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Smart Fisheries in Norway

Partnership between Science, Technology, and the Fishing Sector

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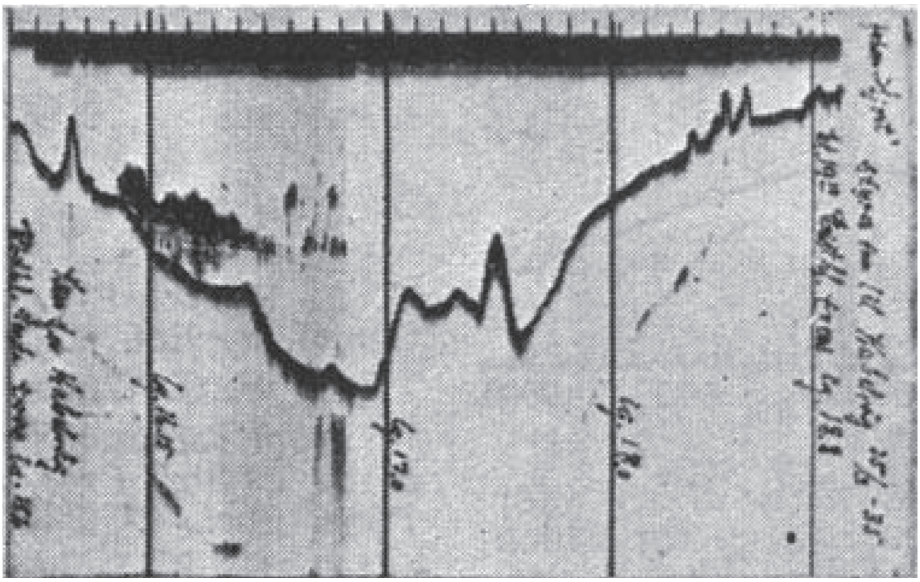

Figure 1: Echogram showing spawning cod in midwater at Lofoten. Reprinted by permission from Springer Nature Customer Service Centre GmbH: Nature Publishing Group. Nature. Echo Sounding in Fisheries Research, Oscar Sund © 1935.

The Research Council of Norway recently funded the Centre for Research-based Innovation in Marine Acoustic Abundance Estimation and Backscatter Classification (CRIMAC). The centre has smart fisheries as one of its main pillars, and will address reliable catch quantification, sizing, and species identification of individual fish. It builds on a long tradition of science-industry partnership in Norway. In this essay, we review how this science-industry partnership has formed through long standing collaborations between marine science organizations, innovative fishing companies, and the marine-tech industry. The results from this collaboration have led to instruments and methods being used worldwide for smart fishing operations and monitoring the marine environment.

In the 1930s, Norwegian fishers started to use the Hughes British Admiralty echo sounders to search for fish. This early adoption of technology became common for the Norwegian fishing industry, a tradition that is still strong within the industry today. In these early days, the objective was to improve the efficiency of the searching phase of the fishing operation.

Soon the researchers followed. In 1935, Oscar Sund used an echo sounder to detect and map the distribution of spawning North East Arctic cod in the Lofoten area, where large spawning aggregations are formed (Figure 1). On their spawning grounds, the cod can be enumerated by dedicated surveys or observed while migrating over permanent bottom mounted observatories, like the LoVe observatory outside Myre, Lofoten. Oscar Sund's paper was the first use of echo sounders in fisheries oceanography.

Willy Simonsen was working as a radio engineer for the Radio Production Unit of the British War Office during the Second World War. After the war, he formed the company Simrad, which produced ruggedized radios and echo sounders for the fishing fleet. Simrad was later acquired by Kongsberg Maritime and today "Simrad by Kongsberg" is a recognized brand used for acoustic instrumentation by fishing fleets and aquatic science organizations around the world.

The worldwide adoption of the Simrad echo sounders was a result of a successful science-industry collaboration. After the Second

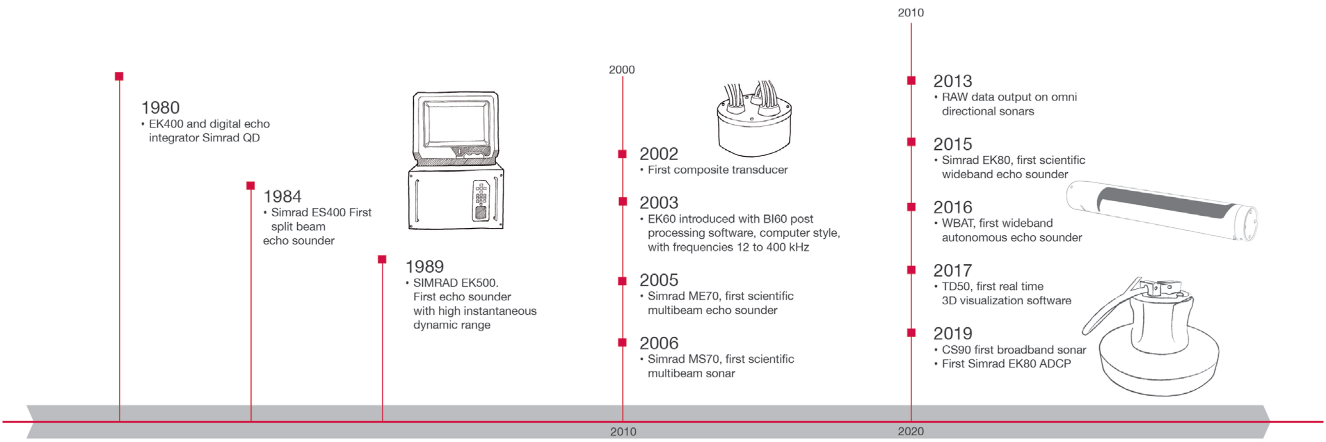

Figure 2: Generations of Simrad sonars and echo sounders resulting from the science-industry collaboration. KONGSBERG MARITIME

World War, a strategic collaboration between the Institute of Marine Research (IMR), the Norwegian Defense Research establishment, and Simrad was formed. This was the start of a long-standing collaboration that is still active today. The early adoption of technology by the fishing industry, the interest within the scientific institutions, and the emerging industry were important prerequisites for its success.

Through this collaboration, several of the techniques used today within fisheries acoustics were developed. Both sonars and echo sounders were developed and prepared for the commercial market, and several generations of sonars and echo sounders (Figure 2) followed. The commercialization aspect is a key driver for further development since it grants researchers and institutions access to high-end instruments, not only to those with the skills and resources to build their own instruments, which was common in the early days.

The acoustic methods that were developed early on included electronics to compensate for geometric spreading and absorption, improved dynamic range, robust bottom detectors, and the echo integration. The "echo integrator" from 1965 was an important milestone since it allowed quantitative scaling of the biomass, a method that is standard practice today. Prototype integrators were commercialized by the industry.

Calibration and system stability were needed for accurate echo integration, and another milestone for both science and fisheries was met when the Simrad ES380 split beam echo sounder was made commercially available in the mid-1980s. This allowed much more accurate calibration methods, including the present method using standard spherical targets. Intercalibration comparisons between cooperating vessels were now superfluous, and system long-term stability could be monitored.

After computerizing echo sounders in the late 1980s, it was possible to efficiently process data from several different frequencies that were operating simultaneously. This improved our ability to separate fish and zooplankton echoes in the water column. Species identification using acoustics was developed, and the fishing industry could start evaluating target species and bycatch. Much of this development was achieved through international collaboration, including the Working Group of Fisheries Acoustics Science and Technology under the International Council for Exploration of the Sea (ICES).

With the recent introduction of broadband echo sounders, more comprehensive echo spectrum of the objects in the water column is available. We are still learning how to utilize the rich detail found in these data. With the commercially available Simrad EK80 broadband system, the method is accessible

Figure 3: The Scantrol Deep Vision system with the prototype selection device mounted after the imaging unit.

to a wider range of fishing companies and marine science institutions, and we can obtain a lot more data across a range of fisheries and ecosystems.

Acoustic instrumentation is also important in the decision phase in modern fishing operations. Fisheries sonars are used in pelagic purse seining for detecting, locating, and evaluating fish schools before capture. These technologies have led seining to become one of the most energy efficient fish capture methods.

Accurate estimates of school size before capture are important where whole schools are encircled and caught with limited possibility to control catch size after the seine is set. Control over catch size (and composition) improves quality of the fish products and reduces the risk of excessively large catches. Information on swimming speed, depth, and direction obtained from sonar data are essential when planning how to deploy the purse seine without losing the fast swimming and reactive school.

Selectivity and catch control are of key importance for the fishing fleet. This involves catching the right amount, the target species, and optimal fish size, in addition to mitigating bycatch and incidental fishing mortality. Mechanical systems have been developed for selective trawl fisheries, including sorting grids, escape holes, and excluder devices. These systems use differences in the size and behaviour of the target and non-target fish to allow non-target fish to escape. Acoustic and optic instruments mounted on the fishing gear and with real-time data transfer to the bridge further improve catch control. Industry-science cooperation has had an important role in the development of many of these instruments.

Scantrol Deep Vision is one example of a commercially available product developed in cooperation with marine science institutions. The Deep Vision is designed for visual fish classification inside a trawl; it is placed on a frame between the extension and codend of a trawl (Figure 3). A scientific version is already in use in fisheries research while the development of a simpler, more compact commercial version continues. The final product will have live transfer of images with automatic species and size information and a remotely controlled release mechanism that opens and closes the codend.

Another example is the trawl HUB (Simrad FX80) developed by Kongsberg Maritime. This includes ethernet connectivity to the head rope of the trawl for live two-way communication with cameras or echo sounders, including remote release mechanisms. The system is used to detect bycatch species and is commercially available.

Modern acoustic instrumentation and camera systems generate substantial amounts of data, and efficient data processing methods are required to tap the potential of the new instruments.

More recently, the collaboration has been extended to include e-science partners. The Norwegian Computing Center (NR) was established in 1952, and has a long track record in computational mathematics, including statistical analysis, image analysis, and machine learning. A notable contribution is the Simula programming language, where NR is credited with inventing the first object-oriented programming language. The Norwegian Research Centre (NORCE), formerly Christian Michelsen Research, has worked within acoustics and acoustic data processing, and is also an important partner with IMR for developing post-processing systems for acoustic data. NORCE is responsible for the acoustic post-processing software package, "Large Scale Survey system," that is used by IMR and other organizations for processing acoustic data from surveys.

Modern machine learning methods are currently being used on data from sonars and echo sounders (Figure 4), and the development within this field happened quickly. IMR, together with NR, published the first deep learning classifier on multifrequency acoustic data. These networks differ from traditional algorithms since they can learn features from the data itself to aid classification. Presented with adequate training data, real or simulated, the system can learn features that are not apparent when hard coding the classifiers. This is a very interesting field, and the e-science partners complement well with the other partners in the collaboration.

Another emerging field is unmanned autonomous vehicles. These are commercially available, and methods for using these for ecosystem surveys and fishing operations are being developed. IMR recently purchased two Sounder unmanned surface vehicles (USVs) equipped with a combined broadband echo sounder and acoustic Doppler current profile system. Methods and algorithms for processing data in real time and submitting information through cloud services are under development – again, in collaboration between the science institutions and industry.

This same unmanned surface vessel will also be used to increase the efficiency of fishing operations. TASA, Peru's largest integrated fishing company, will this year receive the first Sounder USV equipped with Simrad long-range sonar and echo sounder tasked to map fish distributions and obtain generic ocean data from a built-in conductivity-temperature-depth probe.

Recently, the Research Council of Norway awarded the consortia with a seven-year Centre for Research-based Innovation in Marine Acoustic Abundance Estimation and Backscatter Classification to further strengthen and develop the collaboration. The centre has fisheries applications as one of the main pillars.

The developments that have emerged would not have been possible without the strong science-industry collaboration. Both the industry partners and the science partners see a mutual benefit, and this long-standing collaboration, dating back to the late 1940s is one of the key factors of success. Encouraging industry-science collaboration is common today, and many well-formed projects build on this idea. What is remarkable is that these were exactly the ideas that formed the collaboration more than 70 years ago, when this was not necessarily the common way of thinking. Our colleagues from the early days were way ahead of their time, and we still benefit from their foresight.

Figure 4: The Kongsberg Maritime autonomous surface vehicle "Sounder."

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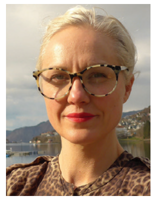
Dr. Nils Olav Handegard has PhD in applied mathematics. He works on sensors to observe behavioural responses in fishes, and how to apply these techniques on the assessment of anthropogenic stressors. He is also interested in how these behavioural changes may bias scientific surveys, as well as an interest in behavioural ecology. More recently, he has been working with machine learning and deep learning algorithms, and how these methods can be applied to ecology and fisheries oceanography. He has leadership experience from international organizations as well Institute of Marine Research, and has been involved in the International Council for Exploration of the Sea (ICES) through a range of working groups, including leading the Fisheries Acoustics Science and Technology group and the steering group overseeing ICES coordinated scientific surveys. He has been part of the science leadership group in the organization and has actively contributed to the ICES strategic plan.

Tonny Algrøy has a Bachelor in Nautical Studies (Sea Captain) from University of South-Eastern Norway and a Master of Business Administration from LaTrobe University in Melbourne. As a completion of the Sea Captain program, he worked seven years on various ocean-going fishing vessels out of Norway, mainly on purse seiners with some experience from blue whiting and cod trawling operations. After changing his line of work in 2011, he currently holds the position as Sales Director Ocean Science, commercially in charge of Kongsberg Maritime's range of scientific acoustic systems focusing on the development of the research market worldwide.

Line Eikvil is the Research Leader for the Image Analysis Group at the Norwegian Computing Center. She has more than 30 years' experience from contract research in image analysis and machine learning for a wide range of applications, with experience from both research and project management for R&D projects funded by industrial customers and public service organizations. She is also co-director of Visual Intelligence, a recently funded centre for research-based innovation on deep learning and AI to extract knowledge from complex image data. Her current research focus within image analysis is on deep learning for applications with complex image data, such as medical images, seismic data, and marine observation data, to solve problems like learning from limited training data, incorporation of context and prior knowledge, estimation of confidence, and explaining of predictions.



Hege Hammersland has a Master of Business Administration in seafood management from the Norwegian School of Economics. She currently holds the position of Business Development Manager at Scantrol Deep Vision. For the past seven years, she has worked to commercialize the Deep Vision technology, a visual fish classification and sorting tool for trawls. After introducing the technology for the marine research market, her current focus is to develop the Deep Vision into a catch sorting device for commercial trawlers to enable more sustainable capture practices.

Dr. Maria Tenningen has a PhD in fisheries biology. She works on bycatch mitigation and unaccounted mortality in fisheries. She has studied the survival of pelagic fish released from fishing gears and has been involved in developing methods for releasing unwanted catches that enhance survival. She has been involved in several cooperation projects with the fishing industry aiming to develop and test catch and gear monitoring systems for improved catch control and selectivity. Dr. Tenningen is also interested in physiological and behavioural stress responses of fish to capture, including causes of discard mortality. She is currently interested in the use of fisheries sonar for monitoring and understanding school behaviour in relation to commercial capture. She is a member of the International Council for Exploration of the Sea (ICES) working group on Fishing Technology and Fish Behaviour and has been involved in several other ICES working groups related to fisheries discards.

Professor Egil Ona has worked for 40 years with fisheries acoustics at Institute of Marine Research (IMR) and with education at University of Bergen as an adjunct professor. He has worked on improving the standard acoustic surveying methods, and with developing methods for individual target strength measurements and target identification. He has also been involved in development of drop keels for improved measurements in bad weather, scanning sonars on trawls, and in measuring the effect on fish from low frequency sound pollution, as from seismic surveys for oil exploration. He has conducted training courses in fisheries acoustics nationally and internationally and arranged ICES training courses in broadband acoustics for the last four years. Currently, he is the leader of the new Centre for Research-based Innovation in Marine Acoustic Abundance Estimation and Backscatter Classification research centre at IMR.