CRIMAC

ANNUAL REPORT 2020

Centre for Research-based Innovation

1. SUMMARY

Centre for research-based innovation in marine acoustic abundance estimation and backscatter classification (CRIMAC) started its research activities October 1st 2020. Prior to the starting date, IMR and the CRIMAC partners developed a detailed Consortium Agreement regulating the R&D activities and budgetary commitments for each partner. The official end date for CRIMAC is 30.09.2028.

The research of the Centre is organized in six scientific work packages (WPs) and one management package.

1. Understand the broadband echo spectrum for classification
2. Experimental measurements of backscatter
3. Ground truthing methods
4. Machine learning and species categorisation methods applied to fisheries acoustics and ground truthing data
5. Applications
6. Extracting gains for science and industry
7. Management

During the reporting period, October to December we have organized a Kick off Meeting in Bergen with participants from all partners and conducted one full survey with G.O.Sars with 16 participants in spite of the Covid situation. The WP leaders are now planning the activity in all the work packages, including master students and formulation the call for 4 new PhD students. All the scientific plans for the survey was successfully conducted, collecting scientific material for work in the work packages. The industry partners have also contributed significantly, both with equipment, testing and personel. In the end of the year, the consortium agreement was signed, and a board was formed and established, where also a scientific advisory committee was established and decided. Apart from a late signing of the CA, and a bit late call for the new PhD students, the centre ship is running and plans for two large surveys for 2021 is finished, and an experimental facility in Matre aquaculture station is up and running with brand new instrumentation. A web page (www.crimac.no) is organized by the centre communication group. The new centre with its will be presented internationally at the important ICES FAST WG in April 2021, together with several scientific presentations from the centre scientists.

2. VISION/OBJECTIVES

2.1 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. This proposal is about marking out the road forward in 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. CO_2 sequestration for the energy sector, and monitor key features like abundance and distribution of key species in a changing marine ecosystem.

2.2 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

3. RESEARCH PLAN/STRATEGY

The research plan of the centre includes six research and one management work package, each of which comprises several sub-projects.

WP 1. Understand broad band spectrum
WP 2. Experimental measurements
WP 3. Ground truthing
WP 4. Machine learning
WP 5. Applications
WP 6. Extract gains for science and industry
WP 7. Management activities

Each work package is led by Havforskningsinstituttet. Most of the work packages involves partners as the university, other research institutes and the industry partners.

4. ORGANISATION

4.1 Organisational structure

IMR in Bergen is the host institution for CRIMAC and is responsible for the administration of the centre. CRIMAC is presently organized as a project in the Marine Processes and Human Impact. Most IMR personnel working in CRIMAC projects belong to the Marine Ecosystem Acoustics and Fish Capture research groups. Scientists working in CRIMAC projects are also involved in projects outside CRIMAC.

Other partners in the project are University of Bergen, NORCE, NR, Kongsberg Maritime, EROS, LIBAS, Norway Royal Salmon and CodeLab.

The Universities of Bergen main function is to secure a formal education environment for PhD and MSc students funded by and associated with the Centre.

Professor Egil Ona at IMR has been appointed director of the Centre since 1. October 2020.

The centre is led by a board, which in 2020 consisted of the following persons:

Lars N. Andersen, Kongsberg Maritime (Horten), Product Line Manager (Chair manager)

Øyvind Frette, UIB, Instituttleder for institutt for fysikk og teknologi.

Annette F. Stephansen, NORCE, Forskningsdirektør ved Digital Systems

Ruben Patel, CodeLab, Forskningsleder

Per W. Lie, Lie Gruppen AS, Skipper

Pål Cato Reite, Eros AS, Skipper

Lars H. Andresen, Forskningsrådet, Seniorrådgiver (Observer)

Andre Teigland, NR, Forskningssjef

Egil Ona, HI, Professor ved faggruppen Økosystemakustikk og Senterleder

Nils Olav Handegard, HI, Forsker ved faggruppen Økosystemakustikk

Geir Huse, HI, Research Director

Turid S. Loddengaard, HI, Advicer, secretary

4.2 Partners

From its start in 2020, the CRIMAC consortium has comprised these partners (the Institute of Marine Research (IMR); NORCE; NR, the University of Bergen (UiB) and these industry partners Kongsberg Maritime AS, Simrad; Scantrol Deep Vision AS; EROS AS, LIBAS AS, CodeLab, Norway Royal Salmon

Institute of Marine Research (IMR)
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 (Sund, 1935), the development of the echo integrator commonly used worldwide in acoustic trawl surveys (Dragesund and Olsen, 1965), and experimentally establishing the basic acoustic linearity principle (Foote, 1983). IMR and partners have established an initial understanding of dorsal side scattering properties through modelling (Gorska *et al.*, 2005) and measurements of multifrequency (Korneliussen *et al.*, 2016) and broad band spectrum (Forland *et al.*, 2014). IMR has also 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 ICES Cooperative Research Reports (calibration methods CRR144, building silent vessels CRR209, target detection CRR235). IMR has a tradition for incorporating the acoustic methods into postprocessing systems (Blindheim *et al.*, 1981; Foote *et al.*, 1991; Korneliussen *et al.*, 2016), and contributing to taking these methods to the commercial market. More recently IMR has established a machine learning lab, and they also host the Norwegian Marine Data centre, which will be used to disseminate the data from the centre.

University of Bergen (UoB), Departments of Physics and Technology (IFT), Biology (BIO) and Mathematics (MATH)
The University of Bergen is Norway's largest marine university and has marine research as one of three priorities in its larger strategy plan. To support the plan, UoB has specifically devised an action plan for innovation and entrepreneurship, which includes the following explicit goals: (i) strengthening the collaboration of research institutes with partners from industry and public sectors,

(ii) increasing the university's focus on innovation and enabling entrepreneurial and commercialization activities, and (iii) increasing external funding for innovation projects and centres. The proposed Centre will contribute to implement all of these elements and contribute to fulfil UoB's responsibility and leadership for the UN goal SDG14, "Life Below Water". IFT, IMR and KM have decades of cooperation within underwater and fisheries acoustics, such as on theoretical models for fish abundance estimation, wideband echosounder operation, single- and volume backscattering employing small- and finite-amplitude (nonlinear) sound fields, echosounder calibration methodologies, and acoustic transducer technology. MATH has been developing methods to distinguish gas seeps from natural seeps (Alendal *et al.*, 2017) and to design program for monitoring these (Hvidevold *et al.*, 2016). IFT will educate MSc and PhD candidates in physical acoustics with applications in fisheries, BIO will educate MSc and PhD candidates in biology, and MATH will educate new scientists within dynamical and data driven modelling, experimental design and uncertainty quantifications.

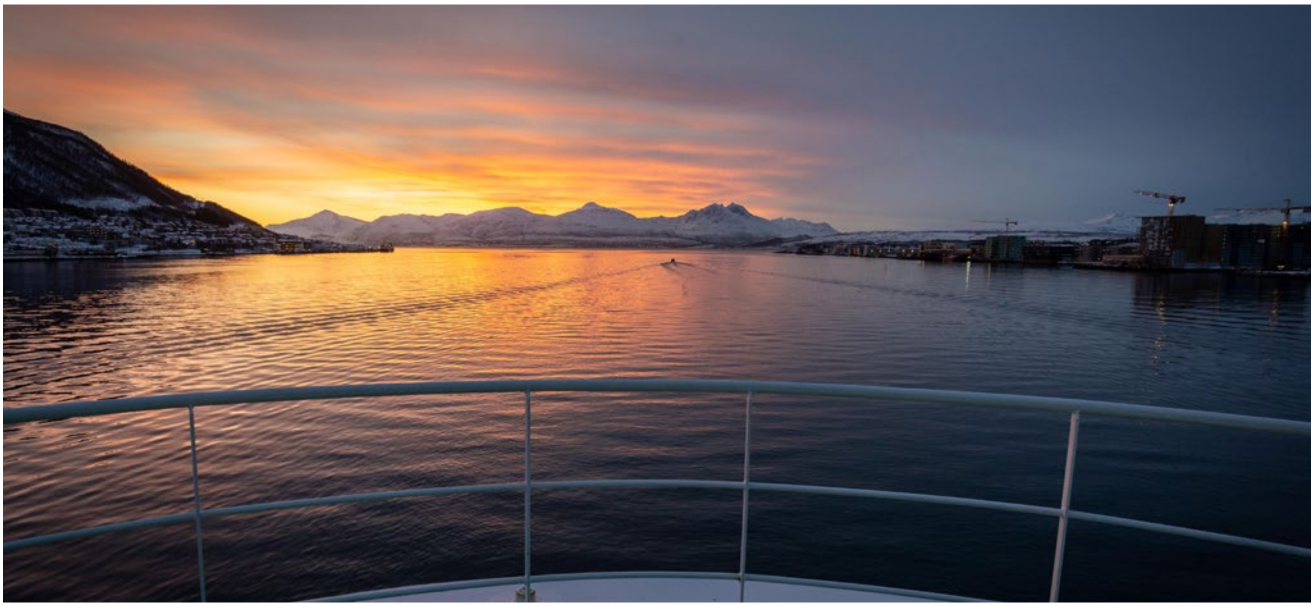
Norwegian computing centre (NR)
NR is a non-profit independent research institute located in Oslo, Norway, and is one of Norway's leading institutions within research-based data analysis, with high competence in survey design, statistical analysis, image analysis and machine learning. NR is also leading the BigInsight centre for research-based innovation supported by the Research Council of Norway. The area of deep learning for image applications is a focus area of the department of Statistical Analysis and Machine Learning, where NR in recent years has acquired experience for various applications of this technology including marine science, Earth observation, seismic analysis and health applications. In CRIMAC, NR will continue the long and successful collaboration with IMR on machine learning in marine science (Malde *et al.*, 2019), and contribute to developing machine learning methods for automatic acoustic categorisation.

Norwegian Research Centre (NORCE)
NORCE is currently Norway's second largest private research institution with approximately 1000 employees. NORCE has a long tradition for cooperation with IMR, UoB and KM, due to their strong competence in acoustics and computer science. They have been key contributions in the development and implementation of acoustic methods into postprocessing systems (c.f. IMR description), and the effect of nonlinear loss in fisheries acoustics. NORCE will contribute to broadband spectrum modelling, broadband noise removal and automatic categorisation of backscatter. They will also be involved in training and education of researchers and PhD students.

User partners
Main markets for the subsea technology company **Kongsberg Maritime** (KM) is fisheries, fisheries research, bottom mapping and subsea sensors for the energy sector. This is also reflected in the history of the company, with a long-term cooperation with IMR and the national and international fishing industry, and the next generation echosounders have been developed in close cooperation with researchers at IMR. As a result, they produce world leading products for scientific investigations and competitive new products for the fishing industry, and new research vessels worldwide are equipped with their instrumentation. More complex data, like broad banded echosounder and sonars, provide complex data and there is a need synthesize this information for both scientists and fishers, such as biomass per volume, species, and size. Similar challenges are relevant for the energy sector and aquaculture, and, if solved, will expand their market and to these sectors. The integration of autonomous platforms in research and fisheries is also a task for the industry, where either KM is a complete product manager, or as a subcontractor for other autonomous platform manufacturers. Cooperation with IMR will provide KM with access to excellent platforms for testing individual instruments and methods.

The **Scantrol Group** (Scantrol, Scantrol Deep Vision and Girona Vision Research) produce and deliver systems for research and industry to improve marine ecosystem observations and to facilitate sustainable fishing. Their expertise is in winch control systems for commercial and marine research vessels and methods to collect and analyse high quality underwater images from trawls for species identification and length measurement. Scantrol Group has a good track record for collaborating with science partners (Rosen and Holst, 2013). They are working towards robust trawl opening and closing devices for discrete sampling from trawls for the research industry and robust sorting devices for the fishing industry based upon optical classification.

CodeLab is a small specialized software company making software for end users in marine science, energy sector, and health. They have expertise in near real time data processing, acoustic wideband processing and machine learning. They 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 sensors and acoustic sensors. They



deliver both self-standing products and libraries that can be interfaced into, e.g. KM's, software.

Norway Royal Salmon (NRS)

Norway Royal Salmon was established by 34 Norwegian salmon farmers in 1992. The philosophy was to build an integrated fish farming chain to ensure superior food quality. Today, Norway Royal Salmon is a fully integrated salmon farming company with control of the process from smolt to market. The challenge in modern fish farming is to observe the farming environment and the behaviour of the fish inside the net pens, day and night, including behaviour during feeding. Norway Royal Salmon will present challenges from the industry to CRIMAC and offer a trial site for commercial products inside our net pens. Data from instruments will be analysed and combined with data from biological sampling of the fish throughout the production cycle.

EROS AS and LIEGRUPPEN AS

Eros and Liegruppen AS are commercial fishing companies active in the demersal trawl, pelagic trawl and purse seine fisheries with long-standing cooperation with IMR and KM. This includes industry challenges as bycatch reduction, sizing and searching. They have both taken advantage of new knowledge by installing protruding instrument keel, a revolutionary and simple device that makes acoustic data more reliable in bad weather conditions. They will provide highest quality fishing knowledge necessary to get ground truth data for building broadband acoustic feature library, and they will in turn get early access to the gradually improved acoustic feature library and new machine learning categorisation methods. Both companies are also involved in developing future, new fisheries.

4.3 Cooperation between centre's partners

CRIMAC will be organised as an independent unit of IMR, which will serve as the host institution. The Centre will have its own Board and Director. A project coordinator will assist the Centre Director in administrative matters. IMR will provide the necessary administrative support systems for the Centre. Each of the work packages will have a WP manager appointed by the Board, selected among the research partners, and an assistant manager from the industry partners. Each work package manager will be responsible for coordinating and organizing the project, budget and project plan, and deliverables according to plans.

Personnel from several partners will be involved in each project, to ensure joint involvement, creativity and synergy. Ideally, at least two industry partners and one R&D partner should be involved in each project. Personnel will normally not be employed by the Centre, but will maintain their positions with the different partners, including the host institution. The Centre will hire personnel from its partners, including the host institution, to carry out its research. Personnel will normally stay at the Centre for a minimum of two months at a time, to ensure that the project groups are co-located both in space and time, and to allow for a common focus on specific research activities.

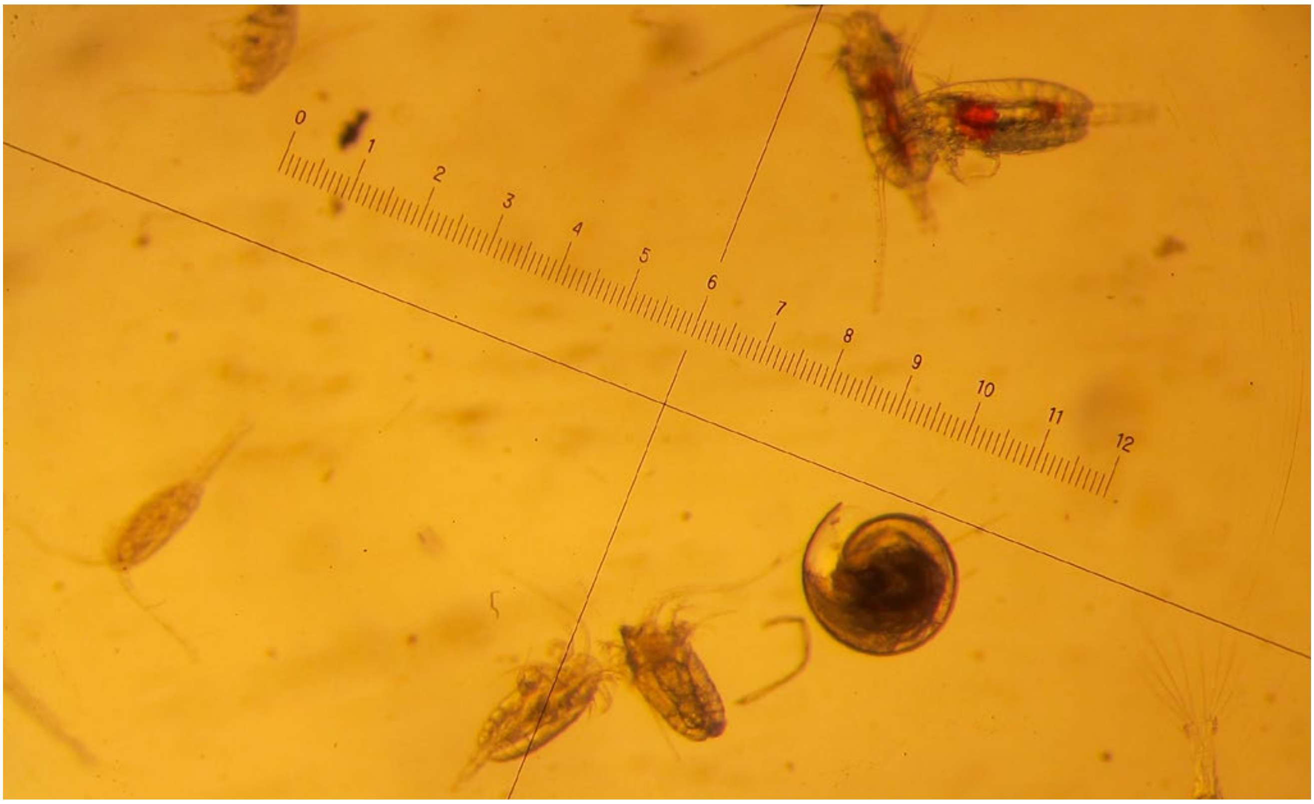
An Annual Science meeting will normally be arranged in September each year. We had a kick-off meeting start in Bergen 29-30. September 2020 due to covid-19.

5. SCIENTIFIC ACTIVITIES AND RESULTS

The scientific activities in CRIMAC are organized in the form of six work packages, the partners involved are shown in Table 5.0.

Table 5.0 Work packages with sub-projects and partners involved

Work package	Objectives	Partners
WP 1. Understand the broadband echo spectrum for classification	To understand the contributors to the complexity of broadband backscatter from individuals and groups of marine organisms and other scatterers; to advance the use of numerical models for backscatter prediction.	IMR, KM, SCV, CODELAB, NOAA, UoB (IFT-PHD)
WP 2. Experimental measurements of backscatter	To develop a library of broadband backscatter responses from a wide range of marine organisms and other scattering objects.	IMR, KM, NORCE, UoB(IFTPHD), NRS
WP 3. Ground truthing methods	To develop and use tools for independently identifying the organisms that generates backscatter.	IMR, KM, Scantrol DV, Scantrol, EROS&LIBAS, UoB (BIOPHD2)
WP 4. Machine learning and species categorisation methods applied to fisheries acoustics and ground truthing data	To automate categorization of acoustic backscatter; to reduce bias and uncertainty in acoustic backscatter categorization.	IMR, NR, UiB, NORCE, CODELAB, MIPHD1
WP 5. Applications	To implement prototype methods; to assess the expected improvements from implementation.	IMR, NORCE, NR, MATH, CODELAB
WP 6. Extracting gains for science and industry	Facilitate the transition of research innovation into practical use in science and industry and suggest new future procedures and products with impact.	IMR, KM, Scantrol Group, Codelab, EROS, LIBAS, NRS



Work package 1 Understand the broadband echo spectrum for classification

Project leader: Geir Pedersen

Background

Scientific questions: *What are and how do the various parts of marine organisms contribute to broadband backscatter?*

The work carried out in this WP will focus on understanding how the complex broadband frequency responses from marine organisms are generated. The basic data for this will involve numerical modelling of backscatter and the *in situ* and *ex situ* measurements from individual and groups of marine organisms carried out in WP2. Models that use detailed internal structure of organisms will be prioritized as this is expected to be the source of much of the structure in broadband responses from single targets. Input to these models will use x-rays, CT scans, and MRI scans of representative organisms. The equipment to obtain these are either available internally with IMR, or through Haukeland University Hospital, Bergen, Norway. Numerical models will be implemented on existing computer resources provided by IMR. Where feasible, the models will be developed in freely available programming languages (e.g., Python and R), noting that the pre-eminent acoustic modelling tool (COMSOL) is commercial, which we will use when appropriate. Where possible, models will be implemented for the measured organisms (WP2) to provide realistic and extensive ground truthing of the models. The models will also be used to explore the change in broadband response with changing input parameters to understand the various contributors to broadband backscatter characteristics (e.g., what parts of an organism determine the shape and variability in the broadband backscatter curve; how does movement of the organism affect the backscatter curve). This knowledge will inform the work in WP3. Development and testing of software tools to present in near-real-time classification metrics will provide value for the industry partners.

Objectives

To understand the contributors to the complexity of broadband backscatter from individuals and groups of marine organisms and other scatterers; to advance the use of numerical models for backscatter prediction.

Research and results

The major activity in WP1 2020 was the first CRIMAC survey with G. O. Sars November 2020 (related to T1.1,T1.3 in WP1 workplan 2020-2021), secondary activities included initializing the international workshop on modelling of acoustic backscatter (related to T1.2 in WP1 workplan 2020-2021) and preparing a work plan for 2020/2021.

The CRIMAC survey (19.11-30.11 2020, RV G. O. Sars) collected broadband and narrowband acoustic data to support research in all WPs using the Kongsberg Maritime EK80 system (18, 38, 70, 120, 333 kHz) and ES150-3C combined ADCP and echosounder. Data were collected using the new mission planning functionality to test recommendations for data collection, including power settings to reduce crosstalk to an acceptable level while collecting data simultaneously over several frequency bands. The same data were used to further develop processing and analysis methodology such as extraction of narrowband data from broadband, enabling the use of traditional methodology for abundance estimation from broadband data.

Improvements to the post-processing software LSSS has been implemented to increase the speed of reading and processing broadband data in a separate project, as reading speed is a potential roadblock for operational use of broadband acoustic in assessment surveys. Initial tests with LSSS on data collected by the CRIMAC cruise shows that the acceptable reading and processing speeds of broadband data is possible.

Broadband recordings of different size groups of herring were collected inside a fjord (Kvænangen) and offshore (Norwegian sea), (Figure 1). These data will be the first entries in the broadband signature library, and a test case for developing recommendations on annotation of broadband data for use with machine learning techniques. In addition, broadband data on herring were collected by the traditional research vessel and a silent unmanned surface vehicle (IMR Echodrone/Kayak). Comparison of data from the two platforms show that the observed broadband signature of shallow layers of herring differs between the platforms, likely due to difference in the behavior as the shallow herring exhibit an avoidance reaction to the traditional vessel (Figure 2) shows the distinct difference between shallow and deep herring as observed from the research vessel). The signature of deeper layers and schools appears unaffected by the observing platforms. Broadband recordings of additional species and zooplankton was also performed with both the Kongsberg Maritime EK80 and ES150-3C systems.

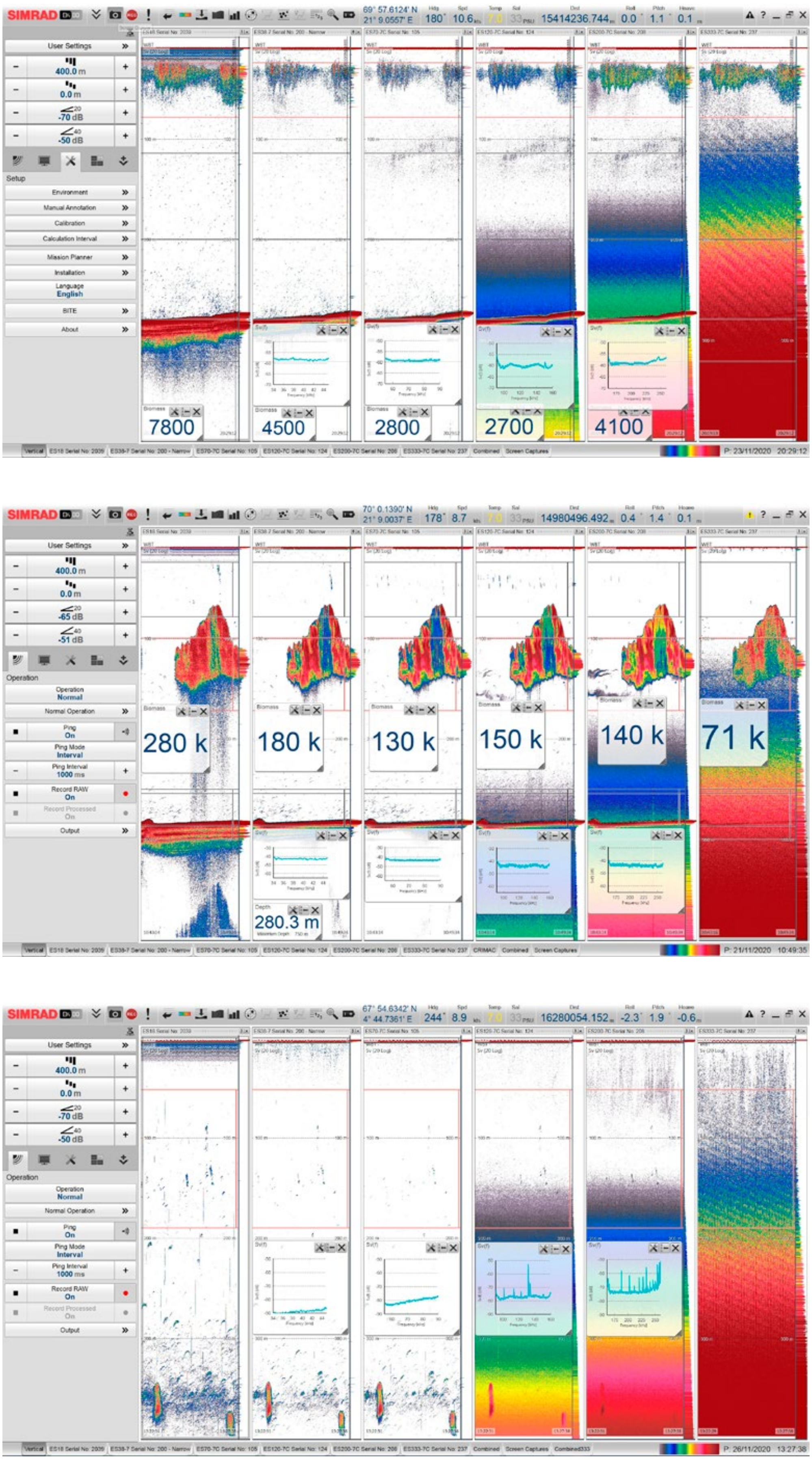


Figure 1.1
Representative echograms of nighttime shallow layers of Atlantic herring in Kvænangen (upper panel), deep day-time schools in Kvænangen (middle panel), and compact deep schools in the open Norwegian Sea, 200 nmi west of Røst / Lofoten islands (lower panel). Echograms left-to-right: 18 kHz (narrowband), 34-45 kHz, 55-90 kHz, 91-160 kHz, 161-260 kHz, and 333 kHz (narrowband).

Planning of the ICES WGFAST Workshop on Acoustic Backscatter Models (WKABM) was initiated in 2020. WKABM will be planned in detail and organized in 2021 (April 7-8). Outcome of this workshop will be an overview of models and gaps (necessary developments to efficiently model broadband backscatter from marine scatterers), and a roadmap on how the fisheries acoustic community want to pursue the endeavor of making scattering models available and accessible to a wider community.

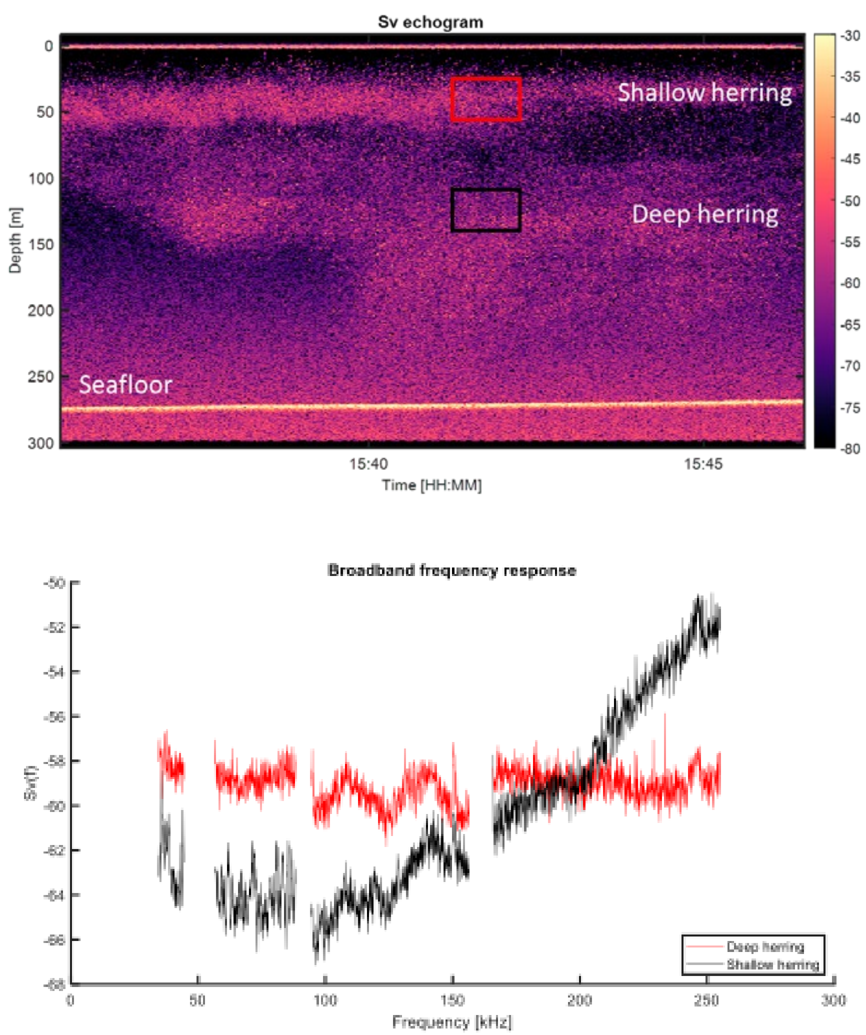


Figure 1.2
Atlantic herring in Kvænangen, broadband frequency response observed by the research vessel of two night-time herring layers (shallow and deep) displaying distinct and divergent broadband backscatter frequency responses.

Work package 2 Experimental measurements of backscatter

Project leader: Tonje N. Forland

Background

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

This WP will develop method for controlled measurements of broadband backscatter responses from a wide range of marine organisms and other scatterers to support WP1 and 4. Important categories of organisms and targets are fish, gas bubbles, fish larvae, krill, copepods, and jellyfish. Existing knowledge about these organisms will be reviewed and used to prioritize our efforts. Experimental measurements will occur in the large tanks and net pen mesocosms at IMR's Austevoll and M atre research facilities and at-sea from vessels and with close-range probing systems (and which will incorporate optical systems to provide target identification – see WP3). Enhancement of existing tools will be necessary, such as the use of narrower opening angle transducers and the use of pulse compressed broadband signals for high range resolution, with the aim of better resolving individual organisms in aggregations. New transducers with increased bandwidth will be developed and used here. A focus of the measurements will be on obtaining scatter from non-dorsal angles – this is to meet the increased use of non-horizontal sonar beams for quantitative surveys (e.g., sideways-looking echosounders) and within purse seine fisheries where the size information inside schools inspected must be extracted without passing over the school. For the tank and net-pen measurements this will be achieved using the IMR fish rotating facility. For the at-sea work, this will be achieved using sideways-looking transducers on probing systems and side mounted systems on drop keels

Objectives

To develop a method for measuring broadband backscatter responses from a wide range of marine organisms and other scattering objects under controlled conditions

Research and results

Dorsal aspect broadband target strength was measured with three broad band echo sounders mounted on a "TS-probe" deployed from G.O. Sars in the Crimac November survey 2020. The TS-probe could be suspended on a desired water depth from a crane on the vessel.

Acoustic recordings were obtained on young Atlantic herring (Figure 2.1) and northern krill (Figure 2.2) resulting

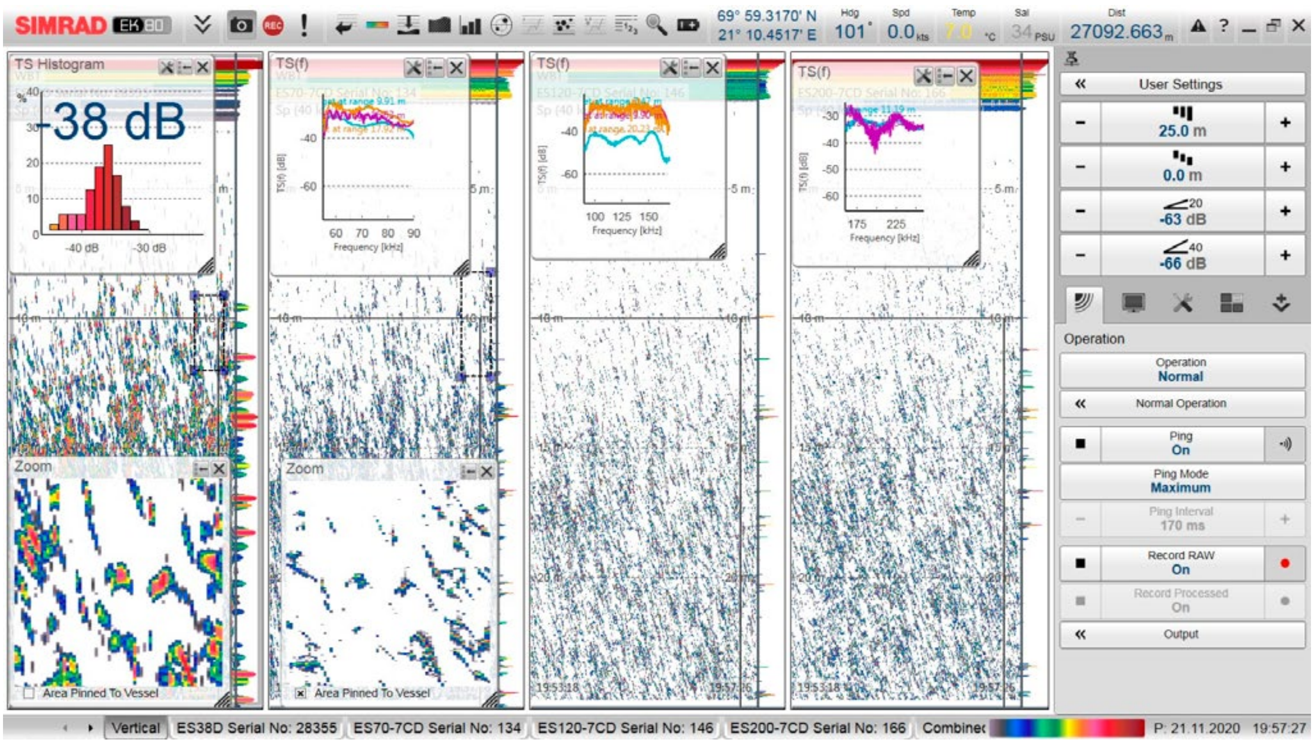


Figure 2.1 Representative echograms of individual Atlantic herring observations with (left-to-right) 38 kHz (narrowband), 55-90 kHz, 90-170 kHz, and 160-260 kHz pulses. TS-probe suspended at 35 m depth in Kænangen fjord during the night-time.

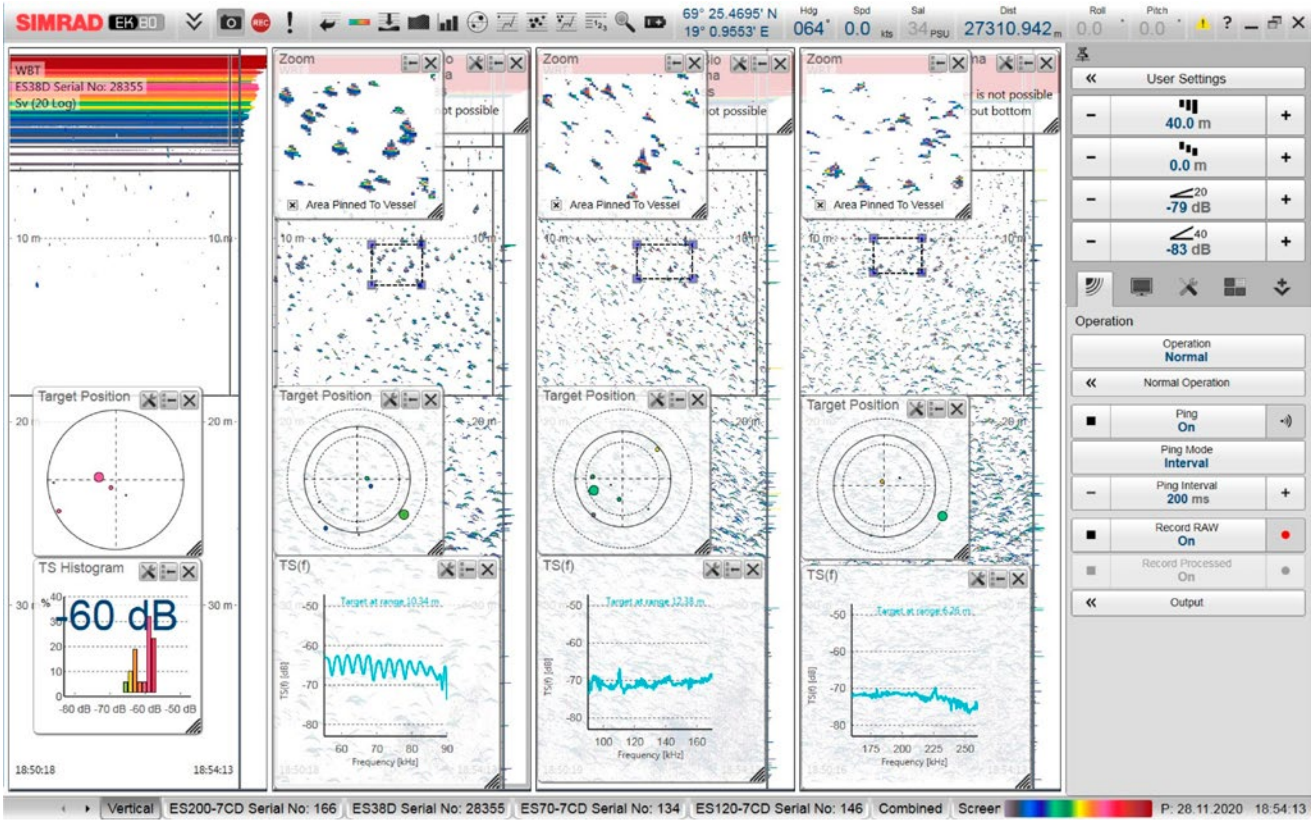


Figure 2.2 Representative echograms of the northern krill broadband acoustic backscattering records. The echograms are left-to-right: 38 kHz (narrowband), 55-90 kHz, 90-170 kHz, and 160-260 kHz.

in good datasets in the frequency range 55-260 Hz. There were also some broadband recordings on young blue whiting and winged snails for the same frequency range.

Other activities

In cooperation with UiB, institute of physics and technology, we are working on calls for two PhD positions who will work on both WP1 and WP2.

The planning of an experimental setup for salmon at the IMR research station in Matre has started. Three master students will work on different aspects of this setup. This will simultaneously use five wide band transceivers with different frequencies with the transducers mounded under the salmon net pens. The experiment in 2021 will be to quantify salmon behavioral changes when the fish is denied access to surface, and they will gradually loose swim bladder gas until they are allowed access again. The experiment is connected to sea-lice infection rate in salmon.

In addition there is a fourth master student who will work on sandeel backscattering in 2021. Two of the master students are related to both WP1 and WP2.

Work package 3 Ground truthing methods

Project leader: Maria Tenningen

Background

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. This will include optical verification tools, such as stereo cameras and high-resolution optic imaging systems (e.g. Deep Vision, laser scan imaging, holographic imaging). These systems will be integrated into a variety of sampling platforms (e.g., Hugin AUV, IMR KayakDrone, trawls, stationary deployment in aquaculture pens) and the sampling platforms will be upgraded as necessary to provide data in fine scale to match the broadband acoustic data. This will require, for example, development of "modern dynamic positioning trawling" where trawls used for ground truthing will be steered automatically and dynamically to capture fish schools tracked on sonar. With the KM dynamic positioning (DP) system, coupled to the auto trawl winch system from Scantrol, and reliable height sensors on the trawl doors and headline, it is feasible to trawl without the door touching the seafloor. This will help to prevent bottom damage in sensitive areas and may be needed in future trawling. DP trawling will be tested to improve the sustainability and efficiency of the commercial fishing industry and will also improve the swept area and swept volume estimates from demersal and pelagic fish surveys. AUV and automatic trawl steering systems will also be developed to ensure representative sampling throughout the water column with active sampling mechanisms to provide biological samples from specific locations or depths. This WP requires the development and implementation of improved communication channels and data integration onboard, and new, faster communication between autonomous sampling platforms and deployment platforms. This will involve close cooperation with the industry partners. This WP will also enhance the processing tools, software, and protocols used for sensor data flow at sea in order to efficiently provide ground truth data for the machine learning and species categorisation techniques to be developed in WP4.

Objectives

To develop and use tools for independently identifying the organisms that generates broadband backscatter

Figure 3.1 The Deep Vision (left) and the ASM (right) mounted to the VITO pelagic trawl.

Research and results

Selective sampling with Deep Vision and the Active Selection Mechanism (AMS) was tested on board GO Sars in November 2020 (Fig 3.1) The AMS allows for selective retention or releasing of fish before entering the codend and designed to be controlled by the Deep Vision stereo camera. In this first survey, the opening and closing of the AMS door was based on pre-determined times and depths. The door moved to the release and catch position while trawling and GO Pro camera footage showed that smaller fish (e.g. herring) were able to escape while the doors were in the release position whereas larger individuals (e.g. cod and saithe) struggled to get out. In 2021 the system will be further developed and tested including two-way communication for door control.

Fish schools measured with hull-mounted echosounder are generally not monitored after the boat has passed over them and their exact positions relative to the trawl opening are unknown, leading to uncertain sampling efficiency. Initial investigations looking at the feasibility of using omnidirectional sonar (Simrad SU90, KM) in order to monitor fish and trawl after the boat had passed over were made on board GO Sars in November. The trawl doors were clearly visible in the sonar, Figure 3.2, but the monitored schools were small and difficult to detect. This work will continue in 2021. Alternative methods and system for trawl positioning and high-resolution catch monitoring will be considered / developed and tested.

Other activities have included establishing a workplan for 2021 and cooperation with the main partners. In cooperation with UiB we are about to announce a call for a PhD position in the WP.

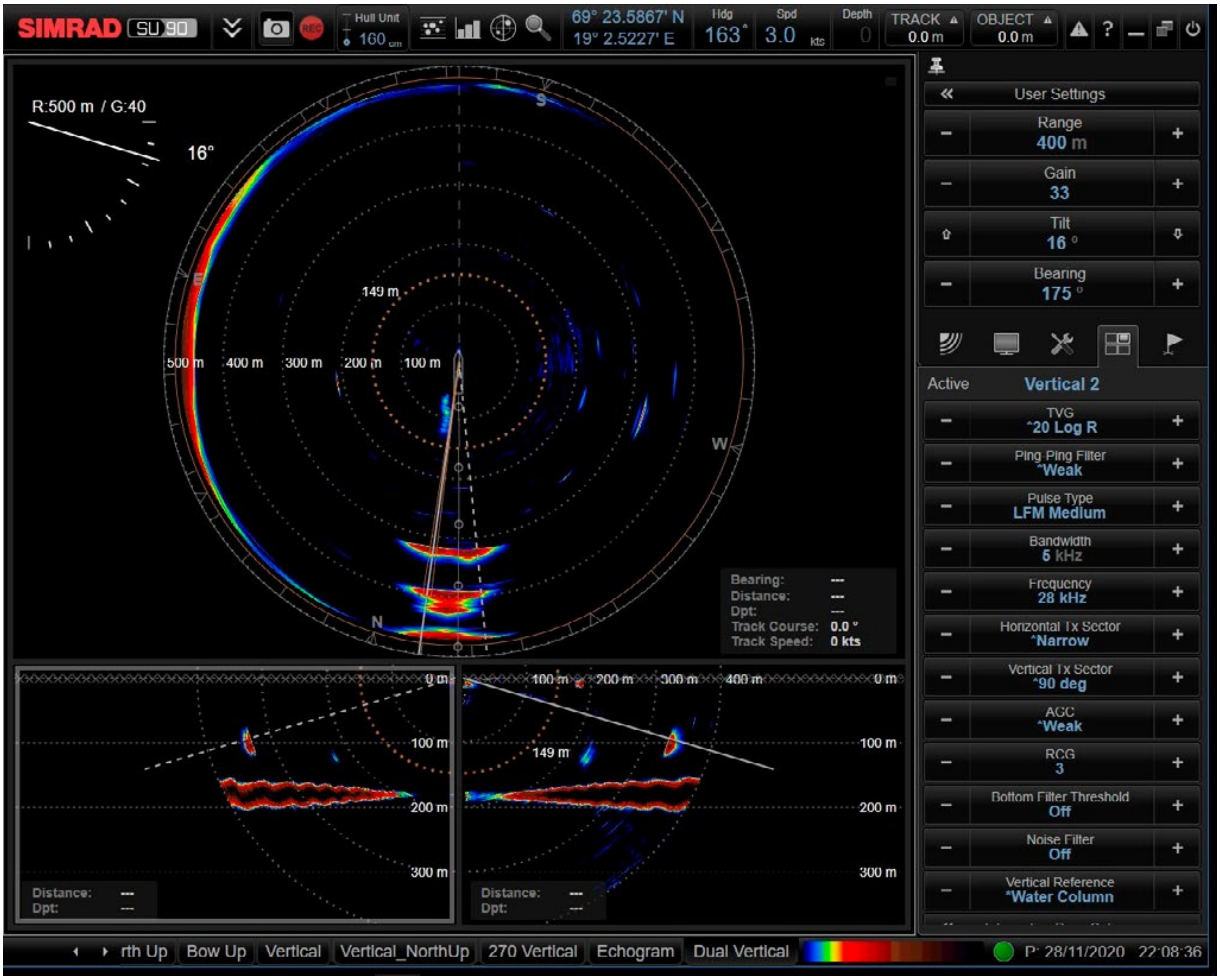


Figure 3.2 Image of SU90 sonar during pelagic trawling. Upper panel shows the horizontal beams, with the vessel in the center and echoes from the trawl doors at ca. 300 m behind the vessel (red/orange/yellow joined two half circles). A second echo at 400 m correspond to the trawl opening. In the bottom panel is shown the two vertical fans, that show the trawl doors at 100 m depth and the bottom echo at about 150 m.

Work package 4 Machine learning and species categorisation methods applied to fisheries acoustics and ground truthing data

Project leader: Nils Olav Handegard

Background

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. The first step will be to prepare the datasets from major IMR acoustic surveys, both multi-frequency and broadband, and prepare these for efficient access for modern machine learning libraries. This includes conversion and exposure of the data through open data formats and data servers, e.g. using OpenDAP or similar. Similarly, existing labels will be converted to open formats and exposed through the same infrastructure. The next step will be to further develop supervised methods e.g. (Brautaset *et al.*, 2020), using a combination of historical labels, the feature library (WP2), and ground truthing information (WP3). The intention is automating and reducing bias from the entire process of ground truthing and categorizing acoustic data and test it on the time series from the acoustic surveys. Subsequent steps will be to develop 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. By clustering historical data and comparing the classes with the classes derived using broad band data, we expect to see an improvement in categorizing historical data

Objectives

To automate categorization of acoustic backscatter; to reduce bias and uncertainty in acoustic backscatter categorization

Research and results

A joint workshop was organized by the COGMAR and CRIMAC projects. The objective of the workshop was twofold. The first objective was to give an overview of ongoing work using machine learning for Acoustic Target Classification (ATC). Machine learning methods, and in particular deep learning models, are currently being used across a range of different fields, including ATC. The objective was to give an overview of the status of the work and form a basis for further collaboration. The second objective was to familiarize participants with machine learning background to fisheries acoustics and to discuss a way forward towards a standard framework for sharing data and code. This included data standards, standard processing steps and algorithms for efficient access to data for machine learning frameworks. The suggested workflow is shown in Figure 4.1 and the different algorithms for reading the acoustic data is shown in Fig 4.2. The results from the discussion contributed to the process in ICES for developing a community standard for fisheries acoustics data. This is organized through the ICES GitHub page: https://github.com/ices-publications/SONAR-netCDF4. A report has been submitted for publication as a hi report.

Another important task was to further detail the work plan for 2021 and establish efficient collaboration across the different partners. Two further workshops are planned for first and second quarter of 2021, and detailed tasks across partners have been identified.

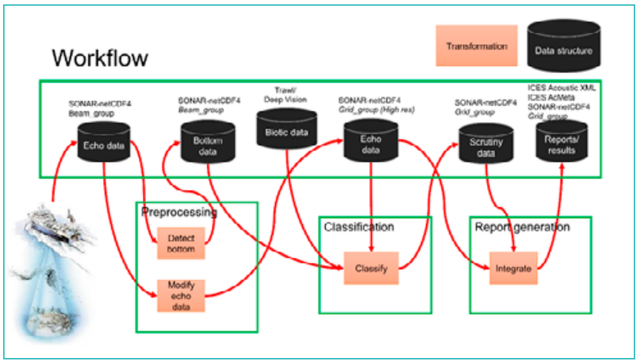


Fig. 4.1 The suggested workflow. The black boxes indicate a data model and the orange rectangles denotes a processing step.

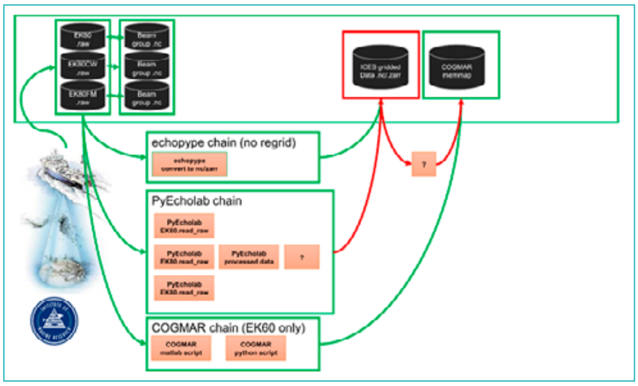


Fig. 4.2 Different python/matlab packages tested for reading the data. Green lines are working software. The echopype package generates the zarr data but does not regrid data in cases where there are different pulse lengths between channels. The pyEcholab chain does not generate gridded data. The COGMAR chain works but relies on matlab functions that can only read EK60 data

Work package 5 Applications

Project leader: Espen Johnsen

Background

Scientific questions: *Do new developments in WP1-4 lead to better products, tools or methods?*

Improved knowledge about broadband backscatter (WP1&2), better ground truthing (WP3), and automation (WP4) should lead to improved methods relevant for the user partners' products and services. To assess any improvements, the methods must be objectively assessed against existing techniques and procedures. This WP will carry out this assessment for ecosystem monitoring, fisheries applications, aquaculture and the energy sector, and advice the implementation of the most promising outcomes from WP1-4. This will also ensure a broad interdisciplinary forum, and feed back to the more technical WP's (WP1-4) on priorities and guidance.

For ecosystem monitoring, quantification of survey uncertainty is of key importance, and will help focus the effort that lead to the largest reductions in the uncertainty. Indicative tasks include development of methods to adjust survey estimates for migration of schools and layer based on multibeam sonar and doppler measurements from new broad band EC150-3C (ADCP), recently tested on "G.O. Sars". Development of two-stage adaptive sampling with fully- or semi-autonomous sonar platforms, as well as direct measurement of vessel avoidance by hearing specialist like herring will be made by silent SAV and AUV's. Re-analyzing survey time series based on the results from (WP4), including improved estimates from the target species and other scattering categories, for a range of IMR surveys, will be tested. The bias in manual categorization of routine acoustic surveys will be investigated by applying the trained machine learning algorithms to IMR's historical acoustic survey time-series. The re-analyzed series will be tested in the assessment framework developed at the institute, where the effect of changes in survey time series can be analyzed.

For fisheries applications the results from improved understanding of the broad-band scattering properties (based on WP1 and 2) and optical methods (WP3) will be explored to provide information about behaviour, size and species the during the catching phase. Narrow beams that can resolve single individual fish within, or at the edge of, dense schools will be explored for the pelagic purse seine fisheries. The objective is to test whether the size and species categorisation algorithms developed in WP1 and 2 can be used in practice in fisheries operations. For the

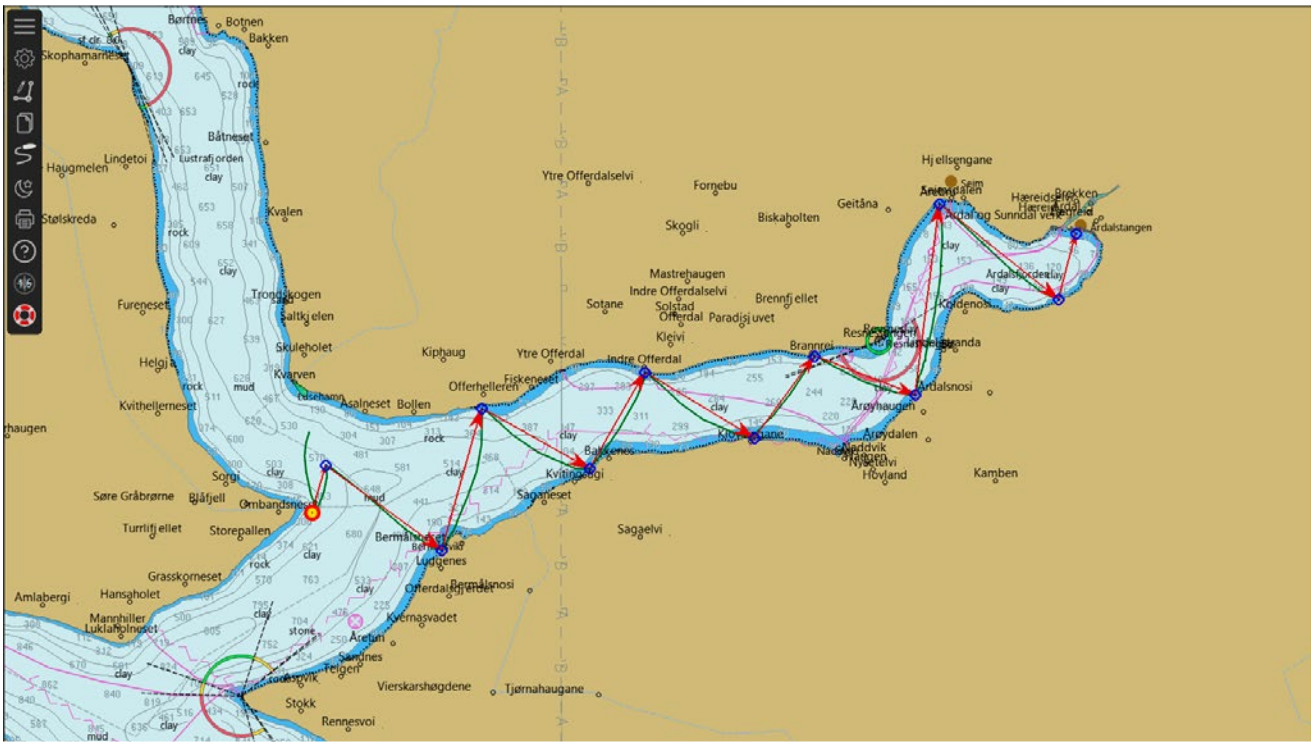


Fig. 5.2 Planned and realized autonomous survey tracks by the KayakDrone in Årdalsfjord 2020.

Figure 5.1 Kayakdrone surveying sprat in Sognefjord.

trawling fleet, in-trawl camera systems (from WP3) will be tested and the potential to use these for selective fishing will be explored

Similar applications will be tested for the aquaculture applications, where size, growth, behaviour and distribution within large aquaculture pens will be explored. The objective is to test whether the acoustic properties resolved in WP1 can be used to assess key parameters in aquaculture, like fish size, behaviour, distribution and welfare. It is expected that outside the concentrated areas of the net pens, also targets like pellets, dead fish and faeces can be measured and separated automatically by spectrum analysis. The sensitivity and dynamic range of existing echo sounders used in farming is set to measure strong targets and vertical distribution,

but not targets 1 million times weaker (-60 dB). We have shown that most sensitive high frequency broad band system to be used here can measure the echo and spectrum of one single cod egg at 1.4 mm diameter, and presence of algal blooms inside the net pens may therefore also be measured and compared with camera observations.

For the energy sector, the detection of bubbles or droplets emerging from the seafloor will be extracted through the automated processes developed in WP4. This will be used to build an environmental baseline to detect changes in gas seeps. Together with other measurements they will serve as reference when designing monitoring programs for CCS projects. We will focus on the Troll area, being the site chosen for the Northern Light project, first explore existing data in view of lessons learned with respect to the use of acoustics in a recent EU project (STEMM-CSS). Later we will implement acoustic data streams in the data treatment being implemented in CCS monitoring projects.

Objectives
To implement prototype methods; to assess the expected improvements from implementation.

Research and results
The first CRIMAC cruise was carried out with FF G.O. Sars November 2020. Here, a long range of calibrations settings for broadband echosounders (EK80) was tested, and the settings were used to record both deep and shallow water layers of herring. Preliminary tests indicate that the LSSS post-processing software can be used in an efficient way to analyses these large data sets. Clearly, the broadband echosounders provide more information about species composition and fish behavior, however, the results comparing acoustic recordings from broadband and narrow band echo sounders are promising with regards to continue long survey time series without introducing significant biases.

During the workshop organized by the COGMAR and CRIMAC projects, organized by WP4, UiB, IMR and other partners discussed different options propagating uncertainty from machine learning for acoustic categorizing. In close co-operation with WP4 a detailed scientific plan for this work will be in place before the end of Q3, 2021.

The standard sandeel survey 2021 will be carried out in close co-operation with CRIMAC, where part of the survey will focus on potential of using broadband echosounder to investigate fish behavior, identify fish size and species with a higher accuracy. The kayak drone, installed with broadband echo sounders, will be used to compare the vertical distribution and avoidance reactions observed from the kayak and the vessel. Ongoing analyses of data recorded with a saildrone in 2019 show that sandeel is distributed closer to the surface than the vessel can observe. A Master thesis with results of these analyses will be submitted in May 2021. Large parts of the future sandeel survey will most likely be conducted by USVs in the future, and CRIMAC will be involved in the planning of these surveys. It should be noted that IMR has decided to buy a Sounder USV, Kongsberg Maritime equipped with needed scientific broadband echosounders and for ~20 days operations. This USV and others may also be used for fjord surveys for sprat.

In 2020, we carried out an experimental and successful survey with the silent kayak drone in the Sognefjord (Figure 5.1 and 5.2) where the survey report concluded that "that future sprat surveys should be carried with silent vehicles where the echo sounders are mounted near the surface". As a continuation of this finding, WP5 will be responsible to carry out similar sprat surveys in the Hardangerfjord and the Sognefjord in 2021. A Master thesis student will work with these data in 2021 and 2022.

The design and time schedule for the future development of the open source software "Echogram Individual Based simulation Model (EchoIBM)" will find place in Q2, 2021. The "EchoIBM" is developed at IMR, and will be used to produce echograms by beams and frequencies based on target attributes such as backscattering properties received from WP1 and WP2, position, depth and tilt, and polarization of targets in schools. The acoustic categories can be labelled, and the echograms can be utilized for the machine learning in WP4.

Work package 6 Extracting gains for science and industry

Project leader: Egil Ona

Background:

Industry question: *Can the methods developed be implemented in products by the user partners?*

Development of products and services is the responsibility of the user partners. This WP is set up to support the transition from verified methods (WP5) to products and services from the user partners. Good demonstration cases are needed to successfully demonstrate the utility of these new products and services. While it is difficult to predict the exact products and services for implementation and commercialization, it is imperative that the user partners are given the opportunity to display their products. WP6 is established as a cross-cutting and interdisciplinary work package to achieve this. This will be achieved through dialog between research and user partners, and through demonstration events organized by CRIMAC, c.f. the exploitation, communication, and data management section. From experience the most successful cases are when the products and tools are demonstrated on site, e.g. through “fisheries acceptance testing” in ruggedized environments with skippers and researchers present. Examples of anticipated products are new calibrations systems, robust and simplified methods and settings for fishing vessel sonar and echo sounders, machine learning techniques implemented in end-user software for analysis of acoustic and optic data, and the Deep Vision system for fisheries research applications. If a new method or tool is developed but only a few advanced users can apply it in science or fishery, the objective is not met. The proof is in the eating of the fish pudding.

Objectives

Facilitate the transition of research innovation into practical use in science and industry and suggest new future procedures and products with impact.

Research and results:

The new ADCP system was mounted (Fig. 6.1) onboard G.O.Sars and tested in the November 2020 survey against moving/ migrating herring. Especially the vertical speed of the herring layer, as seen by the doppler system was studied, with respect to estimating vessel avoidance and effect on herring mean target strength. Data from the herring spawning survey, when the system was mounted on EROS 2020 is under analysis and will be presented at the ICES FAST WG 2021 and published. The main result is that besides normal water column current measurements from surface to about 350 meters depth, the system can also be used to measure the herring migration speed directly, of the schools and layers are large enough to be measured and averaged by the four ADCP beams (Fig. 6.2) The uncertainty in the biomass estimate of spawning herring is tried estimated.

The use of this system for measuring ocean current speed (for science and for fishing must be published and presented) by KM and University of Hawaii, and IMR.

The use of system for measuring fish layers in general (herring, mackerel, meso), especially demo materials for science and fishermen are collected and will be presented, and the current software presentation modes discussed with skippers. Filters are introduced to focus

Fig. 6.1 The ES150-3C transducer and transceiver mounted in the front part of the drop keel of G.O.Sars, inside a ES38B transducer adapter ring.

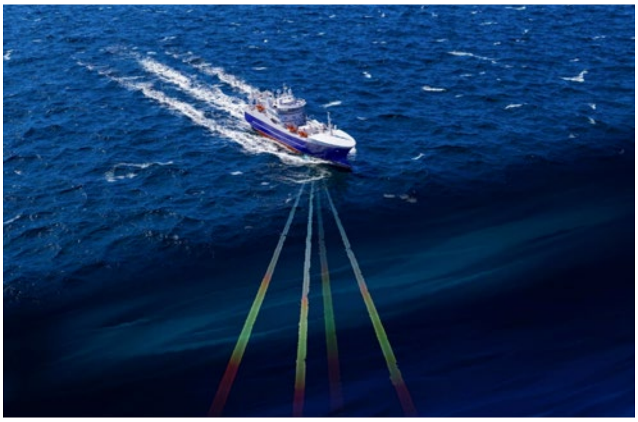


Fig. 6.2 Principal sketch of the four beams of the Simrad EC150-3C ADCP system (Image: Tonny Algrøy, Kongsberg Maritime)

either on fish layers or water layers. These will be tried in echo sounder replay modes.

The way the ADCP is part-processing the data for new displays (and data) can be a model for future wide band processing. The new compressed NETCDF output data works well and can easily be read by post processing systems, (Fig. 6.3).

The ADCP transducer can also be used as a broad band echo sounder with narrow, 2.5 degree beam, and will facilitate single target resolution with 75 times better resolution than a 1 millisecond pulse using a standard 7 degree opening transducer (Fig. 6.4). Demo data sets for this as a basis for fish sizing in dense registrations were made and will be analyzed and demonstrated.

Started the description new acoustic sensors on trawl, and plan trials in Nov 21.

Started making site of "standard settings" for fisherman's EK80, lock that in software KM. – including storage methods for commercial fishing.

Started to establish new rig and calibration methods for SU90 sonar and echo sounders.

Started trying out 3D presenting software TD50 and similar, using multiple sensors.

Started making calibration procedure for CRIMAC fishing vessels.

Assist in "data cleaning activities" for WP4, with real fishery examples.

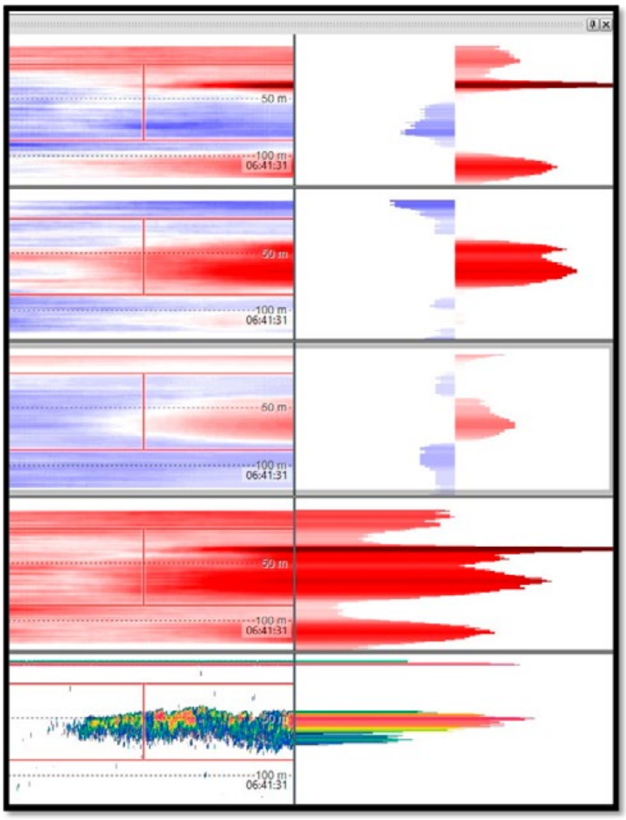


Figure 6.3 A herring layer at 50 meters depth swimming opposite way of the ocean current and diving when passed over by the vessel, Upper panel: N/S, second panel: E/W, third panel : DOWN/UP, fourth panel: Echogram beam 1.

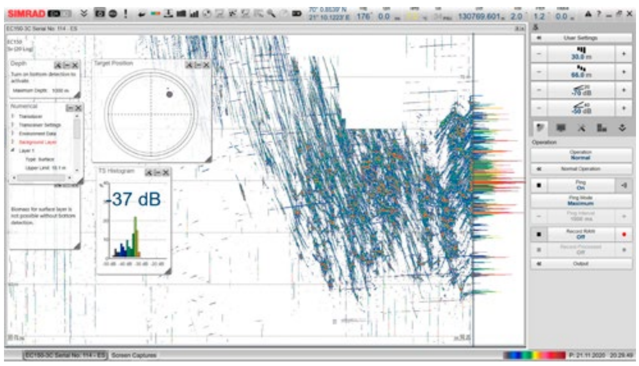


Figure 6.4 Resolving capacity of the herring layer with the EC150-3C showing target strength measurements inside herring layer at 70 – 90 meters depth.

6. INTERNATIONAL COOPERATION

CRIMAC has cooperated with inter¬national research institutions when such cooperation has been beneficial for joint develop¬ment and introduction of sustainable fishing technology outside Norway..

We have deliberately kept the number of international partners low (2) in the Centre, due to the competitive nature of products involved, and only used well known experts within wideband physics from NOAA (USA) and within geo-statistics (IFREMER, France) who can contribute to the research and education of new PhD students within the centre, is selected. IMR will otherwise use their normal cooperating partners within fishery science for data and research problem sharing, scientist cooperation and publication. This will expose the activities of the centre on the international arena and enhance the ability of the Norwegian business sector to put their products and methods to the market.

NOAA, Alaska Fisheries Science Center (AFSC), Seattle, USA and IMR are through the IMR-AFSC cooperative agreement, exchanging people and information in matters relating to the conservation and management of living marine resources. In the fishing technology field, AFSC has a focus in the development of selective trawling methods that actively release unwanted bycatch, such as various salmon species during the pollack fishery. NOAA has also been one of the main cooperating partners within fisheries acoustics, and recently also with using acoustic drone technology to support regular fisheries surveys.

Fisheries Research Services (FRS), Marine Laboratory, Aberdeen, Scotland and IMR have cooperated on various topics in fisheries acoustics during several EU-funded projects as for example the successful SIMFAMI project where methods for multifrequency identification of important fish species were developed. Common survey work and research on North Sea Herring and Atlantic mackerel stocks may also be a platform for centre data collection and processing.

IMR and Kongsberg have close cooperation with Institut Français de recherche pour l'exploitation de la Mer (IFREMER, France) in multibeam sonar technology, in broadband signal analysis, acoustic broad band calibration and in survey design and geo-statistics.

The Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia and the Institute of Marine Research (IMR) have been cooperating closely for 50 years in developing the basis for long-term sustainable management of living resources in the Barents Sea. This work includes topics related to such areas as acoustic methodology and modern fishing technology, as well as education of new personnel.

Havstovan (Faroe Maritime Research Institute), Hafrannsóknastofnunin (Maritime Research Agency, Iceland) and IMR are collaborating closely on measuring the shared stocks of Norwegian Spring Spawning herring and Atlantic mackerel, where the use of modern acoustic methods as well as trawling methods with associated errors are involved. FMRI has also built (2019) a brand-new research vessel with nearly identical instrumentation as "G.O. Sars".

IMR is a member of the International Council for Exploration of the Sea (ICES), and contributes substantially to the working groups on Fisheries Acoustics, Science and Technology (WGFAST) and Fishing Technology and Fish Behaviour (WGFTFB), both highly relevant for the SFI. These are international venues beyond the ICES countries where leading scientists in the field of acoustics and fishing technology meet.

International Scientific Advisory Committee – ISAC
CRIMAC has established an international scientific advisory Committee with three candidates; 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.

7. RECRUITMENT

CRIMAC will have four MSc students involved in project work related to WP2 and also 2-3 PhDs working in the project employed at UiB from 2021. The PhDs will be related to WP3 and WP4. CRIMAC will have 5 PhDs in total for the whole project period.


SWL3T

8. COMMUNICATION AND DISSEMINATION ACTIVITIES

A webpage for CRIMAC has been created under www.imr.no/www.hi.no.

Several news items about CRIMAC activites have been released, including information from the opening ceremony and innovative results from resarch cruise organised by the Centre. Details of projects have been published on the webpage in a series called “Rapporter fra Havforskningen”.

A specific communication group for CRIMAC have been organized with regular meetings and deciding upon a communication strategy for the center with participants from all partners Table 8.1). A strategy document has been developed, including a rotating list of dissemination activities (Table 8.2).

Table 8.1 Members of the communication group

Name	E-mail
Nils Olav Handegard, IMR (Manager)	nilsolav@hi.no
Tonny Algrøy, KM	Tonny.Algroy@simrad.com
Rannveig Haugen Stiberg, NORCE	rast@norceresearch.no
Erlend Astad Lorentzen, IMR	erlend.astad.lorentzen@hi.no
Line Eikvil, NR	eikvil@nr.no

Table 8.2 Dissemination activities.

Title	Channel	Status	Link
Jubel for tildeling: HI skal lede nytt innovasjonssenter	hi.no	Published	https://www.hi.no/hi/nyheter/2020/juni/jubler-for-tildeling
Sjøsatte senter for forskningsinnovasjon med omfattende sildetokt i nord	hi.no	Published	https://www.hi.no/hi/nyheter/2020/desember/sjosatte-senter-for-forskningsinnovasjon-med-spektakulert-sildetokt-i-nord
Tuning in to the sounds of the sea	KM	Published	https://www.kongsberg.com/maritime/the-full-picture-magazine/2020/12/crimac/
Smart fisheries essay	JoT	In prep	
Betre ekkolodd vil gi betre forståing av våre marine økosystem	Skipsrevyen	Sent	

APPENDIX 1 PERSONELL

Key Researchers

Name	Institution	Main research area	Sex
Egil ONA	IMR	Center leader, wide band researach	M
Nils Olav HANDEGARD	IMR	WP leader, Maschine learning, AI	M
Geir PEDERSEN	IMR	WP leader, Wide band research	M
Tonje N. FORLAND	IMR	WP leader, Wide band experiments	F
Maria TENNINGEN	IMR	WP leader, ground thruthing	F
Espen JOHNSEN	IMR	WP leader, Implementation	M
Ketil MALDE	IMR	Scientist, Machine learning	M
Shale ROSEN	IMR	Scientist, Ground truthing	M
Frode OPPEDAL	IMR	Scientist, Fish farming	M
Sindre VATNEHOL	IMR	Scientist, pelagic fish, sonar	M
Rokas KUBILIUS	IMR	Scientist, wide band expert	M
Hector PENA	IMR	Scientist, sonar expert	M
Guttorm ALENDAL	UIB	Scientist, Mathematics, AI, ML	M
Per LUNDE	UIB	Prof. acoustics, wide band theory	M
Anne Gro V. SALVANES	UIB	Prof. Fisheries biology	F
Rune ØYERHAMN	NORCE	Scientist, wideband	M
Inge K. ELIASSEN	NORCE	Scientist, postprocessing	M
Arnt-Børre SALBERG	NR	Scientist, Machine learning , AI	M

Key technicians, research institutes

Name	Institution	Main research area	Sex
Turid S. LODDENGAARD	IMR	Centre management - Finance	F
Atle TOTLAND	IMR	Sonar Technology and Fisheries Instrumentation	M
Liz B.K. KVALVIK	IMR	Engineering, instrument development	F
Erik SCHUSTER	IMR	Engineering, instrument development	M
Ronald PEDERSEN	IMR	Sonar Technology and Fisheries Instrumentation	M

Key personell, industry partners

Name	Institution	Main research area	Sex
Lars N. ANDERSEN	Kongsberg Group	Sonar technology and fisheries instrumentation and Board leader	M
Ivar WANGEN	Kongsberg Group	Sonar technology and fisheries instrumentation	M
Tonny ALGRØY	Kongsberg Group	Sonar technology and fisheries instrumentation	M
Thor BÆRHAUGEN	Kongsberg Group	Sonar technology and fisheries instrumentation	M
Martin TOLLEFSEN	Kongsberg Group	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
Frode GAUPÅS	Scantrol AS	Visual fish classification	M
Hege HAMMERSLAND	Scantrol Deep Vision AS	Visual fish classification/Marketing	F
Ruben PATEL	CodeLab	Low impact trawling	M
Anne-Sofie UTNE	Norway Royal Salmon ASA	Low impact trawling	M
Per Magne EGGESBØ	EROS AS	CEO	F
Pål Cato REITE	EROS AS	Captain	M
Per William LIE	Lie-Gruppen	Captain	M

Master students

Name	Nationality	Period	Sex
Maren ROGN	Norsk	2021-2022	F
Cecillie Kahrs SKAALE	Norsk	2021-2022	F
Kristin Utne BERG	Norsk	2021-2022	F
Miranda VEIM	Norsk	2021-2022	F

APPENDIX 2 STATEMENT OF ACCOUNTS 2020

All figures in 1 000 NOK

Funding

		Budget	Account
The Research Council		3 000	3 444
The Host Institution	Havforskningsinstituttet	3 500	4 495
Research partners	NORCE	-	
	NR	-	
	University of Bergen	-	
Enterprise partners	Kongsberg Maritime AS	1 000	2 772
	Scantrol AS	200	
	Scantrol Deep Vision	-	265
	Lie Gruppen	-	28
	EROS AS	-	323
	CodeLab	50	50
	Norway Roal Salmon	-	40
	Total	7 750	11 417

Costs

		Budget	Account
The Host Institution	Havforskningsinstituttet	6 000	7 423
Research partners	NORCE	250	266
	NR	250	250
	University of Bergen	-	-
Enterprise partners	Kongsberg Maritime AS	1 000	2 772
	Scantrol AS	200	-
	Scantrol Deep Vision	-	265
	Lie Gruppen	-	28
	EROS AS	-	323
	CodeLab	50	50
	Norway Roal Salmon	-	40
	Total	7 750	11 417

APPENDIX 3 PUBLICATIONS

Refereed journal papers

2020
Ona, Egil; Zhang, Guosong; Pedersen, Geir; Johnsen, Espen.

In situ calibration of observatory broadband echosounders. ICES Journal of Marine Science 2020; Volum 77. (7-8) s.2954-2959 HAVFORSK

2021
Khodabandeloo, Babak; Ona, Egil; Macaulay, Gavin; Korneliussen, Rolf

Nonlinear crosstalk in broadband multi-channel echosounders. Journal of the Acoustical Society of America 2021; Volum 149. (1) s.87-101 HAVFORSK

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