ANNUAL REPORT 2014

CRISP

Centre for
Research-based
Innovation

1 SUMMARY

CRISP, the Centre for Research-based Innovation in Sustainable fish capture and Processing technology, started its research activities 1 April 2011. Since its launch, the consortium has consisted of four industry partners (Kongsberg Martime AS, Simrad; Scantrol AS; the Egersund Group; 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).

The research of the Centre is organised in six scientific work packages:

- development of instrumentation for fish identification prior to capture
- monitoring fish and gear behaviour during fishing
- development of methods to release unwanted catch unharmed
- development of low-impact trawl gear
- adaptation of capture and handling practices to optimize catch quality and value
- analysis and documentation of the economical benefits to the fishing industry of converting to more sustainable capture techniques.

In this fourth 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. This year the main focus has been to develop knowhow and components of equipment that has the potential to revolutionize fisheries worldwide when they at a later stage will be compiled into more integrated fishing systems.

The development of acoustic instruments for identification of species, quantity and fish size in schools has been one of the focus areas of CRISP since the start. This research is done by Kongsberg Maritime, Simrad, in close cooperation with Institute of Marine Research, Bergen. A new and improved fishery sonar which can quantify the size of a school prior to shooting the purse seine is currently being developed. This has included development and testing of new sonar data formats, and also the development of a standard calibration procedure for fishery sonars. This work is now nearly completed. Simrad has also developed a new side-looking fishery sonar for school inspection both before catching and school inspections inside the closed seine. The new sonar entered the trial phase on board fishing vessels in 2014. The prototype SN90 was tried on board the fishing vessel Kings Bay in November with promising results, and the development and testing of this sonar will continue in 2015.

Kongsberg Maritime AS, Simrad, has developed an integrated information system for underwater video, trawl sonar and echo sounder information sent through a standard net-sounder cable from the trawl to the bridge. These instruments give *in situ* information about species and size of fish entering the trawl as well as monitoring the performance of the trawl. In addition a new trawl door sensor has been developed. This enables precise positioning of the doors in relation to the seabed. Activities in 2014 included prototype testing of a prototype multi-beam trawl sonar, use of Simrad developed instruments to monitor fish behaviour and trawl performance for development of low impact trawling techniques, and an initial attempt to stream live video, filmed when trawling to the Internet.

A structural and economical analysis carried on by Nofima has shown that the purse seine fleet may increase their income by choosing harvest strategies that optimize the value of the vessel quota. This can only be done if the skipper is given tools for better control of the catch and gear. Therefore, a prototype catch monitoring system for purse seines has been built, holding an instrument package consisting of a high resolution sonar, cameras and instruments for environmental control. The prototype will be further developed into a remotely operated surface vessel.

Deep Vision is an underwater camera system which identifies and measures fish passing through a trawl by use of a camera system mounted inside a deployment frame placed between the trawl and codend. A production-ready deployment frame for Deep Vision was designed and built, and the frame and camera successfully buoyancy tested and adjusted in seawater in preparation for the CRISP sponsored cruise in March 2015. The Deep Vision software that analyses the images from the camera system underwent significant improvements in 2014. Analysis is now faster and more intuitive, and notable improvements have been made in fish detection, identification and counting of individual fish, and processing of data.

Presently, the catch rates of gadoids in the Barents Sea are often higher than wanted, and a system for dynamic catch control is required. A number of systems have been tested in CRISP. The simplest system, called the Excess Fish Exclusion Device (ExFED), use passive techniques where surplus fish are mechanically guided out of the trawl. The ExFED consists of a fish lock just behind a rectangular opening in the upper trawl panel covered by a mat attached only at its leading edge. A fish lock prevents the targeted quantity of fish from escaping during haul back. From 1 January 2014, the Norwegian cod trawler fleet was allowed to use the ExFED combined with a selection grid during fishing. The ExFED has been further developed and tested in 2014, and is shown to function well in four-panel trawls without sorting grids. There are still some challenges for the functionality of ExFED in two-panel trawls, where further experiments will continue in 2015.

Continued full scale experiment with the manoeuvrable SeaFlex trawl doors confirmed approximately 45% spread reduction when opening all hatches, accounting for 20% of the trawl door surface. Acoustic communication using the cNODE system proved to be an acceptable tool for further development of the command and control of a motor that can adjust the hatch openings. It was further concluded that only one hatch with a surface area corresponding to 2–3% of a door area in one of the doors is required for adjusting the doors to equal height above

the bottom during semipelagic trawling. A modified roller gear was successfully tested on board research vessels and in commercial fishing. This ground gear design has fewer contact points with the bottom than a conventional rockhopper ground gear. An interesting observation was that most cod rose above the fishing line when this was positioned 70 cm the above bottom and with large escape openings between the ground gear and the fishing line. Some trials with a pelagic trawl resulted in high catch rates of cod.

In CRISP, one aim is to increase the quality and the value of the raw material through altering the way the trawl is used and how the catch is treated. This can be achieved through minimizing stress during trawling, and by implementing new technologies that makes the handling of the catch more lenient. The effects of different stressors inflicted upon fish during capture and handling are specifically investigated in research carried out aboard fishing vessels as well as in controlled experimental studies such as in the CRISP large scale swim tunnel/trawl simulator. Experiments in collaboration with Nergård Havfiske AS show that pumping from the trawl's cod-end is a gentler way of fish handling than lifting the complete catch onto the deck. Survival is higher, quality higher, and this brings about new aspects regarding the design of future trawlers. Machines for automatic killing and bleeding can be effectively utilized for on-board catch handling in fishing vessels, and their use would make the process more efficient as well as safeguarding the quality of the fish. Thus, new slaughter systems and technology in the processing line on board the trawling fleet must also be developed. This is a necessary step to gain an economic, safe, first-class stable quality and efficient fish processing.

Economic and structural analyses of the Norwegian trawl and purse seine fleets have been carried out. Restructuring seems to have reduced the number of vessels in both groups, but the numbers now seem to be stabilized. Our findings indicate that both the structural process and the level of quotas have led to improved profitability, and in both vessel groups it can be seen that old vessels are being replaced by new vessels. One intention of conducting detailed studies of the structural and economic development of the vessel groups addressed has been to reveal how CRISP can contribute to improve the performance of the vessels. In both groups we find heterogeneity in terms of fuel consumption and value adding. While the analyses show that innovations that reduce the fuel consumption are most important for improving the profitability of the trawlers, innovation that improves value adding will be more important for the purse seine group, as the these vessels have a much lower fuel consumption.

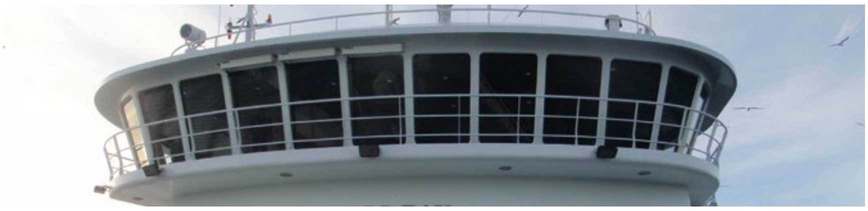
CRISP staff has taken part in a range of dissemination activities during the last year, including lectures about CRISP activities in national and international scientific meetings. Nationally, CRISP staff has promoted their results at several meetings, seminars and fishing exhibitions arranged by various hosts. At the international fishing exhibition Nor-Fishing in 2014, several CRISP staff gave lectures about new innovations produced by the Centre.

In 2014, CRISP hosted two Post doctorial positions, three PhD and three Master students. The majority of these 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 behaviour and gear performance during fishing operation.
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 packages, each of which comprises several sub-projects.

WP 1. Pre-catch identification of quantity, size distribution and species composition

WP 2. Monitoring fish behaviour and gear performance

WP 3. Active selectivity and release in fishing gears

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 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 over the coming years.

4 ORGANIZATION

4.1 Organizational structure

IMR in Bergen is the host institution and is responsible for the administration of CRISP. Within IMR, the Centre is organized as a project in the Barents and Polar Sea research programme. 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 formal education for PhD and MSc students who are funded by and associated with the Centre.

John Willy Valdemarsen of IMR was appointed director of the Centre from its starting date on 1 April 2011.

In 2014, the board of the Centre was as follows:

- Olav Vittersø, Kongsberg Maritime AS, Simrad (Chair)
- Helge Hammersland, Scantrol AS
- Vidar Knotten, Egersund Group AS
- Kjell Larsen, Nergård Havfiske AS
- Geir Lasse Taranger, Institute of Marine Research
- Heidi Nilsen, Nofima AS
- Helge Johnsen, University of Tromsø
- Heine Møgster, Norges Sildesalgslag
- Turid Hiller, Research Council of Norway (Observer)

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

Representatives of the University of Bergen and Norges Råfisklag were board members in 2011 and 2012. From mid 2013, they were be replaced by representatives from the University of Tromsø and Norges Sildesalgslag. Representatives of universities and sales organizations are alternate board members for each other.

4.2 Partners

In 2014, 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; Deep Vision Scantrol AS; the Egersund Group; 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 of live cod for storage in net pens, 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), has particular responsibility for the development of expertise within all areas of fisheries and aquaculture research in Norway. Teaching and research focus is 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 monitors. 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 purpose. 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 IMR's 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. Cooperation with the other industry partners will be helpful in adapting Scantrol DeepVision AS to different trawl designs and benefitting from the development of a new signal cable between the vessel and its trawl gear.

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 (NSS, 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 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 the 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. A major challenge for the Centre is therefore to create an environment for the development of instrumentation and fishing systems where complementary competence can be utilized efficiently to create completely new products. During this fourth year, the various partners have continued to spend time on identifying areas of common interest and on launching cooperative efforts.

The Centre uses various arenas and methods to encourage mutual trust and to form joint projects involving CRISP's partners. 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. In 2014, representatives from the various partners participated in four such research cruises. Industry partners, with the assistance from the Centre's management, have arranged meetings to discuss and plan joint development work. All of the CRISP partners participated in a two-days Technical Conference in Bergen in November where the Centre's activities to date were presented and discussed with invited participants from the fishing industry, management authorities and environmental organizations.

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 with digital fishery sonars 1.2 Pre-catch identification and sizing of fish with broadband split beam echo sounders	IMR, KM and UiB
WP 2. Monitoring fish behaviour and gear performance	2.1 Trawl HUB for camera and acoustic systems 2.2 Catch and gear information system 2.4 Catch monitoring system in purse seine	IMR, KM and Scantrol Deep Vision
WP 3. Active selectivity and release in fishing gears	3.1 Visual fish classification 3.2 Active device for selection in trawls 3.3 Catch regulation in trawls	IMR, Scantrol Deep Vision, KM, UiB
WP 4. Low impact trawl	4.1 Manoeuvrable trawl doors 4.2 Semipelagic trawl design and rigging	IMR, Egersund Group, KM, UiB
WP 5. Quality improvement	5.1 Current quality conditions on board bottom trawlers 5.2 Facility and methods for experimental investigation of fish quality	Nofima, IMR, UiT and Nergård
WP 6. Value adding	6.1 Nergård operation 6.2 Status Norwegian purse seiners	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 measurements of schooling fish species than what is possible with current instrumentation. In this respect, research and industry has a common long term challenge.

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 "poor" sets where 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, instruments that can reduce this risk are needed for future sustainable harvesting of pelagic schooling fish with purse seine gears.

Activities

Simrad is collaborating with IMR for developing new and improved fishery sonar 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 also the development of a standard calibration procedure for multibeam fishery sonars. New data formats and improved software have been delivered by the industry partner in 2013 and tested with participation by Simrad personnel in the trial surveys on herring in 2012 and 2013, and on Atlantic mackerel in October 2014.

A CRISP PhD student has successfully used the raw element data of the sonar transducer to create split beam positioning of the calibration target under sonar beam calibrations. IMR engineers and the student have also been involved in the manufacturing and trials of standard calibration rigs for multibeam sonar. A summary of our sonar calibration work on "G.O. Sars" and 4 fishing vessel sonars will be published with co-authors to the symposium in Nantes, France, in May 2015. We now believe we can calibrate the sonar beams almost to the same accuracy as the echo sounders, and that the extra variability we observe is more related to the environment than to the system itself. Measurements in horizontal mode close to the sea surface have also showed increased variability in echo sounder calibrations. After two years on herring, with validation between a pure sonar estimate and the real catch, algorithms will be put back into the sonar. Some uncertainties with respect to mean target strength of the fish in the horizontal aspect remains but is worked upon by another team. Measurements against a controlled amount of fish in a large, acoustically transparent net pen holding up to 30 tonnes of fish will also be part of this validation. The sonar echo of the empty net pen was –20 to –30 dB lower than the echo of the net pen with fish, showing that the echo contribution from the empty net pen will be less than 1% of the 30 tonnes echo. Fish transfer methods from purse seine to net pen and back have worked well for both herring and mackerel in fair weather conditions in the open ocean.

In order to estimate fish size and species composition inside schools, the main activities this year have been to finalize calibration methods of wide-band echo sounders and trials with the new narrow beam transducer. The wideband echo sounder has been modified and improved by the industrial partner, both with respect

Figure 1.1.
The new transducer mounting on board G.O. Sars, November 2014.

to the hardware, but also significant effort is now being made on the new echo sounder software. The new developments in 2014 also include trials with the new transducer with a sharper beam and determining how this can be arranged in side-view mode on the vessel, but now also with control of the tilt angle of the transducer (Figure 1.1). A powerful pan and tilt motor for underwater heavy duty work was first rented and later bought from UK and mounted inside a small aluminium keel, mounted below the drop keel of "G.O. Sars". The new keel was made in order to reduce the flow force on the transducer head and to ensure that the gear of the tilt and pan unit would withstand the forces with the motors turned off. The transducer could then be used in sideways mode, within tilts from 0–30 degrees, and straight downwards, both modes shooting through open holes in the keel. The setup worked well during the entire mackerel survey in November 2014.

Results

This project element is now in its fourth year, and the work with respect to calibration protocols for fishery sonar and wideband echo sounders is close to being finished in a first version. Most of the problems anticipated in the calibration of both systems are now solved and the work will be published in 2015 in Nantes. The calibration accuracy of fishery sonar may be slightly lower than for single beam echo sounders, and an overall accuracy of 0.5 dB (±10%) seems to be a good goal. The environmental effects on the transmitted and reflected signals are also larger for sonars than for vertical echo sounding, and so is also the backscatter variability due to target orientation relative to the sonar beam. For the broadband echo sounders, the accuracy over the entire band of frequencies is comparable to the accuracy of narrowband systems, typically 0.1 to 0.2 dB, or 2 to 4%.

Further, sonar data from scientific sonar and fishery sonar have been collected and processed on selected herring and mackerel schools, with subsequent catching of the school with purse seine. About 13 successful catches for validation were made after sonar inspections, and 8 or 9 of them will be included in the validation experiment. Catches where there are uncertainties with respect to if the entire school was captured, or ripping the net, are excluded. The variability of school backscatter as the vessel moves around the school is now studied for deciding on how and when the "optimal" biomass estimate is measured, including the uncertainty of the estimate. Also, similar controlled measurements on fixed amount of fish inside an acoustic transparent net pen will be used to establish the conversion factor between acoustic data and school biomass. The initial results have been presented internationally in 2014 and published in 2015.

Analysis of the target spectrum from single fish has continued, and has this year mainly focused on mackerel. Using the new transducer mounting, natural layers in the normal fishing ground for mackerel were well resolved for single target analysis and sizing both horizontally and vertically (Figure 1.2). Algorithms for fish sizing are tried out in new software from the DABGRAF project, which reads and process the wideband echo sounder data directly.

These algorithms now seem to do a much better job than the split beam target strength procedures, when using the information from each track, spectrum nulls and pulse stretching. New algorithms for sizing mackerel based upon acoustically measuring special acoustic interference phenomena inside the mackerel body are also very promising. The sizing algorithms will also be published at the Nantes symposium.

The industry partner in this project is now close to finalizing the wideband echo sounder for release as a product, and is working on finalizing the sonar which is meant to work inside the purse seine with one to three inspection beam for sizing. The prototype SN90 was tried on "Kings Bay" in November 2014 with promising results (Figure 1.3), and a new work package is defined for starting working with this sonar in 2015.

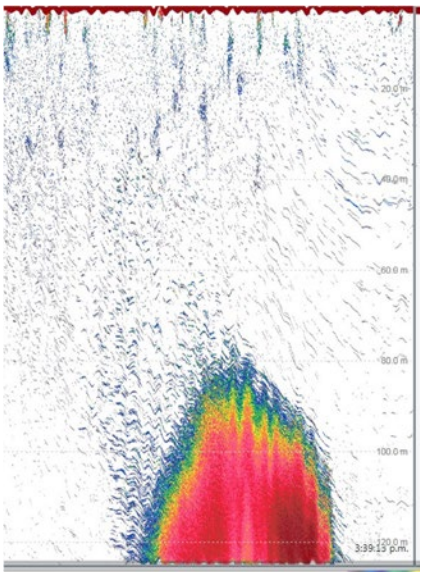


Figure 1.2.
Large mackerel school where the fish are resolved as single individuals for sizing at the border of the school.

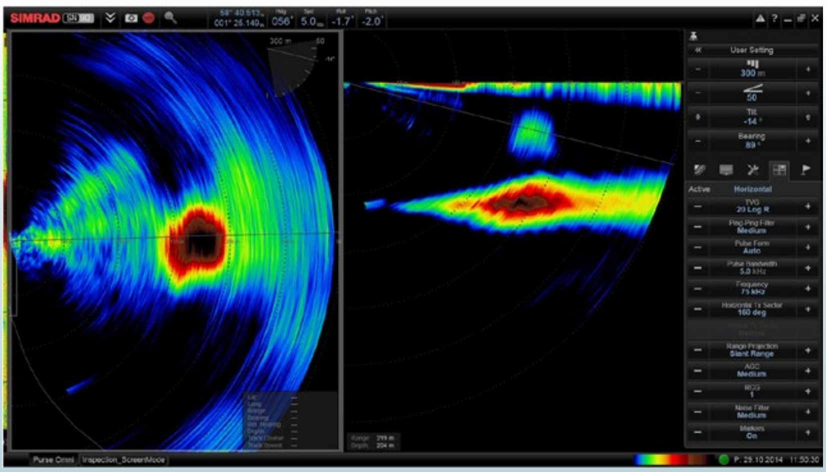


Figure 1.3.
Mackerel school observed with the new Simrad SN90.The horizontal display shows very good data, but the overall Automatic gain contol (AGC) is suppressing she school echo too much in the vertical.

5.2 Monitoring of fish behaviour and gear performance

Background
Kongsberg Maritime AS, Simrad, has developed an integrated information system for underwater video, trawl sonar and echo sounder information sent through a standard net-sounder cable from the trawl to the bridge. These instruments give *in situ* information about fish species entering the trawl, the behaviour of fish within the trawl as well as monitoring the performance of the trawl. In addition, the company has developed trawl door sensors (Simrad PX MultiSensor) giving information about the distance between the doors, distance from the doors to the seabed and roll and pitch of the doors. This enables precise positioning of the doors in relation to the seabed. These instruments have been further developed and tested during fishing trials on board research and commercial vessels in 2014.

In the analysis of the economic status of the purse seine fleet carried out in WP6 "Value adding", it was shown that the purse seine fleet may increase their income by choosing harvest strategies that optimize the value of their limited vessel quota. This can only be done if the skipper is given tools for better control of catch and gear. It would be advantageous if the skippers had instruments that would enable them to: 1) monitor gear shape and performance during fishing; 2) identify species, size or quality of a catch; and 3) monitor fish welfare parameters, to determine whether it is still safe to release fish, with minimal risk of mortality.

Activities
Activites in 2014 included use of instruments developed by Kongsberg Maritime AS, Simrad, to study fish behaviour and gear performance when testing low impact trawl systems. During the "G.O. Sars" cruise in March, a prototype multibeam trawl sonar with 240 degrees beam width was tested. A new housing for the trawl camera was tested during the same research cruise (Figure 2.1). Streaming of video from the trawl camera mounted on the trawl to internet was initiated.

Figure 2.1.
The new housing for the trawl camera.

A prototype monitoring platform for catch identification and surveillance of fish welfare parameters in purse seine fishing was built and tested on a joint cruise with WP1 on board MS Kings Bay in Nov 2014. This integrated instrument package contained: a Sound Metrics ARIS Explorer 1800 High Resolution Sonar; a stereo-camera (consisting of two calibrated Luxus Compact colour cameras; oriented horizontally); a SAIV SD208 CTD to monitor depth, temperature and salinity; GoPro Hero III camera (oriented vertically); a RINKO III Dissolved Oxygen Sensor; and Star Oddi tilt-loggers to monitor the orientation of the instruments. The monitoring platform was set up to be deployed into the catch, during the later stages of hauling, from the vessel's crane (Figure 2.2).

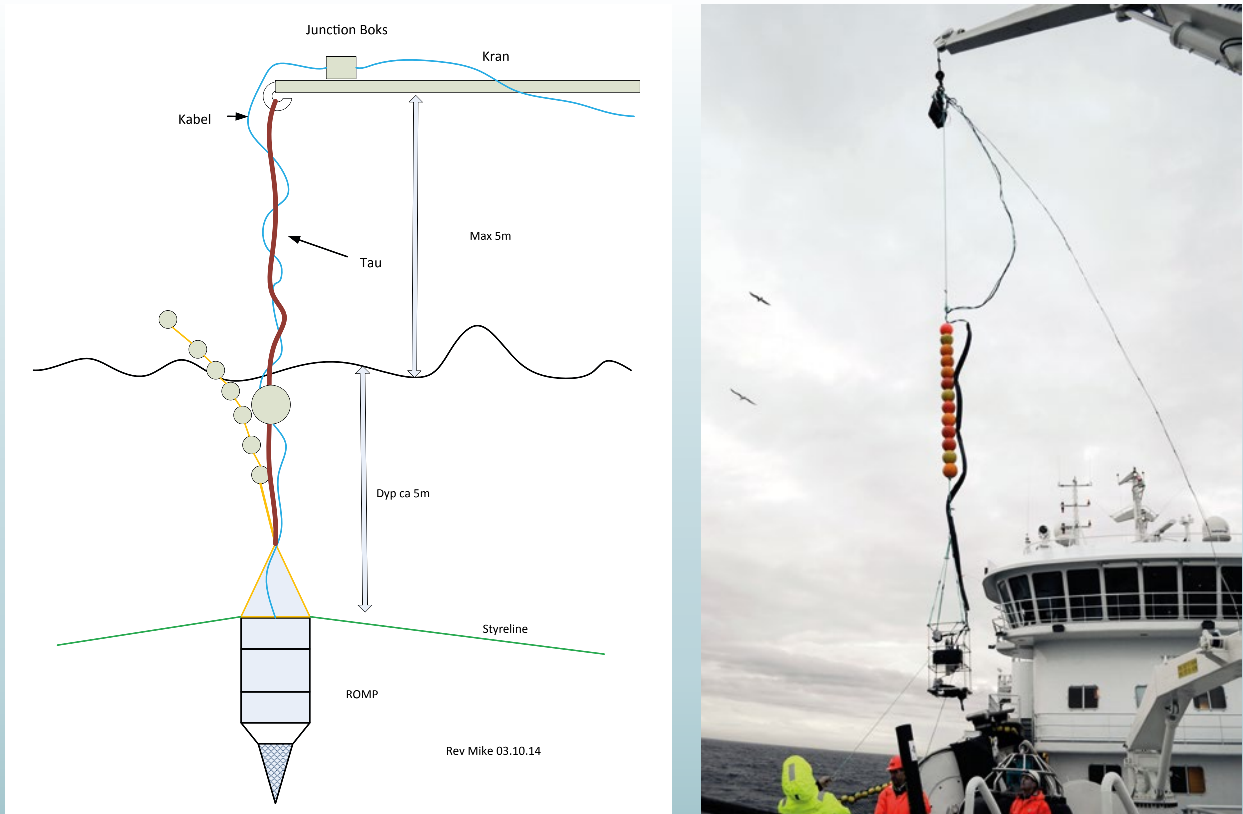


Figure 2.2.
Set up for deploying the monitoring platform from the fishing vessel using a crane.

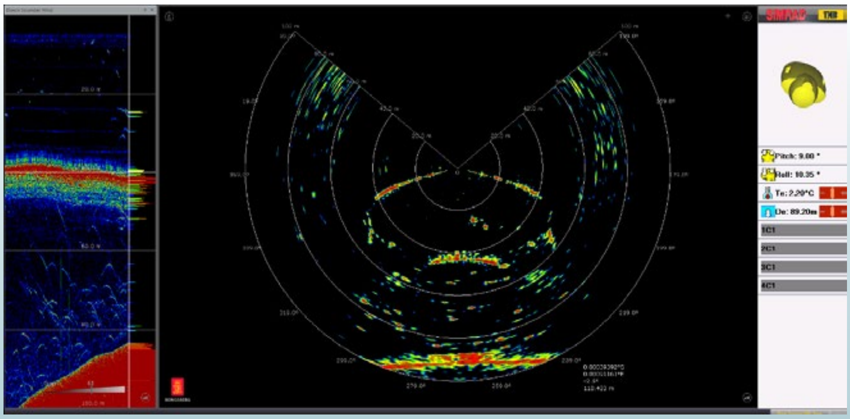


Figure 2.3.
Display from a multibeam trawl sonar used on a pelagic trawl.

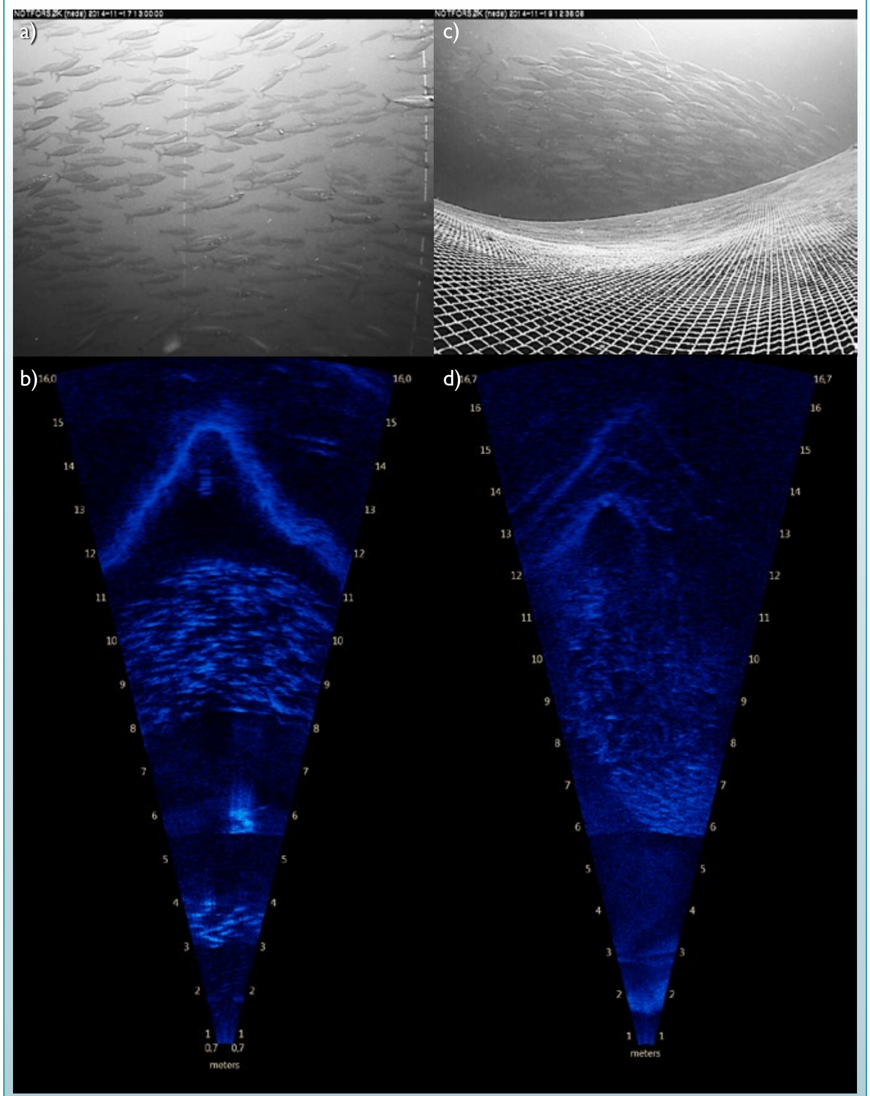


Figure 2.4.
Images from the trials of the monitoring platform at Austevoll: a) mackerel when "uncrowded" swimming in densities comparable to natural densities and with an ordered school structure; b) ARIS sonar image, synchronous with a), showing ordered alignment of individuals within the school; c) mackerel when involuntarily "crowded" swimming in more tightly packed densities [note – net used for crowding in foreground]; and d) ARIS sonar image, synchronous with c), showing higher densities and some evidence of disorder to the school structure.

On the same research cruise, a smaller instrument package that was not constrained by communication and power cables, was also used in and around a large layer of mackerel in the northern North Sea. This integrated instrument package contained: a SAIV CTD; a RINKO III Dissolved Oxygen Sensor; a GoPro Hero 3 (horizontally orientated; a Star Oddi Depth, Temperature & Tilt sensor; and a Simrad Depth Sensor – with direct feed to the vessel – for control of the depth profile. In addition, the vessel's Simrad EK60 echosounder was used for school location and density estimates.

The full integrated instrument package was also tested at the IMR facilities at Austevoll, to assess what observations of fish behaviour and welfare could be made at different states of crowding. Observations were made of a school of mackerel, captive in a net pen, while using a second net inside the pen to induce different states of crowding.

Results
During the "G.O. Sars" cruise, the multibeam trawl sonar proved to be an efficient instrument to monitor fish entrance in a pelagic trawl. The trawl sonar has a cross track swath view of 240 degrees, 200 kHz frequency and can display a vertical beam with 20 degrees opening (Figure 2.3). The streaming of video from the trawl camera was partly successful and will be repeated with more advanced equipment during a similar research cruise in March 2015.

Deployment of the monitoring platform from the crane into the catch, during fishing operations, proved to be impractical. This was because there was insufficient reach to access the catch while the net was being hauled, even in the late stages, as the vessel's thrusters were being used to keep the net stretched out away from the boat. To reach the catch would require a crane with a very considerable reach (>20 m) to guarantee access to the catch. Successful tests of the monitoring platform were achieved however, during the recovery of a caged school of mackerel (on the same cruise) and at the IMR facilities at Austevoll. These showed the integrated instrumentation package worked reliably and provided data on the behaviour and orientation of fish, as well as environmental parameters, in sufficient resolution for various behavioural and welfare metrics to be derived, including direct measurements of crowding density and discerning the internal structure of the school (Figure 2.4).

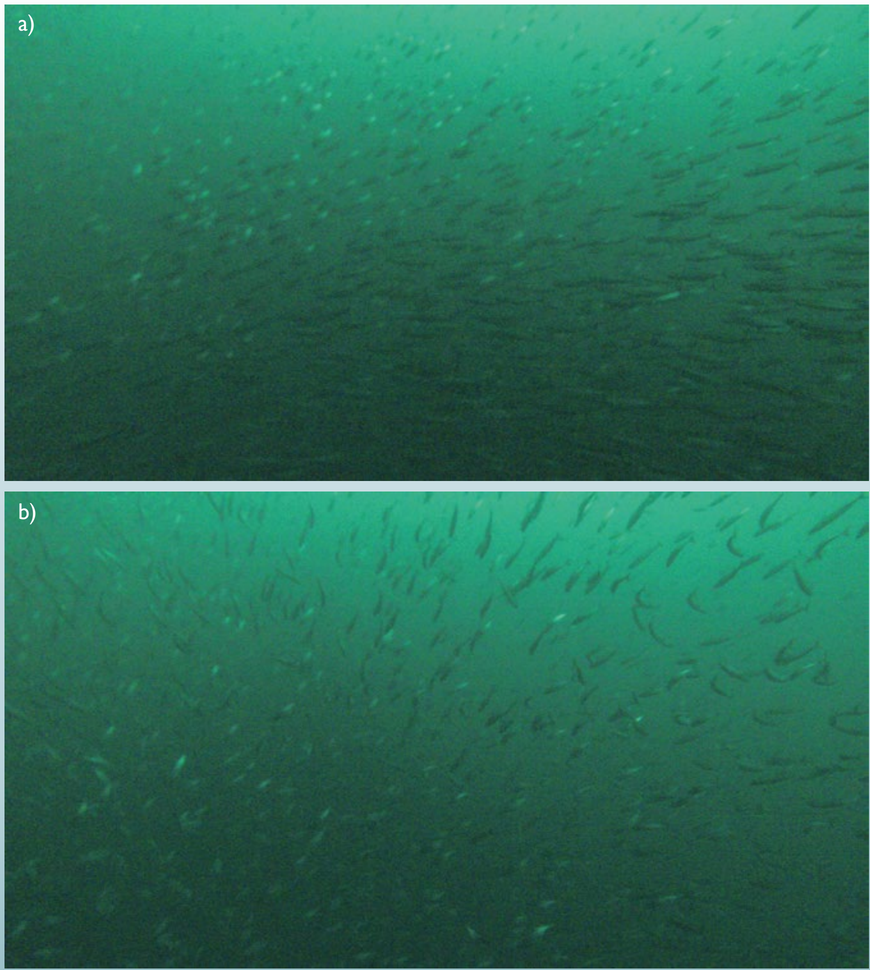


Figure 2.5.
Image inside upper part of a mackerel layer (depth 26.6 m).
a) Time: 12:38 UTC. The orientation of mackerel in the school was typically highly polarised (ordered).
b) Time: 12:39 UTC. This ordered structure was frequently interrupted by short periods of erratic swimming behaviour.

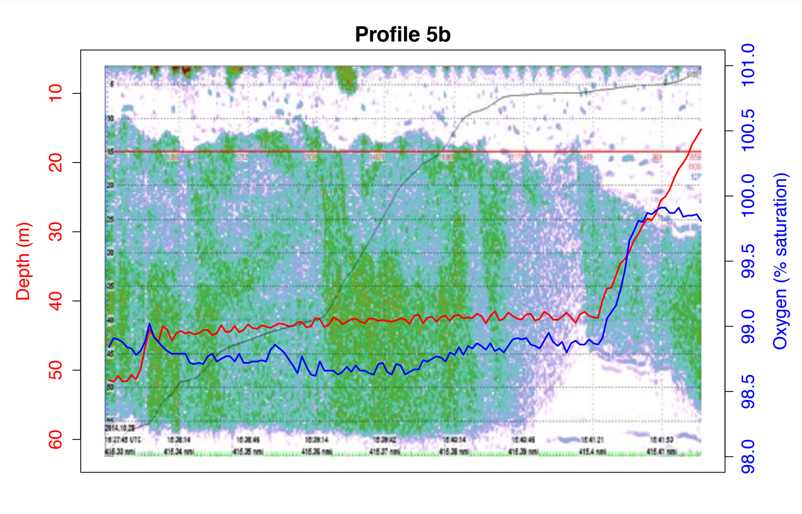


Figure 2.6.
An example of an echogram of a layer of mackerel in the North Sea, overlaid with oxygen saturation (blue) profiles and the sensor depth (red). Oxygen levels are reduced in the densest parts of the layer, but return to baseline levels at the layer's edge (right side of figure).

The opportunist observations in the mackerel schools revealed that the behaviour within the schools was very dynamic, with periods of polarized orientation within school (Figure 2.5a) frequently interrupted by brief periods of erratic swimming (Figure 2.5b). There were no obvious stimuli for these periods of erratic behaviour, other than the presence of the vessel (and associated visual and sound stimuli) and the monitoring platform itself. Oxygen saturation levels in mackerel schools were only slightly reduced (difference = 0.63%) (Figure 2.6). This supports current theories that schooling structure and collective behaviour is at least partly driven by the need of the individual to avoid oxygen depleted waters. With respect to the welfare of mackerel during the capture process, the fact that this data was collected from particularly large and apparently dense natural schools, provides useful preliminary information on the voluntary tolerances of this species to hypoxia.

5.3 Active selectivity and release in fishing gears

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 and purse seines 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 an interactive method capable of actively releasing unwanted catch from trawls and purse seines based on early identification of size and species inside these gears, and to develop systems that can regulate the catch in both trawl and purse seine fisheries.

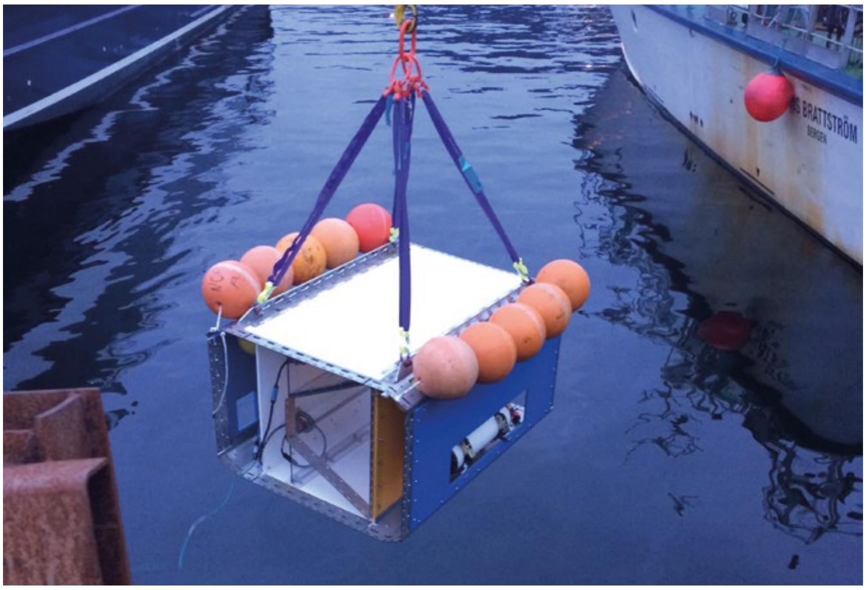


Figure 3.1.
The prototype commercial production Deep Vision deployment frame undergoing buoyancy tests at the Institute of Marine Research's Nykirkekaien facility in December 2014.

Deep Vision is an underwater camera system which identifies and measures fish passing through a trawl by use of a camera system mounted inside a deployment frame placed between the trawl and codend. 2014 marked the final steps in the development of a commercial prototype for the Deep Vision system. In order to bring focused attention to the development of the Deep Vision system, and move the product into a commercial phase, the commercial partner Scantrol AS separated the project into a new company, Scantrol Deep Vision AS, which employs three people. The main goal for the company in 2014 was to finish the production of a Deep Vision system ready for commercial rental in 2015.

High populations of Atlantic cod in the Barents Sea are currently leading to excessively large trawl catches, which lead to reduced fish quality as the catch exceeds the vessel's production capacity, increased risk of discarding, gear damage and safety concerns. Therefore, on request from the fishing industry and managers, a passive system, the Excess Fish Exclusion Device (ExFED), was developed and tested in 2012 to limit the maximum catch size.

The ExFED consists of a fish lock just behind an escape opening in the upper trawl panel covered by a rubber mat attached only at its leading edge. The fish lock prevents the targeted quantity of fish from escaping during haul back. Initially, the mat rests against the top panel of the trawl sealing the escape opening. As fish accumulate and fill up in the codend to the fish lock, water flow is diverted out the escape opening, lifting the mat and allowing excess fish to escape at fishing depth. The system is mounted at a distance from the cod line to achieve the target catch size for the vessel.

The industry reported in 2013 that the metal frame mounted around the ExFED opening was damaged due to tension when taking in the trawl. In addition, there was a request from the industry to test different types of covers above the opening and to verify if the distance behind the grid section and the ExFED could affect the performance of the ExFED. Therefore the improvement and testing of the ExFED was continued in 2014.

Activities

In cooperation with the industrial design company Inventas AS, a production-ready deployment frame for Deep Vision was designed in the first half of 2014 and later built by a mechanical workshop. The frame and camera were successfully buoyancy tested and adjusted in seawater in December (Figure 3.1) in preparation for launch of the fully functioning prototype during a CRISP sponsored cruise in March 2015.

The ExFED system mounted in a four panel trawl without a sorting grid was observed using underwater cameras mounted on the trawl and a towed underwater-vehicle on board "G.O. Sars" in March 2014. During these trials, tests were carried out either with a rubber mat or a netting panel (50 mm) covering the rectangular opening in the upper panel (Figure 3.2). In addition, hauls were carried out to test the effect

Figure 3.2.
Netting panel covering the fish escape opening.

of replacing the metal used to frame the escape opening in the upper panel with ropes and rubber bands (Figure 3.3).

Further tests using the ExFED mounted on a two-panel trawl behind the grid section were carried out on FV "Gadus Poseidon" in November 2014. During this cruise, the main objective was to document the performance of the ExFED at different distances aft of the grid section. In addition, continued testing on the use of ropes and rubber bands to frame the opening in the upper panel, different types of covers (netting panel and netting chaffer (Figure 3.4) above the rectangular opening and to verify the effects of using floats on both sides of the rubber mat to reduce the space between the rubber mat and the netting (observed during the trials in 2013).

Figure 3.3.
Fish escape opening framed with ropes and rubber bands.

Figure 3.4.
Netting chaffer covering the fish escape opening.

Results

The Deep Vision software that analyses the images from the camera system underwent significant improvements in 2014. Analysis is now faster and more intuitive (Figure 3.4). Notable improvements include:

- Multiple fish can be measured in the same image.
- Length can be accumulated across multiple images for fish that are not entirely within the field of view of a single image.
- Fish that are present in multiple images can be tagged as recurring fish and thus counted just once.
- Empty images are removed from the dataset upon loading, greatly speeding up the analysis process.
- Automatic matching of points between the right and left images has been improved, making the procedure for measuring fish length both faster and more accurate.
- Data on species, length, location and depth of each fish are output in standard .csv format for easy integration with third-party software.

Next steps in the software development are to:

- Integrate the Deep Vision data with acoustic data to provide an improved tool for scrutinizing acoustic data.
- Implement automatic species recognition.
- Further automate length measurement.

During sea trials carried out in March 2014, various rigging improvements were made to improve how the frame is integrated into the trawl. Notably, a stone and excess fish excluder was installed immediately in front of the Deep Vision frame (Figure 3.5). Footage taken of the excluder demonstrated that it worked as

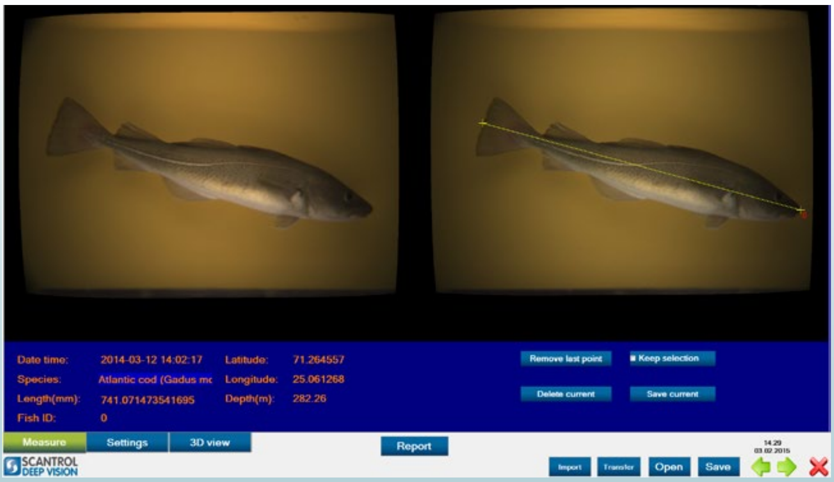


Figure 3.5.
Screen shot from Deep Vision analysis software (Fish imaged during CRISP cruise in March 2014).

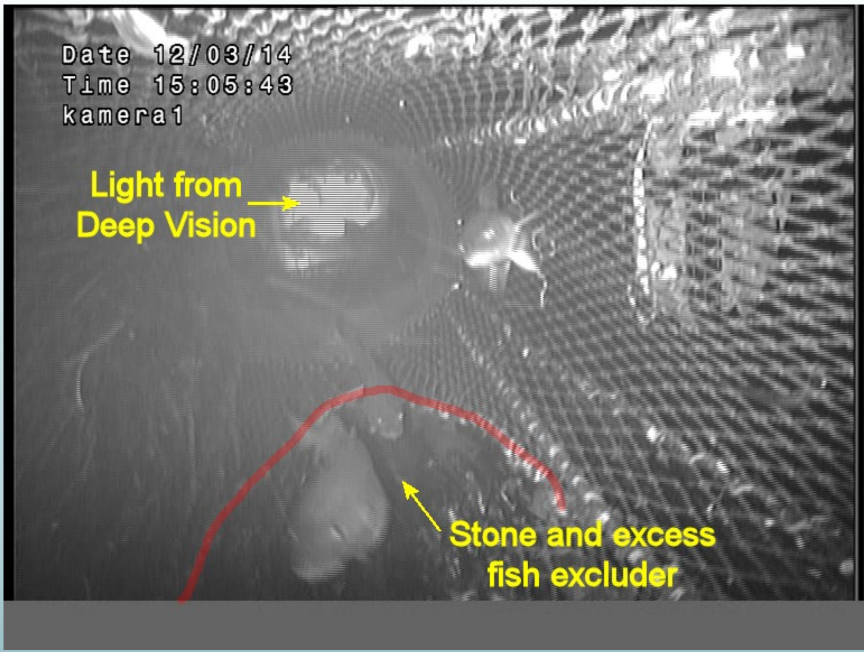


Figure 3.6.
View looking aft in trawl during trials on CRISP cruise in March 2014. Stone and excess fish excluder in foreground, light from Deep Vision system in background.

designed, preventing excessive numbers of fish from entering the Deep Vision frame even when catch rates were as high as 190 large cod per minute (over 1 tonne per minute) while allowing very few fish to escape under lower, more typical, catch rates. A Peer-reviewed article based upon Deep Vision data was published in November 2014.

Video observations of the ExFED mounted in a four panel trawl without a sorting grid showed that the system worked as intended. Fish were observed to calmly swim out through the escape opening at the fishing depth once the codend was filled to the desired catch size. Initial trials using ropes and rubber bands to frame the escape opening and with a netting panel above the opening, indicated that they worked as intended.

During the experiments carried out in November, low visibility due to sand clouds stirred up by trawl doors and ground gear, limited the possibility to properly document the performance and efficiency of the ExFED at the fishing depth.

Figure 3.7.
Floats mounted on both sides of the rubber mat.

In addition to camera observations, the performance of the ExFED was verified by comparing the catch rates during twin trawling: one trawl with and one trawl without ExFED.

To verify results from 2013, experiments were carried out adding floats to the selvage ropes on both sides of the rubber mat (Figure 3.7). Video observations during shooting of the trawl showed that the mat took up a convex shape thus reduced the gap between the mat and the panel.

When a long extension (20 m) was used between the grid section and the ExFED on a two-panel trawl, the circumference (net opening) of the ExFED section was severely reduced (vertical opening between lower and upper panel estimated to be approximately 20–30 cm). With such a narrow opening, fish were "squeezed" out trough the escape opening before the codend was filled to the fish lock. When the extension was removed and the ExFED section was mounted directly behind the grid system, the circumference of the ExFED section increased and the ExFED worked as intended.

Because of the problems with low visibility at the fishing depth and also to too few hauls carried out, the functionality of the ExFED in a two-panel trawl was not fully documented in 2014, and the development and testing will therefore continue in 2015. This applies both to the netting panel, the netting chaffer as well as the use of ropes and rubber bands instead of metal to frame the opening.

5.4 Low impact trawling

Background
Current trawling practice is regarded as unsustainable, as it may be harmful to the seabed, takes too much bycatch and uses too much expensive fuel that pollutes the atmosphere. The future of trawling will thus largely depend on the development of trawling techniques that significantly reduce these negative impacts. This work-package addresses the design, rigging and operation of trawl gears that might achieve such objectives.

Activities
In 2014, focus has been to identify design and operational requirements for vertical trawl door adjustments while semipelagic trawling. In the context of this project, semipelagic trawling means a trawling practice where both trawl doors have clearance to the bottom. Linked to this activity was continued performance testing the cNODE acoustic communication link to be used for controlled opening and closing of the upper hatch on one trawl door during trawling. Another focus area in 2014 was to evaluate performance and catchability of the new ground gear equipped with bobbins rollers which lift the sections between the rollers clear from bottom contact. The 2014 experiments also included catchability test of a pelagic trawl for cod.

Development and evaluation work was conducted during research cruises with the research vessel “G.O. Sars” along the coast of Northern Norway in March, with the smaller 50 feet experimental trawler “Fangst” in the Varanger fjord in August, and with the commercial fishing trawler “Gadus Poseidon” in November 2014.

During the “G.O. Sars” cruise in March 2014, the 7.5 m^2 SeaFlex trawl doors were rigged with the Multpelt 832 pelagic survey trawl. These tests included three different rigging of the sweep arrangement behind the doors (V-rigging, parallel rigging and a combination of these two) aimed to evaluate how the rigging arrangement effected the vertical manoeuvability and performance during shooting and haul back of the SeaFlex doors. The SeaFlex doors were also used during capture trials with a high opening bottom trawl equipped with a netsounder cable attached to a triangular top wing extending forward from the center headrope. This trawl gear arrangement was used for semipelagic towing throughout the cruise in March. The semipelagic trawl was rigged with the bobbins roller ground gear (Figure 4.1), which was towed on various bottom types to evaluate if trawl protection compared with a traditional Rockhopper ground gear, including if the intake of stones was reduced compared with that experienced in the 2013 trials. The ground gear evaluation tests also included observation of gear performance and behaviour of cod entering the trawl from the towed Focus vehicle equipped with a live video camera. In the trials on board “G.O. Sars”, capture efficiency of cod for both pelagic and a semipelagic trawl was evaluated by counting fish

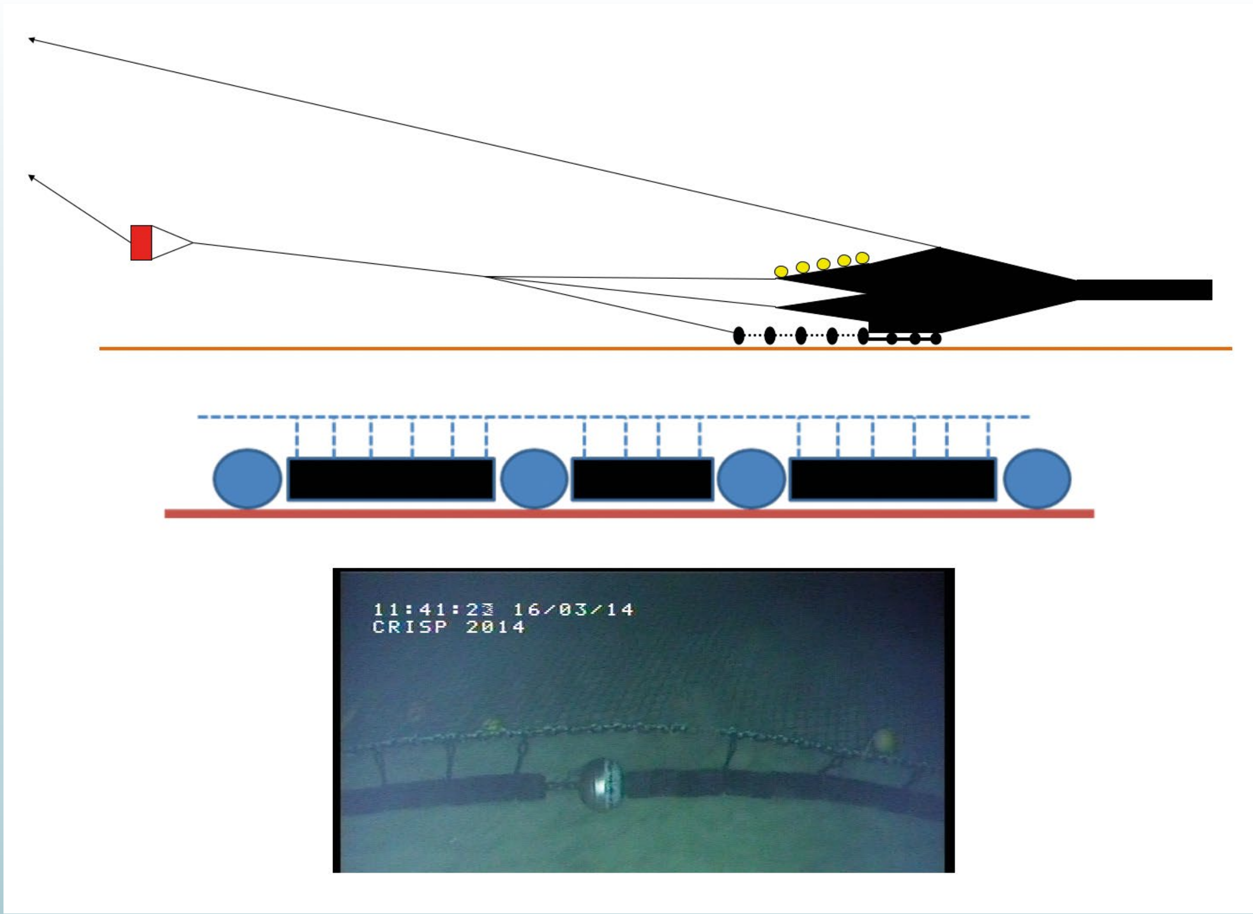


Figure 4.1.
A semipelagic rigged bottom trawl (top) rigged with a ground gear and roller bobbins (middle) observed during fishing from a towed vehicle (bottom).

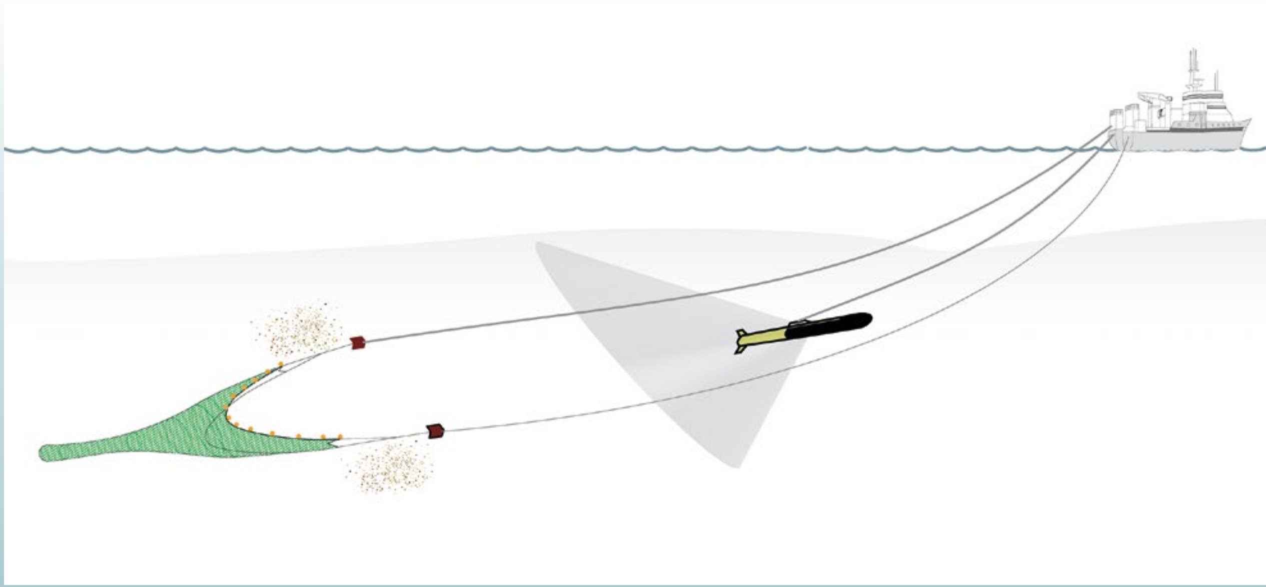


Figure 4.2.
The towed side scanner used to observe fish prior to the trawl.

passing the camera positioned in front of the codend. While on the "G.O.Sars", the use of a towed side scanner was tested to observe fish behaviour prior to entering the trawl (Figure 4.2).

The "Fangst" trial in August focused on acoustic communication with the cNODE system between the vessel and one motor arranged to open and close the upper hatch located in the starboard SeaFlex 2 m^2 aluminium trawl door during towing. Active closing and opening of one hatch was used to evaluate what size of hatch is required to equalize the height above bottom of both trawl doors when towing along a slope. The test also included observation of fish behaviour when these entered a trawl equipped with roller bobbins as the bottom contact points and with clearance of the ground gear sections between.

The fullscale 716 mesh bottom trawl equipped with the rolling bobbins gear was finally tested in November on board the commercial trawler "Gadus Poseidon" aimed to evaluate capture performance and trawl protection when compared with a trawl having a Rockhopper gear in a double trawl towing arrangement.

Results
The tests with the 7.5 m^2 SeaFlex trawl doors confirmed earlier tests of approximately 45% reduction in spread forces generated by the door when both hatches, each accounting for 10% of the door surface area, were fully open. The results from testing of various openings of the upper hatches demonstrated that a hatch size corresponding to 2,5% of the door area is sufficient to move the door vertically by 20–25 meters. In a practical semipelagic trawling situation this means that a hatch with a size corresponding to 2.5% of the trawl door surface is sufficient to adjust a door vertically in most situations when towing along slopes and with side currents. In one of the tows with "G.O. Sars" a difference of 10 meters above bottom was observed between the two doors when towed in an area with flat bottom but with a current direction transverse of the towing direction. During the "Fangst" trials, when towing along a slope where the depth difference was 10–12 m between the positions of the doors 60 m apart from each other, both doors were adjusted to same height above bottom by closing the upper hatch of the door on the deepest side moving this door downward.

The 2014 trials with the SeaFlex doors thus demonstrated that only one of the doors need to be adjusted vertically by opening and closing of the upper hatch during towing to equalize the door distances above the bottom. The depth of the other "Master" trawl door can be adjusted by the warp length and partly by the towing speed. Consequently, vertical adjustment of trawl doors when semipelagic trawling is a combination of warp length adjustments, and tilting of one of the doors to rise or dive till the same height above the bottom as the other one. An optimal situation for a semipelagic trawling technique is when the topography along the trawling path is accurately known and linked to position of both trawl doors in such a way that automatic adjustment of both trawl doors can be performed during towing. The CRISP partners have competence to develop such systems, and are among the priorities for continued cooperation within the Centre.

The system with a movable acoustic transducer and receiver in combination with a transportable control unit tested on "Fangst" seems to be a useful test system for the development of acoustic communication unit to become a test equipment for SeaFlex doors on board commercial trawlers.

The roller ground gear tests demonstrated reduced intake of stones during trawling compared with the 2013 experiences. Besides modification of the ground gear design including the use of larger bobbins (16" diameter) the doors spread used was greater than in 2013. Underspreading of the trawl seems to reduce the fishing line height from the bottom. An interesting observation both during the "G.O. Sars" and the "Fangst" trial was that cod swimming in front of the ground gear lifted itself above the fishing line of the trawl which was positioned 50–70 above the bottom, and thus entered the trawl and was captured (Figure 4.3).

The fishing trials with a pelagic trawl also resulted in commercial catch rates of cod when fishing on pelagic concentrations of cod. An interesting result was that the largest cods were captured in the upper 50–75 m below the surface.

During the "G.O. Sars" cruise, the towed side scanner was able to observe fish in the water column and show the distance

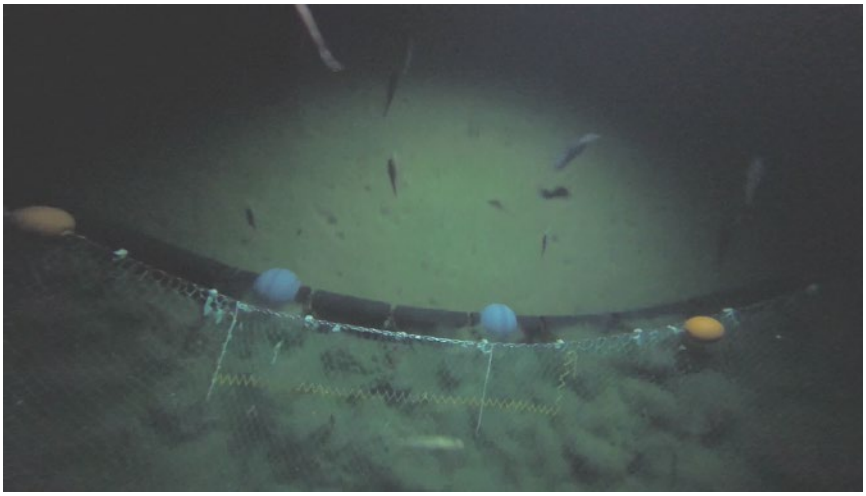


Figure 4.3.
Cod lifting above the fishing line of a trawl equipped with a roller gear.

the fish were from the side scanner (Figure 4.4). The use of a side scanner to observe fish showed promising results as an observational technique. The depth at which fish were observed using the side scanner was limited to the length of towing cable. However, in future experiments, the side scanner placed on a remotely operated vehicle would allow for observations closer to the seabed.

A possible future for trawl trawling for codfish in the Barents Sea, is that 25% of the fish quotas are captured with pelagic trawls whereas the remaining 75% is taken with semipelagic rigged bottom trawls resulting in a total reduced gottom impact of more than 50%. Manoeuvrable trawl doors will become important tools in such a development.

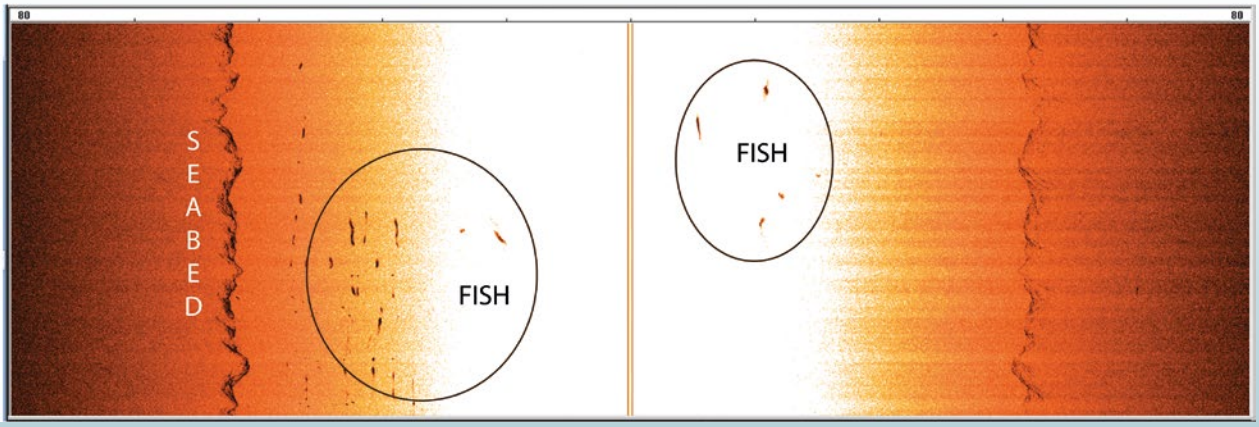


Figure 4.4.
The echograms from the side scanner.The red central lines indicate the side scanner with views of 80 m on each side of the scanner. Circles indicate areas where fish can be seen in the water column above the seabed.

5.5 Quality improvement

Background

To produce new high-quality products it is essential to thoroughly implement the various mechanisms that govern quality. Capture, transfer, transport and pre-processing 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 hence a potential reduction in profitability. Differences in catch and handling methods have significant impacts on the sensory quality of raw materials. The fish should be bled as soon as possible after catch and preferably immediately after capture, but this is difficult for trawlers. Few crew members, on board fishing vessels, combined with high capture efficiency, limits the ability to bleed the fish in a proper way. It is not unusual that large hauls of fish can be kept in storage bins for hours before bleeding and gutting. Often, the last fish in the storage bin dies long before bleeding, and this leads to insufficient exsanguination and muscle discoloration. Earlier studies show that live storing on board the vessel prior to slaughter leads to better bleeding and whiter fillets.

The results from a series of projects point to the fact that more than 90% of bottom trawl catches may be kept alive in tanks on board the vessels, and a machine can be utilized to mechanically stun and bleed the fish to make the process more efficient as well as safeguard the quality of the fish. Several ship-owners are also considering installing pumping facilities when refurbishing old boats or building new ones. Nevertheless, before this can be implemented on board trawlers today, it is of great importance to gain new knowledge partly to determine when and how the fish can be killed (slaughtered) and to understand the fish tolerance, fatigue, recovery, blood flow and blood distribution in the muscle at any given time.

Figure 5.1.
The crew is tightening the codend to the pump hose (Photo: © NOFIMA).

Figure 5.2.
The vacuum pump delivered 20 tonnes per hour and the fish was pumped down into the trawler's receiving bins (Photo: © NOFIMA).

Activities

CURRENT QUALITY CONDITIONS ON BOARD BOTTOM TRAWLERS

In May 2014, a 6-day cruise was performed with a commercial trawler ("J. Bergvoll", Nergård Havfiske). Atlantic cod was captured in six hauls at Thor Iversen-Banken (N 73.00, E 033.00) at depths of 246 ± 19 meter and bottom temperature of 2.9 ± 0.6 °C. The cod was caught using an RFG-Hunter 610 single trawl (RFG, Tromsø, Norway), with an installed catch limit lock. Trawl catches were on average 14 ± 4 tonnes for average tow duration of 4 ± 1 hour. From the catch, a total of 194 cod (76 ± 8 cm; 3.5 ± 1.0 kg) were sampled for analysis of quality-related parameters.

In cooperation with Nergård Havfiske, it was implemented large-scale pump experiments aboard the trawler. To our knowledge this is the first time vacuum pumping has been used to get the fish on board from the cod-end and onto a trawler, see images 5.1 and 5.2. From four out of six hauls, the fish were pumped from the codend. The pump (Tendos Vacuum pump and tank 2500 L, 14 inches inlet and outlet, MMC TENDOS AS) was placed on top of the trawl deck, 4 feet above the waterline. The fish were pumped from the cod-end and transferred into the trawlers receiving bin. Pumping ensures that the fish are in contact with water all the time, and they are not subject to gravity. From each haul, a random sample of cod (n = 70–80) was collected from the outlet and brought into 800 L containers, filled with sea water to allow the cod to recover for 3–6 hours. During recovery, fresh seawater was pumped into the tank with a water flow at approximately 50 L per min. Live cod (n = 15) was randomly collected and killed with a blow to the head immediately after capture. Next batches of cod were killed 3 hours (n = 15) and 6 hours (n = 15) after capture. After killing the cod, the blood-pH, blood lactate, blood glucose, fish size (total length and weight), muscle-pH and rigor 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 were tagged and frozen pre-rigor in blocks and stored. The mortality in the tank was estimated after 6 h of live storage and the remaining live fish was slaughtered and brought into the trawler's processing line.

Figure 5.3
Cod crowded in experimental codend.

Experiments on "J. Bergvoll" in May 2014 show that pumping is considerably gentler than pulling the codend up the slipway, and survival rates of 80–100% can be achieved. However, after a longer period in live fish tanks, the fish recuperate and may be difficult to kill and bleed. Thus, in February 2014, we conducted experiments with mechanical stunning and bleeding (Baader SI-7) Atlantic cod (n = 111) at Sjøfisk AS, Bjarkøy, Troms. The machine was initially designed for salmon processing. However, adjustments were made to the knife and to the entry of the machine to make it fit to the head shape of the cod. These adjustments to the machine gave satisfactory results in terms of processing efficiency. The machines were placed directly on the receiving bin. Despite poor working conditions, more than 30 cod were killed and bled per minute. The machine's ability to kill cod was documented by heavy hemorrhages in the brain. Mechanical stun and bleed also resulted in an equivalent bleeding quality as compared to the traditional manual methods – such as throat – or gill cut.

EXPERIMENTAL INVESTIGATION OF FISH QUALITY

The CRISP large scale swim tunnel, which serves as a trawl simulator for the study on fish physiology and quality, underwent further improvement and testing in 2014. A small scale experimental codend has been attached to the tunnel. This makes it possible to study the cumulative effect of swimming and crowding on the physiology and quality of fish in a controlled environment (Figure 5.3). The experimental codend is created from net of 80 mm bar mesh size and constitutes four panels with a total length of two meters. Different crowding densities are obtained by tightening ropes around the bag at various positions.

Two CRISP experiments were conducted in the tunnel in 2014. The first experiment was a pilot designed to test for survival and quality at two different crowding times (three and six hours) following swimming and to evaluate the use of imaging diffuse reflectance spectroscopy for identification of residual blood not visible with sensory techniques. The method is developed at Nofima in other projects and is based on creating a setup where the area of measurement is illuminated with diffuse light (Figure 5.4). The reflectance specter has values between 0 and 1, where 0 is full absorptions of light and 1 is full reflectance. As the fillet passes the measuring range, an image of the fillet with high spatial resolution (0.5 x 1.0 mm^2) builds up. Each pixel consists of a full spectrum characterizing the fillet in this point. Based on this, spectrum models for detecting blood is developed.

The second experiment was a pre-trial for a larger experiment (2015) investigating the physiology and quality of wild caught cod after recuperating from simulating trawling by swimming and crowding. The experiment was design to make cod swim at accelerating water velocity from 0.2 m/sec to 1.2 m/sec. As fish ceased swimming, the water current would guide them into the experimental codend, where they would be crowded for 1 or 5 hours and then recuperated for 0, 3 or 6 hours. The fish used in this trial, however, had very low muscle mass, and so quality measurements were not relevant. The preliminary data was used to improve the final design of the experiment, which will start again 1 February 2015.

From late February until early July tests were also carried out to investigate how muscle pH and related blood physiology, develops during and after swimming to exhaustion in cod. This was done through implantation of a pH-sensor in the muscle and a cannula in the caudal aorta of live cod, see image 5.5. The fish were then subjected to swimming tests and recovery in normal and hypoxic conditions; the latter designed to mimic what happens in the codend of a trawl.

The application of the trawl simulator has been presented at two international conferences and one workshop in 2014 and attracted international attention. The tunnel has also been used in aquaculture projects investigating effect of swimming stress of full grown salmon on bleeding and flesh quality.

Figure 5.4.
Measurement set-up for diffuse reflectance spectroscopy for registration of residue blood in fish fillets, here measured on a salmon fillet.

Figure 5.5
Implantation of a pH-sensor in the muscle.

Results

CURRENT QUALITY CONDITIONS ON BOARD BOTTOM TRAWLERS

The rigor development was measured on cod collected from the trawlers receiving bin, 1 hour after capture. Rigor development was also measured on cod collected from the codend and slaughtered immediately after capture (0 h. rest) and after 6 hours of restitution, see Figure 5.6.

The fish that were killed immediately after capture (0 h. rest.) and fish from the trawlers receiving bin entered rigor mortis significantly faster than the live stored fish (6 h. rest), making them unsuitable for pre-rigor handling. By processing fish in rigor, the muscle is often torn up, and this may cause soft flesh and increased filet gaping in the fillet product.

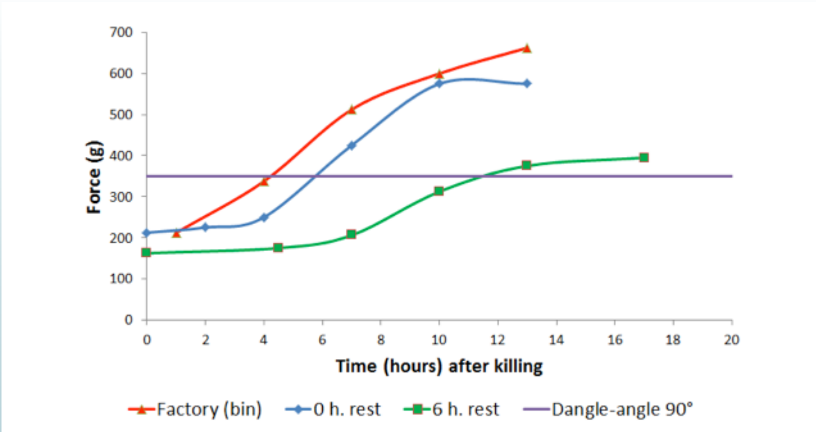


Figure 5.6.
The rigor development in trawl-caught Atlantic cod. The stiffness of rigor mortis is measured with a penetrometer. The "Dangle-angle 90°" indicates when the fish is visually observed to be in full rigor.

During fishing in 2014, ahead of the codend, catch limits trapdoor and a fish-lock was mounted to prevent too large hauls. When the ratio of fullness is reached during hauling, the opening in to the codend is locked and the trapdoor is opened. Remaining fish that enter the trawl then escapes through the trapdoor. Observing the effect of the catch limiting system, it seems it may have resulted in larger density of fish in the codend. Thus, more pressure was applied to the fish during hauling which can explain the increased mortality, compared with experiments that were conducted in 2011 at Thor Iversen-Banken (Figure 5.7). However, the experiments in May 2014 has shown that pumping is considerably gentler than pulling up the codend onto the ramp, and survival rates of 80–100%, depending on species, can be achieved.

In general, the experiments showed that for Atlantic cod captured during commercial trawling, and then directly transferred to a live storage tank, the following capture pH increased, with near-normal resting blood pH levels being restored within 6 hours (Figure 5.8). Atlantic cod hauled up the slipway (haul 2 and 4) resulted in fish

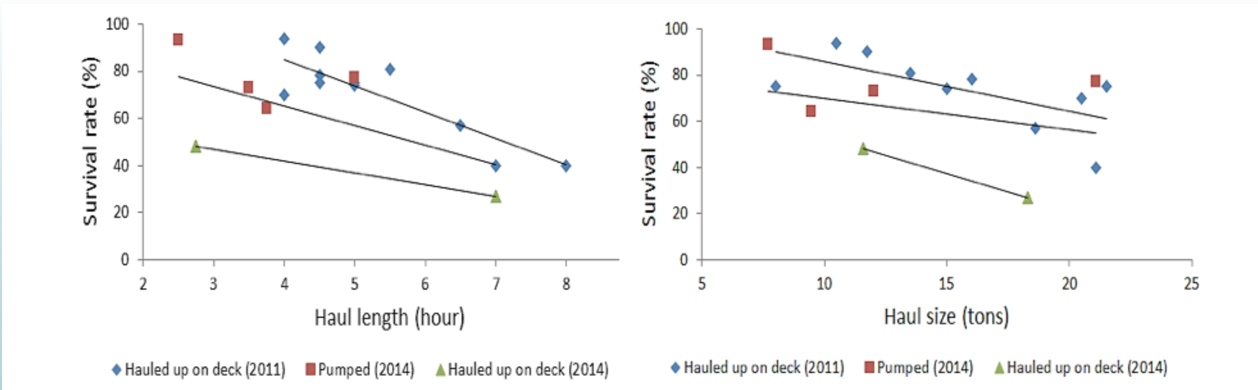


Figure 5.7.
Haul size and length and the effect on survival (%) of cod during live storage for 6 hours.
The results are from commercial fishing at Thor Iversen-Banken in October 2011 and May 2014.

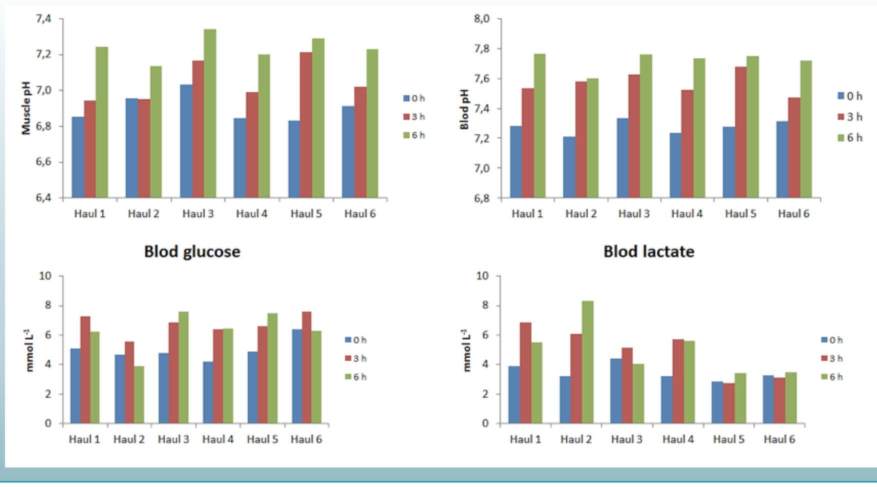


Figure 5.8.
The muscle- and blood pH, plasma glucose and lactate in cod during recovery (0, 3 and 6 hours) after capture. Haul 1, 3, 5 and 6 was pumped from the cod-end.

which are more exhausted, as compared to cod pumped from the codend. For blood lactate levels, there is also a trend that fish hauled up the slipway (haul 2 and 4) have elevated levels after 6 hours of live storage, compared to fish which were pumped from the codend. It was also measured lower muscle pH in cod from haul 2 and 4, even after 6 hours live storage.

Mechanically stunned and bled

Fish caught by trawling should be kept alive in tanks for 5–6 hours, long enough for the blood to withdraw from the white muscle. However, additionally after a longer period in live fish tanks, the fish has recuperated and may be difficult to kill and bleed. It is therefore necessary to stun and bleed the fish automatically in order to exploit the quality potential after recovery.

At harvest trials conducted in February 2014, applying the Baader SI-7, 93.4% of the test fish showed no movement after stunning and 97.3% were bleeding (blood loss of 1.6 ± 0.2% of body weight) (Figure 5.9). Earlier trials have shown that the method produces bleeding that is equally as good as traditional methods, such as cutting the throat. In this trial we also observed that the machine struck accurately on both large and small cod (2–14 kg) alike. Consequently, this machine can be able to be utilized in catch handling on board the trawler and make the catch handling safer and more efficient.

This project will contribute to the establishment of live storage to improve the fish quality within the Norwegian fishing industry. Experiments in collaboration with Nergård Havfiske AS show that pumping from the trawl's cod-end is a gentler way of fish handling than lifting the complete catch onto the deck. Survival is higher, quality higher, and this brings about new aspects regarding the design of future trawlers. Machines for automatic killing and bleeding can be effectively utilized for on-board catch handling in fishing vessels, and their use would make the process more efficient as well as safeguarding the quality of the fish. Thus, new slaughter systems and technology in the processing line on board the trawling fleet must also be developed. This is a necessary step to gain an economic, safe, first-class stable quality and efficient fish processing.

EXPERIMENTAL INVESTIGATION OF FISH QUALITY

In the first pilot experiment, 21 cod were swum and crowded in trawl simulator. As fish ceased swimming, they turned and swum/glided back into the experimental codend. When the fish saw the net, they turned and swum against the direction of the flow, away from the net. This indicates that the cod stops swimming before complete physical exhaustion. Fish were allowed to swim in the mouth of the codend for approx. 30 minutes before they were crowded. After three hours, seven fish were taken out and placed in a recuperation cage with constant low water flow. All seven fish were fully recovered after 24 hours. The remaining fish were crowded for additional three hours. The rope was adjusted so that the crowding density remained the same as the first three hours. There was about 10% mortality during the 24 hours of recuperation for this group.

All the cod were filleted and the quality was evaluated by both a sensory panel and by using imaging diffuse reflectance spectroscopy. Analyses from the spectroscopy measurements showed that there were significant differences in residual blood between different crowding times after 24 hours of recuperation. This difference was not observed with the sensory evaluation.

The second experiment revealed a few problems with the initial experimental setup and additional improvements of the trawl simulator were set to be completed in January 2015. These improvements involve dressing the outlet of the tunnel with fiberglass plates to direct the water current more into the mouth of the codend and adjust the crowding densities to make it more similar to a commercial trawling situation.

The main experiment will be conducted in February 2015 and will include swimming, crowding and recuperation, physiological measurements on blood and muscles, and sensory and spectroscopically quality evaluations of cod fillets.

Testing and evaluation of blood physiology proved to be difficult. Measurements on muscle and blood physiology on live individual fish in swimming tunnels are normally labour intensive. The measurements have a large failure rate, which was also the case in these tests. Throughout the months of testing, we had to discard using cannulas to draw blood from the fish and focus on muscle pH-sensors to maximize the chance of success. Despite this sacrifice, we were only able to obtain complete data sets data from three individuals, which displayed very different responses to the treatments. It was therefore decided to end the testing in July and focus on the other ongoing activities on fish in the swim tunnel.

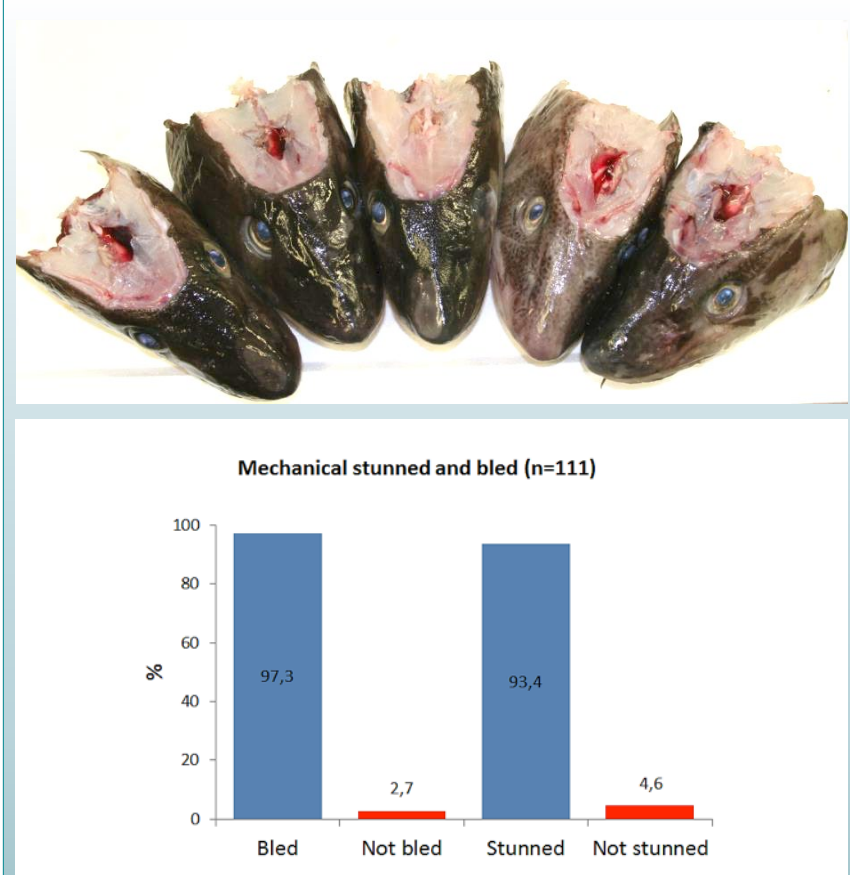


Figure 5.9.
Effect of automatic stunning and bleeding.

5.6 Value adding

Background

Strategies for harvesting wild fish resources depend on several factors, including the migration pattern of the target species and choice of fishing technology. This work package focuses on how technical developments resulting from CRISP activities will contribute to value adding in two groups of vessels – ground fish trawlers and the purse seine fleet. A basic analysis of the economic status of the Norwegian trawler fleet was conducted in 2011 and an analysis of the economic status of the Norwegian purse seine fleet in 2013.

Activities

The primary activity in 2014 in WP6 has been on fuel consumption and quality improvement. Both vessel groups studied in CRISP have been in a renewal process where several new vessels have entered the Norwegian fishing fleet. They have been allowed to increase the numbers of quotas on each vessel and the numbers of vessels have been reduced during the decade studied. Additionally, old vessels have been replaced by new and modern vessels. The new vessels have been identified in both the ground fish trawler group and in the purse seine fleet. 2014 was also used to explain the variation in fuel consumption and value adding among vessels in the same group. In a study we have documented how the structural process has impacted on fishing pattern and fuel consumption among the ground fish trawlers. In the years to come we will focus on how introduction of new vessels, i.e. vessels that are at the technological forefront, perform with regards to these dimensions.

Results

Restructuring seems to have increased the number of new vessels in both vessel groups. We have identified eight new trawlers since 2011. Six of them entered the fishery in 2013. In the purse seine fleet, nine new vessels have entered in the same period. In the study of fuel consumption among the trawlers, we find that the fuel usage has declined dramatically during the period from 2002 to 2012 (Figure 6.1). Due to the ability to gather more quotas on each boat, the structural process has contributed to improve the utilization of the capacity among the vessels, see Figure 6.2. Both operating days and catch per vessel have increased. At the same time the Norwegian cod quota has increased. Together these two factors have led to an increased focus on the cod fisheries. This means that the prawn fishery, which is known to be very fuel intensive, has declined. We also find that the production of on board frozen fish has increased and that the on board fillet production has declined. Even though the fuel consumption has declined, we still find heterogeneity among the vessels. In order to further understand this, it is important to study the group in more detail. Our findings indicate that both fish pattern and product portfolio are essential in the terms of fuel usage.

As the new vessels are entering the fleet, we will analyse how this will impact both fuel consumption and value adding in the two groups. In addition, we will continuously add input to these models from the other work packages in CRISP in order to measure how innovations from CRISP will impact on value adding in the two vessel groups studied.

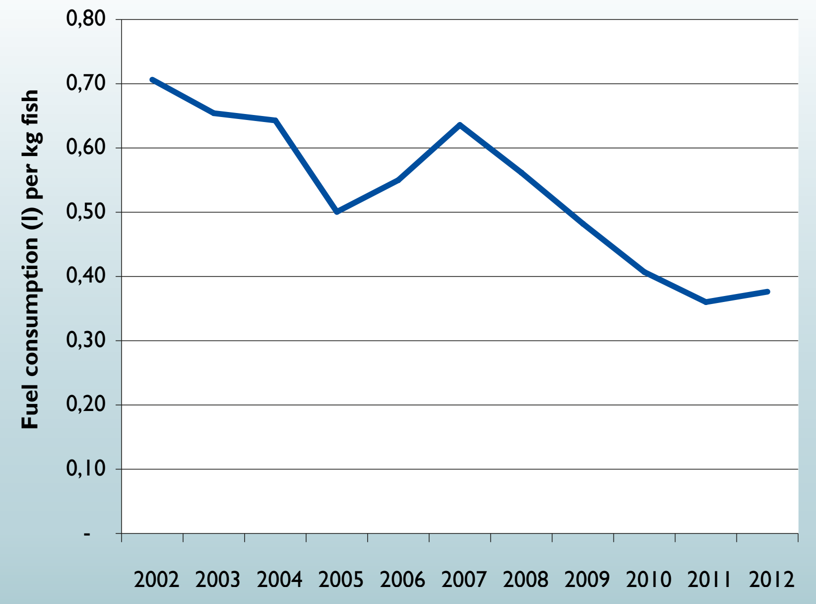


Figure 6.1.
Fuel consumption per kg fish caught by the Norwegian ground fish trawlers in the period 2002–2012.

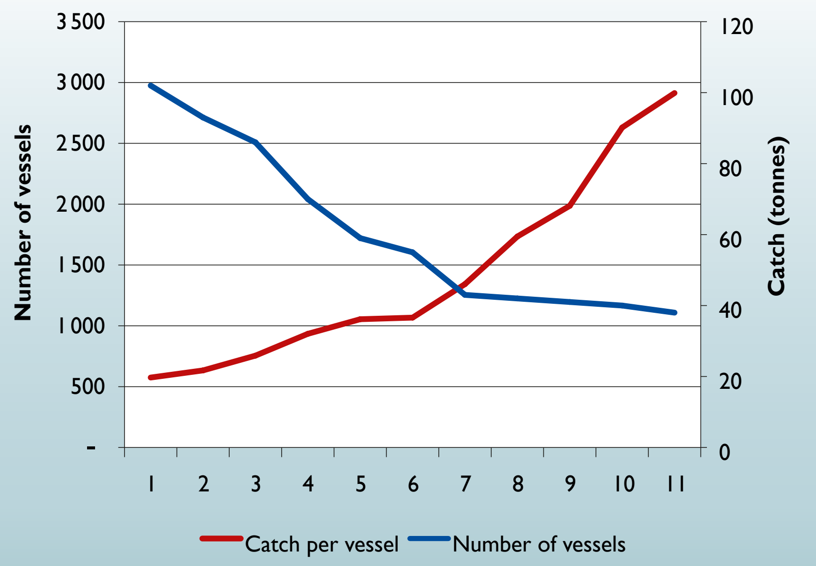


Figure 6.2.
Number of vessels compared to the catch per vessel in the period 2002–2012 among Norwegian ground fish trawlers.

6 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.

Introduction of new fishing technology and marketing of products developed within CRISP by the industry partners have to be legalized by fishing management authorities in the countries where any new technologies should be implemented. CRISP's focus is for a major part on environmental friendly trawl technology for cod fish in the Barents Sea. These resources are managed jointly by Norway and Russia, and therefore involvement of scientific experts from Russia with CRISP activities has been given priority by the centre management. A Russian fishing gear expert participated in the research cruise with "G.O. Sars in March 2014.

The Deep Vision technology has generated interest from several research institutes globally and consultations with them are ongoing. An EU-funded project "Science, Technology, and Society Initiative to minimize Unwanted Catches in European Fisheries", (MINOUW), starting in 2015, will make extensive use of the DeepVision technology in research activities lead by researchers from several European countries. Experts in underwater acoustics from institutes in USA and Europe participated in the November 2014 survey with the research vessel "G.O. Sars" and are involved in tutoring one of the PhD students of CRISP on sonar calibration.

7 RECRUITMENT

At present the CRISP center hosts three PhD students: *Ragnhild Svalheim* is employed by Nofima (2013–2016). Her study focus on how muscles of captured fish restore during the post capture phase. *Melanie Underwood* is employed by UiB (2012–2016) and has IMR as her working place. Her project deals with behaviour of demersal fish during trawl capture. *Sindre Vatnehol* is employed as a PhD student at IMR (2012–2015), and his focus area is sonar technology.

CRISP also employs two Postdoctoral researchers: *Anders Karlsson* at UiT, working with fish physiology and *Shale Rosen*, dealing with visual fish classification and fish behaviour.

Wenche Haver Vigrestad was a master student at UiB, conducting a study related to fish behaviour during passage of a trawl till they pass through the Deep Vision system. Another master student from UiB, *Rachael Morgan*, was analyzing video material to see if crowding to different densities during purse seine capture may causes short or medium term changes in swimming behaviour of herring. They both fulfilled their Master degree in June 2014. A third master student also finishing her Master degree this year was *Tonje Jensen*, associated with the quality improvement project at Nofima, focusing on triploid cod.

8 COMMUNICATION AND DISSEMINATION ACTIVITIES

CRISP staff has taken part in a range of dissemination activities during the last year. This includes lectures about CRISP activities and results in national and international scientific meetings, among which may be mentioned the 44th WEFTA (West European Fish Technologists Association) conference in Bilbao in June, the ICES Symposium on Effects of Fishing on Benthic Fauna (Tromsø, June), AFS (American Fisheries Society) annual meeting (Québec, August) and International Congress of the Biology of Fishes (Edinburgh, August).

Nationally CRISP staff has promoted their activities and results at several meetings, seminars and fishing exhibitions arranged by various Norwegian hosts. At the international fishing exhibition Nor-Fishing in 2014, all partners of the centre had roll-ups informing about their participation in CRISP, and several CRISP staff gave lectures about new innovations produced by the centre. CRIPS staff has also participated with lectures in the annual Fish-Tech seminar arranged by SINTEF and FHF. Several meetings have been arranged between CRISP staff and various Norwegian organizations and management authorities, including the Directorate of Fisheries. In November 2014, CRISP arranged a technical conference in Bergen were activities and results were presented for the fishing industry representatives and management authorities.

IMR staff publish most of their work as technical reports in the series "Rapport fra Havforskningen" ("IMR report"), while Nofima staff publish their work in Nofima Report Series. Many CRISP highlights are published in short communication brochures in the "Havforskingsnytt" series ("Marine Research News"). Videos taken with underwater cameras to illustrate fish behaviour and performance of various devices developed in CRISP are published on the web for viewing on YouTube. During a research cruise with "G.O. Sars" in March, live video from a trawl was successfully streamed on internet. To our knowledge, this was first time that a live video from a trawl in action could we watched in an office location ashore.

APPENDIX: I

Personell

Key Researchers

Name	***Institution***	***Main research area***	***Sex***
Torbjørn TOBIASSEN	Nofima	Quality improvement	M
Kjell MIDLING	Nofima	Quality improvement	M
Stein Harris OLSEN	Nofima	Quality improvement	M
Leif AKSE	Nofima	Quality improvement	M
Bent DREYER	Nofima	Value adding	M
Marianne SVORKEN	Nofima	Value adding	F
John Willy VALDEMARSEN	IMR	Low impact trawling, Centre management	M
Arill ENGÅS	IMR	Low impact trawling/Instrumentation	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	F
Mike BREEN	IMR	Purse seine technology	M
Helge JOHNSEN	UiT	Quality improvement	M
Ragnar OLSEN	UiT	Quality improvement	M
Arne JOHANNESSEN	UiB	Researcher training, recruitment	M

Key technicians, research institutes

Asbjørn AASEN	IMR	Trawl technology	M
Jan Tore ØVREDAL	IMR	Engineering, instrument development	M
Kjartan MÆSTAD	IMR	Information logistics	M
Turid LODDENGAARD	IMR	Centre management - economy	F
Atle TOTLAND	IMR	Sonar Technology and Fisheries Instrumentation	M
Bjørn TOTLAND	IMR	Engineering, instrument development	M
Ronald PEDERSEN	IMR	Sonar Technology and Fisheries Instrumentation	M
Kathryn DONELLY	NOFIMA	Information logistics	F
Tor H. EVENSEN	NOFIMA	Quality improvement	M
Ronny JAKOBSEN	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
Olav VITTERSØ	Kongsberg Group	Management, Board leader	M
Thor BÆRHAUGEN	Kongsberg Group	Monitoring fish and gear	M
Tor Herman GUNHILDSTAD	Kongsberg Group	Monitoring fish and gear	M
Helge HAMMERSLAND	Scantrol Deep Vision AS	Visual fish classification/Management	M
Bowei DONG	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
Monica LANGELAND	Egersund Group	Marketing	F
Kjell LARSEN	Nergård Havfiske	Quality improvement and value adding	M
Torgeir MANNVIK	Nergård Havfiske	Fish quality/skipper	M

Visiting Researchers

Postdoctoral researchers with financial support from the Centre budget

Name	***Funding***	***Research area***	***Sex***	***Duration***	***Nationality***
Anders KARLSSON	Universitetet i Tromsø	Fish physiology	M	3 years	Norwegian
Shale ROSEN	CRISP	Visual fish classification, fish behaviour	M	3 years	USA

PhD students with financial support from the Centre budget

Name	***Nationality***	***Period***	***Sex***	***Topic***
Melanie UNDERWOOD	Australian	07.05.2012-06.05.2016	F	Capture behaviour
Sindre VATNEHOL	Norwegian	01.09.2012-30.08.2015	M	Sonar Technology
Ragnhild SVALHEIM	Norwegian	01.04.2013-31.03.2016	F	Fish Quality

Master students

Name	***Nationality***	***Period***	***Sex***	***Topic***
Wenche H. VIGRESTAD	Norwegian	2013-2014	F	Fish behaviour
Rachel MORGAN	British	2013-2014	F	Fish behaviour
Tonje JENSEN	Norwegian	2013-2014	F	Quality improvement

APPENDIX: 2

Funding

Statement of Accounts 2014

All figures in 1 000 NOK

Funding		**Budget**	**Account**
The Research Council		10 000	10 000
The Host Institution (name)	Havforskningsinstituttet/IMR	7 300	13 448
Research Partners	Nofima	1 200	1 028
	University of Bergen	250	209
	University of Tromsø	1 200	509
Enterprise partners	Kongsberg Maritime AS	3 530	12 338
	Egersund Group AS	1 250	1 155
	Scantrol AS	1 002	2 749
	Nergård Havfiske AS	1 000	1 934
Public partners	Sildesalgslaget	100	100
	Råfisklaget	100	100
		26 932	43 570

Costs

		Budget	**Account**
The Host Institution (name)	Havforskningsinstituttet/IMR	13 800	19 798
Research Partners	Nofima	3 450	3 428
	University of Bergen	850	809
	University of Tromsø	2 050	1 359
Enterprise partners	Kongsberg Maritime AS	3 530	12 338
	Egersund Group AS	1 250	1 155
	Scantrol AS	1 002	2 749
	Nergård Havfiske AS	1 000	1 934
Public partners	Sildesalgslaget	0	0
	Råfisklaget	0	0
		26 932	43 570

ATTACHMENT: 3

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