# ANNUAL REPORT | 2016

CRISP

# 1 SUMMARY

CRISP, the Centre for Research-based Innovation in Sustainable fish capture and Processing technology, started its research activities in April 2011. Since its launch, the consortium has consisted of four industry partners (Kongsberg Maritime AS, Simrad; Scantrol Deep Vision AS; the Egersund Group AS; Nergård Havfiske AS), four research partners (the Institute of Marine Research; Nofima AS; the University of Bergen; the University of Tromsø), and two sponsors (Norges Råfisklag; Norges Sildesalgslag).

In this sixth CRISP year, the process of developing new knowledge, new fishing gears and instruments for the fishing fleet as important tools for making the trawl and purse seine fisheries more sustainable has continued. These achievements have only been possible because of extensive cooperation between the centre's industry partners and research institutes.

The research of the Centre is organized in six scientific work packages (WPs):

**WP1:** Both the fishing industry and research institutes need more accurate density and abundance measurements of schooling fish species than what is possible with current instrumentation. Simrad collaborates with IMR to develop new and improved fishery sonars which can quantify the volume of a school prior to shooting the purse seine, and high definition echo sounders which may accurately measure the fish size. Calibration protocols for fishery sonars and methods for correct volume estimation are now finalized. In 2016, the major work has been to study the extremely variable backscattering of fish when observed from the side, which has been shown to be the major source of uncertainty in biomass estimation of schooling fish.

**WP2:** Purse seine fishermen need tools to improve their control over the capture process, including better characterisation of the catch before they shoot their nets, as well as being able to monitor the geometry of the purse seine and the behaviour of the catch during capture. Improved catch characterisation will enable fishermen to optimise harvesting strategies to maximise the value of limited vessel quotas, while improving the sustainability of the fishery by helping to avoid taking unwanted catches. In 2016, we focused on four topics: 1) using integrated instruments to better describe the behaviour of mackerel in response to capture related stressors; 2) developing a platform for deploying instruments to monitor the behaviour of the catch in relation to key environmental parameters (e.g. dissolved oxygen concentration); 3) further testing of the "In-seine" sonar technology for catch control; and 4) monitoring purse seine geometry and performance using sonar and transponder technology.

**WP3:** Unwanted catches often occur in mixed trawl fisheries regulated by quotas for individual species. A major topic for CRISP is therefore to develop interactive methods capable of actively releasing unwanted catch from trawls based on early identification of size and species inside these gears. The Deep Vision system, developed by Scantrol Deep Vision AS, takes constant stereo images of all objects passing through the trawl. These images can be used to identify and measure fish inside a trawl, opening opportunities to improve fisheries surveys by employing new techniques or providing evaluation of the trawling methods presently used. In 2016 the focus has been to implement the Deep Vision system into IMR's stock assessment survey trawling and to develop a down-scaled system for use on-board smaller fishing vessels. Deep Vision was awarded first prize for innovation at the 2016 Nor-Fishing expo, where the judges recognized the technology's potential to revolutionize both marine research and commercial fishing.

**WP4:** The current trawling practice is regarded as unsustainable. It may be harmful to the seabed, have high bycatch rates and high fuel consumption that can affect the environment. The future of trawling will thus largely depend on the development of trawling techniques that significantly reduce these negative impacts. WP4 addresses the design, rigging and operation of trawl gears that might achieve such objectives. Development of adjustable trawl doors have been one focus area. Experiments so far have shown that the doors can be maneuvered both vertically and horizontally, but the acoustic communication system between the vessel and the trawl doors is currently too unreliable to be applied commercially. Another focus area has been to develop catch regulation systems to avoid excessively large cod catches. Two different systems have been tested. Video observations showed that after some modifications both systems performed promising, but the catches in the survey period were not sufficiently large to challenge the systems.

**WP5:** The Norwegian fleet of ocean trawlers has gone through large changes since the turn of the millennium. Based on the encouraging results from the previous CRISP-experiments on quality improvement both in field and in laboratory, Nergård Havfiske AS has contracted a new trawler which will be implementing results from recent research regarding fishing efficiency, optimal product quality and improved welfare for the fish as well as for the crew. This year several quality issues during bottom trawling have been studied. One has been to investigate how prolonged buffer towing, which is commonly used by the Norwegian trawler fleet, influences filet quality. The experiments indicate that such practice has a negative effect on the catch quality. In addition, a selection study proved that a significant selection process is going on while buffer towing in upper water layers. The survival of these escapees is questionable.

**WP6:** The last work package in CRISP focuses on how the technological improvements developed in the other work packages will contribute to value adding and environmental friendliness among trawlers and purse seiners. An overview of the modified and developed technologies that have been achieved in CRSIP has been made and updated. A framework for cost-benefit analysis is developed, which is relevant when estimating the potential economic premium of the technological improvements achieved. The framework is based on analysis of the economic performance of the trawler and purse seine fleets.

CRISP staff has taken part in a range of dissemination activities during the last year, including lectures about CRISP activities in national and international scientific meetings. Nationally, CRISP staff has promoted their results at several meetings, seminars and fishing exhibitions arranged by various hosts.

In 2016 Crisp hosted two Post-doctoral position, six PhD positions and four Master students. Half of the recruitment candidates were females, which is an important step towards increasing gender equality in a formerly male dominant industry.

# 2 VISION/OBJECTIVES

## 2.1 Vision

The Centre for Research-based Innovation in Sustainable fish capture and Processing technology aims to enhance the position of Norwegian fisheries-related companies as leading suppliers of equipment and seafood through the development of sustainable trawl and purse seine technology.

## 2.2 Objectives

1. To develop and implement instrumentation to identify species and sizes prior to the catching process.
2. To develop and implement instrumentation for commercial fishing to monitor fish behavior and gear performance during fishing operations.
3. To develop methods and instrumentation to actively release unwanted bycatch unharmed during trawl and purse seine fishing.
4. To develop new trawl designs that minimize the environmental impact on bottom habitats and reduce air pollution.
5. To develop capture and handling practices to optimize quality and thus value of captured fish.
6. To analyze and document the economic benefits to the fishing industry resulting from implementation of the new technologies developed by the project

# 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.** Pre-catch identification of quantity, size distribution and species composition

**WP 2.** Gear and catch monitoring systems in purse seine

**WP 3.** Methods for capture monitoring and catch control during trawling

**WP 4.** Low-environmental impact trawl

**WP 5.** Quality improvement

**WP 6.** Value adding

**WP 7.** Management activities

Each work package is led by one of the two research partners along with a counterpart leader from one of the four industry partners. Most of the work packages involve one of the research institutes and one of the industry partners. Some work packages involve more than two partners, and it is a priority to increase cooperation among more partners in several of the work packages.

# 4 ORGANISATION

## 4.1 Organisational structure

IMR in Bergen is the host institution and is responsible for the administration of CRISP. From 2016 CRISP has been organized as a project in the Biological Mechanisms Program at IMR. Most IMR personnel working in CRISP projects belong to the Marine Ecosystem Acoustic and Fish Capture research groups. Scientists working in CRISP projects are therefore also involved in projects outside CRISP. A similar organizational structure also applies to Nofima, the other major research partner in CRISP.

The Universities of Bergen and Tromsø are research partners in the CRISP consortium. Their main function is to provide a formal education environment for PhD and MSc students who are funded by and associated with the Centre.

Aud Vold of IMR has been appointed director of the Centre from September 1, 2015.

The board of the Centre in 2016 was as follows:

Olav Vittersø, Kongsberg Maritime AS, Simrad (Chair)
Helge Hammersland, Scantrol AS
Bjørn Havsø, Egersund Group AS
Kjell Larssen, Nergård Havfiske AS
Geir Huse, Institute of Marine Research
Heidi Nilsen, Nofima AS
Arne Johannessen, University of Bergen
Jonny Caspersen, Norges Råfisklag
Turid Hiller, Research Council of Norway (Observer)

The director of the Centre acts as secretary to the board.

Representatives of the University of Bergen and University of Tromsø, as well as Norges Råfisklag (Norwegian Fishermen's Sales Organization) and Norges Sildesalgslag (Norwegian Fishermen's Sales Association for Pelagic Fish), alternate as board members every second year.

Chairman of the Board, Olav Vittersø from Simrad (Kongsberg Group)

## 4.2 Partners

In 2016, the CRISP consortium comprised four research partners (the Institute of Marine Research (IMR); Nofima AS; the University of Bergen; the University of Tromsø), four industry partners (Kongsberg Maritime AS, Simrad; Scantrol Deep Vision AS; Egersund Group AS; Nergård Havfiske AS) and two sponsors (Norges Råfisklag and Norges Sildesalgslag).

IMR has relevant R&D competence in fisheries acoustic, fish behaviour, fishing gear design and operation, capture based aquaculture, fish welfare and fishing gear selectivity. IMR also maintains infrastructure for ex situ and in situ experiments at its research stations in Austevoll and Matre and on board its three large research vessels.

Nofima AS possesses competence in handling, storage and feeding of live cod, fish welfare and restitution, sensory, processing and technological quality of fish and fish products, the assessment of quality aspects of fish captured by various fishing methods, and economic competence to evaluate the socio-economic consequences of changes in fishing patterns.

The University of Bergen has relevant scientific and supervision expertise in general fish biology, experimental biology, fish behaviour, fisheries acoustics and fish capture. For the past six years, the Department of Biology (BIO) has led a Nordic Research School in Fisheries and Marine Biology, NMA (Nordic Marine Academy). UiB also has excellent experimental marine research facilities and a Marine Biological Station in addition to the research vessels operated jointly with IMR.

University of Tromsø, Faculty of Biosciences, Fisheries and Economics (BFE), is responsible for education within all areas of fisheries and aquaculture research. Teaching and research focus are primarily on biological oceanography, fishery biology, assessment and management. CRISP will particularly benefit from the University's multidisciplinary expertise and approach. BFE has systematically developed competence, facilities and equipment closely related to marine and fishery biology and processing, including gear technology.

Simrad, which is part of Kongsberg Maritime AS (KM), has been developing tools for fishery research and commercial fisheries for more than 60 years. Simrad is a leading provider of acoustic systems for fish finding, pre-catch evaluation and catch monitoring. The company has a strong tradition of innovation and a history of developing acoustic instruments in cooperation with IMR; for example, instruments for fish size detection and species identification with echo sounders. Other KM subsidiaries manufacture underwater cameras, bottom profilers, underwater telemetry links, underwater positioning systems and subsea transponders for various monitoring and regulating purposes. The company's largest contribution to the Centre will be their leading-edge expertise in acoustics, electronics and instrumentation. The company also operates an experimental acoustic tank, calibration and test facilities on its own vessel and prototypes for full-scale testing.

Scantrol Deep Vision AS has developed a unique technology for taking high-quality stereo photos of fish inside a trawl (DeepVision technology), which can be used to identify species and measure their length through computerized image analysis. DeepVision may be combined with a mechanism that can subsequently retain or release organisms captured during fishing. The present status of DeepVision has partly resulted from cooperation with IMR scientists, including prototype testing on board research vessels. The development of an instrument that can be used in commercial fisheries requires the documentation of benefits compared to traditional selectivity methods, and the optimization of design and performance under practical conditions.

The CRISP consortium gathered at a visit to Egersund Group's premises during the Annual Science Meeting in Egersund September 2016.

The Egersund Group AS is a leading producer of pelagic trawls and trawl doors and a significant producer of purse seines for the Norwegian and Nordic markets. The company provides extensive practical experience to the Centre in the design of trawls, trawl doors and purse seines. The company in turn benefits from close cooperation with producers of gear instrumentation and technologists who have wide-ranging knowledge of fish behaviour and methods to evaluate gear performance, including access to modern research vessels. This cooperation helps The Egersund Group to develop trawl and purse seine technologies that will satisfy future requirements for green harvesting, which will be an advantage in the Norwegian and international markets.

The Nergård Group AS is one of the largest Norwegian exporters of seafood. The company focuses on maintaining local traditions and communities while sharing the sea's valuable assets with the rest of the world. Nergård has made major investments in white-fish vessels and quotas. Throughout the entire production chain the focus is on taking care of quality requirements on board, during landing, production, processing and transport - all the way to the customer. In 2008, the Nergård processing industry accounted for 30% of herring (human consumption) production, 18% of whitefish production and 40% of frozen shrimp production in Norway.

Norges Sildesalgslag (Norwegian Fishermen's Sales Association for Pelagic Fish) is Europe's largest marketplace for first-hand sales of pelagic species. The marketplace is owned and operated by Norwegian fishermen. Approximately 2 million tonnes of pelagic fish are sold every year through NSS, which is equivalent to 2 – 2.5 % of global wild fish catches. The main interest of NSS in CRISP is the development of sustainable purse seine fisheries, particularly in relation to eco-labelling and certification.

Norges Råfisklag (The Norwegian Fishermen's Sales Organization) handles important national functions in the seafood trade, together with five other fish sales organisations in Norway. The organisation also plays a national role in resource management. Norges Råfisklag organises and arranges the sales of whitefish, shellfish and molluscs landed on the coast from Nordmøre in the south-west of Norway to Finnmark in the north-east. The most important species are cod, saithe, haddock and shrimps/prawns.

## 4.3 Cooperation between centre's partners

The six research work packages are organized under the leadership of a representative from one of the research partners, and with a counterpart assistant leader from one of the industry partners with a main interest in that work package. The work packages often involve more than two partners, especially those who involve MSc and PhD students, where the universities are a natural third partner. The four industry partners have complementary competence with minor or no overlapping business interests.

The Centre uses various arenas and methods to encourage mutual trust and to form joint projects involving CRISP's partners. Every second month a regular contact meeting is held between the research partners over video link where matters of mutual interest are being discussed. Most projects within CRISP are conducted jointly by staff from a research institute and one or two of the industry partners. Field studies are normally done on-board a research or a fishing vessel. The key role of the researchers is to evaluate the efficiency and environmental benefits of the developed tools. The staff from all the partners participates in planning and execution of the research cruises followed by evaluation and reporting of the results. Industry partners, with the assistance from the Centre's management, have arranged meetings to discuss and plan joint development work.

The Annual Science meeting which is arranged each September, is the main meeting point for the whole CRISP consortium. All scientists and industry partners involved in CRISP then meet up for a two-day meeting where the scientific progress and other matters of importance for all partners are being discussed. In 2016 the Annual Science meeting was held in Egersund. The programme this year was centred around the theme "Next generation fishing vessels based on CRISP values". Also, the discussion on how to proceed after 2019, when the CRISP centre no longer will be funded by the Research Council. A visit to the premises of the Egersund Group was part of the programme.

CRISP staff visiting Egersund Trawl.

The leader speaks at the Annual Science meeting in Egersund.

# 5 SCIENTIFIC ACTIVITIES AND RESULTS

The scientific activities in CRISP are organized in the form of six work packages, including several subprojects; the partners involved are shown in Table 5.1.

***Table 5.1***
Work packages with sub-projects and partners involved

| Work package | Sub projects | Partners |
|---|---|---|
| WP 1. Pre-catch identification of quantity, size distribution and species composition | 1.1 Biomass estimation using digital fishery sonars<br>1.2 Pre-catch identification and sizing of fish with broad band split-beam echo sounders | IMR, KM and UiB |
| WP 2. Gear and catch monitoring systems in purse seine | 2.3 “In-seine” sonar technology for catch control<br>2.4 Catch monitoring system in purse seine<br>2.5 Monitoring seine geometry and performance | IMR, KM and UiB |
| WP 3. Methods for capture monitoring and catch control during trawling | 3.1 Visual fish classification<br>3.2 Trawl HUB for camera and acoustic systems | IMR, Scantrol Deep Vision, KM, UiB |
| WP 4. Low impact trawl | 4.1 Manoeuvrable trawl doors<br>4.2 Semipelagic trawl design and rigging<br>4.3 Catch regulation in trawls | IMR, Egersund Group, KM, UiB |
| WP 5. Quality improvement | 5.1 Current quality conditions onboard bottom trawlers<br>5.2 Facility and methods for experimental investigation of fish quality | Nofima, IMR, UiT and Nergård |
| WP 6. Value adding | 1.1 Nergård operation<br>1.2 Status of Norwegian trawlers | Nofima, Nergård and UiT |

## *5.1 Pre-catch identification of quantity, size distribution and species composition*

**BACKGROUND**
Both the fishing industry and research institutes need more accurate density and abundance measurement methods of schooling fish species than what is possible with currently available instrumentation used for detecting and observing fish horizontally, so-called multibeam sonar systems. In this respect, research and industry has a common long term challenge. This includes both robust calibration methods but also better understanding of the backscattering of fish in lateral aspects.

There is also a definite need for more precise estimates of size and species composition of fish schools prior to shooting a purse seine. This will reduce the number of unwanted sets where the catch is of the wrong species, wrong size composition or exceeds the amount that can be handled by the fishing vessel and therefore may have to be partly released. As this practice often result in unintended mortality of captured fish, instrument development which can reduce this risk are needed for future sustainable harvesting of pelagic schooling fish with purse seine gears. Similar challenges are also present in commercial trawl fisheries, where pre-catch species identification and sizing will be important in the future.

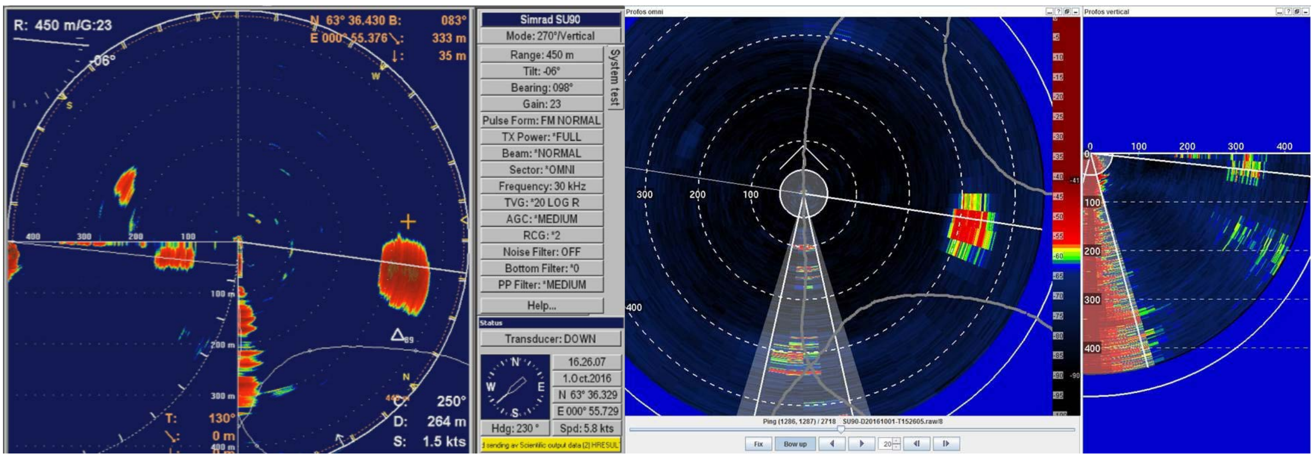



Figure 5.1. A mackerel school used in the verification work, where the school first was encircled by the vessel (FV “Brennholm”) and measured, and subsequently fished. The catch was 203 tonnes. Left panel: sonar display, Right panel: raw data during processing in PROFUS.

## ACTIVITIES

Simrad is collaborating with IMR for developing new and improved omnidirectional fishery sonars which can quantify the size of a school prior to shooting the purse seine, and high definition echo sounders which may accurately measure the fish size. This includes development and testing of new sonar raw data output formats, and the development of a standard calibration procedure for modern multibeam fishery sonars. New data formats and improved software have been delivered by the industry partner and tested with participation by Simrad personnel in the trial surveys on herring in 2012 and 2013, and on Atlantic mackerel in October 2014, 2015 and 2016. Simrad has this year mainly been working with the new matrix sonar (SN90) for studying the school and the purse seine net itself during setting and retrieval. Calibration protocols for the matrix sonar are also being made, and one successful calibration have been made on FV "Eros". Sonar processing software have also been adjusted to read data from SN90.

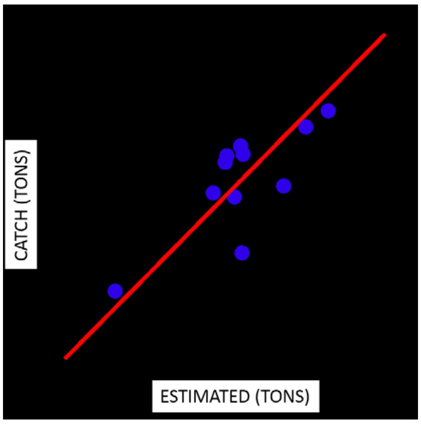



Figure 5.2. Preliminary correlation between sonar volume estimate and validation catches for Atlantic mackerel. Improvements in TS and other parameters is now made.

A CRISP PhD student has successfully used the raw element data of the omni sonar (SX 90 and SU90) transducer to create split beam positioning of the reference target under sonar beam calibrations. The sonar calibration method is published in three separate articles, and will be implemented directly in the sonar itself in connection with the next full software upgrade of the sonar. Further refinement and simplification of the calibration rig for holding and moving the reference target will be made, and simplification of the software. The fishery sonar of totally 10 vessels (3 research and 7 fishing vessels) have been calibrated, and the sonar of some of the fishing vessels have even been calibrated several times. The method is now robust, and 5 calibration rigs will probably be manufactured for IMR in 2017.

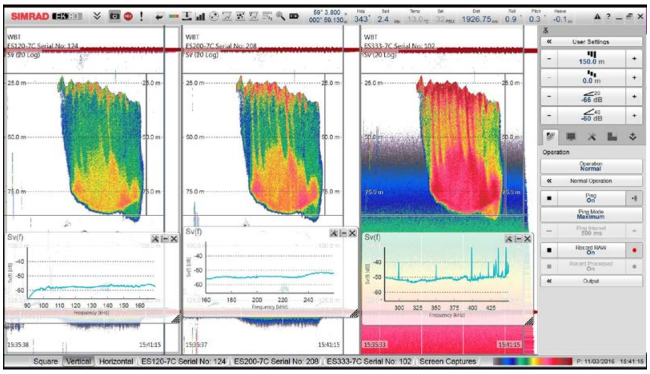


Fig. 5.3. A relatively large mackerel school, shown at three broadband frequencies, 90-160 kHz, 160-260 kHz and 260-450 kHz. SV spectrum shown below each figure.

Measurements of single schools, immediately followed by a complete catch; so-called validation measurements, where the recently developed algorithms to estimate the expected catch, and compare directly with actual catch, was still ongoing for mackerel in 2016 (3 new validation points), Figure 5.1 and 5.2.

Some more validations both for larger schools of herring and large schools of mackerel will be made both on a dedicated CRISP survey in 2017, and by following a commercial vessel in the herring fishery in 2017. Publication of the algorithms for biomass measurements will be prioritized in 2017. We also plan to implement the new algorithms in the sonar directly, and to test them on selected fishing vessels in 2018.

## FISH SIZING

For estimating fish size and species composition inside schools and layers the main activities this year have been to finalize calibration methods of broadband echo sounders and further trials with the new narrow beam transducer. The broadband echo sounder has been modified and improved by the industrial partner, both with respect to the hardware, but also significant effort is now being made on the new echo sounder software. The echo sounder is now commercially available both in for scientific and fishery versions. Software and setup was tried with good results in the October 2015 and 2016 mackerel surveys (see example of a mackerel school in Figure 5.3). Full broadband echo sounders setup was also run during an international training course for scientists were conducted on-board G.O. Sars in December 2016, with 21 participants from 13 countries. The training course was run as an ICES training course, but several of the methods and results developed in CRISP surveys were demonstrated for international experts here.

We now regard the first version of the DABGRAF fish sizing system to be finished, and ready for commercial testing. New mountings arrangements for the transducer on fishing vessels must be made in 2017 if a commercialization project is started.  It is now yet clear if the narrow beam, broadband transducer beam should be mechanically or electronically tilted. This must be discussed with the industry partner, as an electronic tilting would greatly simplify the mounting arrangements on fishing vessels.

A new, light drop-sonde system with a Simrad WBAT, broadband echo sounder has been tried inside mackerel and herring schools in 2016, and shows promising results for real time sizing (Fig

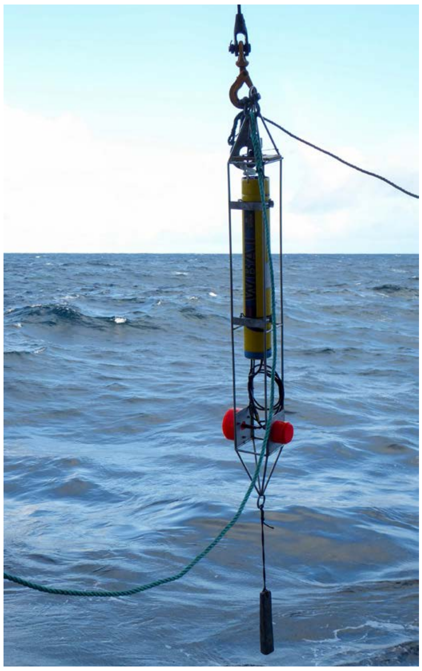


Figure 5.4. Simrad WBAT system with 70 and 200 kHz transducers, dropped into herring schools for measuring mean lateral TS of mackerel. Very good videos from inside the mackerel schools were also obtained in the 2016 survey.

5.4). This system may in the future be considered used as a basis both free-floating, transmitting the data to the vessel or inside the purse seine. If this is an interesting fishery product, the industry partner must add the data transmit facility on the buoy.

**RESULTS**

This project element is now in its sixth year. Calibration protocols for fishery sonar and methods for correct volume estimation are now finalized, and the largest uncertainty factor in the biomass computation can be further studied. This uncertainty lies in the extremely variable backscattering of fish when observed in the lateral aspect, especially for fast swimming schools. The mean backscattering, averaged over all orientations is now investigated for herring and mackerel at several frequencies. For fast swimming schools, however, the mean volume backscattering of the entire school may vary with as much as 20 dB, or a linear factor of 100, depending on the sonar observation aspect. To increase precision, the skipper normally encircles the school with the vessel before catching, and the sonar data from the entire encircling must be used for either estimation of a robust mean value, or for extraction of its maximum echo. Methods for extracting the most stable data to support the biomass estimation have been developed, but are still in the refinement stage. Huge deviations from the simplified method presently used in the sonar software is observed.

During the CRISP research vessel survey in 2016, the work was targeting in situ TS measurements in lateral mode using three independent systems: 1: a tilt-able narrow-beam broadband transducer, observing horizontally (Fig. 5.5), 2: the IMR TS probe with horizontally observing transducers (See 2015 report) and 3: a new, portable broadband echo sounder system, lowered into the mackerel schools (Fig 5.4). The last system also carried a Go-pro video camera which provided some nice clear footages inside mackerel schools together with the acoustic TS data. In addition, broadband EK80 data on whole mackerel schools were recorded from the research vessel. These data will help refining the fish identification algorithms for research and fisheries. Processing and publishing of the data will be done in 2017.

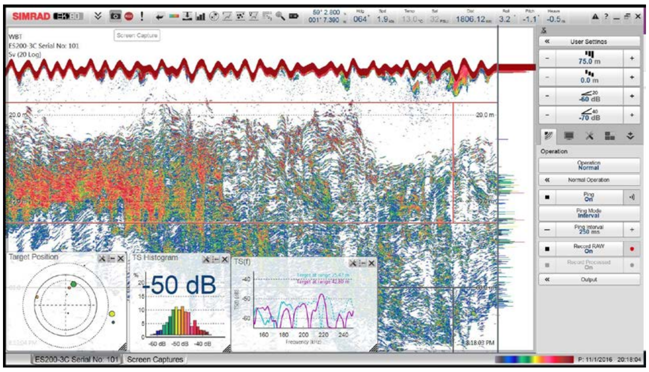



Figure 5.5. Resolving a mackerel school for sizing by DABGRAF with the narrow-beam, side looking transducer, showing TS and frequency spectrum from single mackerel targets.

## 5.2 Gear and catch monitoring systems in purse seine

Purse seine fishermen need tools to improve their control over the capture process, including better characterisation of the catch before they shoot their nets, as well as being able to monitor the geometry of the purse seine and the behaviour of the catch during the capture process. Improved catch characterisation will enable fishermen to optimise harvesting strategies to maximise the value of limited vessel quotas, while improving the sustainability of the fishery by helping to avoid taking unwanted catches. Avoiding unwanted or too much catch may not always be possible, so it may sometimes be necessary to release or “slip” some of the catch. At these times, having tools to describe the geometry and volume of the net, as well as monitoring the stress experienced by fish in the catch, through observing changes in behaviour and environmental parameters, will enable the development of responsible slipping practices that ensure the survival of any released catch.

In 2016, this work package focused on four topics: 1) using integrated instruments to better describe the behaviour of mackerel in response to capture related stressors; 2) developing a platform for deploying instruments to monitor the behaviour of the catch in relation to key environmental parameters (e.g. dissolved oxygen concentration); 3) further testing of the “In-seine” sonar technology for catch control; and 4) monitoring purse seine geometry and performance using sonar and transponder technology.

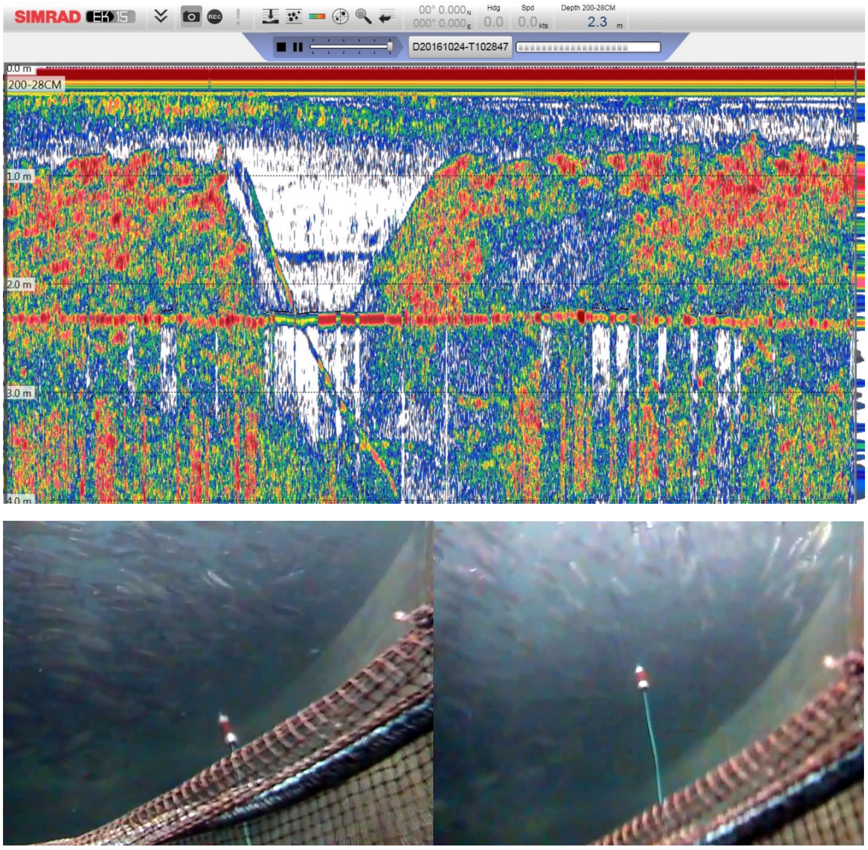
**INTEGRATING INSTRUMENTS TO DESCRIBE FISH RESPONSES TO STRESS**

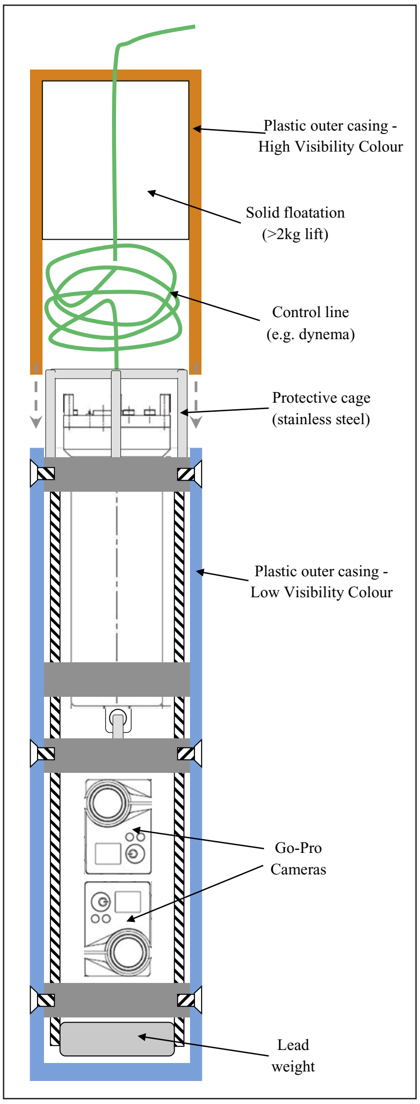
Work continued, in collaboration with Project RedSlip (NFR 243885), using an integrated suite of instruments to monitor various behavioural and environmental metrics in a school of mackerel, under simulated capture conditions at the IMR field station at Austevoll. This integrated instrument package contained a stereo-camera; a vertically orientated GoPro Hero III camera; a high-resolution sonar (ARIS); a vertically orientated EK60 echo-sounder; a horizontally oriented EK15 echo-sounder; and a CTDO to monitor depth, temperature, salinity and dissolved oxygen concentration.

By using an integrated suite of instruments, it is possible to combine the qualities and data from individual instruments to provide a much-improved description of behavioural responses of fish to stressors (e.g. crowding and predatory threats). That is, optical-camera systems provide high resolution information, in a localised area, that enables species identification and descriptions of individual behaviour in response to stressors. When used in combination as a stereo-pair, fish size can be estimated and the orientation and inter-fish distances (i.e. schooling density) of fish within the school can be precisely described. Acoustic systems are excellent for describing the distribution and density of fish in space and time. This enables us to describe behaviour at a lower resolution, but over a greater spatial range and when visibility is poor. In combination, these methods allow a much better description of the behaviour of a school of fish, across the whole school as well as for individual fish with it, which is invaluable for describing and understanding the responses of fish when stressed.

The 2016 CRISP Report described the Austevoll experiments in detail, and explained how this integrated suite of instruments was enabling us to demonstrate that even relatively low, non-fatal, levels of capture related stress (i.e. crowding and hypoxia) can induce measurable behavioural responses schooling

Figure 5.6. Optical cameras and echo-sounders can provide complimentary information about behavioural responses to stressors. In this example, a school of mackerel responds to the threat presented by a "model predator" in the form of a bottle pulled at speed through the captive school. The camera images clearly show the behaviour of individual fish before (a) and during (b) the approach of the "predator", including information on their movement and orientation with respect to the threat and each other.




mackerel. This suggests that monitoring behaviour of mackerel caught in a purse seine could be used to provide early indications of when the captive conditions are becoming potentially dangerous for the fish, and thus provide measurable limits of when any unwanted catch could safely be released.

## MONITORING STRESS IN FISH DURING CAPTURE

In 2016, work started on the development of a prototype probe for monitoring fish behaviour and oxygen concentrations in purse seine catches. This work was conducted in collaboration with Project Red-Slip (NFR 243885) and Slipping: Best Practice (FHF 900999). The first version of the probe contained just a CTDO and GoPro Camera, which was deployed into the catch using a pneumatic canon. The probe consists of two main parts: a surface float and the instrument package (figure 5.7). When fired from the canon, the two halves are linked together as a single cylinder. As the cylinder enters the water, the weight of the instrument package separates it from the surface float, and it sinks to a pre-determined depth (typically 5-15m). The CTDO records the depth, temperature, salinity and oxygen content of the water every second, while the camera provides visual information to put those data in context; i.e. the proximity of the probe to the catch and/or net (figure 5.8). This probe was successfully deployed 15 times on separate research cruises aboard FV "Sjarmør", FV "Brennholm" and FV "Fiskebas", and provided over 10 hours of behavioural and environmental data.

In 2017, work will continue, in collaboration with Project Catch Control in Purse Seines (FHF 901350), on the development of the probe to upgrade the instrument package to include a stereo-camera for improved description of behaviour, as well as estimation of fish size. Further planned developments include instrumentation for describing the position and orientation of the probe, as well as the inclusion of an EK15 echo-sounder to compliment the acoustic data from the "In-seine" sonar.

Figure 5.7. A prototype probe for monitoring behaviour and oxygen concentration in purse seine catches.

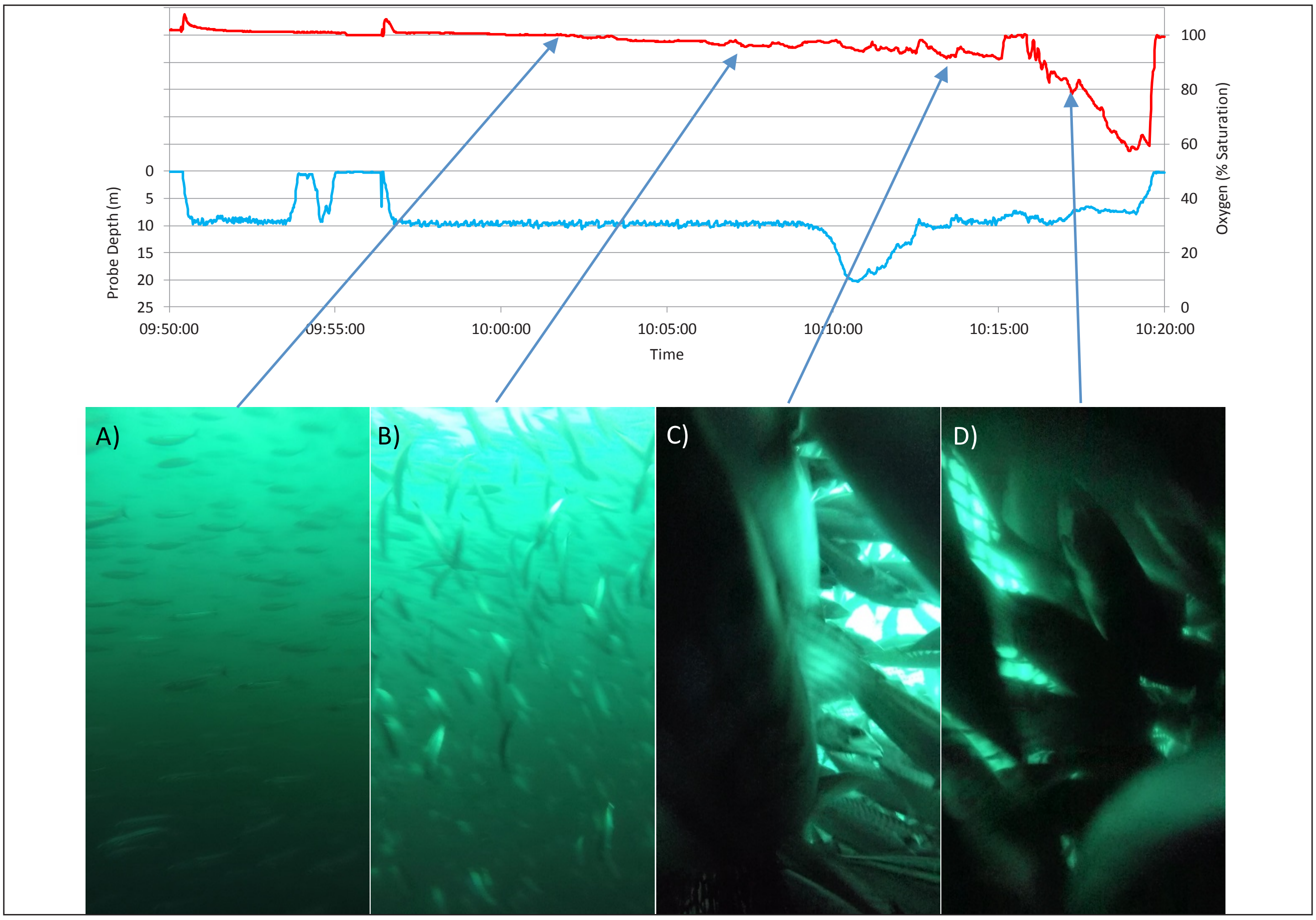



Figure 5.8. The concentration of dissolved oxygen (% saturation) in a purse seine catch over time, in context with the proximity of the CTDO to the catch and the net. A) Mackerel school swimming inside the purse seine at low crowding density, with no signs of stress. B) The school becomes more densely crowded and begins to display occasional episodes of unpolarised behaviour, while oxygen concentrations begin to drop. C) As crowding density increases the behaviour of the mackerel becomes increasingly disorderly and oxygen concentrations decline further. D) At high crowding densities, the oxygen concentration declines rapidly and camera images are mostly dark; except when the camera is at the netting wall, where it is clear the fish make physical contact with the netting.

**"IN-SEINE" SONAR TECHNOLOGY FOR CATCH CONTROL**

For the Crisp survey in 2016 it was decided to offset the purse seiner FV "Brennholm" from RV "G.O. Sars", because the period allocated for the research vessel was later in the fishing season, when mackerel stop aggregating in schools and instead aggregate in large layers. This situation was observed in 2015, and make searching of individual schools of a suitable size (about 100 ton) a challenging task. With FV "Brennholm" starting about two weeks earlier, it was easier to find the schools required to fulfil the objectives of the survey.

During the first trip, there was a problem with the operation of SN90 sonar during the school inspection period, before setting the net. A strong noise was present in all the sonar beams, due to electrical interference when starting-up the electrical motors of the bow thruster. This thruster needs to be operating during the catch operation, and therefore the sonar data recorded during this period could not be used to monitor the school behaviour. Despite this problem, sonar data was also collected with the SU90 sonar, which was used for WP1, for single school biomass estimates. Of the three purse seine sets targeting suitable individual mackerel schools, two resulted in catches of 150 and 300 ton.

In addition to the Crisp survey, sonar data on fish schools was also collected during June 2016, in the North Sea herring fishery on board FV "Kings Bay". During the two-week survey, data from small and compact schools was collected during normal fishing operations. Schools were smaller and closer to the bottom than previous seasons, creating a challenge for the skipper to catch a whole school without losing or damaging the net on the seabed. Of the 20 purse seine shots, only 3 captured schools were considered of good enough quality to be used for analysis.

A new version of the SN90 sonar software was used, with improved stability during the storing of raw data. Also tested was a new function in the post-processing software PROFOS to extract the inspection beams from the raw data files. These resulted in files containing the 1-3 inspection beams in a format like echo sounder data, allowing its display and processing with the tools available in LSSS software. An example of the acoustic data from the horizontal, vertical and one inspection beams of a herring school during the period of June 2016 is show in Figure 5.9.

A more complete calibration of the SN90 on board FV "Brennholm" was performed, and preliminary analysis showed similar results as obtained earlier with the omni sonars. In 2017 it is expected to finalize the work establishing the calibration equations, which then will be integrated into the PROFOS software.

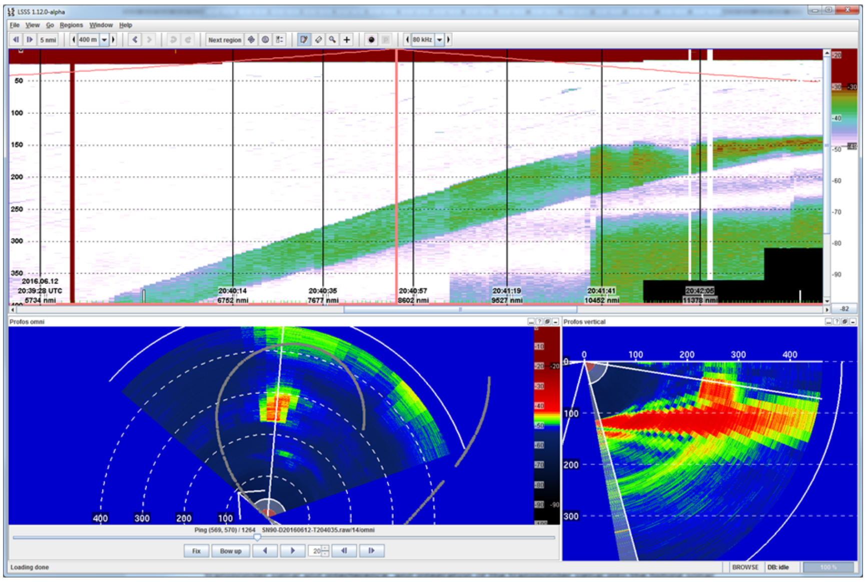


Figure 5.9. Example of a North Sea herring school displayed in the post-processing system PROFOS. In the echogram window (top panel) is the acoustic data from the SN90 inspection beam over time, where the vessel is at 0 m and a herring school approaches at decreasing ranges from 400 to 150 m. A single ping from the horizontal (left panel) and vertical beams (right panel) show the same school located just above the seabed at a range ca. 270 m. The straight white line in both panels crossing the school indicates the bearing and tilt of the inspection beam.

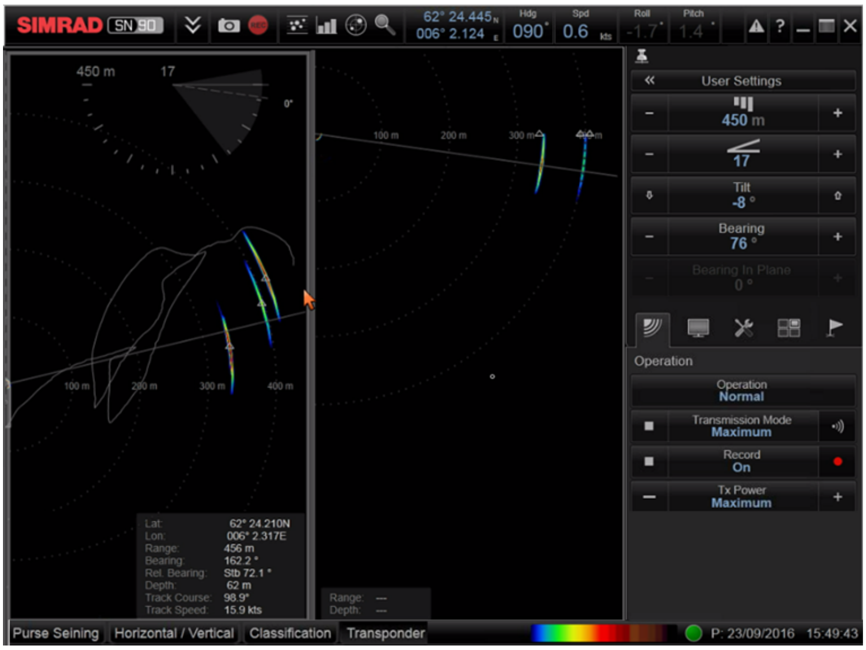



Figure 5.10. Screen grab of the SN90 sonar software using the Transponder Mode. In the left panel, the three transponders are displayed as multi-coloured elongated bands in the horizontal beams, at distances between 300 and 400 m. In the centre panel, two transponders appear in the vertical beams, at a depth of about 50 m.

## MONITORING SEINE GEOMETRY AND PERFORMANCE

For monitoring the purse seine geometry, new trials were performed during the CRISP cruise in 2016. For testing the new Transponder Mode in the SN90 software, three transponders where deployed in individual buoys at a depth of 50 m. The buoys were released about 50 m between each other and drifted freely inside Sulafjorden, close to Ålesund. The transponders were observed as very strong targets in the sonar display, both in horizontal and vertical beams, up to 400 m from the vessel (Figure 5.10). Also, the accuracy of the transponder depth computed by the sonar was tested, using a depth sensor attached to one of the transponders. Results showed a good agreement between the depth estimated by the sonar from the vertical beams and the depth sensor.

The current sonar software version allows either a Transponder Mode or a Purse Seine Mode (which is the normal view for school inspection) but not an integrated mode, where the transponders can be visualized together with the target schools in the same screen. Therefore, it was not possible to test the transponders during a purse seine shot targeting a mackerel school. Instead, an empty set was performed inside Sulafjorden to test the transponders attached to the bottom line of the purse seine.

Two sets were performed, adjusting the location of the transponders on the bottom line in the second set, to optimize the monitoring during the setting and pursing of the net. A continuous monitoring of the position of the three transponders was possible after the transponders reached a depth between 60 to 80 m (Figure 5.11). Adjusting the tilt of the horizontal beams, each of the transponders were followed as they approach the vessel during the pursing phase. Also, it was possible to follow the ascent of the transponders in the middle of the net from the maximum depth (ca. 130 m) up to the surface during the 20 min of the net pursing (Figure 5.11).

In 2017, Simrad has planned to work on a new version of the SN90 software with an integrated transponder and purse seine mode, which will enable the testing of transponders during catches. Also, the design of a smaller transponder model, better tailored to monitoring the purse seine net has been discussed.

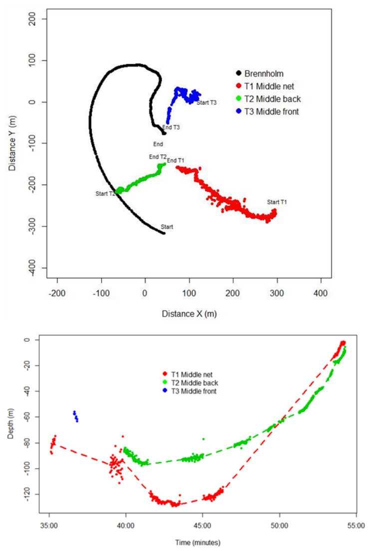



Figure 5.11. Monitoring three transponders during an empty set inside Sulafjorden. Positions in the horizontal plane of the three transponders and the vessel track (top panel). Depth of the transponders during the setting (from minute 35 to 43) and pursing (from minute 43 to 55) of the seine (bottom panel).

## *5.3 methods for capture monitoring and catch control during trawling*

**BACKGROUND**

Unwanted catches often occur in mixed trawl fisheries regulated by quotas on individual species. In some fisheries, high grading, meaning that the most valuable fish are preferred leading to a risk of discarding low-value fish, has been identified as a non-sustainable fishing practice. The large catches sometimes taken by trawls may result in burst nets and loss of catch, as well as reduced fish quality when on-board production time is too long. A major topic for CRISP is therefore to develop technologies for early identification of size and species inside trawls, combined with interactive methods capable of actively releasing unwanted catch.

The Deep Vision system, developed by Scantrol Deep Vision AS, takes continuous stereo images of all objects passing through a trawl. These images can be used to identify and measure fish inside a trawl, opening opportunities to improve fisheries surveys by employing new techniques or providing evaluation of the trawling methods presently used. Development work carried out under CRISP activities in 2016 has largely followed the plans and goals for the year, with focus on continued testing of the system by researchers and work on automating image analysis.

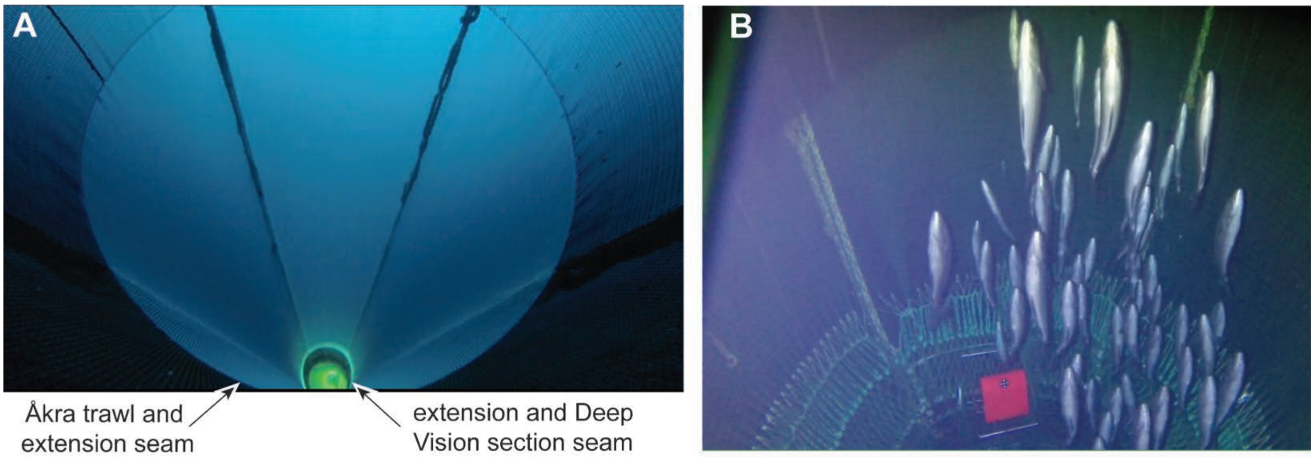
**VISUAL FISH CLASSIFICATION (DEEP VISION)**


Winner, Nor-Fishing Innovation prize. Deep Vision was awarded first prize for innovation at the 2016 Nor-Fishing expo, where the judges recognized the technology's potential to revolutionize both marine research and commercial fishing. Photo: Nor-Fishing.
From left to right: Director of Fisheries Liv Holmefjord, Minister of Fisheries Per Sandberg, Hege Hammersland-White and Håvard Vågstøl, Scantrol Deep Vision

ADVANCES IN DEPLOYMENT:

The Deep Vision deployment frame, which protects and positions the stereo cameras and in relation to fish passing through the trawl, continues to work well and was unchanged since minor modifications were carried out in 2015 (described in 2015 Annual report). Similarly, the three-meter-long mesh sections designed and constructed in 2015 for mounting the Deep Vision between the extension and codend of the trawl continued to work well and were not further modified in 2016. Poor fit with the Institute of Marine Research's standard "Åkra" pelagic sampling trawl during a cruise in October, 2015 was solved by the addition of an eight-meter-long tapered section constructed by CRISP partner Egersund Group. Video observations from tests on a CRISP-sponsored cruise in February 2016 confirmed that the extension eliminated the problems of pockets and delayed passage of Saithe (Pollachius virens) observed in 2015 when the Deep Vision was connected directly to the Åkra trawl (Figure 5.12, 5.13).

Figure 5.12. The addition of an 8-m long tapered section (lighest blue portion, between the arrows in A) eliminated pockets which we believe caused saithe (Pollachius virens) to accumulate ahead of the deep vision during a cruise in October, 2015 (B).



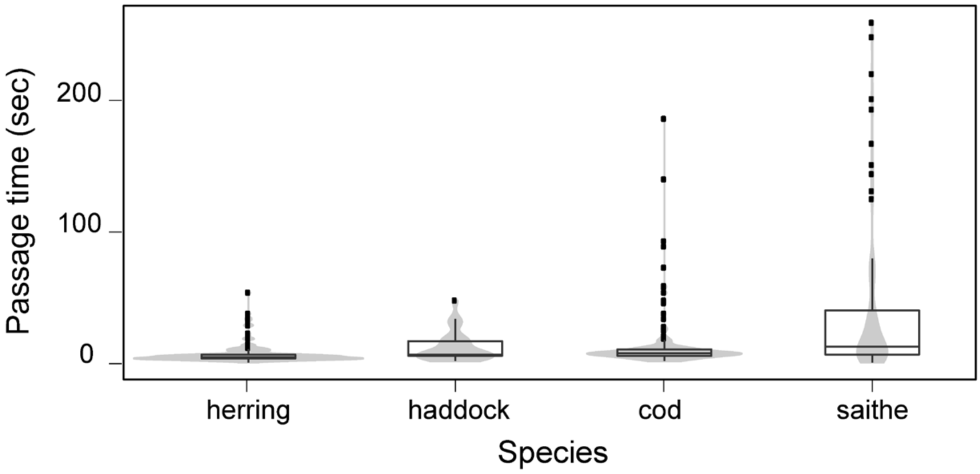




Figure 5.13. With the addition of the 8-m long tapered section, most saithe and other fish species passed through the Deep Vision with less than a minute's delay (data from February 2016 CRISP cruise).

In addition to the standard frame, tests were carried out using a downsized frame and fish passage constructed from a flexible white tarpaulin. This work was done as part of the Fisheries Innovation Scotland project "SMARTFISH: Selective management and retention of target fish" cooperation onboard Marine Science Scotland's research vessel "Alba na Mara" in November 2016 in the Moray Firth, west of Fraserburgh, Scottland. The frame constructed for these tests (Figure 5.14) was a mere 115 x 80 x 30 cm (1/7 the volume of the standard frame) and weighs just 41 kg (1/12 the weight of the standard frame).

Image quality with the downsized frame and tarpaulin background was somewhat diminished from the standard large frame, with light concentrated at the centre and shadows from wrinkles in the tarpaulin (Figure 5.15), but we are confident that with improvements to the frame and tarpaulin design image quality could be improved significantly.

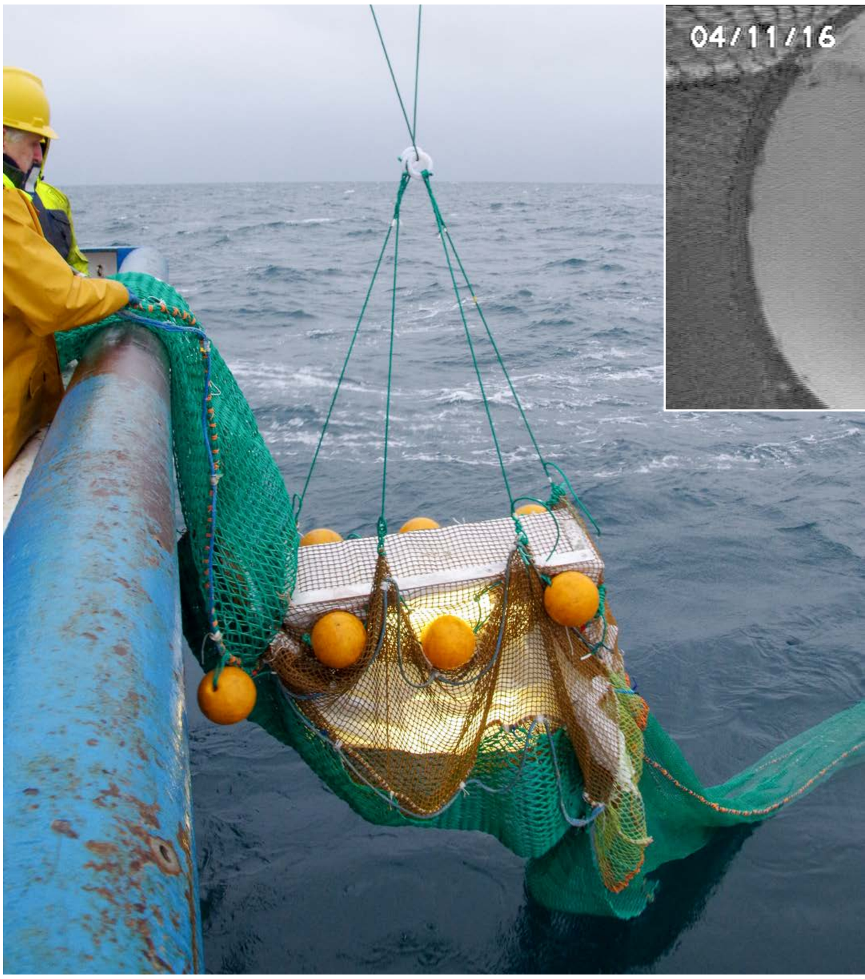



Figure 5.14. Downsized frame being set out from RV "Alba na Mara" (left) and image showing frame and tarpaulin background held taught by water flow during trawling (right).

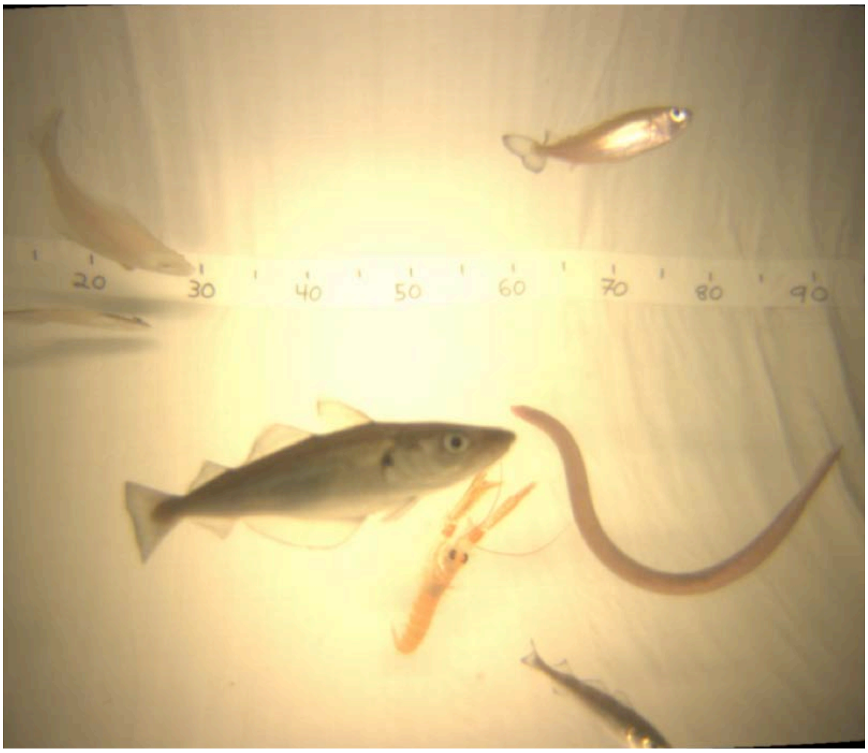



Figure 5.15. Example image from cruise onboard "Alba na Mara."

**APPLICATION OF DEEP VISION IN MEDITERRANEAN SEA:**

The Deep Vision system was tested in April 2016 in the EU Horizon 2020 project "MINOUW" (http://minouw-project.eu/) off the northeast coast of Spain (Figure 5.16). This proved to be a very challenging deployment, due both to water clarity (operating with a demersal trawl on grounds with very fine sediments) and difficulties rigging the trawl onboard an oceanographic vessel not designed to deploy trawl gear. Handling of the Deep Vision system (the large 500 kg frame) was unproblematic using the vessel's swinging gantry (Figure 5.16 A), however just 30 minutes of useable images were collected as visibility then deteriorated due to suspended sediments and the trawl was subsequently heavily damaged during retrieval. Nonetheless, the images collected before visibility deteriorated were of sufficient quality to identify and measure the organisms passing (Figure 5.16 B)


Figure 5.16. Deep Vision being used as part of the EU Horizon 2020 project "MINOUW" off the Catalan coast of Spain. A. Launching using the vessel's swinging gantry. An example image of a European hake (Merluccius merluccius), one of the principal target species in the region's commercial trawl fishery.

Further trials as part of the MINOUW project are planned for summer/autumn 2017 in Greek waters of the Aegean Sea.

**ADVANCES IN IMAGE COLLECTION AND AUTOMATED ANALYSIS:**

Segmentation, the automatic selection of objects from images, is a necessary first step for automating analysis from Deep Vision images and significant progress was made in 2016. This included both changing the format in which images are collected (from a compressed format to RAW uncompressed which preserves all image detail) and implementing a new image analysis algorithm to automatically define the outline of fish and calculate a rough centre-line for measuring length (Figure 5.17).

Segmentation techniques will continue to be improved in 2017, and hardware and software upgrades to the camera unit have already been carried out to facilitate increasing the frame rate in order to track fish in sequential images and prevent double-counting.

Figure 5.17. Examples of automatic segmentation to find the outlines of saithe (left), and haddock (right) from Deep Vision images. Red mid-line is calcuated from the segmented shape and can be used to automatically calculate fish length.

## 5.4 low impact trawling

**BACKGROUND**
The current trawling practice is regarded as unsustainable. It may be harmful to the seabed, have high bycatch rates and high fuel consumption that can affect the environment. The future of trawling will thus largely depend on the development of trawling techniques that significantly reduce these negative impacts. Part of this work-package addresses the design, rigging and operation of trawl gears that might achieve such objectives.

Positioning of the two trawl doors in equal heights above the bottom is important to maintain geometry of the trawl system and thus the catchability when fishing with a semi-pelagic trawling technique, i.e. with the doors off and the trawl on the seabed. This cannot be done by adjusting the warp lengths. Trawl doors where the horizontal and vertical spread forces can be adjusted by opening and closing hatches in the doors have been developed.

High populations of Atlantic cod in the Barents Sea are currently leading to excessively large trawl catches. This leads to reduced quality when the catch exceeds the vessel's production capacity, increasing risk of damage and safety concern. Therefore, at request from the industry and management authorities, a passive catch reduction device, the Excess Fish Exclusion Device(ExFED), has been developed and tested by the industry. The ExFED consist of a fish lock just behind a rectangular opening (kept open by a metal frame) in the upper panel covered by a rubber mat attached only at its leading edge. The fish lock prevents the target quantity of fish from escaping during haul back. Initially, the mat lies against the top panel of the trawl sealing the escape opening. As fish accumulate and fill up to the fish lock, water flow is diverted out the escape opening, lifting the mat and allowing excess fish to escape at the fishing depth. The system is mounted at a distance from the cod line selected to achieve the target size catch for the vessel. Trials carried out by commercial vessels have shown that metal frame is frequently damaged when the trawl is hauled up the ramp and needs to be replaced by another system keeping the escape area opened during fishing.
An alternative catch control system to the ExFED is a system used by the Norwegian seine fleet. It consists of two 2.5 m long cuts foremost in the codend, just in front of a fish lock. The slots are kept closed by threading a rope along its edges. The rope is slightly shorter than the edges of the net, keeping the slots closed during towing, but when catches build up, the codend expands and the openings expand laterally, releasing excess fish.

**ACTIVITIES**
In 2016 testing of acoustic communication between the vessel and the motors adjusting the hatch openings on the Seaflex trawl doors continued during a research cruise with RV "G.O.Sars" off the coast of Finnmark in February.

During the same cruise, both the ExFed and the catch regulation system developed for Norwegian seine fleet were tested during demersal trawling. Both catch regulation systems were further tested onboard the commercial trawler FV "Kågtind" in March.

Figure 5.18. The ExFed system as previously used with a supporting steel frame to the left. To the right, the same system modified by removing the frame.

**RESULTS**

**ADJUSTABLE TRAWL DOORS.**
The trials onboard RV "G.O. Sars" showed that by opening and closing of the upper hatch in the trawl doors, the doors can be maneuvered both vertically and horizontally. However, the acoustic communication system between the vessel and the trawl doors is currently too unreliable to be applied commercially. Further development of a cost effective and robust acoustic communication system is required to commercialize this trawl door function.

**CATCH REGULATION IN TRAWLS.**
During the trials on board RV "G.O. Sars", a conventional two panel trawl with a sorting grid (Flexigrid) was used. A modified two panel ExFed and the system with longitudinal splits as developed for the Norwegian demersal seine fleet were tested. The ExFed was modified by removing the steel frame and a making 'V' cut in the netting behind the square opening (Figure 5.18). A remotely towed underwater vehicle was deployed to monitor the systems during fishing. Video observations showed that the modifications of both systems resulted in stable performance, but during the cruise, catches were not sufficiently large to challenge the systems.

During the trials on board FV "Kågtind", fishing on grounds with dense aggregations of fish, both the two mentioned systems were tested in a conventional two panel trawl with Flexigrid. Underwater cameras with red (620 nm) lights were mounted on fixed positions, monitoring the escape holes. The removal of the steel frame yielded a more user-friendly solution; the escape opening held a stable shape covered by the rubber mat, which lifted to release fish when catches built up. The longitudinal splits also worked sufficiently. No fish escaped in the beginning of the tow, and the splits opened with build-up of catches. The splits however, gradually opened as the catches build up, with occasional loss of fish before the codend was filled up (Figure 5.19). Both systems worked as expected to limit catches and were user-friendly. One problem, however, when fishing with a selection grid, is that some fish remained in the proximity of the grid and did not enter the codend. In addition, there was usually some fish just in front of the fish lock. In accordance with previous observations, this resulted in fish being washed out at the surface. Methods for resolving this problem will be tested out in 2017.

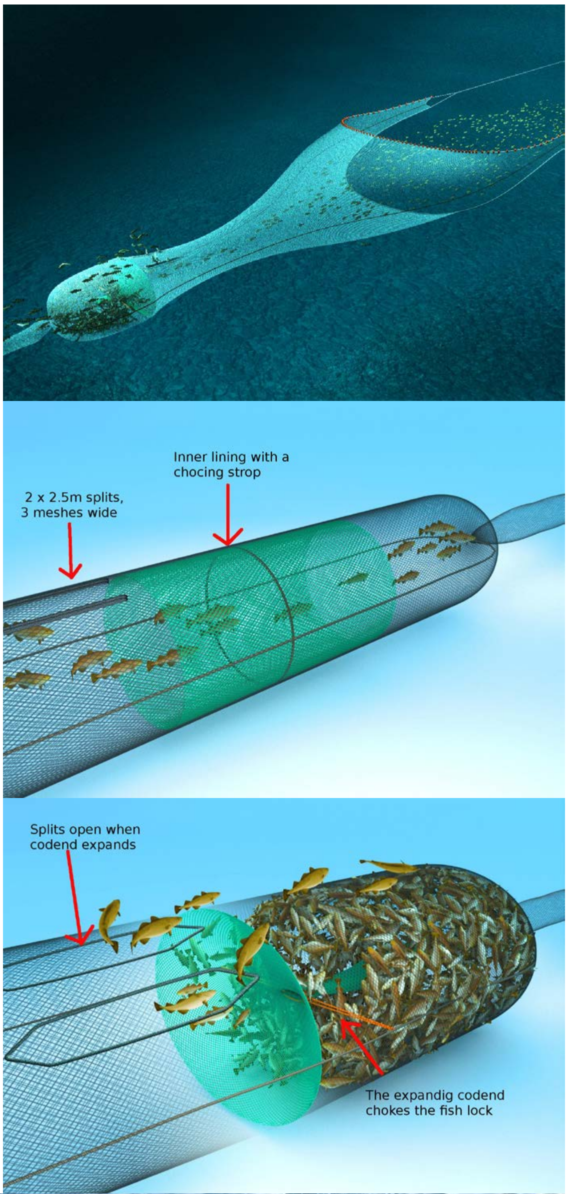



Figure 5.19. The catch control system used by the Norwegian seine fleet adapted to bottom trawl. It consists of two 2.5 m long cuts foremost in the codend, just in front of a fish lock. The slots are kept closed by threading a rope along its edges. When catches build up, the codend expands and the openings expand laterally, releasing excess fish.

Figure 5.20. A 12-tones catch taken on-board FV "Kågtind". The catch builds up to the ExFed opening only.

## 5.5 quality improvement

**BACKGROUND (WP 5)**
The fishery for Northeast Arctic cod is the largest and most important fishery in the Barents Sea, both in terms of catch weight landed and in terms of value. The Barents Sea is their feeding and nursery grounds. The cod is mainly caught with bottom trawls throughout the summer, autumn and early winter, when the cod is present in the northern and central part of the Barents Sea. However, the Northeast Arctic cod stock conduct annual spawning migrations from the Barents Sea in November/December, south towards the shelfs and the coastline along the Norwegian coast. The cod spawns in March and April on spawning grounds along the entire coast of North Norway. During spawning migration, the cod aggregates in huge densities on their way southwards.

These migrations consequently affect the fishing pressure, fishing time, fishing ground and choice of fishing method. The largest fishery occurs when the cod arrives at the coast of Norway, both in terms of fishing methods, as well as quantity landed. The high densities of cod currently encountered in the Barents Sea and at the spawning areas along the coast of Norway, frequently lead to excessive catches on-board trawlers and Danish seines. Thus, it can entail reduced product quality due to catch size exceeding the vessels production capacity.

Generally, fish caught by trawl is reputed to have a poorer quality, especially in comparison with other more lenient fishing methods. Nevertheless, the product quality of a catch is influenced by various factors. Season, fish-species and -condition, as well as fishing depth, catching methods and processing practices are all known to have an impact on the final product quality. Fish caught with bottom trawl may have incurred visual detectable scrape marks, scale loss, internal and external ecchymosis and reduced ability of sufficient bleeding. However, both catch size and length of the haul influence the quality. A practice among trawlers is "prolonged buffer towing". If the trawl has caught the desired amount of fish, while the crew is still producing the catch from the previous haul, the skippers choose to lift the catch off the seabed and continue towing at low speed until the production from the previous haul is finished. The rationale for this practice is securing a continuous supply of fish to avoid any unnecessary stop in the factory on-board the vessel. However, this practice is likely to have negative impact both on the product quality and on survival during live storages.

Capture, transfer, transport and preprocessing procedures are the initial stages in the production line of food from fisheries. Quality flaws incurred at this stage will reduce product quality throughout processing, and is hence a potential reduction in profitability. Therefore, it is of great importance to gain new knowledge, partly to determine when and how to slaughter fish, and partly to understand the fish tolerance, fatigue, recovery and why blood is where in the body at any given time, especially if live storage of fish and new technology in the processing line shall be developed and implemented on-board the trawling fleet.

**ACTIVITIES AND RESULTS**
During November 2016, we conducted a cruise on-board RV "Helmer Hanssen" owned by the Arctic University of Norway with the aim of investigating the effect of prolonged buffer towing on the catch quality of cod (Gadus morhua). Prolonged buffer towing (also called "short wiring", NOR: "vass-haling") is a method often applied during conditions with high densities of fish, as currently encountered in Barents Sea. However, this practice has caused some concern, both from the fishing industry, due to indication of reduced catch quality, and also from the management authorities due to possible selection of fish while buffer towing. Therefore, we wanted to document the effect of prolonged buffer towing on the catch quality. Additionally, we investigated if any size selection of fish occurs during this towing phase. To reduce the between haul variance, the data was sampled in an alternate hauls setup, alternating between taking the catch directly on-board, and prolonged buffer towing. The buffer towing was conducted for 60 minutes, at a depth equivalent to 40 % reduction in the ambient water pressure of the maximum depth. From each haul, Atlantic cod (n=30) were collected from the codend and immediately stunned with a blow to the head. Blood samples were taken from 10 fish in order to measure levels of lactate and glucose. All 30 fish were bleed and kept in running water for 30 minutes before gutting and heading. All fish were block-frozen for later analysis at Nofima, Tromsø in January 2017. The fish was thawed in fresh water (1°), before conducting the sensory evaluation of the catch quality. The Catch Damage Index (CDI) was applied to evaluate gear related damages, bruises, bleeding and skin damage in a scale from 0 to 2, where 0 is flawless, 1 is moderate, and 2 is severe. Then the fish was filleted by hand and a fillet index was applied on both fillets evaluating fillet gaping, colour, texture and surface. Finally, the fillets were measured instrumentally using hyperspectral images to objectively measure the amount of residual blood in the fillet. The current results indicate a significant difference in the levels of glucose, bleeding, and fillet colour. This indicates that prolonged buffer towing has a negative effect on the catch quality. In addition, the selection study proved that significant selection takes place during buffer towing. However, the fate of the fish escaping during this process is unknown. The results from both studies will be submitted to scientific journals in 2017.

During November 2016, we also conducted a cruise on-board at FV "J. Bergvoll", Nergård Havfiske. The aim of this study was to determine the effect of stress associated with commercial trawling for Atlantic cod and survival during live storage, and to compare changes between two different fishing grounds.

Atlantic cod was captured in seven hauls; 3 haul at Sentralbanken (N 74.50, E 030.50) and 4 haul at Thor Iversen-Banken (N 73.00, E 033.00), at depths of 250 to 360 meter and a bottom temperature of 2.8 ± 0.9 °C. The cod was caught using an Alfredo No. 5 twin trawl (REFA, Tromsø, Norway). Trawl catches were on average 9.9 ± 4.6 tons for an average tow duration of 4.5 ± 1 hour. A total of 138 cod (66 ± 9 cm; 2.7 ± 1.2 kg) were sampled for analysis.

From each haul, a random sample of cod (n=60-70) was collected from the outlet and transferred to a 800 L container filled with sea water to allow the cod to recover for 3–6 h. During recovery, fresh seawater was pumped into the tank with a water flow at approximately 50 L per min. Live cod (n = 7) was randomly collected and killed with a blow to the head immediately after capture. Next cod was killed both 3 h (n = 7) and 6 h (n = 7) after capture. After killing the cod, the blood-pH, blood lactate, blood glucose and fish size (length and weight) was measured. Then the throat was cut manually and the cod was exsanguinated into clean seawater for 30 min prior to beheading, gutting and cleaning. All cod was tagged and frozen pre-rigor in blocks and stored. The mortality in the tank was estimated after 6 h live storage and the remaining live fish was slaughtered and brought into the trawler's processing line.

Survival on board is essential for increasing the value of the catch and the average mortality after 6 h live storage was 30±5%. Compared to earlier CRISP cruses in 2012 and 2014, the cruse in November 2016 show no correlation between haul duration, haul size and mortality (Figure 5.21). Some of the mortality during live storage may be related to barotrauma and supersaturation of the blood. Thus, causing gas bubbles in the veins and brain tissues when the fish enters the sea surface and that can have influenced the survival of the fish (Figure 5.22). However, it is still uncertain why gas in the swim bladder of some fish did not escape during ascent from the depth. The cod caught at Sentralbanken had feasted on capelin prior to catch and had significantly higher condition factors (0.90±0.05) than that of cod caught at Thor Iversen-banken (0.84±0.06), which mainly had haddock juveniles and cold-water shrimp in the stomach. Nevertheless, there were no significant differences in physical stressindicators associated with trawling and mortality between the two different fishing grounds (Table 5.1).

Table 5.1. The plasma glucose, lactate and blood pH, in cod during recovery (0, 3 and 6 hour) after capture. Generally, for Atlantic cod, which was transferred directly to a live storage tank, following capture pH increased, with near-normal resting blood pH levels being restored within 6 hours. This result is similar to what was measured on cod during fishing in October 2011 and May 2014.

| Live storage (hour) | Glucose | Lactate | Blood pH |
|---|---|---|---|
| 0h | 6.5±2.7 | 2.1±1.4 | 7.2±0.1 |
| 3h | 9.1±4.3 | 4.0±2.2 | 7.3±0.1 |
| 6h | 11.7±5.0 | 2.9±2.2 | 7.5±0.1 |

Figure 5.21. The relationship between haul duration, haul size and survival of cod during recovery.

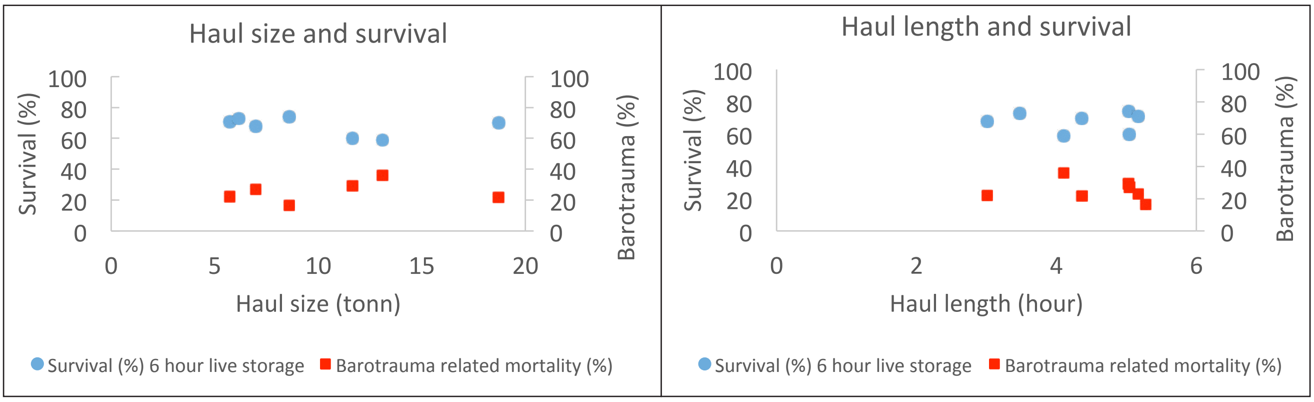



Figure 5.22. Atlantic cod with gas bubbles in the brain, surrounding fluids and tissues.

Figure 5.23. Cod recuperating in an experimental live-fish tank on-board a trawling vessel.

A prototype for live storage of cod on board trawlers has been designed (Figure 5.24). The development is done in close collaboration with Norwegian sub-contractor Optimar, Nergård Havfiske and Nofima, supported by FHF (The Norwegian Seafood Research Fund). A full-scale tank will be built in 2017.

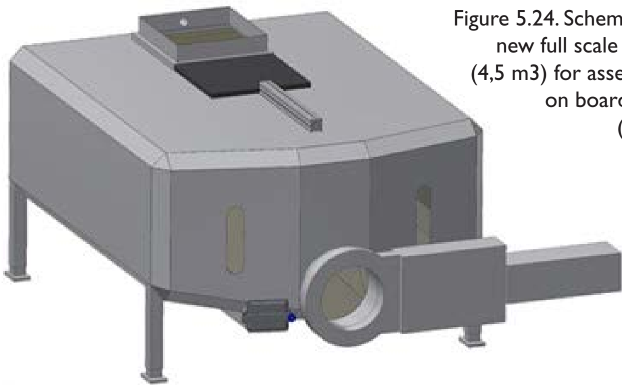


Figure 5.24. Schematic diagram of a new full scale live storage tank (4,5 m3) for assembly and testing on board FV "J. Bergvoll". (Photo: Optimar)

## 5.6 Value adding

**BACKGROUND**

Harvesting wild fish resources depends on several factors, like migration pattern of the target species and the harvesting technology chosen. This work package focuses on how the technological improvements developed in CRISP will contribute to value adding and environmental friendliness among trawlers and purse seiners.

**ACTIVITIES**

A framework for cost-benefit analysis is developed in CRISP (Figure 5.25), which is relevant when estimating the potential economic premium of the technological improvements achieved. The framework is based on analysis of the economic performance of the trawlers and purse seiners, in addition to work on quality as carried out in the other work packages. As illustrated in Figure 5.25, the mapping phase was the starting point, where the potential costs and benefits were studied, in addition to the management regime. Some of the costs and benefits are easy to quantify. However, to quantify the further costs and benefits of new technology is a more complicated issue.

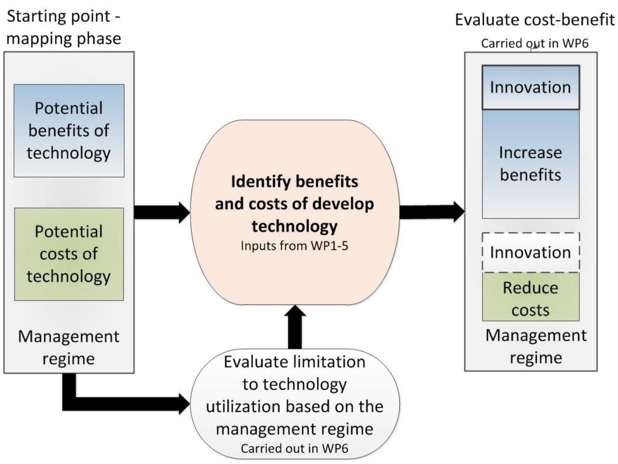



Figure 5.25. Framework for cost-benefit analysis for evaluating the impact of developed technology in CRISP.


Figure 5.26. Development in number of vessels, average age and days in operation for cod trawlers (in blue – upper) and purse seiners (in orange – lower) for the period 2002–2015

In order to study how the technological improvements developed in CRISP will contribute to value adding, an overview of the modified and developed technologies in the project is updated during the program.

**STRUCTURAL CHANGES**

During the program the structural development, catches, financial performance and fuel consumption among the trawlers and purse seiners are analyzed (Figure 5.26). Several new vessels have been introduced in both vessel groups during the program. How the new vessels perform, both in terms of value adding and environmental friendliness is studied in this work package.

Changes in the governance tools for both vessel groups are addressed. The management regime may influence the ability to utilize the technology developed, and it is assumed to have a significant impact on such implementation and the reduction of environmental footprints. Both improved technology and changes in the management regime may reduce the environmental impacts from the fleet. Therefore, the number of allowed licenses on each vessel and also fuel consumption within the fleet are studied.

The illustrations show that the number of vessels in both vessel groups have been reduced substantially in the period. The structuring of the cod trawler fleet is, however, more prominent than in the purse seiner fleet, where the number of trawlers have been reduced by 60 percent the corresponding figure for the purse seiners is 22 percent. This is reflected by the share of structural quotas in the vessel groups' total quotas, which in the case of cod trawlers' cod quota is 62 percent, while for purse seiners' quota for spring spawning herring is 20 percent.

The middle graphs show the development in average age of the vessels in the two vessel groups. It shows, for the cod trawlers that the vast reduction in number of vessels from 2002-2010 was not sufficient for reducing the age of the fleet. As several new vessels where introduced to the fleet in 2013-2014, replacing older vessels, the average age fell substantially. (It should be noted that without entries or exits in the groups, the age would increase linearly over the period adding 13 years to the average age. Moreover, the average age can serve as a proxy to technological development, and also reflects the profitability of the fleet.) For the purse seiner fleet, we see that the average age of the fleet decreases considerably after 2010.

The illustrations to the right (Figure 5.26) show the development in average operative days in the vessel groups. While the cod trawlers have become busier over the years – increasing their activity from 240 to 330 days a year – the opposite is the case for the purse seiners, who are active only half the year. The explanations behind these figures can be found partly in the level of structuring within these groups, in addition to the development in quotas and renewal of the fleet. Newer vessels are in general more effective, structuring implies larger quotas per vessel, while larger quotas demand higher activity.

Below the Norwegian catches of cod, saithe and haddock are portrayed together with the catches of herring, blue whiting, mackerel and capelin in the period (Figure 5.27).

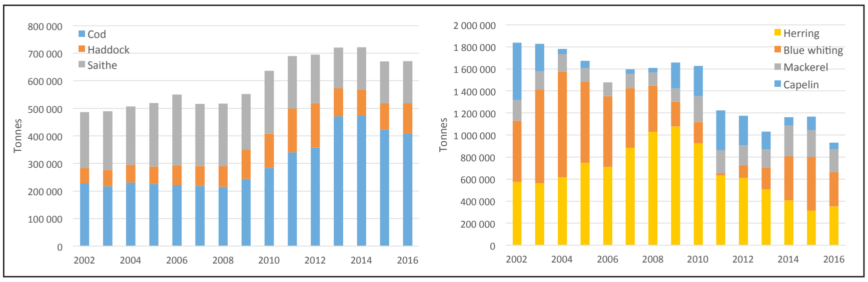



Figure 5.27. Annual Norwegian catches of cod, saithe and haddock (left) and herring, blue whiting, mackerel and capelin (right) in the period 2002-2015

The species portrayed in the figures to the left are those most important for the cod trawlers, whereas those to the right are the most important for the purse seiners, and they are allotted substantial shares of the national TAC's. These species were responsible for 75 and 96 per cent of the first value of the catch for the cod trawlers and purse seiners respectively in 2015. As shown, the graphs portray a different development in quotas and catch for the two vessel groups, where the increase for the cod trawlers are enhanced due to the structuring of the fleet.

## IMPACT OF MANAGEMENT CHANGES

One of the most important drivers for change in fleet size and composition is the managerial framework under which the vessel owners operate: rules and regulations regarding vessel size and the opportunities for merging fishing licenses and quotas regulations, levies and taxes, etc. As shown in Figure 5.26, the recent development in number of vessels in the two groups under scrutiny here is quite different. The historical trails of these vessels groups are also quite different, where the purse seiners were granted structural measures in the early 1970's as the Atlantic herring stock collapsed, while cod trawlers were granted different commissioning and support measures from the onset of the 1980's as the variations in the cod stock became evident. After different capacity adjusting measures, utilized for both vessel groups throughout the late decades of the 19th century, a shift came in 2005 where structure quotas were introduced for most vessel groups in Norwegian fisheries. When utilizing this arrangement, a fishing vessel could obtain the quota belonging to another vessel in the same vessel group (for 20 or 25 years) if the ceding vessel was scrapped. The fishing possibilities where limited by a roof for how many structural quotas could be gathered on one hull – a quota ceiling.

The vessel groups under scrutiny here have become more homogeneous regarding size, which can also be found regarding the way they operate. Earlier, the element of vessels landing fresh fish and on board fillet processors in the cod trawler group were much greater than today, when most vessels land headed gutted frozen fish. Over the years, cod trawlers had obtained quotas in such a magnitude that many vessels had reached the quota ceiling. In January 2015, the ceiling was therefore lifted from three to four quota units per vessel. At the same time, the purse seiners' quota ceiling was lifted 30 percent – from 650 to 850 basic tones.

Hitherto, few vessels in the cod trawler or purse seiner group have seized the opportunity to buy quotas in the range above the old quota ceiling. Anecdotal evidence at present (February 2017) from the Norwegian vessel registry show that among the 37 remaining cod trawlers, only one vessel have taken the opportunity to structure in quotas above the old ceiling of three quotas, and just marginally – an opportunity that opened more than two years ago (January 2015). In many instances, quota prices are so high that few transactions take place between vessel owning companies, since the opportunity to calculate in a profitable take-over of quotas of limited time span (20 years). Hence, a perpetual quota has usually greater value for the potential seller than as an asset of limited life span for the potential buyer. However, if quotas or fish prices fall below some unknown thresholds this might change as scale economies seems to be present in both these vessel groups. To some degree, quota transactions have taken place internally in multi-vessel owning companies. Moreover, the industry is also awaiting a clarification regarding a new quota system after the proposal from the governmental appointed committee on quotas was put forward in 2016. Among other things, there seems to be a large degree of uncertainty surrounding what will happen with the structural quotas as their life span expires.

## VALUE ADDING AND QUALITY

Previous studies indicate that there is a potential for adding more value among the purse seiners by reducing the part of the landings achieving relatively low prices. By explaining the dispersion in attained price per kilo fish in the purse seine fleet, it is possible to identifying important factors in catching and storing onboard to improve quality. In a master's thesis based on data for one year (2013), the performance level of the vessels was determined by the average price per kilo they obtained during 2013. Even though this is known as one of the most homogeneous vessels, there was a distinct difference in prices achieved. For mackerel, the best vessel managed to get 10,11 NOK/kg, the worst 7,65 NOK/kg and the average for the fleet was 8,57 NOK per kilo mackerel. The same results were found for Norwegian spring-spawning herring (NSSH), were the price per kilo attained per vessel ranged between 5,95 NOK/kg to 5,05 NOK/kg. If all vessel had held the same standard and obtained price (for mackerel and NSSH) as the top performers the fleet would have earned 170 mill. NOK more in total, a 11 % increase in value.

To evaluate the level of innovation, or new technology, the vessels age was used as a proxy. Other variables, such as size of fish, size of catch and size of vessel were also tested to study if there were significant differences between the top performers of the purse seine fleet and the rest. Due to the study's limitation in only testing one year, a significant difference was not found in any of the tested variables. But, the average size of fish showed promises, and the top group age-variable was too skewed to give a reasonable result, due to an old vessel excelling.

As a part of a PhD thesis in WP6, this work has been continued with data for two more years (2014 and 2015). The three-year time series exposed a clear trend in renewal of the fleet, as the oldest vessel are scraped or inactive in this fishery. With newer vessel replacing them, the fleet size is unchanged but its capacity (measured in VCU) increased. The model established in the master's thesis will be further developed in this PhD.

A study by Grundvåg et al., focusing on the pelagic buyers, indicate that 70-90 % of the variance in mackerel price is explained by factors related to fish quality, bid-area, size of the buyers themselves and a few others.

**TECHNOLOGY DEVELOPED - OVERVIEW**

During the program, several technologies have been modified/developed in CRISP. The below listed technologies are at different stages, and some of the technologies are for scientific use, whereas other have potential commercial value. It is assumed that these technologies will contribute to value adding in different ways, e.g. by improving quality of the fish, lower costs (reduction of fuel consumption), decreasing amount of bycatch and reducing environmental impact of fishing.

**WP1 - pre-catch identification of quantity, size distribution and species composition**

1. Acoustic methods: Development of sonars and echo sounders for measuring quantity, species and size of a school prior to catching
2. Calibration of the fisheries sonars: Development of equipment and procedures to calibrate the fisheries sonars with an accuracy of 2-3 %.
3. Echo sounder system: Development of a new echo sounder system and methods to measure the size of individual fish inside a school.

**WP2 - gear and catch monitoring systems in purse seine**

4. Transponders: Development of transponders that may be attached to the seine during fishing, which may be used to visualize the net geometry of the seine on the sonar screen in the wheelhouse.
5. Sonar: Development of a new sonar for use inside a seine

**WP3 - methods for capture monitoring and catch control during trawling**

6. Operationalized Deep Vision in-trawl camera system: Development of in-trawl camera system for species identification and sizing of fish
7. Simrad FX Integrated information system: Development of information system to stream live video, trawl sonar and echo sounder information from the trawl to the bridge
8. Simrad PX MultiSensor trawl door sensor and TVI topside interface

**WP4 - low impact trawl**

9. Trawl doors: Developed trawl doors, which can adjust the spread and position in the water column.
10. Flexible trawl: Developed a flexible trawl and rigging for both semi-pelagic and demersal fishing.
11. Catch regulation device: Developed and implemented a catch regulation device for trawls that releases excess fish at fishing depth

**WP5 - quality improvement**

12. CRISP trawl simulator: Developed as a scientific tool to simulate trawling conditions in small scale, which \`produce trawl caught fish in the laboratory\`.
13. Live fish technology: Development of knowledge and a prototype tank for live storage of cod on board trawlers
14. Vacuum pumping from cod-end: Test vacuum pumping onboard a commercial trawler to improve the landing of fish from the cod-end
15. Stunning and bleeding machines: Tested a modified stunning and bleeding machine (Baader- SI7) on a commercial fishing vessels

## 6 SCIENTIFIC ADVISORY COMMITTEE

One important result of the midway evaluation in 2015 was the formation of an International Scientific Advisory Committee (SAC) as recommended by the panel. This Committee is now constituted and their work is regulated by a Terms of Reference. The Committee consists of Dr. Stephen Walsh, Scientist Emeritus, Fisheries and Oceans Canada (leader), Dr. Petri Suuronen, FAO Rome, and Dr. Sveinn Margeirsson, MATIS, Iceland. The first meeting between the CRISP consortium and the advisory committee was at the Annual Science Meeting in Egersund in September 2016. Before attending the conference, the SAC had a short meeting with the Board to discuss ways of future cooperation.

A Review report was delivered after the Annual Meeting, based on received working documents from the CRISP consortium and their impressions from the meeting. The report contained some important recommendations for scientific and administrative improvements. One important point on the agenda at the conference was to start preparing for the time after 2019 when the funding from the Research Council comes to an end. The SAC shared some valuable ideas for continuation of some of the research areas which have been in focus in CRISP, particularly on internationalization of the CRISP innovations.

Figure 6.1. Dr. Petri Suuronen, member of the Scientific Advisory Committee at World Fisheries Congress in Busan in May 2016.

## 7 INTERNATIONAL COOPERATION

CRISP intends to cooperate with international research institutions when such cooperation is beneficial for joint development and introduction of sustainable fishing technology outside Norway. The industry partners in CRISP are all Norwegian owned, and they all have their production activities based in Norway. They are therefore reluctant to involve foreign partners that can share knowledge of product development with foreign potential industry competitors.

It is, however, important to disseminate the main CRISP philosophy (profitable fisheries and supply industries through development of technology for responsible fishing) to the world community. This has been done by CRISP staff participating in scientific meetings and symposia, but also through the wide international network of the members of our Scientific Advisory Committee.

Deep Vision technology was used in a survey off the northeast coast of Spain in April, 2016 as part of the EU Horizon 2020 project Science, technology and society initiative to minimize unwanted catches in European fisheries (MINOUW). This cruise was conducted in cooperation with researchers from the Mediterranean Centre for Marine and Environmental Research (Spain), Portuguese Institute for Sea and Atmosphere and Consorzio per il Centro Interuniversitario di Biologia Marina ed Ecologia Applicata G. Bacci (Italy). Shale Rosen, IMR, was responsible for the testing of Deep Vision. One additional Deep Vision survey is planned as part of the MINOUW project, scheduled for October 2017 in the Saronikos Gulf portion of the Aegean Sea in cooperation with the Hellenic Centre for Marine Research, Greece.

Deep Vision technology was included in the Fisheries Innovation Scotland project "SMARTFISH: Selective management and retention of target fish." Helge Hamersland (Scantrol Deep Vision) and Shale Rosen (IMR) attended a Smartfish project meeting in June, 2016 which led to testing in cooperation with Marine Science Scotland onboard the research vessel "Alba na Mara" in November, 2016 in the Moray Firth, west of Fraserburgh, Scotland (Figure 7.1). Further development of Deep Vision to enhance selectivity in commercial demersal trawl fisheries has been included in the SenseFish proposal submitted to the EU Horizon 2020 call Smart fisheries technologies for an efficient, compliant and environmentally friendly fishing sector.

Also, linked to the EU Horizon 2020 project MINOUW, CRISP staff from IMR participated in a purse seine survey on the Algarve coast of Portugal in spring. The aim of the survey was to investigate and improve slipping methodology for sardines in Portuguese purse seine fisheries in order to reduce slipping mortality.

Simrad and IMR have cooperated with ISMAR (Institute of Marine Sciences) in Ancona, Italy (Dr. Giovanni Canduci). In May, IMR engineer Jan Tore Øvredal visited Ancona to install the FX80 system (Simrad's HUB, Digital sonar and trawl camera) in one of their trawls and to give a training course for the ISMAE staff in using the system. The mission was not fully successful due to some unforeseen technical problems.

Figure 7.1. Testing of a down-scaled version of Deep Vision onboard the research vessel "Alba na Mara" in November, 2016 in the Moray Firth, west of Fraserburgh, Scotland. In this version the camera system is mounted inside a canvas cover instead of a solid frame.

# 8 RECRUITMENT

In 2016 the CRISP center hosted six PhD students:

Sindre Vatnehol (Figure 8.1) was employed as a PhD student at IMR from 2012 to 2016, and his focus area has been sonar technology (WP1), particularly calibration methods for fisheries sonars. He submitted his synthesis spring 2016 and conducted a successful dissertation in September. Sindre is now employed as Post Doc at IMR, where he continues to work on sonar technology.

Ragnhild Svalheim has been employed by Nofima from 2013 to 2017. Her study focuses on how muscles of captured fish restore during the post capture phase (WP5). Melanie Underwood has been employed by UiB in the period 2012-2017 and has IMR as her working place. Her project deals with behavior of demersal fish during trawl capture (WP3 and 4). These two PhD students are both in their final stage of their projects and are expected to deliver their thesis and have their dissertation in 2017.

Three new PhD students started up their projects in 2016. The first, Neil Anders, who started in January, focuses on how handling of the catch during purse seining influence fish welfare and thus fish survival (if the fish is released) or meat quality (if taken on board). His project is a cooperation between WP2 and 5, and his team of supervisors comprises scientists both from IMR and Nofima.

The second new PhD, Jesse Brinkhof, started in spring 2016, studying the consequences of different trawl innovations on catch quality (WP 4 and 5) of whitefish. Jesse is supported by supervisors from University of Tromsø, Nofima and IMR to assure successful progress in his multidisciplinary study.

The last new PhD, Helene Jensen, started in September 2016. She will focus on value adding caused by CRISP innovations (WP6), and works at Nofima.

With three new PhDs in 2016 in addition to the three PhDs that have newly dissertated or are close to delivery, we feel that CRISP is truly adding to the recruitment of new scientists within the field of fishing technology. One positive aspect is that 50% of our recruits are females, which is a high proportion in a traditionally masculine field of science.

CRISP also employs two Postdoctoral researchers: Anders Karlsson at UiT, working with fish physiology (WP5) and Shale Rosen, with main objective to adapt the Deep Vision system for visual fish classification for fish assessment purposes (WP3).

Four students finalized their research for their Master Degree under the CRISP umbrella in 2016. Bård Årbakke, Kirsten Howarth and Eugene Kitsios were master students at University of Bergen. The first two conducted studies related to fish behavior during trawl and purse seine fishing processes (WP 2, 3 and 4), while the last focused on fish welfare during purse seine fishing (WP2). One master student, Helen Jensen, was attached to University of Tromsø and Nofima, focusing on value adding (WP6). Helene Jensen is now employed as PhD student at Nofima linked to WP6

Figure 8.1. Sindre Vatnehol presenting his PhD thesis for the audience at Annual Science Meeting in Egersund in September 2016.

# 9 COMMUNICATION AND DISSEMINATION ACTIVITIES

CRISP staff has participated in several meetings and symposia in 2016, were the scientific output of the centre has been presented for international audiences, among which we will mention:

- The IIFET (International Institute of Fisheries Economics & Trade) conference in Aberdeen (Bent Dreyer, Nofima).
- International workshop on innovation and development in acoustics and use in fisheries and science. Wednesday, 13 January 2016, Copenhagen (Hector Peña, IMR)
- South Pacific Regional Management Organization, Task group on fishing vessels as scientific platforms. 2nd workshop, Lima, 7-11 Nov. 2016 (Hector Peña, IMR).
- The Ny-Ålesund Symposium 2016 - Planet Ocean; Ny-Ålesund, Svalbard, 19.-21.09.2016 (Aud Vold, IMR).
- Working group on fisheries, acoustics, science and technology (WGFAST). Vigo, April 20 2016 (Hector Peña, IMR)
- 7th World Fisheries Congress, Busan, South-Korea, 23 – 27.05.2016 (Figure 9.1 and 9.2). At this congress, several aspects of CRISP research and innovation was disseminated: The CRISP concept (Aud Vold, IMR); sonar/echo sounder development (Lars Nonboe Andersen and Tonny Algrøy, Simrad); use of acoustic techniques to monitor gear and schools (Maria Tenningen, IMR); the Deep Vision technology (Hege Hammersland-White, Scantrol Deep Vision).

Our activities and innovations have also been promoted at several national meetings, seminars and fishing exhibitions arranged by various Norwegian hosts. One of these was the biennial fishing exhibition Nor-Fishing in Trondheim in August 2016. Here several aspects of our work were presented at different mini-seminars at several stands and at side-events. All partners also flagged their CRISP affiliation on their stands. This year Scantrol Deep Vision was awarded Nor-Fishing's Innovation Award for their development of the Deep Vision underwater camera system for fish measurement and sorting in the trawl. Minister of Fisheries Per Sandberg handed over the award at the official opening at Nor-Fishing (See chapter 5.3).

IMR staff publish most of their work as technical reports in the series "Nytt fra Havforskningen" ("News from IMR"), while Nofima staff publish their work in Nofima Report Series. Many CRISP highlights have been published in short communication brochures in like "Marine Research News" ("Havforskningsnytt") and on CRISP's and the institutes' web pages. A selection of scientific results was published in reviewed scientific journals. CRISP achievements, particularly news on the Deep Vision technology and on fish quality, have been presented in radio and on TV news (Norwegian Broadcasting Corporation) both locally and nation-wide, as well as in newspapers and magazines like "Fiskeribladet Fiskaren" (the fisheries magazine of Norway) and internet magazines like "Forskning.no" (the news magazine of the Norwegian Research Council). Videos taken with underwater cameras to illustrate fish behaviour and performance of various devices developed in CRIPS are published on the web for viewing on YouTube.

Figure 9.1. Scantrol Deep Vision (Hege Hammersland-White) and Simrad (Tonny Algrøy) at World Fisheries Congress in South Korea where they presented CRISP innovations.

Figure 9.2. Maria Tenningen, IMR, asking questions at World Fisheries Congress in Busan May 2016.

# APPENDIX I

## Personell

### Key Researchers

| *Name* | *Institution* | *Main research area* | *Sex* |
|---|---|---|---|
| Torbjørn TOBIASSEN | Nofima | Quality improvement | M |
| Kjell MIDLING | Nofima | Quality improvement | M |
| Heidi NILSEN | Nofima | Quality improvement | F |
| Stein Harris OLSEN | Nofima | Quality improvement | M |
| Karsten HEIA | Nofima | Quality improvement | M |
| Bent DREYER | Nofima | Value adding | M |
| Kine KARLSEN | Nofima | Value adding | F |
| John R. ISAKSEN | Nofima | Value adding | M |
| Marianne SVORKEN | Nofima | Value adding | F |
| Arill ENGÅS | IMR | Low impact trawling/Instrumentation | M |
| Shale ROSEN | IMR | Low impact trawling/Instrumentation | M |
| Olafur A. INGOLFSSON | IMR | Low impact trawling/Instrumentation | M |
| John Willy VALDEMARSEN | IMR | Low impact trawling | M |
| Egil ONA | IMR | Sonar technology and fisheries instrumentation | M |
| Hector PENA | IMR | Sonar technology and fisheries instrumentation | M |
| Aud VOLD | IMR | Purse seine technology, Centre management | F |
| Maria TENNINGEN | IMR | Purse seine technology | F |
| Mike BREEN | IMR | Purse seine technology | M |
| Roger LARSEN | UIT | Quality improvement | M |
| Anders FERNØ | UIB | Researcher training, recruitment | M |
| Arne JOHANNESSEN | UiB | Researcher training, recruitment | M |

### Key technicians, research institutes

| | | | |
|---|---|---|---|
| Jan Tore ØVREDAL | IMR | Engineering, instrument development | M |
| Kjartan MÆSTAD | IMR | Information logistics | M |
| Turid LODDENGAARD | IMR | Centre management - Finance | F |
| Atle TOTLAND | IMR | Sonar Technology and Fisheries Instrumentation | M |
| Jostein SALTSKÅR | IMR | Engineering, instrument development | |
| Bjørn TOTLAND | IMR | Engineering, instrument development | M |
| Ronald PEDERSEN | IMR | Sonar Technology and Fisheries Instrumentation | M |
| Tor H. EVENSEN | Nofima | Quality improvement | M |

### Key personell, industry partners

| | | | |
|---|---|---|---|
| Ole Bernt GAMMELSÆTER | Kongsberg Group | Sonar technology and fisheries instrumentation | M |
| Lars N. ANDERSEN | Kongsberg Group | Sonar technology and fisheries instrumentation | M |
| Ivar WANGEN | Kongsberg Group | Sonar technology and fisheries instrumentation | M |
| Olav VITTERSØ | Kongsberg Group | Management, Board leader | M |
| Thor BÆRHAUGEN | Kongsberg Group | Monitoring fish and gear | M |
| Jon Even CORNELIUSSEN | Kongsberg Group | Monitoring fish and gear | M |
| Helge HAMMERSLAND | Scantrol Deep Vision AS | Visual fish classification/Management | M |
| Bowei TONG | Scantrol Deep Vision AS | Visual fish classification | M |
| Håvard VÅGSTØL | Scantrol Deep Vision AS | Visual fish classification | M |
| Hege HAMMERSLAND-WHITE | Scantrol Deep Vision AS | Visual fish classification/Marketing | F |
| Arvid SÆSTAD | Egersund Group | Low impact trawling | M |
| Trond NEDREBØ | Egersund Group | Low impact trawling | M |
| Roy SKULEVOLD | Egersund Group | Low impact trawling | M |
| Vidar KNOTTEN | Egersund Group | Low impact trawling | M |
| Bjørn HAVSØ | Egersund Group | Low impact trawling/Management | M |
| Kjell LARSEN | Nergård Havfiske | Quality improvement and value adding | M |
| Torgeir MANNVIK | Nergård Havfiske | Quality improvement and value adding | M |
| Morten HERMANSEN | Nergård | Quality improvement and value adding | M |
| Øyvind BERG | Nergård | Quality improvement and value adding | M |

**Postdoctoral researchers with financial support from the Centre budget**

| *Name* | *Funding* | *Research area* | *Sex* | *Duration* | *Nationality* |
|---|---|---|---|---|---|
| Anders KARLSSON | Univ. i Tromsø | Fish physiology | M | 3 years | Norwegian |
| Shale ROSEN | CRISP | Visual fish classification, fish behavior | M | 3 years | USA |

**PhD students with financial support from the Centre budget**

| *Name* | *Nationality* | *Period* | *Sex* | *Topic* |
|---|---|---|---|---|
| Melanie UNDERWOOD | Australian | 07.05.2012-01.02.2017 | F | Capture behaviour |
| Sindre VATNEHOL | Norwegian | 01.09.2012-03.03.2016 | M | Sonar Technology |
| Ragnhild A. SVALHEIM | Norwegian | 15.04.2013-01.12.2017 | F | Fish Quality |
| Jesse BRINKHOF | Norwegian | 14.03.2016-13.03.2019 | M | Fish Quality/Capture behaviour |
| Helene JENSEN | Norwegian | 01.09.2016-31.08.2019 | F | Value adding |
| Neil R. ANDERS | Great Britain | 01.01.2016-31.12.2019 | M | Purse seine |

**Master students**

| *Name* | *Nationality* | *Period* | *Sex* | *Topic* |
|---|---|---|---|---|
| Bård AARBAKKE | Norwegian | 2015-2016 | M | Fish behaviour |
| Kirsten HOWARTH | Great Britain | 2015-2016 | F | Fish welfare |
| Helene JENSEN | Norwegian | 2015-2016 | F | Value adding |
| Eugene KITSIOS | Greece | 2017-2016 | M | Fish welfare |

# APPENDIX 2

## *Funding*

### Statement of Accounts 2016

All figures in 1 000 NOK

| **Funding** | | **Budget** | **Account** |
|---|---|---|---|
| The Research Council | | 10 000 | 10 000 |
| The Host Institution | Havforskningsinstituttet | 6 320 | 10 214 |
| Research partners | Nofima | 1 955 | 739 |
| | University of Bergen | 260 | 667 |
| | University of Tromsø | 1 200 | 600 |
| Enterprise partners | Kongsberg Maritime AS | 2 750 | 2 480 |
| | Egersund Group AS | 570 | 437 |
| | Scantrol AS | 500 | 374 |
| | Nergård Havfiske AS | 1 000 | 2 305 |
| Public partners | Sildesalgslaget | 100 | 100 |
| | Råfisklaget | 100 | 100 |
| | | 24 755 | 28 016 |

## *Cost*

| **Costs** | | **Budget** | **Account** |
|---|---|---|---|
| The Host Institution | Havforskningsinstituttet | 12 690 | 16 549 |
| Research partners | Nofima | 4 305 | 3 089 |
| | University of Bergen | 890 | 1 332 |
| | University of Tromsø | 2 050 | 1 450 |
| Enterprise partners | Kongsberg Maritime AS | 2 750 | 2 480 |
| | Egersund Group AS | 570 | 437 |
| | Scantrol AS | 500 | 374 |
| | Nergård Havfiske AS | 1 000 | 2 305 |
| Public partners | Sildesalgslaget | 0 | 0 |
| | Råfisklaget | 0 | 0 |
| | | 24 755 | 28 016 |

# APPENDIX 3

## Publications

### Refereed journal papers

Macaulay, Gavin; Vatnehol, Sindre; Gammelsæter, Ole Bernt; Pena, Hector; Ona, Egil. 2016. Practical calibration of ship-mounted omni-directional fisheries sonars. Methods in oceanography 17: 206-220.

Tenningen, Maria; Macaulay, Gavin; Rieucau, Guillaume; Pena, Hector; Korneliussen, Rolf. 2016. Behaviours of Atlantic herring and mackerel in a purse-seine net, observed using multibeam sonar. ICES Journal of Marine Science 74(1): 359-368.

Vatnehol, Sindre; Pena, Hector; Ona, Egil. 2016. Estimating the volumes of fish schools from observations with multi-beam sonars. ICES Journal of Marine Science doi:10.1093/icesjms/fsw186.

Vatnehol, Sindre; Totland, Atle; Ona, Egil, 2016. Two mechanical rigs for field calibration of multi-beam fishery sonars. Methods in oceanography http://dx.doi.org/10.1016/j.mio.2016.02.011.

### Journal papers without referee

Isaksen, John Roald; Dreyer, Bent; Grønhaug, Kjell, 2016. Supply Chain Management under uncertain supply. Økonomisk fiskeri-forskning: Ledelse, marked, økonomi 2016; Volum 26.(1) s. 17-40.

### Books

Iversen, Audun; Hermansen, Øystein; Henriksen, Edgar; Isaksen, John Roald; Holm, Petter; Bendiksen, Bjørn Inge; Nyrud, Thomas; Karlsen, Kine Mari; Sørdahl, Patrick Berg; Dreyer, Bent. 2016. Fisken og folket. Orkana Forlag 2016 (ISBN 978-82-8104-288-9) 308 s.

### PhD thesis

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