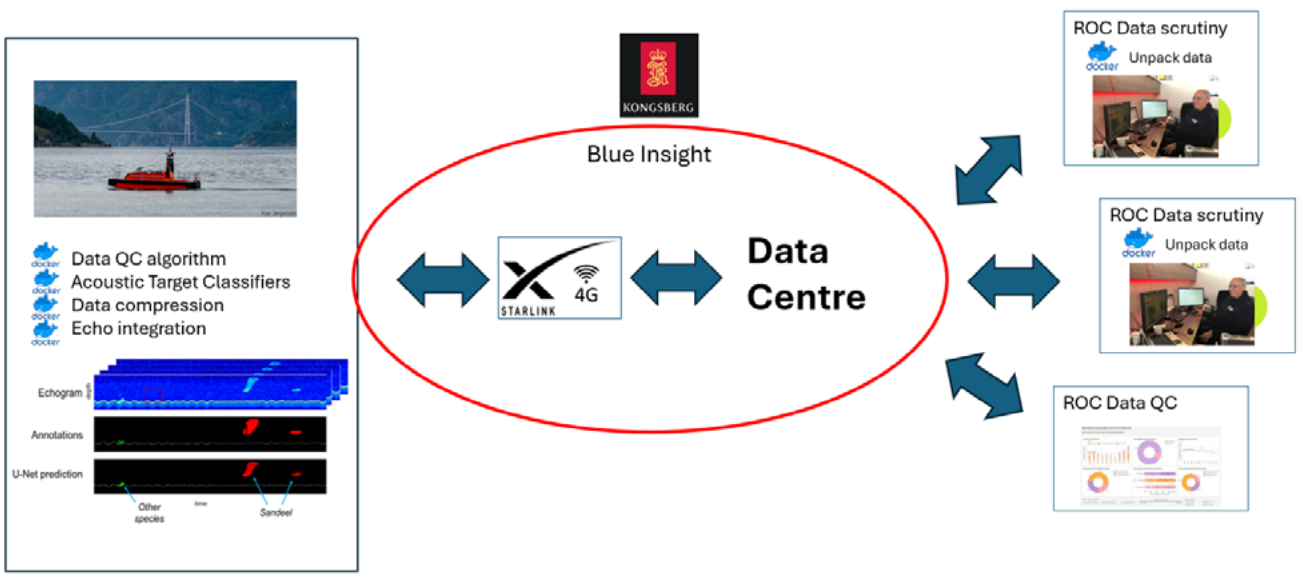


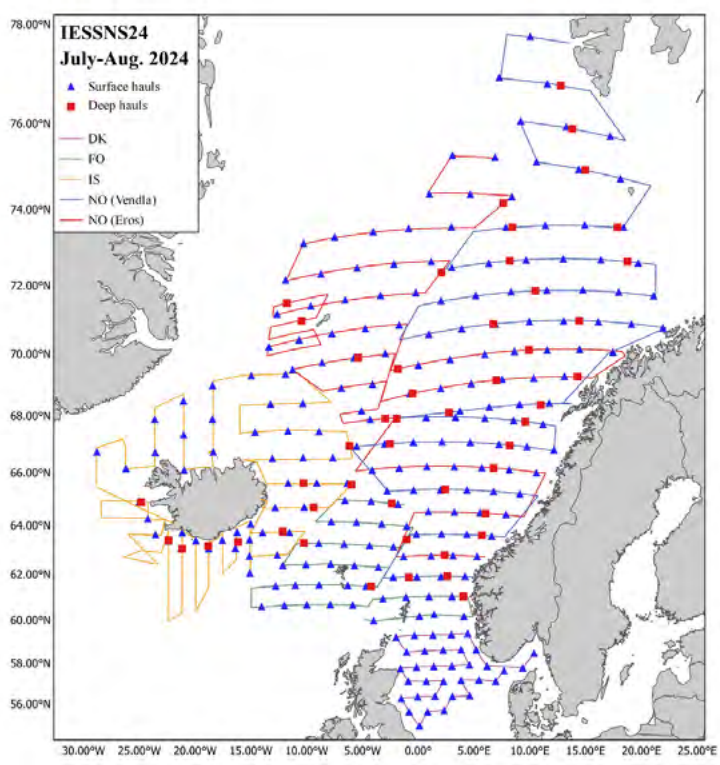
Figure 26. KD Blue Insight framework and how it is envisioned for the Sounder implementation and the remote operating centre.

User Story:
International Ecosystem Summer Survey in the Nordic Seas (IESSNS)

The International Ecosystem Summer Survey in the Nordic Seas (IESSNS) primary aim is to provide an abundance index for the northeast Atlantic mackerel (Scomber scombrus) using a standardized pelagic swept surface area trawl method (Figure 27). The survey is carried out by several nations, including Norway. Since the catches are used as a measure of the swepa area, there are occasional large catches. IMR pay market price for the catches and there is a desire to reduce the costs by only taking subsamples for biological parameters and use optical systems for counts and species identification. The process involves HI digital, DV product team, the mackerel survey monitoring program, and the CRIMAC centre. The overarching goal is to test the camera systems for mackerel fish in 2025.

CRIMAC has been instrumental in the building of a pipeline, in collaboration with Scantrol, that facilitates the automatic image analysis from the thousands of images collected by the in-trawl camera system. We will further develop this pipeline and use it for the IESSNS.

Figure 27. The IESSNS survey by Denmark (DK), Faroes Islands (FO), Iceland (IS), and Norway (NO). This is a swept area survey where the catches are used to calculate swept area indices of abundance.



Workshops

CRIMAC – Workshop on data processing

Acoustic data are being collected from a range of platforms and purposes, leading to an increase in data volume. Additionally, historical records from years of data collection are now more accessible for analysis. In both scenarios, traditional manual data processing methods are challenging as they do not scale well. A CRIMAC workshop was held September 26.–27. 2024 covering both the use cases where large amounts of data are collected and the technological and logistical solutions for processing and analysing the data. The objectives of the workshop were to investigate best practices for big data processing on fisheries acoustic data, to identify current bottlenecks, and to write up a summary report with guidance for the community.

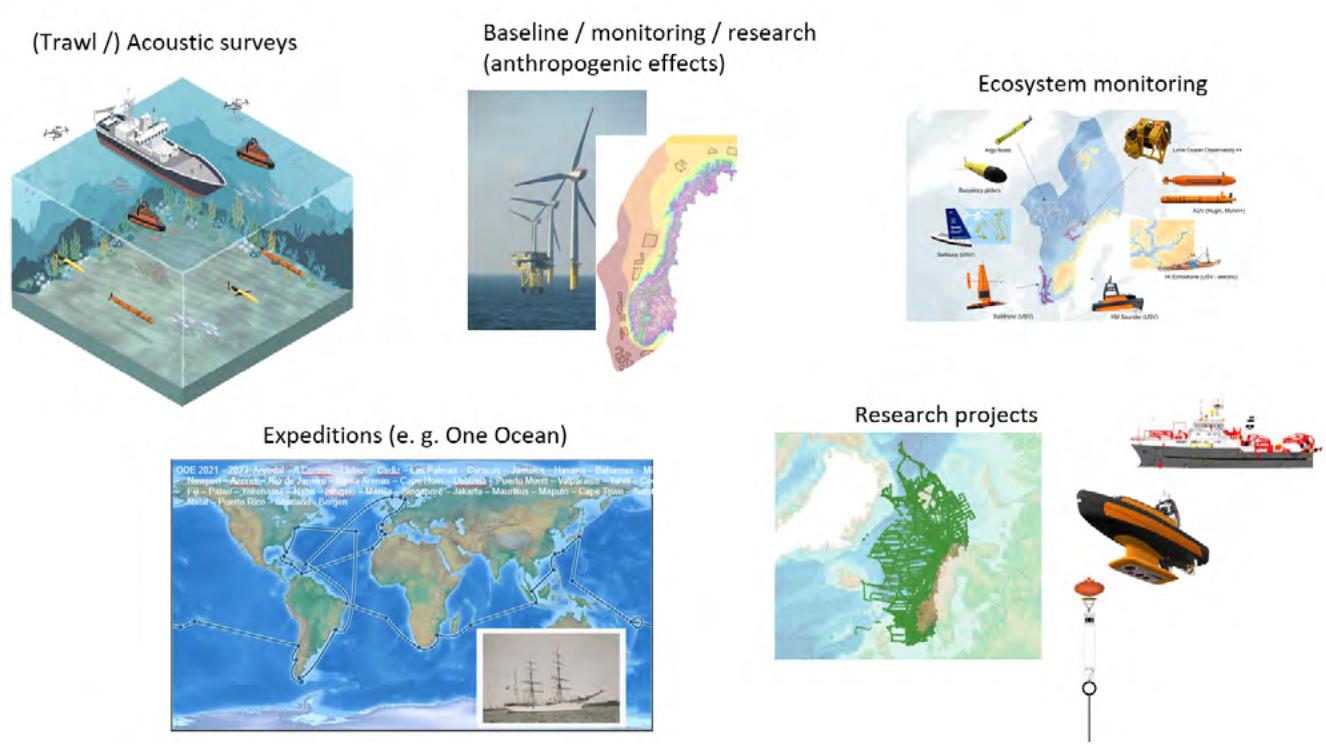


Figure 28. Examples of use cases where large amounts of data are collected where modern data processing techniques are needed.

Associated projects

CRIMAC IS COLLABORATING WITH OTHER SFI'S AND HAVE SEVERAL ASSOCIATED PROJECTS FUNDED TO STRENGTHEN THE ACTIVITY IN THE CENTRE.

Acoustic estimation of fish size before catch during commercial fishing for pelagic species

The Norwegian Seafood Research Fund funded project (FHF) «Akustisk estimering av fiskestørrelse før fangst under kommersielt fiske etter pelagiske arter» (Acoustic estimation of fish size before catch during commercial fishing for pelagic species) is associated with SFI CRIMAC and aims to develop methodology for estimating fish size using broadband echo sounders. Experiments using a narrow transducer were carried out on board the fishing vessel "Libas" during mackerel fishing in British waters off the coast of Scotland in September 2023, showing that individual fish could be resolved in dense schools of mackerel.

Can whale deterrent devices also scare the fish?

In a Norwegian Seafood Research Fund funded project (FHF) the aim is to investigate if whale by-catch in herring purse seine fisheries can be mitigated by using acoustic deterrent devices. Some of the sound signals used are also in the hearing range of herring. One of the tasks in the project is to ensure that herring behaviour is not affected by the sound signals. The field experiments for the project were carried out on board RV G.O. Sars in collaboration with CRIMAC. The paper describing the experiments and results are under revision.

Smart AUVs for detection and quantification of greenhouse gas seepage in the oceans (Smart AUV)

The Research Council of Norway funded project "Smart AUVs for detection and quantification of greenhouse gas seepage in the oceans" aims to improve the monitoring capabilities of AUV by applying artificial intelligence and signal processing technics to enable UAV decision autonomy. CRIMAC tools were tested for detection and characterization of CH4 and CO2 seeps measured with scientific echosounders during a field campaign in 2024. The project will contribute to improved monitoring of the oceans and sound management of marine activities. The project is coordinated by The Norwegian Geotechnical Institute (NGI).

Harvest SFI

HARVEST SFI and the CRIMAC SFI is collaborating on platform navigation methods. This collaboration is through co-supervising a PhD student, c.f. the student presentation in this report. The work addresses automated USV control with data quality as a metric for the operation.

Visual Intelligence SFI

Visual Intelligence SFI focus on deep learning-based solutions for cutting-edge complex image analysis, and SFI CRIMAC and SFI Visual Intelligence work together on image-based acoustic target classification methods and error propagation from deep learning model predictions.

Cooperation

INTERNATIONAL COOPERATION

Northwest Fisheries Science Centre, NOAA, Washington, USA
Alaska Fisheries Science Centre, NOAA, Washington, USA
Southwest Fisheries Science Centre, NOAA, California, USA
Florida International University, Florida, USA
NOAA Fisheries, Office of Science and Technology, Maryland, USA
Memorial University of Newfoundland, Saint Johns, Canada
Cupar Analytics Ltd, Great Britain: Cupar, Fife (Scotland)
Heriot-Watt University, United Kingdom, Edinburgh, Scotland
Ifremer Centre de Brest, Brest, France
Ifremer, Nantes, France
Instituto Español de Oceanografia, Spain
Universitat Politècnica de València, Spain
Wageningen University & Research, Netherlands
Thünen Institute, Germany
Aqualyd Limited, New Zealand
Fisheries, NIWA, New Zealand
NIWA, New Zealand

Students

Training of the next generation researchers within the field is vital for future development, and CRIMAC contributes to this by supervising six PhD students. Five of these are hired within the centre and one is funded by the HARVEST project and co-supervised by CRIMAC.
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.

PhD STUDENTS

Ahmet Pala

Ahmet Pala has a master's degree in industrial engineering on machine learning and is currently doing a PhD. in Applied Mathematics at UiB. Ahmet also holds a bachelor's degree in Naval Architecture and Marine Engineering. He is included in the work package 4 of the CRIMAC Project and aims to apply machine learning/deep learning methods on acoustic data.

Ahmet is currently in his last year of his PhD. He has been working on machine learning techniques for acoustic target classification. The first project dealt with imbalance in data distribution between target species and background classes for acoustic target classification. A challenge lies in balancing the sampling process prior to identifying the correct class.

In his second project he tested several machine learning models and tested what would be the result if these were blindly used for the target classification.

In his third project, he has adapted unsupervised methods typically used in image processing to address acoustic target classification problems. This adaptation enables deep learning models to be trained on raw data without the need for labelled samples. Such an approach proves particularly advantageous when analysing datasets from new surveys or experiments. The fourth project tested this model on downstream tasks.

Ahmet is supervised by Guttorm Alendal and Anna Oleynik from UiB and Nils Olav Handegard from IMR.

Figure 29. Ahmet presenting his thesis work.

Sakura Komiyama

Sakura Komiyama received her second master's degree in biology and currently works for the CRIMAC project as a PhD research fellow. Her overarching interests are fish behaviour and species interaction within marine ecosystems, observing through up-to-date instruments such as broadband echosounders and uncrewed surface vehicles (USVs).

Sakura has work on time dependent (seasonal and diurnal) vertical distribution of sandeel schools based on echosounder data from Saildrone, which provides undisturbed observations of this strongly schooling fish species. Sandeel bury into the sediments for protection from predators but also need to migrate higher up in the water column to feed. This induces two components to the vertical distribution, one close to the bottom and one mid-water. Explaining this behaviour is of interest to Sakura, particularly in relation to the zooplankton layer. Her paper on this phenomenon was accepted late 2024 and published in February 2025. The paper is described under WP5.

In her next project, she will delve into inter-platform changes in acoustic backscatter and fish behaviour, aiming to provide insight into USV sourced acoustic data.

Sakura is supervised by Espen Johnsen and Arne Johannes Holmin from IMR and Arild Folkvord from UiB.

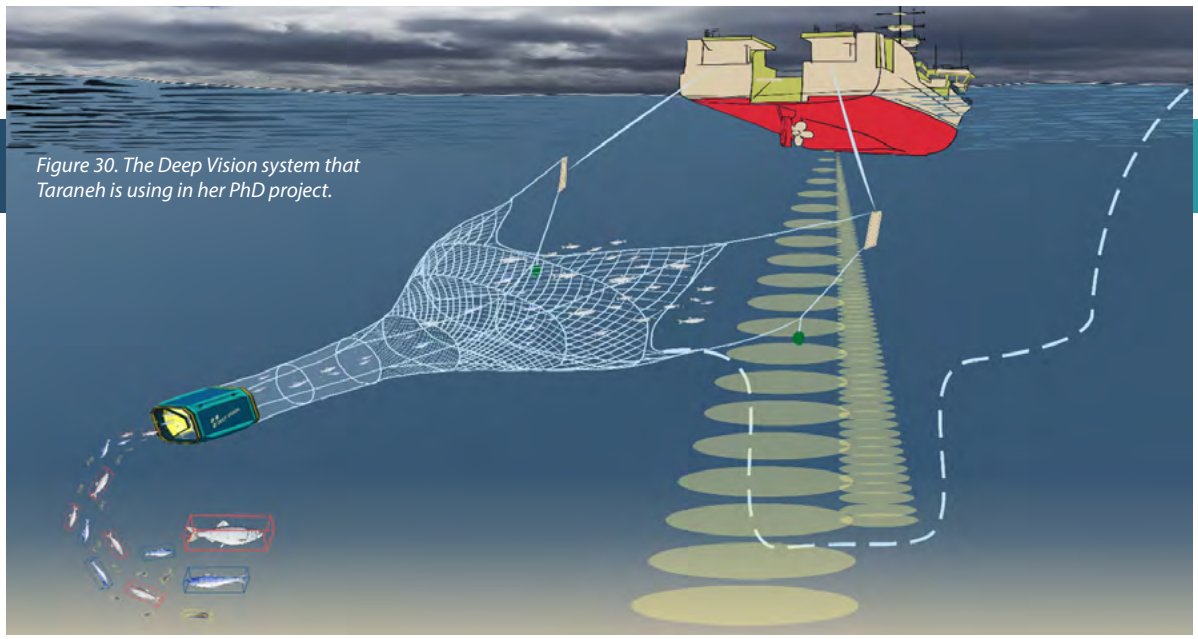


Figure 30. The Deep Vision system that Taraneh is using in her PhD project.

E. H. Taraneh Westergerling

Taraneh Westergerling completed an international Master's program in Marine Biological Resources (IMBRSea) in 2021. She is now a PhD Research Fellow at the Department of Biological Sciences at the University of Bergen and part of WP3 in CRIMAC. In her master's thesis she worked with applying the Deep Vision in-trawl camera system to pelagic fish research. The higher temporal and spatial resolution of trawl image data compared to trawl catches can aid interpretation of acoustic data and in the future image data may replace some of the trawl catch samples. Taraneh continues with the same topic in her PhD, but with focus on mesopelagic species.

Taraneh is now in her fourth year of the PhD. She has submitted her first paper where she studied fish behaviour in the trawl and how that affects the quality and accuracy of image-based fish counts and length distributions. In her second paper she is developing algorithms that can automatically detect, identify and count a range of mesopelagic species in trawl images. This will allow for scientific data collection of mesopelagic species (commonly lost in the codend) in traditional pelagic fish surveys. She will use the methods and algorithms in her final paper to describe the spatial distribution of mesopelagic species in the Norwegian Sea.

Taraneh is supervised by Maria Tenningen and Shale Rosen from IMR and Anne Gro Salvanes from UiB.

Figure 31. Taraneh using echosounders to look at biological organisms in the water column.

Yngve Bøe

Yngve Bøe has a Master in Instrumentation and Measurement Science and a bachelor's in physics. He started his PhD. in physics in September 2023. Yngve is working echosounder measurements and simulations on wide band backscatter from marine organisms, and he uses the salmon data set from Austevoll where 5 TB of acoustic echo sounder data from a netpen with salmon measured on six size groups of fish are available. The purpose is to estimate the size of the salmon based on frequency dependent target strength (TS) measurements. Parts of the signal processing pipeline combined with tracking with korona in LSSS provided TS(f) for each ping in each track for each transducers for the whole dataset. The information from the different channels/transducers are combined in the postprocessing to include TS(f) for the whole frequency range from 34–380 kHz. Information about the swimming angle of the fish is also found from the tracking, in addition to the position in the sound beam. A matrix of TS(f) for a range of frequencies and the tilt of the fish was used to train a convolutional neural network. The preliminary results from this looks promising for estimating the fish size.

Yngve is supervised by Tonje Nesse Forland from IMR and Audun Oppedal Pedersen from UiB.

https://mediearkiv.hi.no/fotoweb/archives/5000-Bilder/Bilder/Forskningsvirksomhet/Pr%C3%B8vetaking%20og%20m%C3%A5linger/HI-057924.jpg.info

Figure 32. Yngve connecting transducer cables for the echo sounder rig in Austevoll.

Helge Brøndbo Plassen

Helge Brøndbo Plassen holds a Master of Science in particle physics and a Bachelor in physics from the University of Bergen. He began his PhD. in physics in September 2023. His work is an integral part of the efforts carried out in Work Package 1 of CRIMAC. The main goals of Helge's PhD. are to improve our understanding of broadband acoustic processes and to enhance our ability to extract information from broadband acoustic signals.

He has developed a numerical simulation framework for broadband echosounder transducers, controlling each step from electric signal generation to reception. Additionally, he has an experimental setup in the acoustics lab at UiB, where he can test different signals and processing in a controlled environment. By combining modelling and measurements, he is now investigating partial wave analysis to improve calibration methods for broadband transducers. Partial wave analysis offers several yet fully exploited advantages over full wave analysis for calibrating broadband echosounders. The partial wave echo eliminates resonances in the frequency spectrum and is less sensitive to uncertainties in material parameters and dimensions of the calibration sphere.

Helge is supervised by Audun Oppedal Pedersen (UiB) and Geir Pedersen (IMR).

https://mediearkiv.hi.no/fotoweb/archives/5000-Bilder/Bilder/Forskningsvirksomhet/Pr%C3%B8vetaking%20og%20m%C3%A5linger/HI-057927.jpg.info

Figure 33. Helge (in blue) was helping with calibrating the echo sounder rig in Austevoll.

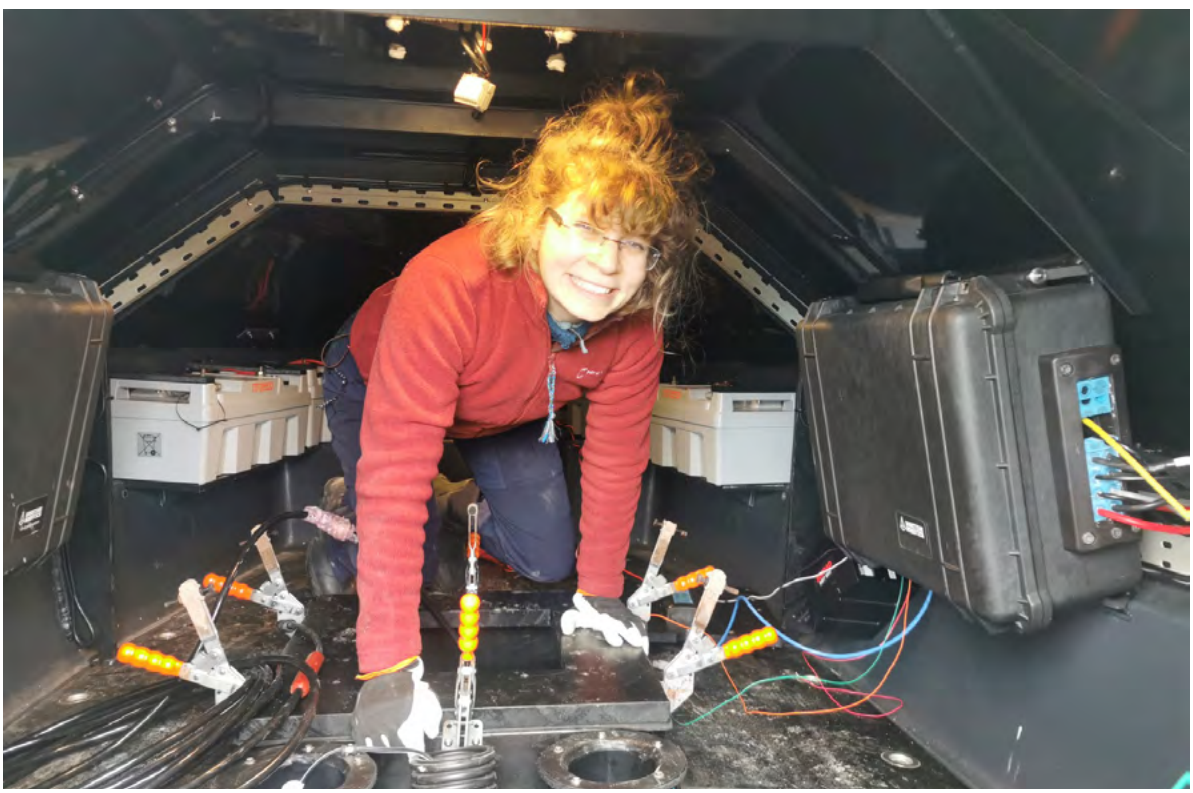
ASSOCIATED STUDENTS

Rabea Rogge

Rabea Rogge has a master's degree in electrical engineering and information technology from ETH Zurich, Switzerland, and she is currently employed as a PhD candidate at the Department of Marine Technology at NTNU. She is funded through the HARVEST SFI, and her work is associated with work package 5 in CRIMAC. Her PhD topic is Data-driven navigation, guidance and control for autonomous surface vehicles in harsh conditions.

She participated at the CRIMAC cruise in November 2023 and contributed to the USV noise estimation work as well as her own project on control systems for the USV using the backseat driver functionality in the Maritime Robotics control system on the Sounder USV.

Rabea is supervised by Asgeir Johan Sørensen (NTNU), Eleni Kelasidi (Sintef) and Nils Olav Handegard (CRIMAC, IMR).



MASTER STUDENTS

Adrian Røsland

Adrian Røsland started his masters project in August 2024. The working title of his thesis is "Sampling with an in-trawl stereo camera system in pelagic swept area trawl surveys: Effect of fish behaviour in the trawl". The main objective is to investigate if and how an in-trawl stereo camera system can be used for sampling in the international Ecosystem Summer Survey in the Nordic Seas (IESSNS) trawl swept area survey.

Nikolina Juraco

Nikolina Juraco finished her Masters project in 2024. The title is "Catch efficiency in acoustic trawl surveys for Norwegian spring spawning herring and blue whiting – effect of environmental and biological factors". She compared acoustic estimates of fish density with trawl-based estimates and investigates what environmental and biological factors may influence the relationship.

Vilde Strand Dybevik

Vilde's master project is titled "Transmit-receive switching for ultrasound pulse-echo measurements". She seeks a new solution for switching between high-voltage transmission and sensitive reception for sonar and other ultrasound measurements for the Acoustics laboratory at UiB, enabling precise measurements and undistorted signals upon both signal transmission and reception. The main deliverable from the project will be a prototype for a versatile switching unit for laboratory use. Existing equipment is characterized, and solutions found in industry and scientific literature are reviewed and discussed, as basis for the chosen solution. At least one prototype design will be characterized and compared to the existing equipment. Vilde started her project in August 2024 and is set to finish in June 2025.

Supervised by Audun Oppedal Pedersen (UiB) and Mathias Sæther (UiB).

Mats Nicolai Hübschle

Nicolai started on his master's project in August 2024 and will finish in June 2025. His project is titled "Nonlinear sound propagation in fisheries acoustics". The linear wave equation assumes negligible sound pressure amplitude and particle velocity. When the amplitude of a sound wave becomes so high that the linearity assumption introduces significant model error, the sound wave is said to be of finite amplitude. This is sometimes the case in fisheries acoustics, where target strengths (TS) and volume backscattering coefficients (sv) are measured quantitatively. Two second-order finite-amplitude effects become significant: (1) «Nonlinear loss» at the fundamental (transmitted) frequency component leads to underestimation of measured TS and sv if it is not accounted for in the measurement model. The practical effect of nonlinear loss is complicated further when there is also significant nonlinear loss upon echosounder calibration. (2) Harmonic overtones are generated in finite-amplitude sound propagation and can cause «nonlinear crosstalk» in multi-frequency and wideband echosounder systems. Such crosstalk can act differently in different system configurations and may be more challenging to manage through the measurement model than nonlinear loss.

The main goal of the Master project is to quantitatively compare the outputs from two numerical solutions of the Khokhlov-Zabolotskaya-Kuznetsov equation. The equation describes finite-amplitude sound propagation in a sound beam to the second order. One numerical solution is known as the «Texas code» and operates in the time domain. This has been used at IMR in the past. Seawater absorption is accounted for by amending the equation with relaxation terms. The other solution is known as the «Bergen code» and solves the equation in the frequency domain. This version of the equation does not include relaxation terms, but frequency dependent absorption coefficients are enforced for each harmonic frequency. This code has been used, and is still in use, in collaboration between UiB, IMR, and KD. A new master student will continue on this topic based on Nicolai's results, starting in August 2025.

Supervised by Audun Oppedal Pedersen (UiB) and Babak Khodabandeloo (IMR)

Sander Marx

The project is titled "Machine learning architectures for simulated broad band data". The implementation of the physical model for oblate spheroids has now been optimized for computational efficiency, improving execution times by an order of magnitude. It is now being applied to generate a large set of broadband spectra. This data set will be used to train different machine learning models and architectures to see which geometric properties of the simulated objects can be recovered from the spectra. Successful models will then be applied to real data sets with known targets, and the efficacy in target classification estimated.

Sander is supervised by Babak Khodabandeloo (IMR) and Ketil Malde (IMR, UiB).

Communication and dissemination activities

Disseminating our activities and results to selected target audiences as well as the broader public is central to achieving CRIMAC's objectives.

In addition to CRIMAC's own web page, stories and updates from the centre are regularly featured on IMR's web page and social media channels, where they reach a wide audience.

An overview of CRIMAC news can be found here: https://crimac.no/nyheter

Appendices

Publications

An up-to-date list of publications can be found here: https://crimac.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.

Allken, V., Rosen, S., Handegard, N. O., and Malde, K. 2021b. A deep learning-based method to identify and count pelagic and mesopelagic fishes from trawl camera images. ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsab227 (Accessed 26 November 2021).

Andersen, L. N., Chu, D., Handegard, N. O., Heimvoll, H., Korneliussen, R., Macaulay, G. J., Ona, E., et al. 2023. Quantitative processing of broadband data as implemented in a scientific split-beam echosounder. Methods in Ecology and Evolution, n/a. https://onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.14261 (Accessed 23 December 2023).

Bandara, K., Basedow, S. L., Pedersen, G., and Tverberg, V. 2022. Mid-summer vertical behavior of a high-latitude oceanic zooplankton community. Journal of Marine Systems, 230: 103733.

Berge, D. S. 2023, June 2. Spatiotemporal variation in the growth and size distributions of lesser sandeel (Ammodytes marinus) in the north-eastern North Sea. The University of Bergen. https://bora.uib.no/bora-xmlui/handle/11250/3073098 (Accessed 24 October 2023).

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Forland, T. N., Pedersen, G., Bøe, Y., Kubilius, R., Korneliussen, R., and Handegard, N. O. 2024. Applications of broadband echosounders in fisheries and plankton acoustics: A compilation of test data sets. http://metadata.nmdc.no/metadata-api/landingpage/f0bdafac077ee736926b57c422221f27 (Accessed 3 October 2024).

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Khodabandeloo, B., Ona, E., Macaulay, G. J., and Korneliussen, R. 2021a. Nonlinear crosstalk in broadband multi-channel echosounders. The Journal of the Acoustical Society of America, 149: 87–101. Acoustical Society of America.

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Komiyama, S., Holmin, A. J., Pedersen, G., and Johnsen, E. 2024. Silent uncrewed surface vehicles reveal the diurnal vertical distribution of lesser sandeel. ICES Journal of Marine Science: fsae159.

Kubilius, R., Bergès, B., and Macaulay, G. J. 2023. Remote acoustic sizing of tethered fish using broadband acoustics. Fisheries Research, 260: 106585.

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Tenningen, M., Rosen, S., Taraneh Westergerling, E. H., and Handegard, N. O. 2023. How to obtain clear images from in-trawl cameras near the seabed? A case study from the Barents Sea demersal fishing grounds. Fisheries Research, 268: 106856.

Totland, A., and Johnsen, E. 2022. Kayak Drone – a silent acoustic unmanned surface vehicle for marine research. Frontiers in Marine Science, 9. https://www.frontiersin.org/articles/10.3389/fmars.2022.986752 (Accessed 12 September 2022).

Academic lectures

Academic lectures for 2024. A complete list of results can be found through CRISTIN.

Eliassen, Inge Kristian; Malde, Ketil. 2024. Processing of large datasets using python and Korona. CRIMAC Workshop on data processing methods for large volumes of plankton and fisheries-acoustics data

Handegard, Nils Olav. 2024. Examples of AI and Machine Learning methods applied to data from marine ecosystems. SAMSAS tekniksprångsserie

Handegard, Nils Olav. 2024. Presentation of SFI CRIMAC. SFI Smart Ocean Seminar series

Handegard, Nils Olav. 2024. Visual Intelligence – Marine science. Visual intelligence days.. Visual Intelligence (VI) Days 2024

Handegard, Nils Olav; Bildøy, Leif; Brautaset, Olav; Furmanek, Tomasz; et. al. 2024. Analysing large amounts of echosounder data using cloud based data access combined with deep learning models. ICES Annual Science Conference

Handegard, Nils Olav; Bildøy, Leif; Brautaset, Olav; Furmanek, Tomasz; et. al. 2024. Fisheries acoustics and deep learning. International Conference on Marine Data and Information Systems - IMDIS

Handegard, Nils Olav; Holmin, Arne Johannes; Johnsen, Espen; Korneliussen, Rolf; et. al. 2024. Testing acoustic data quality and performance on Sounder USV. WGFAST - ICES Working Group on Fisheries Acoustics, Science and Technology

Holmin, Arne Johannes; Pala, Ahmet. 2024. Pipeline for testing convolutional neural networks for Acoustic Trawl Surveys. NOT CACHED CRIMAC Workshop on data processing methods for large volumes of plankton and fisheries-acoustics data

Khodabandeloo, Babak; Pedersen, Geir; Forland, Tonje Nesse; Korneliussen, Rolf. 2024. Effects of pulse duration on nonlinear crosstalk in wideband backscattering measurements. WGFAST - ICES Working Group on Fisheries Acoustics, Science and Technology

Khodabandeloo, Babak; Pedersen, Geir; Forland, Tonje Nesse; Korneliussen, Rolf; et. al. 2024. Exploring the impact of Fourier window lengthon target strength frequency response estimation in broadband echosounders. 47th Scandinavian Symposium on Physical Acoustics

Pala, Ahmet; Oleynik, Anna; Malde, Ketil; Handegard, Nils Olav. 2024. Annotation-Free Feature Learning for Improved Acoustic Target Classification. SFI Visual Intelligence Seminar

Pala, Ahmet; Oleynik, Anna; Malde, Ketil; Handegard, Nils Olav. 2024. Unraveling Acoustic Signal Patterns in Fisheries Through DINO-Based Self-Supervised Learning. 94th Annual Meeting of The International Association of Applied Mathematics and Mechanics (GAMM)

Pedersen, Geir. 2024. Acoustic interpretation for Calanus in real time and post processing methods. SFI Harvest Workshop - Collaborative multiagent networks for zooplankton detection and estimation

Pedersen, Geir. 2024. Active acoustics on a glider : scientific and technological challenges. EGO Webinar on glider collaboration at global level

Pedersen, Geir. 2024. Advancing Fisheries Acoustics: The Role of CRIMAC in Expanding Applications through Innovative Technologies. OCEANOLOGY INTERNATIONAL 2024

Pedersen, Geir. 2024. Projects at IMR relying on large scale analysis of acoustic data. CRIMAC workshop

Pedersen, Geir; Khodabandeloo, Babak; Johnsen, Espen; Handegard, Nils Olav. 2024. Behaviour and platform dependent broadband backscattering by physostome fish (Clupea harengus L.) revisited. WGFAST - ICES Working Group on Fisheries Acoustics, Science and Technology

Tenningen, Maria. 2024. Bedre fangstkontroll med trålkamera og kunstig intelligens. Nor Fishing 2024 - Forskningstorget

Tenningen, Maria; Pedersen, Geir; Khodabandeloo, Babak; Handegard, Nils Olav; et. al. 2024. Identifying size and behavior of Mueller's Pearlside (Maurolicus muelleri) by combining measured broadband frequency responses with backscattering models and in-trawl observations. ICES Annual Science Conference

Westergerling, E. H. Taraneh; Rosen, Shale; Allken, Vaneeda; Tenningen, Maria. 2024. Advancing the interpretation of fisheries acoustics with in-trawl cameras: A survey method for mesopelagic resources. ICES Annual Science Conference 2024

Posters

Brautaset, Olav; Utseth, Ingrid; Eikvil, Line; Salberg, Arnt-Børre; et. al. 2023. Learning from weakly labelled marine acoustic data. Visual Intelligence Days

Choi, Changkyu; Kampffmeyer, Michael Christian; Handegard, Nils Olav; Salberg, Arnt-Børre; et. al. 2023. Deep Semi-supervised Semantic Segmentation in Multi-frequency Echosounder Data. VI days 2023

Choi, Changkyu; Kampffmeyer, Michael; Handegard, Nils Olav; Salberg, Arnt Børre; et. al. 2021. Semi-supervised Semantic Segmentation in Multi-frequency Echosounder Data. SFI Visual Intelligence days 2021

Handegard, Nils Olav; Algrøy, Tonny; Eliassen, Inge Kristian; Forland, Tonje Nesse; et. al. 2023. Centre for research based innovation in marine acoustic abundance estimation and backscatter classification (CRIMAC). Geilo Winter School

Ona, Egil; Zhang, Guosong; Vatnehol, Sindre; Berg, Sverre; et. al. 2023. Direct measurements of the migration speed of spawning herring. From Echosounders to the Cloud: Transforming Acoustic Data to Information

Pala, Ahmet; Oleynik, Anna; Handegard, Nils Olav; Alendal, Guttorm. 2023. Deep Learning for Acoustic Target Classification: Addressing Class-Imbalance with a Similarity-Based Sampling Approach. Geilo Winter School

Pala, Ahmet; Oleynik, Anna; Handegard, Nils Olav; Alendal, Guttorm. 2023. Similarity-Based Data Selection to Improve Automatic Acoustic Target Classification. Foundations of Computational Mathematics (FoCM) 2023

Utseth, Ingrid; Ordonez, Alba; Eikvil, Line; Brautaset, Olav; et. al. 2021. Improving marine acoustic target classification with context information. Visual Intelligence Days 2021

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Reports

Handegard, Nils Olav; Andersen, Lars Nonboe; Brautaset, Olav; Choi, Changkyu; et. al. 2021. Fisheries acoustics and Acoustic Target Classification - Report from the COGMAR/CRIMAC workshop on machine learning methods in fisheries acoustics. Havforskningsinstituttet

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Handegard, Nils Olav; Tenningen, Maria; Bildøy, Leif; Corneliussen, Jon Even; et. al. 2023. CRIMAC cruise report: Development of acoustic and optic methods for underwater target calssification - G.O. Sars 22.11 - 03.12 2022. Havforskningsinstituttet

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Ona, Egil; Handegard, Nils Olav; Johnsen, Espen; Kubilius, Rokas; et. al. 2021. CRIMAC cruise report 2020116. Havforskningsinstituttet

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Business journal publication

Handegard, Nils Olav; Algrøy, Tonny; Eikvil, Line; Hammersland, Hege; et. al. 2021. Smart Fisheries in Norway: Partnership between Science, Technology, and the Fishing Sector. Journal of Ocean Technology

Handegard, Nils Olav; Eikvil, Line; Jenssen, Robert; Kampffmeyer, Michael; et. al. 2021. Machine Learning + Marine Science: Critical Role of Partnerships in Norway. Journal of Ocean Technology

Feature article

Handegard, Nils Olav; Algrøy, Tonny; Ona, Egil. 2021. Betre ekkolodd vil gi betre forståing av våre marine økosystem. Skipsrevyen

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Lorentzen, Erlend Astad. 2021. Har gitt sonaren evne til å beregne hvor mange tonn fisk den ser. www.hi.no

Personell

KEY RESEARCHERS

Name	Institution	Main research area	Gender
Nils Olav HANDEGARD	IMR	Center leader	M
Geir PEDERSEN	IMR	WP1 manager	M
Tonje N. FORLAND	IMR	WP2 manager	F
Maria TENNINGEN	IMR	WP3 manager	F
Ketil MALDE	IMR	WP4 manager	M
Arne J. HOLMIN	IMR	WP5 manager	M
Shale ROSEN	IMR	Researcher	M
Frode OPPEDAL	IMR	Researcher	M
Sindre VATNEHOL	IMR	Researcher	M
Rokas KUBILIUS	IMR	Researcher	M
Hector PENA	IMR	Researcher	M
Vaneeda S.D. Alken	IMR	Researcher	F
Rolf Korneliussen	IMR	Researcher	M
Guttorm ALENDAL	UiB	Professor, Department of Mathematics	M
Anna OLEYNIK	UiB	Researcher, Department of Mathematics	F
Per LUNDE	UiB	Professor, Head of the Acoustics Group, Department of Physics and Technology	M
Audun Oppedal PEDERSEN	UiB	Associate Professor, Acoustics and Ocean Technology, Department of Physics and Technology	M
Anne Gro V. SALVANES	UiB	Professor, Head of the Fjord and Coastal Ecology Research Group, Department of Biological Sciences	F
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Yngve Heggelund	NORCE		M
Bjørnar Ystad	NORCE		M
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Ingrid UTSETH	NR		F
Amund H Vedal	NR		M
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KEY RESEARCHERS, TECHNICIANS, RESEARCH INSTITUTES

Name	Institution	Main research area	Gender
Turid S. LODDENGAARD	IMR	Centre management - Finance	F
Liz B.K. KVALVIK	IMR	Engineering, instrument development	F
Jostein SALTSKÅR	IMR	Engineering, instrument development	M
Tomasz FURMANEK	IMR	Engineer, data science	M
Guosong Zhang	IMR	Engineer, instrument	M

KEY PERSONELL, INDUSTRY PARTNERS

Name	Institution	Main research area	Gender
Lars N. ANDERSEN	Kongsberg Discovery	Sonar technology and fisheries instrumentation and Board leader	M
Ivar WANGEN	Kongsberg Discovery	Sonar technology and fisheries instrumentation	M
Tonny ALGRØY	Kongsberg Discovery	Commercialization and applications	M
Leif BILDØY	Kongsberg Discovery	Sonar technology and fisheries instrumentation	M
Jens HEINSDORF	Kongsberg Discovery	Sonar technology and fisheries instrumentation	M
Arne FURDAL	Kongsberg Discovery	Kongsberg Group Sonar technology and fisheries instrumentation	M
Martin TOLLEFSEN	Kongsberg Discovery	Sonar technology and fisheries instrumentation	M
Robert SØRHAGEN	Kongsberg Discovery	Sonar technology and fisheries instrumentation	M
Helge HAMMERSLAND	Scantrol AS	Visual fish classification/Management	M
Kristoffer LØVALL	Scantrol Deep Vision AS	Visual fish classification	M
Jacob Grieg EIDE	Scantrol AS	Visual fish classification	M
Eirik Svoren OSBORG	Scantrol Deep Vision AS	Visual fish classification	M
Hege HAMMERSLAND	Scantrol Deep Vision AS	Visual fish classification/Marketing	F
Ruben PATEL	CodeLab	Software/Sonar technology and fisheries instrumentation	M
Espen Lie Dahl	Salmar Aker Ocean	Aquaculture	F
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Pål Cato Reise	EROS AS	Captain	M
Per William Lie	Lie-Gruppen	Captain	M
Bjarne Haldorsen	Lie-Gruppen	CEO Lie-gruppen AS	M

KEY RESEARCHERS

PhD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET

Name	Nationality	Period	
Ahmet Pala	Turkey	2021-2024	M
Taraneh Westergerling	Germany	2021-2025	F
Sakura Komiyama	Japansk	2022-2025	F
Yngve Bøe	Norsk	2023-2026	M
Helge Brøndbo Plassen	Norsk	2023-2026	M

MASTER STUDENTS

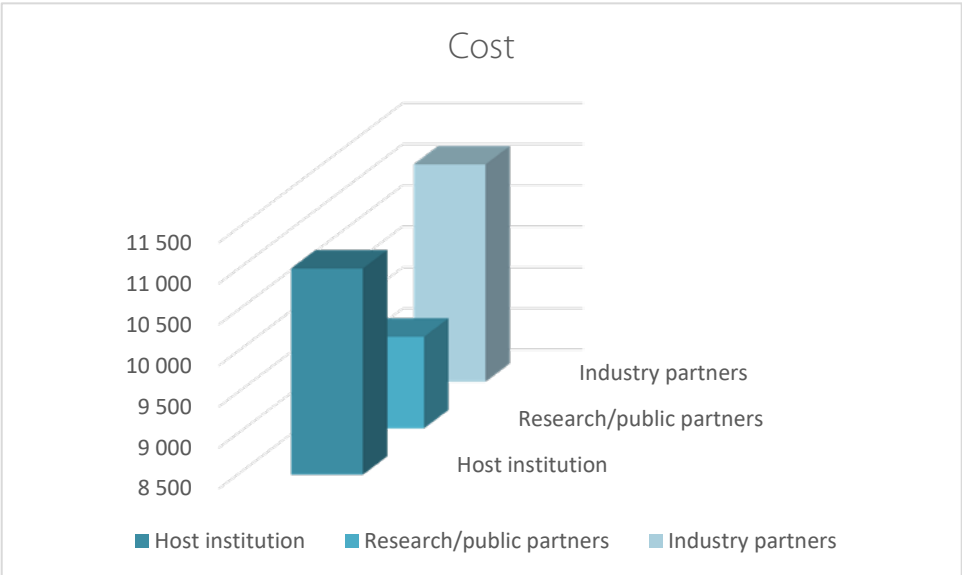
Name	Nationality	
Maren Rong	Norsk	F
Kristin Utne Berg	Norsk	F
Cecilie Kahrs Skaale	Norsk	F
Miranda Veim	Norsk	F
Daniel Jarl Skåtøy Stiti	Norsk	M
Knut Thormod Aarnes Holager	Norsk	M
Robert Løland	Norsk	M

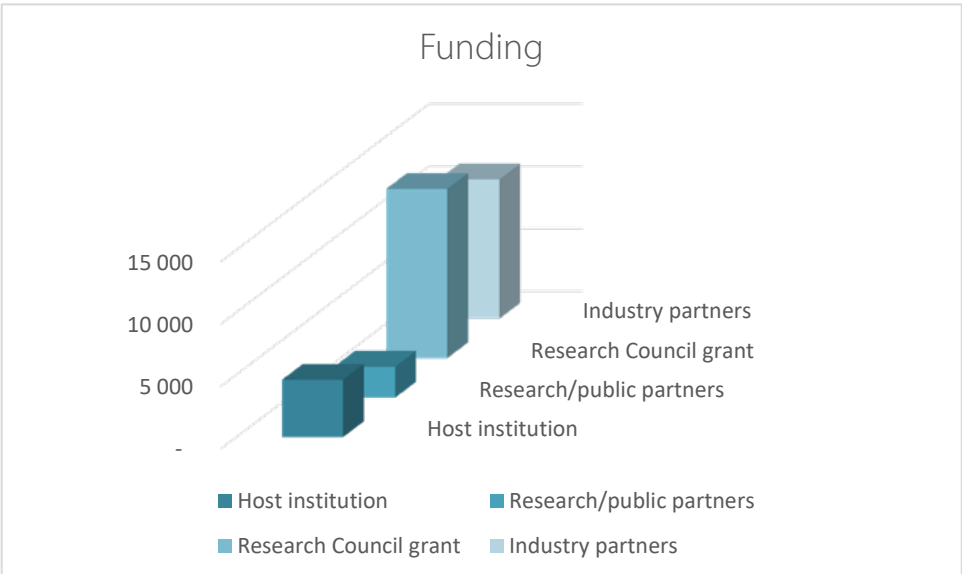
Annual accounts 2024

Host institution:
Havforskningsinstituttet

Research/public partners:
University of Bergen, Norce, Norsk Regnesentral

Industry partners:
Kongsberg Discovery, Scantrol Deep Vision, Lie Gruppen, EROS, CodeLab, Salmar Aker Ocean





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