FINAL REPORT 2019

CRISP

sfi Centre for Research-based Innovation

CONTENTS

1. SUMMARY 6

2. SAMMENDRAG 8

3. VISION AND GOALS 10

4. BASIC FACTS ABOUT CRISP 12

4.1 The Consortium 12
4.2 Organizational structure 13
4.3 Board of Directors 14
4.4 Scientific advisory Committee 15
4.5 Senior researchers 16
4.6 Cooperation between partners 16

5. FINANCING THROUGH THE LIFE OF THE CENTRE 17

6. RESULTS – KEY FIGURES 18

7. RESEARCH 19

7.1 Research plan 19
7.2 Reasearch activities in the work packages 21
7.2.1 WP1 - Pre-catch identification of quantity, size distribution and species composition 21
7.2.2 WP2 – Gear and catch monitoring systems in purse seines 26
7.2.1 WP 3 - Capture monitoring and catch control during trawling 34
7.2.4 WP4 - Low impact trawling 38
7.2.5 WP5 - Kvalitetsforbedring 40
7.2.6 WP6 - Value adding 44
7.3 Highlights 47
7.3.1 More accurate catch information with better sonar systems 47
7.3.2 Nine years with Deep Vision 48
7.3.3 Catch control is a key factor for raising product quality 49
7.3.4 Handling fish gently brings rewards 50
7.3.5 The big picture 52
7.4 Technology developed - overview 53
7.5 Awards 54

8. INTERNATIONAL COOPERATION 56

9. TRAINING AND RECRUITING RESEARCHERS 58

9.1 PhD-students 59
9.1.1 Computer correction of sonar images 59
9.1.2 Alternatives to bottom trawling 60
9.1.3 Gentle handling improves quality 61
9.1.4 Catch quality and size selectivity during bottom trawling for cod 62
9.1.5 How to reduce injuries to mackerel 63
9.2 PostDoc-positions 64
9.2.1 Fish in the cod family cope well with exhaustion 64

10. COMMUNICATION 65

11. THE EFFECT OF THE CENTRE FOR THE PARTNERS 66

11.1 “CRISP paves the way for new approaches to monitoring fish stocks” 66
11.2 Deep involvement throughout the CRISP period 68
11.3. Scantrol Deep Vision AS: a camera in the trawl paves the way for automatic sorting 69
11.4 Successful development of adjustable trawl doors 70
11.5 Nergård Havfiske AS will use systems developed through CRISP on a new vessel 71

12. WHERE NEXT? 72

13. CONCLUSION 74

APPENDIX 1 Statement of accounts for the complete period of centre financing 76

APPENDIX 2 Personell 77

APPENDIX 3 Publications 80


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FUGLØYHAV

FOREWORD

by Research Director Geir Huse

Geir Huse, Research Director at the Institute of Marine Research and member of the board of CRISP (Photo: IMR).

CRISP, which is a Centre for Research-Based Innovation (CRI), has focused on key challenges facing the Institute of Marine Research and the fishing industry in relation to developing sustainable fisheries. This is a key field of work for the Institute of Marine Research, and CRISP has involved several of our research groups. The consortium behind CRISP consists of four research partners, four industrial partners and two sponsors who have all participated throughout the project. There are several reasons why CRISP has been so important to the Institute of Marine Research. It has allowed us to perform important, useful research and development work on observation and fishing gear technology that will make fisheries more sustainable. The Institute of Marine Research has been working in these areas for many years, but the scope and duration of CRISP has enabled us to deliver excellent research, come up with useful applications and develop and test new methodologies. The centre has also helped the Institute of Marine Research to recruit new researchers and build up its expertise.

The unique thing about CRIs is their focus on innovation through close cooperation between the research and business communities. That system has worked exceedingly well within CRISP, not least for the Institute of Marine Research. We have continued our long-standing cooperation with the Kongsberg Group, as well as significantly strengthening our ties with Scantrol Deep Vision AS. The development of their "camera unit" has been very successful, and the Institute of Marine Research has now bought two complete Deep Vision systems, which is used on many of its surveys, both for research and monitoring purposes. Deep Vision is an example of award-winning new fishing technology developed through CRISP!

One important area of focus for CRISP has been improving the accuracy of school size estimates and species identification using sonar. This is crucial to getting a good estimate of the size of a school, and of the species and size distribution within it, before setting the trawl. With more precise information, fishers can avoid setting a trawl around schools that are too big or for whatever other reason shouldn't be targeted. This reduces the risk of crowding the fish, which in the worst case may kill them, and it saves fishers from wasting time on schools that they shouldn't catch.

Another research topic has been how to reduce the impact of bottom trawling on benthic habitats. Within CRISP, a semi-pelagic trawling method where the trawl doors don't come into contact with the sea bottom has been developed and tested. This significantly reduces the impact on the bottom, although it also slightly lowers the catch rate.

Another important aspect of CRISP is that many PhD students and post docs have been involved. For them, CRISP will hopefully mark a significant milestone in their careers and help to shape them as researchers. As such, the programme has played an important role in recruiting researchers. The scope of the programme is unique, in terms of the number of people involved and its eight-year duration, and dedicating lots of resources over an extended period has made CRISP exceptionally important. It has also enabled us to fully develop a series of technological innovations, which there is not usually time for within the framework of normal research projects. At the Institute of Marine Research we are therefore delighted that we were allocated CRISP and that the programme group has worked so well together and achieved such outstanding results. The final report on the programme makes impressive reading and gives a great overview of all of the things to come out of it. I would also like to extend my warm thanks to Aud Vold and John Willy Valdemarsen as programme directors, and to the work package managers who together have steered the programme safely into harbour!

FOREWORD

by Aud Vold, Programme Director for CRISP

Programme director Aud Vold briefing the EU Commission in Brüssels about CRISP (Photo: IMR).

CRISP, or to use its full name the Centre for Research-based Innovation in Sustainable fish capture and Processing technology, has been operating since 1 April 2011, in other words for eight years. This report is the programme's final document, and gives a short description of the centre and its partners. It also provides a glimpse of our ways of working and presents the most important results that we have achieved.

In CRISP, partners from industry and research have worked together to develop the fishing industry in a way that is sustainable. We have done this by developing "smart technologies" to promote responsible fishing at the same time as improving the profitability of the fishing fleet and its suppliers.

This report does not give a detailed description of all of our innovations and scientific advances. People who are interested in the various innovations and research results should visit our industrial partners' websites and use the reference list at the back of the report.

After operating for eight years, CRISP has now run its course. Over the course of those years, the partners in CRISP have developed close ties that they will build on through various collaborations. Over the course of eight years we have faced a variety of challenges, and some of our efforts have failed completely. But looking back at the partnership as a whole, it is the many success stories that it has produced that really stand out. We hope this report will demonstrate that.

The three most important types of output have been: 1. New products/smart technologies; 2. Scientific results, papers and participating in scientific forums; and 3. Training researchers. We are particularly pleased that half of our newly qualified researchers are women, in spite of the fact that fishing technology has traditionally been a very male-dominated field.

The Institute of Marine Research is proud to have been the host institution for CRISP for eight years. The aim behind CRISP – sustainable harvesting of marine life – is a perfect fit with the institute's core values and has thus helped to reinforce our reputation.

As the Programme Director for the second half of CRISP's duration, I would like to thank all of the partners in CRISP for their close cooperation. Many good friendships have been forged under the umbrella of CRISP. I would also like to thank the previous Programme Director for CRISP, John Willy Valdemarsen, who played a key role during the start-up phase and guided the centre safely through its first four years. I would also like to extend my special thanks to Olav Vittersø, the Managing Director of Simrad (part of the Kongsberg Group), who has chaired the centre's board for the full eight years.

Aud Vold
Programme Director

1. SUMMARY

CRISP, the Centre for Research-based Innovation in Sustainable fish capture and Processing technology, started its research activities in April 2011 and ended up 30 Mars 2019. Since its launch, the consortium has consisted of the same four industry partners (Kongsberg Maritime AS, Simrad; Scantrol Deep Vision AS; the Egersund Group AS; Nergård Havfiske AS), four research partners (Institute of Marine Research (IMR); Nofima AS; University of Bergen; University of Tromsø), and two sponsors (Norges Råfisklag; Norges Sildesalgslag).

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

1. Pre-catch identification of quantity, size distribution and species composition
2. Gear and catch monitoring systems in purse seine
3. Methods for capture monitoring and catch control during trawling
4. Development of low-impact trawls
5. Quality improvement
6. Value adding

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

WP1: At the start of CRISP both the fishing industry and research institutes needed more accurate density and abundance measurements of schooling fish species than what was possible with existing instrumentation. In CRISP Simrad has collaborated with IMR to develop new and improved fishery sonars which can quantify the volume of a fish school prior to shooting a fishing net. This includes both new robust sonar calibration methods, but also a better understanding of how fish behaviour affects the backscattering when observing the fish in lateral aspects. Also, high definition echo sounders, which can measure the fish size and species prior to setting the net, has been developed. This may substantially reduce the amount of unwanted catch and consequently also the lower the level of discarding and unintentional mortality.

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 the capture process. Improved catch characterisation enables 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 CRISP this work package has focused on three topics: 1) testing of sonar technology for catch control inside a seine net; 2) monitoring purse seine geometry and performance using sonar and transponder technology; and 3) monitoring the behaviour and welfare status of purse seine catches, particularly during slipping of unwanted catches from the net.

WP3: had the goal of reducing unwanted catches during commercial trawling by providing the skipper with real-time information on the performance of their fishing gear and the amount, type, and sizes of fish being captured. The following innovations have been developed: 1) Trawl HUB for camera and acoustic systems; 2) Catch and gear information system for trawl, Simrad FX80; 3) Visual fish classification system for trawl, Deep Vision;

4) Active device for selection in trawls. The cooperating partners in WP3 were Kongsberg Maritime Simrad, Scantrol Deep Vision, IMR and UiB.

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 has addressed the design, rigging and operation of trawl gears to achieve such objectives. This includes development of manoeuvrable trawl doors (Egersund Group, Simrad and IMR), investigation of the efficiency of semi-pelagic trawling, and development of catch reduction devices for trawls.

WP5: The Norwegian fleet of trawlers has gone through substantial changes since the turn of the millennium. In CRISP, one aim has been 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. Better quality can be achieved by minimizing stress during trawling, and by implementing new technologies that makes the handling of the catch more lenient. Studies of the effects of different stressors on fish during capture and handling have been carried out aboard fishing vessels as well as in controlled experimental studies in CRISP's large-scale trawl simulator. Experiments in collaboration with Nergård Havfiske AS has shown that applying handling techniques similar to those used in capture-based aquaculture (gentle handling, storing in live fish tanks before slaughter, automatic stunning and bleeding, and others) has a positive effect on fish quality.

WP6: The activity in this work package has been aimed at measuring the value creation and sustainability of the new technologies developed through the activities of CRISP. CRISP has focused on two vessel groups: demersal trawlers and purse seiners. In the initial phase, the economic status of the vessel groups was surveyed. Thereafter, the development of the vessel groups has then been monitored throughout the 8-years period of CRISP. This has been the basis for measuring the effect of the new technologies that have been developed through the work in CRISP. In this WP models have been developed that visualizes how technology development has affected the environment and value creation in the form of reduced fuel consumption and improved quality.

CRISP hosted seven PhD positions, of which four have finished their project, while the last two will finalize shortly after the termination of the centre. Half of our PhD candidates and Master students were females, which is a key step towards increasing gender equality in a formerly male dominant industry.

CRISP has cooperated with international research institutions when such cooperation has been beneficial for joint development and introduction of sustainable fishing technology outside Norway. The industry partners in CRISP are all Norwegian owned, and all have their production activities based in Norway. They have therefore been reluctant to involve foreign partners that can share knowledge of product development with potential industry competitors. However, it has been important to disseminate the main CRISP philosophy and CRISP technology to the international community. Examples are by participation in international meetings and congresses, in international projects (e.g. Horizon 2020 projects) and by giving courses in the use of CRISP technology for international students and institutions.

After 8 years of business, the CRISP collaboration has now come to an end. However, the strong trust and cooperation between the partners will be continued in various forms. We feel confident that the strong expertise that has been built up over the past eight years will also be in demand in the time to come. Several collaborative projects are already on the stairs.

2. SAMMENDRAG

CRISP, Senteret for forskningsbasert innovasjon innen bærekraftig fangst og prosesseringsteknologi, startet sin forskningsaktivitet i april 2011 og avsluttet 30. mars 2019. Konsortiet har siden starten bestått av de samme fire industripartnerne (Kongsberg Maritime AS, Simrad; Scantrol Deep Vision AS; Egersund Group AS; Nergård Havfiske AS), fire forskningspartnere (Havforskningsinstituttet (HI); Nofima AS; Universitetet i Bergen; Universitetet i Tromsø) og to sponsorer (Norges Råfisklag; Norges Sildesalgslag).

Senterets forskning var organisert i seks vitenskapelige arbeidspakker (WP'er):

1. Identifikasjon av kvantitet, størrelsesfordeling og art før fangst
2. Redskaps- og fangstovervåkingssystemer i ringnotfiske
3. Metoder for fangstovervåking og fangstkontroll under tråling
4. Utvikling av tråler med redusert miljøpåvirkning
5. Kvalitetsforbedring
6. Verdiskapning

I løpet av CRISP sin levetid har senteret utviklet ny kunnskap, nye fiskeredskaper og instrumenter for fiskeflåten som viktige verktøy for å gjøre trål- og ringnotfisket mer bærekraftig. Disse framskrittene har kun vært mulige på grunn av et omfattende samarbeid mellom senterets industripartnere og forskningsinstitusjoner.

WP1: Både fiskeindustrien og forskningsinstitusjonene trenger mer nøyaktige tetthets- og mengdemålinger av stimdannende fiskearter enn det som var mulig med de instrumentene som var tilgjengelige da CRISP startet opp. Simrad har samarbeidet med HI for å utvikle nye og bedre fiskerisonarer som kan kvantifisere volumet av en stim før nota settes ut. Dette inkluderer både nye robuste sonarkalibreringsmetoder og en bedre forståelse av hvordan fiskens adferd påvirker tilbakespredningen når man observerer fisken sett fra siden. Bredbandsekkolodd, som kan måle fiskestørrelse og art før redskapet settes, er også utviklet. Dette kan medføre en betydelig reduksjon i mengden uønsket fangst og dermed også bidra til at mengden av fisk som kastes ut reduseres.

WP2: Skipperen på et ringnotfartøy har behov for verktøy som kan gi bedre kontroll over fangstprosessen. I tillegg til å få bedre identifikasjon av fangsten før nota settes ut, trenger han å overvåke notas geometri gjennom fangstprosessen og den fangede stimens atferd inne i nota. Forbedret fangstovervåkning gjør det mulig for fiskerne å optimalisere sine fangststrategier for å maksimere verdien av en begrenset fartøyskvote, samtidig som man bidrar til økt bærekraft ved å unngå uønskede fangster. I CRISP har denne arbeidspakken særlig satt søkelys på tre emner: 1) utvikling og testing av sonarteknologi for fangstkontroll inne i en ringnot under fiske; 2) overvåking av notredskapets geometri og funksjon ved hjelp av sonar- og transponderteknologi; og 3) overvåking av atferden og velferdsstatusen i ringnotfangster, særlig i forbindelse med slipping av uønskede fangster.

WP3: hadde som mål å redusere uønskede fangster under kommersiell tråling ved å gi skipperen sanntids informasjon om fiskeredskapets ytelse, og om mengden, typen og størrelsen på fisken som fanges. Følgende innovasjoner har blitt utviklet: 1) Trål «HUB» for kamera og akustiske systemer; 2) Fangst- og redskapsinformasjonssystem for trål, Simrad FX80; 3) Visuelt klassifiseringssystem for fisk i trål, Deep Vision; 4) Teknologi for aktiv seleksjon i trål. Samarbeidspartnere i WP3 var Kongsberg Maritime Simrad, Scantrol Deep Vision, HI og UiB.

WP4: Gjeldende trålpraksis anses ikke som bærekraftig. Den er skadelig for havbunnen, har ofte høy bifangst og høyt drivstofforbruk som kan påvirke miljøet. Trålingens fremtid vil således i stor grad avhenge av utviklingen av trålteknikker som reduserer disse negative virkningene betydelig. WP4 har adressert design, rigging og bruk av trålredskaper for å oppnå slike mål. Dette inkluderer utvikling av styrbare tråldører (Egersund Group, Simrad og HI), undersøkelse av effektiviteten til semipelagiske tråler og utvikling av fangstreduksjonsinnretninger for trål.

WP5: Den norske flåten av havgående trålere har gjennomgått betydelige endringer siden tusenårsskiftet. I CRISP har det vært et mål å øke kvaliteten og verdien av råstoffet gjennom å endre måten trålen handteres på og hvordan fangsten behandles. Økt kvalitet kan oppnås ved å minimere stress under tråling og ved å innføre ny teknologi som gjør håndteringen av fangsten mer skånsom. Studier av effekter av ulike stressfaktorer på fisk under fangst og håndtering har blitt utført ombord på fiskefartøyer, men også i kontrollerte eksperimentelle studier i CRISP sin trålsimulator. Forsøk i samarbeid med Nergård Havfiske AS har vist at bruk av liknende håndteringsteknikker som brukes i fangstbasert akvakultur og oppdrett (mild håndtering, levende lagring i tanker før slakting, automatisk bedøvelse og blødning, m.m.) har en positiv effekt på fiskekvaliteten.

WP6: Aktiviteten i denne arbeidspakken har vært rettet mot å måle verdiskapingen og bærekraften til den nye teknologien som er utviklet gjennom CRISP sine aktiviteter. CRISP har satt søkelys på fartøygruppene bunntrål og ringnot. I innledningsfasen ble fartøygruppenes økonomiske status undersøkt. Den videre utviklingen av fartøygruppene er deretter overvåket gjennom hele prosjektperioden. Dette har vært grunnlag for å måle hvilke effekter de nye teknologiene som er utviklet gjennom arbeidet i CRISP har hatt for flåten. I dette arbeidet er det utviklet modeller som kan visualisere hvordan teknologiutviklingen har påvirket miljøet og verdiskapningen i form av redusert drivstofforbruk og forbedret kvalitet.

CRISP hadde syv doktorgradsstillinger, hvorav fire disputerte før senteret ble avviklet, mens de to siste vil fullføre innen kort tid. Halvparten av våre PhD-kandidater og mastergradsstudenter var kvinner, noe som er et viktig skritt mot økt likestilling i en tidligere sterkt mannsdominert bransje.

CRISP har samarbeidet med internasjonale forskningsinstitusjoner når et slikt samarbeid har vært gunstig for felles utvikling og innføring av bærekraftig fiskeriteknologi utenfor Norge. Næringslivspartnerne i CRISP er alle norske-eide, og alle har sin produksjonsvirksomhet i Norge. De har derfor vært motvillige til å involvere utenlandske partnere som kan dele kunnskap om produktutvikling med utenlandske industrikonkurrenter. Det har imidlertid vært viktig å formidle CRISP-filosofien og CRISP-teknologien til det internasjonale samfunnet. Eksempler dette har vært å delta i internasjonale møter og kongresser, ta del i internasjonal prosjekter (for eksempel Horizon 2020-prosjekter) og ved å gi kurs i bruk av CRISP-teknologi for internasjonale studenter og institusjoner.

Etter 8 års virksomhet er CRISP-samarbeidet nå avsluttet. I løpet av disse årene har partnerne i CRISP utviklet et nært og godt samarbeid som vil bli videreført i ulike former. Vi føler oss sikre på at det sterke kompetanse-miljøet som er bygget opp gjennom de siste åtte årene også vil bli etterspurt i tiden som kommer, og flere samarbeidsprosjekter er allerede på trappene.

3. VISION AND GOALS

VISION

The Center for Research-based Innovation in Sustainable fish capture and Processing technology aimed 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.

GOALS

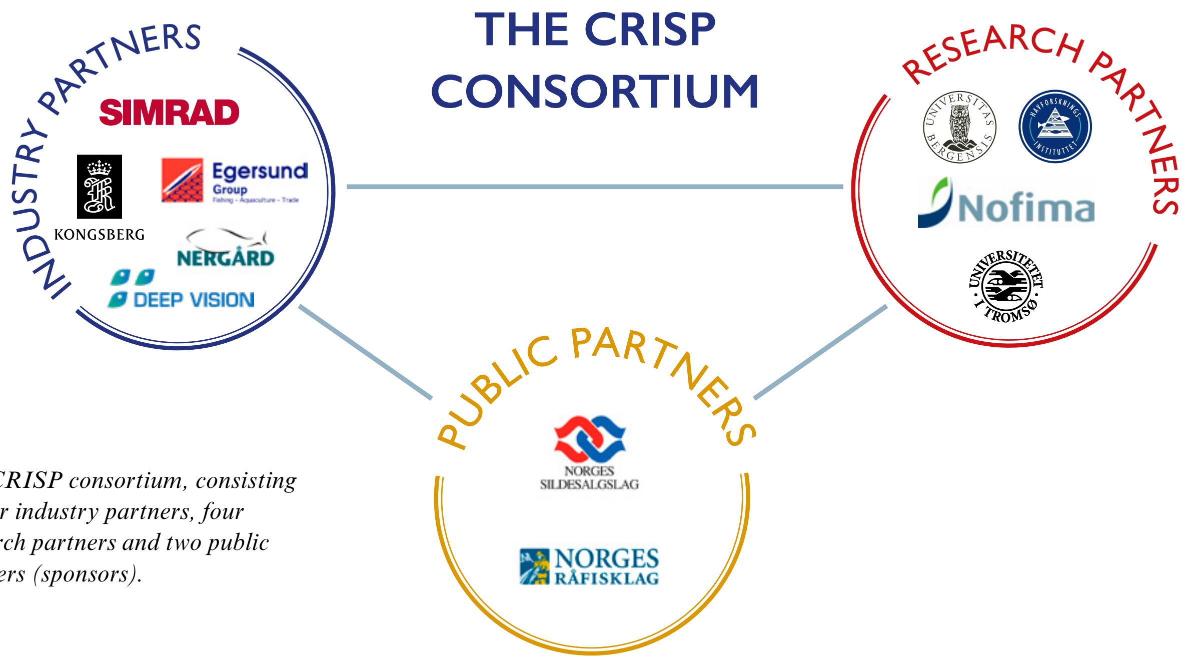
The main goal of the center has been to develop "smart technologies" which may lead to responsible fisheries and at the same time improve the profitability of the fishing fleet and supporting industries.

THIS WAS DONE BY THE FOLLOWING SUB-GOALS:

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

4. BASIC FACTS ABOUT CRISP

4.1 THE CONSORTIUM



The CRISP consortium, consisting of four industry partners, four research partners and two public partners (sponsors).

Since its start, CRISP has consisted of the same 10 partners:

Four Industry partners

1. Simrad (part of the Kongsberg Maritime AS) 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.

2. Scantrol Deep Vision AS (originally Scantrol AS) has developed a unique technology for taking high-quality stereo photos of fish inside a trawl (Deep Vision technology), which can be used to identify species and measure their length through computerized image analysis.

3. Egersund Group AS is a leading producer of pelagic trawls, trawl doors and purse seines. The company has a strong focus on green harvesting, which will be an advantage in the Norwegian and international markets.

4. Nergård Group AS is one of the largest Norwegian exporters of seafood with strong focus on fish quality. The company focuses on maintaining local traditions and communities while sharing the sea's valuable assets with the rest of the world.

Four Research partners

1. Institute of Marine Research (IMR) is the leading centre of expertise for Norway as a maritime nation. The institute's research covers a wide spectre of ocean research, ranging from sustainable harvest and aquaculture to safe and healthy seafood. The research vessel fleet of IMR has been of particular importance for CRISP as a platform for testing the technological achievements gained in the centre.

2. 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, and economic competence to evaluate the socio-economic consequences of changes in fishing patterns.

3. University of Bergen (UiB) with its relevant scientific expertise in general fish biology, experimental biology, fish behaviour, fisheries acoustics and fish capture has acted as supervisors and provided a learning environment for the CRISP Master and PhD students.

4. Arctic University of Norway, Tromsø (UiT) with its Norwegian College of Fishery Science, has been responsible for education within all areas of fisheries and aquaculture research. CRISP has particularly benefited from the University's multidisciplinary expertise and approach.

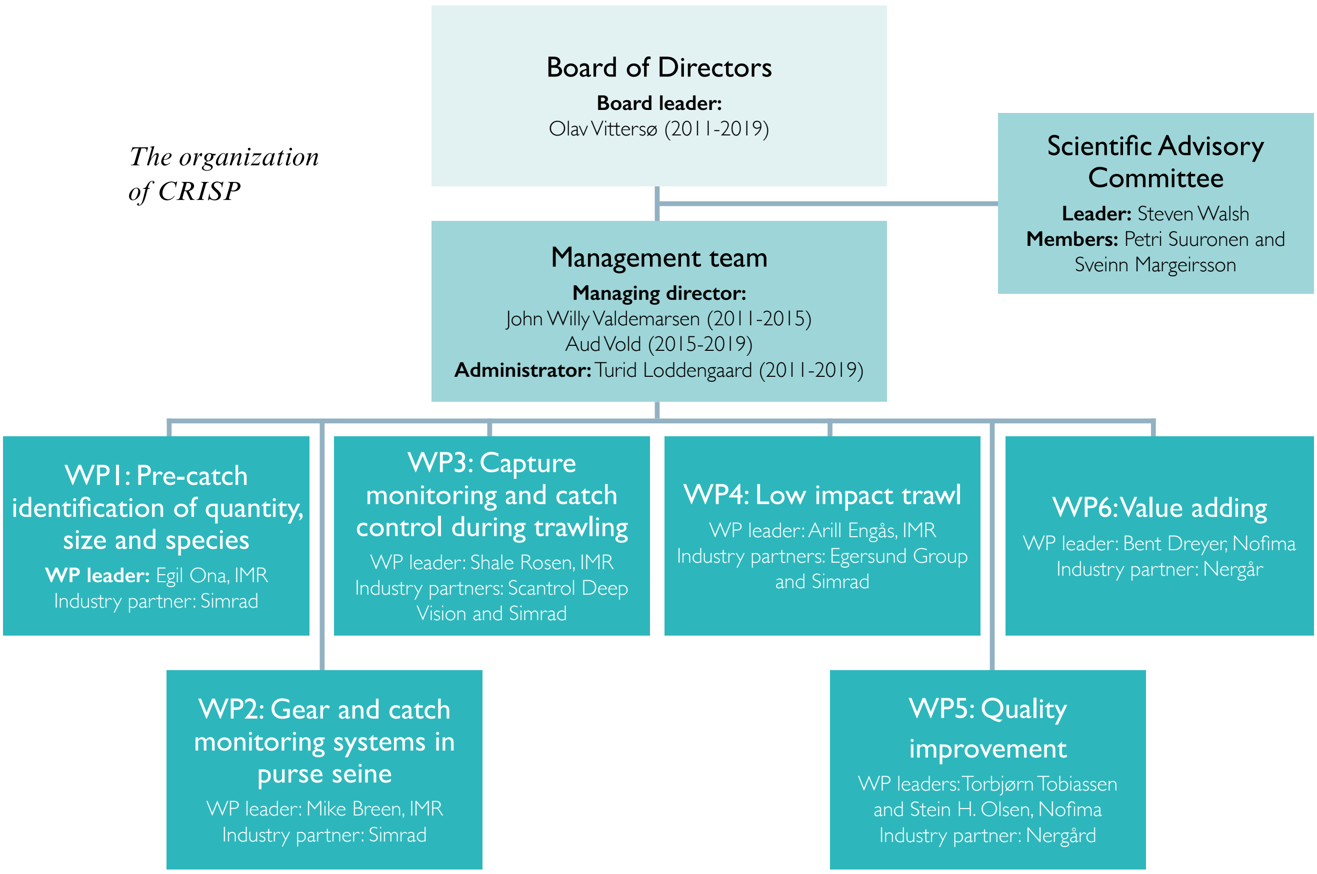
Two public partners

1. Norwegian Fishermen's Sales Association for Pelagic Fish (Norges Sildesalgslag) is Europe's largest marketplace for first-hand sales of pelagic species. The marketplace is owned and operated by Norwegian fishermen. Their main interest in CRISP is the development of sustainable fisheries, particularly in relation to eco-labelling and certification.

2. The Norwegian Fishermen's Sales Organization (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.

4.2 ORGANIZATIONAL STRUCTURE

IMR in Bergen has been the host institution for CRISP and responsible for the administration of the centre since its start in 2011. In the first half, CRISP was placed in the organization structure as an independent research programme but was later organized as a project in the Marine Processes and Human Impact Program. Most IMR personnel that have worked in CRISP projects belong to the Marine Ecosystem Acoustics and Fish Capture research groups. Scientists working in CRISP projects were also involved in projects outside CRISP. A similar organizational structure also applied to Nofima in Tromsø, the other major research partner in CRISP, where scientists from the research groups Seafood industry and Economy took part in CRISP activities.



The organization of CRISP

Senior scientist John Willy Valdemarsen from IMR was appointed managing director of CRISP from the beginning in 2011. He acted untill september 2015 after which Aud Vold, also from IMR, took over.

4.3 BOARD OF DIRECTORS

The centre was led by a board, which at termination consisted of the following members:

Olav Vittersø, Managing Director,
Kongsberg Maritime AS, Simrad (Chair 2011-2019)

Helge Hammersland, Managing Director,
Scantrol AS (2011-2019)

Bjørn Havsø, General Manager,
Egersund Group AS (2011-2013 and 2016-2019)

Kjell Larsen, General Manager,
Nergård Havfiske AS (2011-2019)

Geir Huse, Research Director,
Institute of Marine Research (2016-2019)

Heidi Nilsen, Research Director,
Nofima AS (2012-2019)

Arne Johannesen, Professor,
University of Bergen (2011-2013 and 2015-2017).

Helge K. Johnsen, Professor,
The Norwegian College of Fishery Science,
University of Tromsø (2013-2014 and 2017-2019)

Jonny Caspersen, Norwegian Fishermen's Sales
Organization (2015-2017)

Jonny Garvik, Chair of board, Norwegian Fishermen's
Sales Association for Pelagic Fish (2017-2019)

Turid Hiller, Special Advisor,
Research Council of Norway (Observer 2011-2018)

Liv Jorunn Jenssen, Special Advisor,
Research Council of Norway (Observer 2018-2019)

Olav Vittersø, Managing Director in Kongsberg Maritime AS, Simrad, has been Chair of the Board of Directors during the whole lifetime of CRISP (2011-2019).

Leader of the Scientific Advisory Committee, Steven Walsh (left) and SAC member Petri Suuronen together with CRISP PhD Ragnhild Svalheim (right). Petri acted as Ragnhild's opponent at her PhD dissertation in December 2018 (Photos: Left IMR, right Nofima).

The director of the Centre acted as secretary to the board. The representatives of the University of Bergen and University of Tromsø, as well as Norwegian Fishermen's Sales Organization (Norges Råfisklag) and Norwegian Fishermen's Sales Association for Pelagic Fish (Norges Sildesalgslag), alternated as board members every second year.

The scientific work was organized in 6 Work Packages (WPs) as shown in Figure 2. In addition a separate WP7 contained the administrative work.

4.4 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 evaluation panel. The Committee's work was regulated by a Terms of Reference. The Committee consisted of Dr. Stephen Walsh, Scientist Emeritus, Fisheries and Oceans Canada (leader), Dr. Petri Suuronen, FAO Rome, and Dr. Sveinn Margeirsson, MATIS, Iceland.

The CRISP family at the Annual Science meeting in Åsgårdstrand (2015) where we visited CRISP partner Kongsberg Maritime, Simrad (top). In 2016 the Science meeting were held in Egersund (bottom) where we visited partner Egersund Trawl (Photos: IMR).

The CRISP-family gathered for the final seminar at IMR in Bergen 23. may 2019 (Photo: IMR).

4.5 SENIOR RESEARCHERS

For full list of researchers involved in CRISP, see list in Appendix 2.

4.6 COOPERATION BETWEEN PARTNERS

The six research work packages were organized under the leadership of a representative from one of the research partners, and initially also with a counterpart assistant leader from one of the industry partners with a main interest in that work package. The work packages often involved more than two partners, especially those involving MSc and PhD students, where the universities were natural third partners. The four industry partners had complementary competence with minor or no overlapping business interests, which made cooperation between partners straight-forward.

The Centre used various arenas and methods to encourage mutual trust and to form joint projects involving CRISP's partners. Every second month a regular contact meeting was held between the research partners over video link where matters of mutual interest were being discussed. Most projects within CRISP were conducted jointly by staff from one research institute and one or two of the industry partners (See figure 4). Field studies were normally done on-board research or fishing vessels. The key role of the researchers was to evaluate the efficiency and environmental benefits of the developed tools. The staff from all partners participated in planning and execution of the research cruises followed by evaluation and reporting of the results.

Except for 2018, an Annual Science meeting was arranged September each year. This has been the main meeting point for the whole CRISP consortium, where all scientists and industry partners involved met up for a two-day symposium where the scientific progress and other matters of importance for all partners were discussed. In 2018 it was decided to merge the Annual Science meeting it with the final symposium held in Bergen, May 2019.

5. FINANCING THROUGH THE LIFE OF THE CENTRE

SUMMARY SHEET FOR THE MAIN CATEGORIES OF PARTNERS (MNOK)

Contributor	Cash/Funding	In-kind	Total
Host		88 710	88 710
Research partners		10 855	10 855
Companies		77 493	77 493
Public partners	1 600	7 730	9 330
RCN	80 000		80 000
Sum	81 600	184 788	266 388

DISTRIBUTION OF RESOURCES (MNOK)

Type of activity	MNOK
Research projects - WP1	88 918
Research projects - WP2	34 208
Research projects - WP3	33 507
Research projects - WP4	35 247
Research projects - WP5	33 966
Research projects - WP6	15 694
Common centre activities & Administration	24 848
Total	266 388

6. RESULTS – KEY FIGURES

OVERVIEW OF THE PRODUCTION OF THE CRISP-CENTER THROUGH ITS LIFETIME.

Type of result	2011	2012	2013	2014	2015	2016	2017	2018	2019	Sum
Scientific publications (peer reviewed)		7	4	5	1	4	6	7	6	**40**
Dissemination measures for users	12	48	20	20	25	39	13	14	8	**199**
Dissemination measures for the general public	37	78	22	43	17	37	8	8	1	**251**
PhD degrees completed						1		2	1	**4**
Master degrees	2	1		2	2	4		4		**16**
Number of new/improved methods/models/prototypes finalised	3		1	2	1	1	1			**9**
Number of new/improved products/processes/services finalised		3			1	3	1	1		**9**
New business activity				1			1			**2**

7. RESEARCH

7.1 RESEARCH PLAN

ORIGINAL RESEARCH PLAN (2011)

WP1. Pre-catch identification
1.1 Broadband fish identification
1.2 High resolution sizing
1.3 New in-seine sonar
1.4 Biomass sonar
WP2. Monitoring fish and gear
2.1 Vision technology for trawls
2.2 Integrated information systems
2.3 New signal cable
2.4 Density measurem. purse seines
2.5 Integr. catch monitor purse seines
WP3. Active selectivity and release
3.1 Active selection device for trawls
3.2 System to regulate trawlcatches
3.3 Gentle release purse seines
WP4. Low-impact trawl
4.1 Off-bottom trawl designs
4.2 Adjustabel trawl doors
4.3 Low impact ground gear
WP5. Quality improvement
5.1 Gear mod. and capture methods
5.2 Handling and fresh fish processing
WP6. Value adding
6.1 Quality improvement
6.2 Technological innovation
6.1 Environmental friendliness
WP7 Management activities

RESEARCH PLAN AT TERMINATION (2018)

WP1. Pre-catch identification
1.1 Biomass estimation with digital fishery sonars
1.2 Pre-Catch identification and sizing of fish with broadband
WP2. Gear and catch monitoring systems in purse seine
2.3 "In-seine" sonar technology for catch control
2.4 Catch monitoring system in purse seine
2.5 Monitoring seine geometry and performance
WP3. Methods for capture monitoring and catch control during trawling
3.1 Visual fish classification
3.2 Trawl HUB for Camera and acoustic systems
4. Low-impact trawl
4.1 Manoeuvrable trawl doors
4.2 Semipelagic trawl design and rigging
4.3 Catch regulation in trawls
4.4 Improving the quality of the pelagic trawl survey for NEA mackerel
5. Quality improvement
5.1 Current quality conditions on board bottom trawlers
5.2 Facility and methods for investigation of fish quality
6. Value adding
6.1 Nergård operation
6.2 How renewal and harvest strategies impact fleet performance
WP7 Management activities

Have developed "smart technologies" to ensure responsible fishing in parallel with improving the profitability of the fishing fleet and its suppliers.

The main goal of CRISP has been to reinforce the position of Norwegian companies in fishing-related industries as leading suppliers of equipment and seafood to a global market by developing sustainable technology for trawling and seine fishing. In other words, the goal has been to develop "smart technologies" to ensure responsible fishing, but at the same time improve the profitability of the fishing fleet and its suppliers.

The original research plan for CRISP is shown above alongside the research plan as it stood at the end of 2018. The research programme was split into 6 technical work packages and one management package. Broadly speaking, the work has followed the original plan throughout the centre's existence. Around half way through the programme, for practical reasons it was decided to restructure work packages 2 ("Monitoring fish and gear") and 3 ("Active selectivity and release") in order to bring together all research relating to gear and catch monitoring in purse seines in a new work package 2 called "Gear and catch monitoring systems in purse seines", and all work on monitoring during trawling in a new work package 3 called "Methods for capture monitoring and catch control during trawling". This was almost entirely an organisational change, which had little impact on the technical content of the research work.

Although we have stuck quite closely to the original main objectives, there have been minor changes of direction within all of the work packages in response to experiences and the results of prior research. Some new topics have also been introduced. These kinds of changes are described under the individual work packages.

In its mid-programme assessment, performed in the spring of 2015, CRISP received generally positive feedback on the development of practical innovations for the fishing fleet and for the good cooperation achieved between the research community and industry. However, CRISP was strongly advised to set up a Scientific Advisory Committee to advise it on scientific questions. The committee would be tasked with evaluating the overall direction and strategic choices for the remainder of the programme and advising on decisions relating to research, recruitment and communicating research findings. A committee of this kind was set up that same year.

The centre was also advised to seek to raise its international profile, for example by publishing more of its research results in recognised international journals and attending international meetings and forums. We have subsequently striven to do that, and the publication rate has risen, particularly after several of our PhD and Master's students completed their projects. However, in certain cases there has been some conflict between the desire to publish scientific results and our industrial partners' need for confidentiality.

7.2 REASEARCH ACTIVITIES IN THE WORK PACKAGES

7.2.1 WP1 - Pre-catch identification of quantity, size distribution and species composition

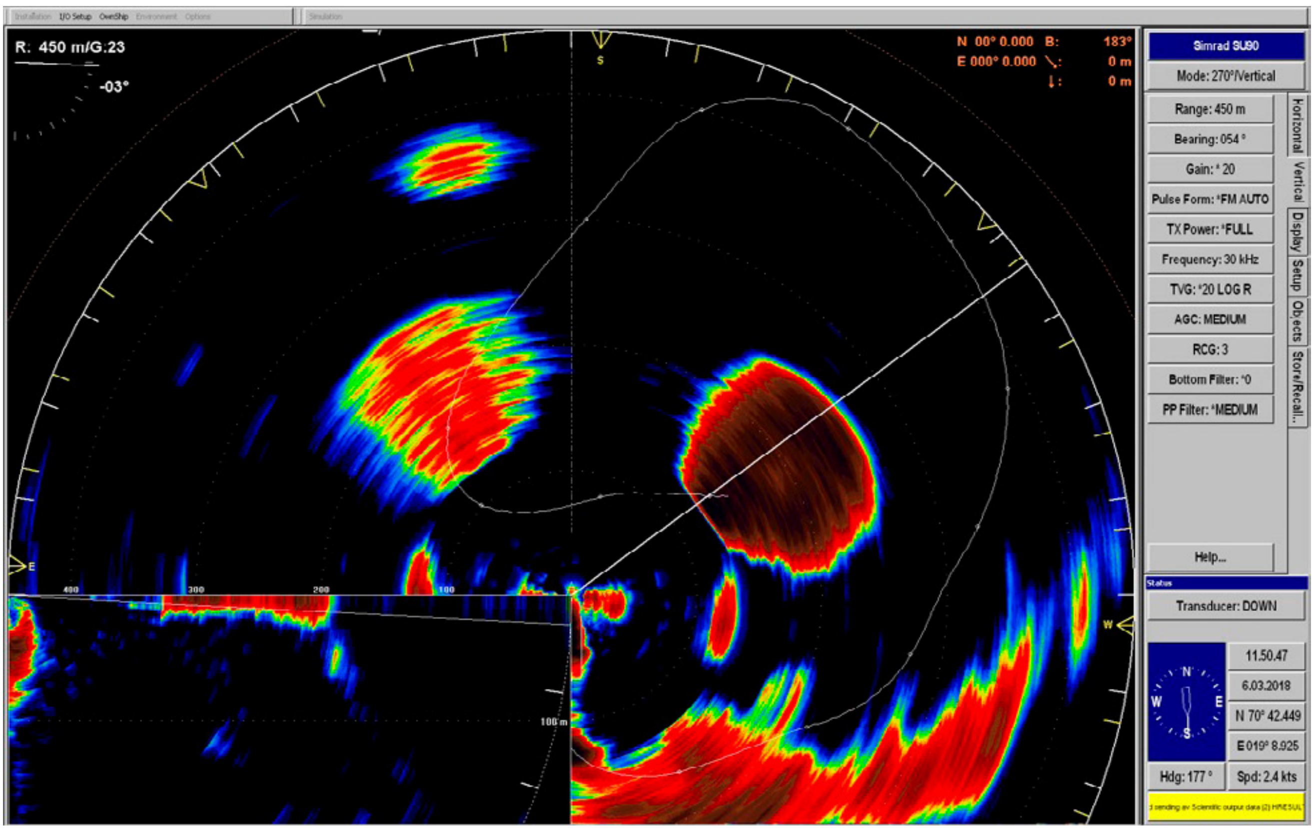
Background

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 sonar calibration methods but also better understanding of how fish behaviour affects the backscattering when observing the fish in lateral aspects.

There is also a definite need for more precise estimates of individual size and species composition of fish schools prior to shooting a purse seine. This may reduce the number of unwanted sets where the catch is of the wrong species, wrong size composition or exceeds the amount which can be handled by the fishing vessel. If the whole school or parts of a catch must be released, unwanted mortality can occur, and instruments and technology which can reduce this risk are needed for future sustainable harvesting of pelagic schooling fish with purse seine gears. Comparable challenges are also present in commercial trawl fisheries, where pre-catch species identification and sizing will be important in the future. We believe that the instrumentation and methods developed under this work package may now and in the future, deliver important information helping the skipper in his difficult decisions both during purse seining and trawling.

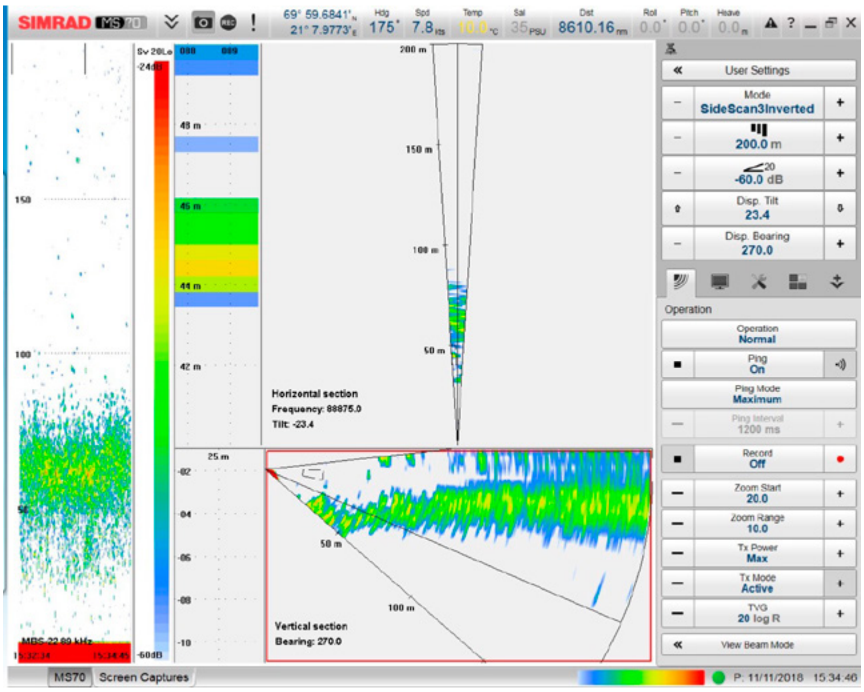
Activities

Simrad is collaborating with IMR for developing new and improved omni-directional 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 and/or mixtures. This includes development



Dense capelin school from the 2018 survey, where acoustic extinction occur, but not clearly shown in the sonar display.

KayakDrone used to measure herring layers in Kværnangen, 2018. The herring reaction to the research vessel was studied and quantified and compared with four other measuring methods.

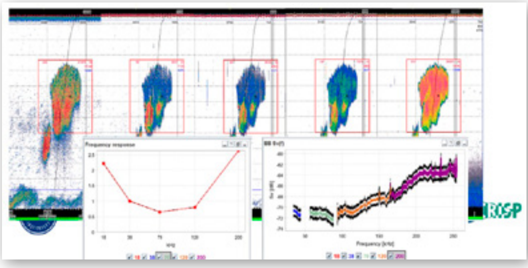


Measuring herring close to the sea surface with special settings of the MS70 sonar

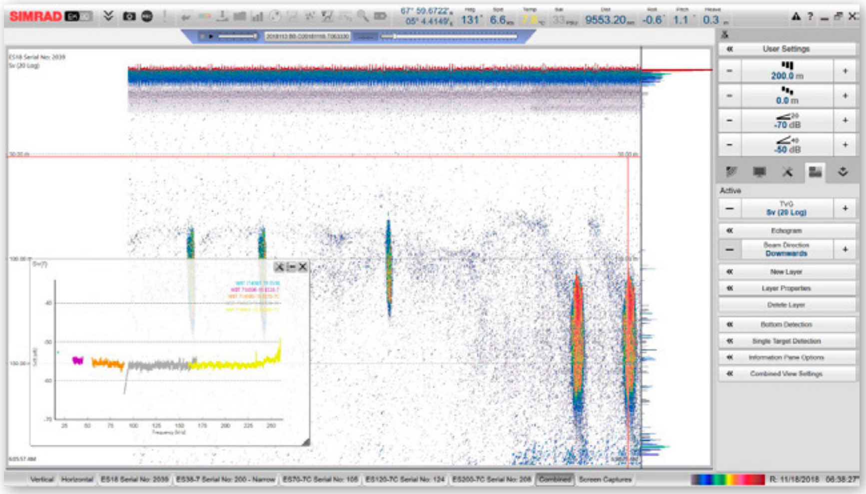
and testing sonar and echo sounders and establishing internationally accepted standard calibration procedures and protocols. Important work on this topic have been made during the first four years of CRISP, both with respect to sonars SU90 and SN90 and broadband echo sounder EK80. Calibration of echo sounders and SU90 sonars of about 10 different fishing vessels and 3 research vessels have been reported and published. New, robust methods for calibration of broad band, split beam echo sounders are also implemented inside the instrument software and published.

Further, improved algorithms for estimating the volume of schools, their mean backscattering, and the mean target strength of herring, mackerel and capelin, when observed in lateral mode have been made. In theory, we should now be able to estimate the biomass in a fish school, using physical terms only. However, the biology and behaviour of fish may still play us some tricks, and procedures for inspection and verification catching have been necessary for establishing correct conversion factors between measurement and real catch. A procedure for these measurements has been established and followed, and the "best" data have been selected for biomass estimation, also with a critical evaluation whether the entire school was caught. Only about one third of the total verification catches could be used in the comparison due to the uncertainties of the catching process.

Even following a strict procedure during inspection, with extraction of the best data from each school, still some uncertainty remains when targeting a specific biomass, probably related to the behaviour of the fish inside the school. If the measurements from verified catches are used, the uncertainty in the prediction is in the order of ± 20- 25% on schools from 0 – 300 tons. How this uncertainty develops for larger schools is not yet known, as we have only targeted schools within this size window. Another important factor observed for larger schools, is that we need to correct for acoustic extinction, or acoustic attenuation of the signal through the school for estimation a correct mean SV. Particularly this



Broad band frequency response, SV(f) of a large herring school during strong vertical avoidance, showing non-normal backscattering.



EK80, Echogram combined view, 5 frequencies, where the frequency response, SV(f) from 18 to 260 kHz is shown in real-time, snapped for last, large herring school in the right part of the image.

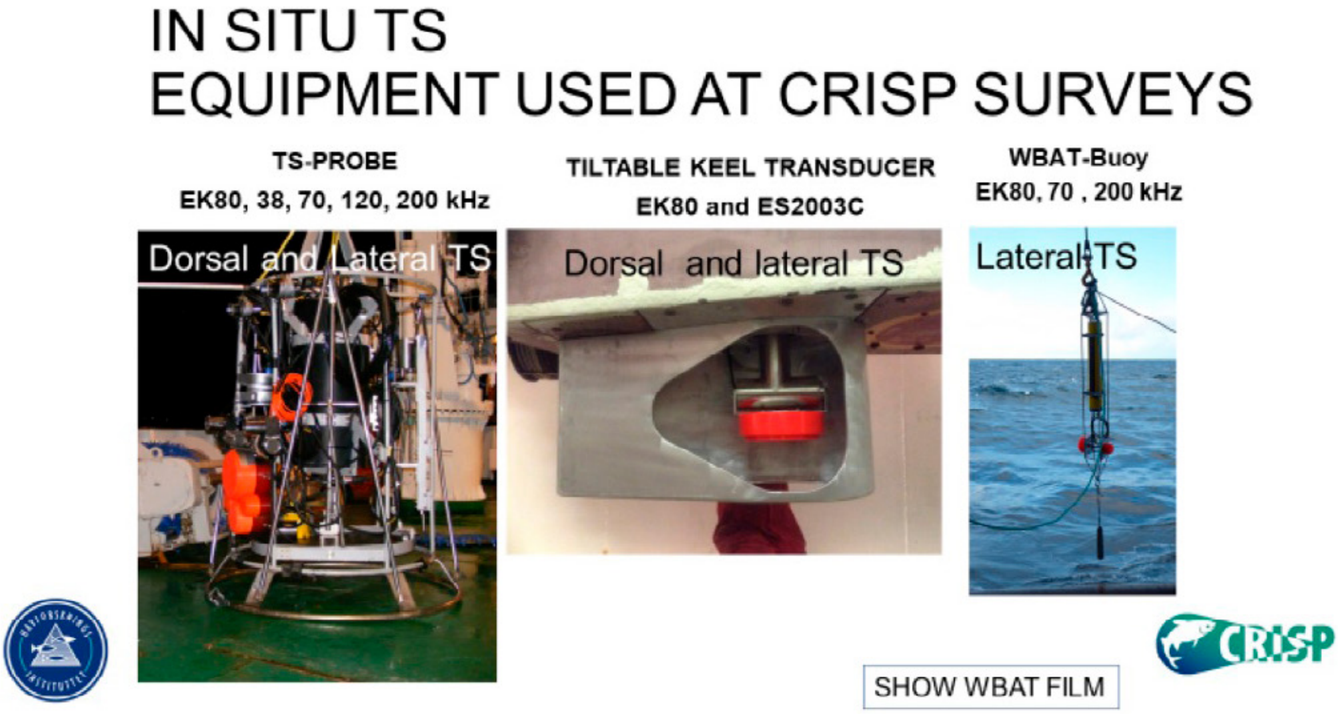
effect was clear in large capelin schools. This work in yet not finished, while scientific data on large schools of herring and capelin was collected in November 2018 and in March 2019. Some new scientific, theoretical work remains to be done on this topic, and maybe simpler methods for removing the extinction effect, like only using SV data in the front end of the school may be implemented while waiting for a more detailed correction algorithm. For herring and capelin schools up to 300 tons we do not expect large corrections for extinction, and the established relationships may be used as is. For mackerel schools, we do not expect acoustic extinction at the sonar frequencies used.

If simplified algorithms are still going to be used, it is necessary also on existing sonars to implement an improved colour scale to be used when inspecting the density of the school. It is today very difficult to evaluate the internal density of the school from the sonar image directly, where most of the dynamic scale is compressed into the red colour, and the image is filtered for noise. How this may be implemented will be discussed with the manufacturer and the users. Maybe full dynamic range the new inspection beams may be a good solution, like already implemented in the SN90 software?

Also, tools within the sonar system for allowing the skipper to enter his own valid catches together with concurrent measurements of the school could be implemented. This is a way of storing experience, and further improving the algorithms inside the sonar. How to practically do this will be discussed with the manufacturer.

From the fishing operations, we have also seen that the initial inspection of the schools from several directions is a prerequisite for obtaining a correct catch. Attacking the school directly from the detection phase may lead to large over or underestimation of the catch, independent of the skills of the skipper. This is especially the case for migrating fish, and for large fish where the fish directivity may easily change the mean backscattering by one order of magnitude. This should be clearly communicated in meeting with the fishing industry both from the manufacturer and from the scientific community.

Kongsberg Maritime has over the last years worked 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 nearly ready, and one successful calibration have been made on FV "Eros". The IMR Sonar processing software PROFUS have also been adjusted to read data from SN90. Due to major problems with air bubbles from the side thrusters on the original



Instruments used for measuring target strength of fish in lateral (sonar)-aspect.

A: IMR TS probe with side-mounted transducers. B: Broadband narrow beam transducer ES200-3C, in motorized platform. C: Simrad WBAT system with broadband 70 kHz and 200 kHz transducers.

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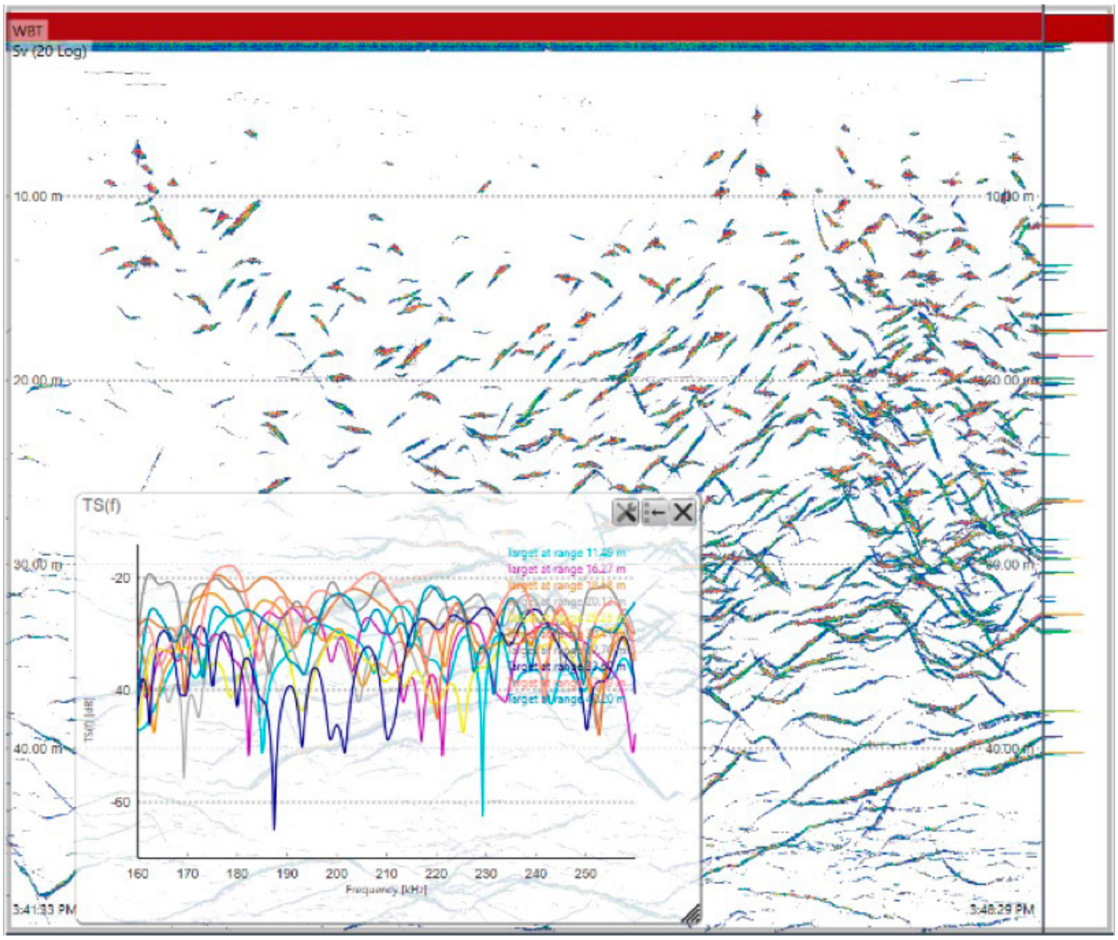
mounting of the transducer, which is a normal hull blister, the transducer on FV "Eros" was in 2017 moved to the side of the drop keel. Much better data and images was then made with this sonar, and the catch process could now be properly monitored during shooting and retrieval. In practice, this sonar is then also ready for measuring biomass of schools in the pre-catch situation, and parallel biomass estimates with the SU90 data could be developed and implemented.

Fish sizing

For acoustic estimation of fish size, we anticipate that the developments and methods tried early in the CRISP project, and in the DABGAF project may be commercialized by the industrial partner. In short, we used the 170-270 kHz broad band echo sounder EK80, connected to a special transducer, built by Kongsberg Maritime, the ES200-3C with a very narrow beam. In this manner, we used the advantages from pulse compression methods and a narrow beam to resolve single targets in mackerel and herring schools at distances up to 100 m from the ship, either observing vertically (echo sounder mode) or laterally (sonar mode). The real time DABGRAF software (Coded by CMR), used TS, orientation, pulse duration and spectrum to compute the probability for the target to a certain size. This probability was presented like a histogram in the processing software. We believe that modification of the transducer for electronically tilting the narrow beam could achieve the same resolution in the laterally observing beam, and that the software otherwise could easily be implemented inside the echo sounder software in a dedicated EK80 system. This could be marketed as a size indicator in pelagic fisheries, and for tuna vessels. Some new results from the AcoSize (IMR) project with respect to measuring target dimensions in the time domain could then favourably be included, especially for larger tuna targets. When the results from the AcoSize project is finished, similar methods on demersal fish should be tried, and the frequency and beam widths estimated for proper sizing of demersal fish could be made. The present narrow 200 kHz transducer will only be effective for this job to 150 meters' depth, which is too short for Norwegian demersal fish.

Fish identification

identification of the fish is seldom a problem in the Norwegian purse seining industry, and since most of the CRISP surveys in WP1 have been focusing



Broadband frequency response of single herring targets during lateral TS measurements.

either on herring, Mackerel or capelin, we have not worked much on this topic, directly. However, the development of broadband systems will naturally lead to improved identification of target species and mixtures. Inside the echo sounder itself, the use of a "combined" echogram, when ensonifying the targets with multiple frequencies is a good start for manual, direct interpretation of fish species, as the output of total SV(f), or the frequency response of the target or layer is directly available. A further, natural development is to include a zooming tool or box tool, where the skipper can isolate special regions on the echogram and obtain this frequency response from the region directly. An image of a large herring school (Figure 1?) with frequency response curves can exemplify this. The data is now loaded into the IMR post-processing system LSSS for measuring SV(f) inside the region, but this may today be done directly inside the echo sounder software. The herring school shown in this image has a special, unexpected frequency response, increasing at the higher frequencies and becoming strong at 200 kHz, indicating an avoidance reaction during passing. Most of the herring is swimming downwards with a high, negative tilt angle. In this case, the backscattered spectrum also indicates the behaviour of the fish!

Since the measured frequency response have been used in research for two decades now to identify species, training data sets from research surveys may in the future be fed into the echo sounder systems for the fishing industry. In some cases, like for sand-eel, even the size categories of sand-eel schools can be identified by studying differences in SV(f).

As a summary, the CRISP projects and surveys have been important for solving some of the main questions asked in the start of the project for WP1, but it has also been important for testing and preparing a research table for new technology and methods on acoustic broad band characterisation of marine targets, fish and zooplankton. Some of these have also been packed into small, battery driven systems, giving high-quality data from any depth, or drones sent from the vessel as non-disturbing observers. We have therefore only seen the first scratches of this technology mounted on fishing gears like trawls, purse seines and stationary fishing gears.

7.2.2 WP2 – Gear and catch monitoring systems in purse seines

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.

The purse seine fleet today is well equipped with fish-finding instruments. However, less attention has been paid to monitoring gear performance and the catch within the seine. With respect to gear performance, instrumentation is generally limited to monitoring the depth of the bottom of the net (i.e. the lead- and purse-lines) relative to the seabed. While characterisation of the catch, with respect to species, size or quality, cannot be reliably achieved until the seine is pursed at the vessel side and the catch can be sampled to decide whether to retain or slip it. Standard acoustics have limited application in high-density restricted volumes like a purse seine, where side-thrusters also produce substantial amounts of bubbles causing acoustic extinction close to the surface. Moreover, instruments fitted to a purse seine are subjected to severe mechanical strains during setting and hauling, so careful considerations are required when designing hardware for monitoring systems for purse seine fishing.

Objective: To develop and implement instrumentation for commercial fishing to monitor fish behaviour and gear performance during purse seine fishing operations. To this end, this work package focused on three themes:

1) testing and development of the "In-seine" sonar technology for catch control;

2) monitoring purse seine geometry and performance using sonar and transponder technology; and

3) monitoring the behaviour and welfare status of purse seine catches.

"In-seine" sonar technology for catch control

During purse seining it is important for the skipper to be able to reliably monitor the targeted fish school and the gear. The movement of the school, prevailing current, sea state and wind conditions are all factors that the skipper needs to consider throughout the whole capture process. The fish school is monitored by omni-directional sonars during the search and inspection phases, providing continuous information of the school position (relative to the vessel), swimming speed and direction, and an estimate of school biomass. However, omni-sonar transducers are mounted on a shaft protruding out of the vessel's hull. This needs to be retracted when the seine is being pursed (i.e. the bottom/purse-line is hauled) to avoid that the net or wires becoming entangled with the transducer. The pursing stage is critical because the net is not yet fully closed, and the fish school can escape capture by swimming out of the net or under the vessel.

A new "in-seine" sonar (i.e. SN90 model, Simrad-Kongsberg Maritime AS) was developed to allow for continuous monitoring of the purse seine capture process. The sonar has a flat transducer mounted in starboard side of the vessel hull, close to the bow. As with the omni-sonar, the in-seine sonar transmits horizontal and vertical beams, but with an increased ping rate and higher beam resolution. In addition, 5 inspection split beams enable the collection of more detailed information about fish density and behaviour in the frequency range of the sonar (70 to 120 kHz). This information is important for making more accurate estimates of school size and how the school is reacting to the seine and vessel. The performance of the SN90 sonar was tested in several CRISP surveys and despite continuous operation during the whole capture process, the quality of the data was lower than expected. One of the reasons is that the sonar transducer is mounted near the vessel bow thruster (Figure 1). Along with the main propellers, the bow thruster is commonly used to keep the vessel away from the seine during pursing and hauling, and the generated air bubbles interfere with the sonar signals. In an effort to reduce the effect of vessel propeller generated air bubbles, the SN90 transducer was installed on a drop-keel during a CRISP survey on FV "Eros" (Figure 1). The drop-keel can be lowered 3 m below the vessel hull and does not need to be retracted during the pursing. This new location, deeper and in the middle of the vessel, significantly improved the data quality provided by the SN90, reducing the adverse effects of air bubbles.

The SN90 sonar was used to monitor school behaviour in the early catch stages as the seine was deployed around the school and pursed. Using the inspection beams it will also be possible to observe internal school dynamics (Figure 2). In addition, it was possible to monitor of the net in the early stages of pursing and the lead- and purse-lines (i.e. bottom of the net) during hauling; when omni-sonar operation is not possible (Figure 3). A good agreement was found between the depth of the lead-line measured with the sonar and the attached depth sensor. However, in adverse weather conditions and high wave heights, the quality and continuity

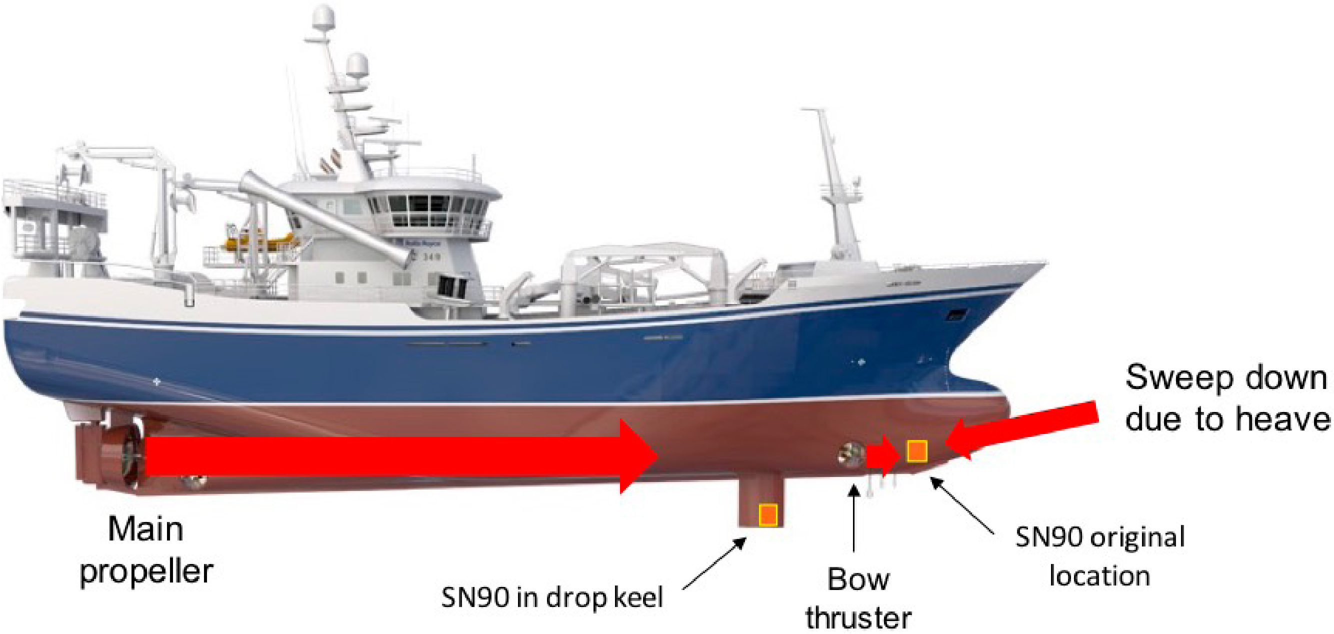


Figure 1. New location of the SN90 transducer in the protruding keel of FV "Eros", 3 m below the vessel hull. The original location closer to the bow attached to the vessel hull is also shown, where it was more exposed to the air bubbles from bow thruster, main propeller and sweep down from vessel heave (picture source: Rolls-Royce, ship design)

of the sonar data from this drop-keel mounted transducer decreased.

In parallel with these activities, efforts were made to calibrate the SN90 sonar, using the knowledge gained in WP1 with the calibration of the omni-sonars. A new software version was developed by Simrad to allow the use of the built-in inspection split beams during the calibration, facilitating the monitoring of calibration sphere inside the horizontal and vertical sonar beams. During the sonar calibration work, a detailed knowledge of the data format and description of the main parameters contained was also gained.

Our results indicate that the SN90 sonar, is a valuable tool for monitoring the net and school behaviour during the early capture stages of purse seine fishing, particularly when mounted deeper (i.e. on a drop-keel) where it is exposed to less bubble noise.

Currently we are investigating alternative methods for monitoring the catch during purse seining in new projects, e.g. attaching acoustic instruments to the net or deploying directly inside the catch (FHF No. 901350 "Catch control in purse seines"). The development of the SN90 is ongoing, building on the achievements of this work package, and proposals for improving the monitoring of fish and gear during purse seining, are being evaluated.

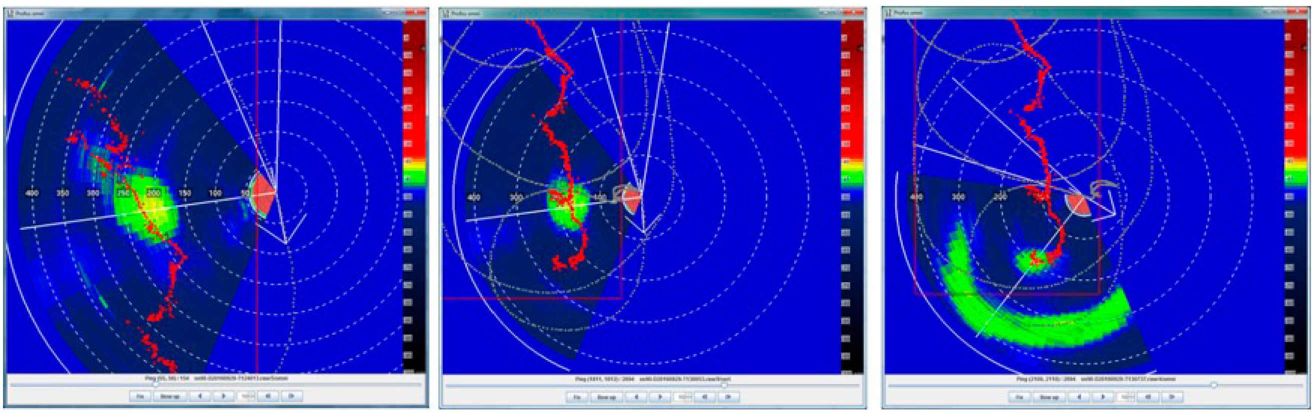


Figure 2. School monitored using SN90 with a 120 degree horizontal fan during inspection phase. The school is shown as a yellow/green circle, with the vessel in the centre of the image, sailing south as indicated by a white arrow (left panel). During the setting of the net, the school became smaller (middle panel) and during pursing the purse seine was visible around the school (right panel).

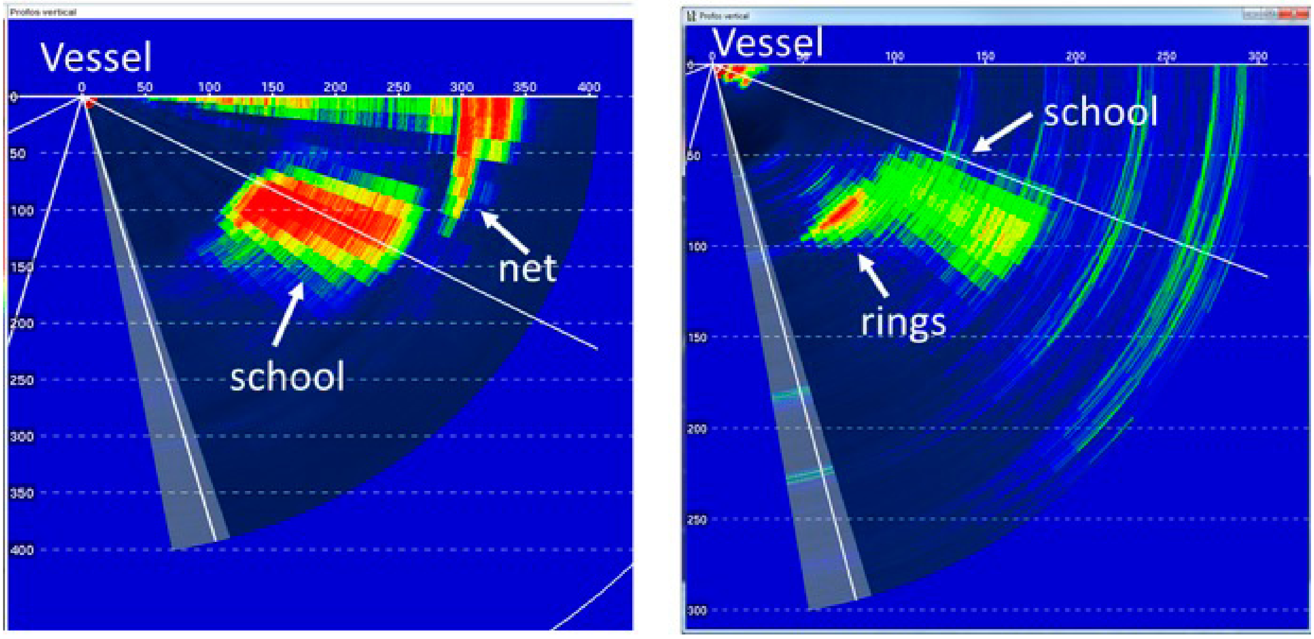


Figure 3. Vertical beams of SN90 during catch monitoring of a mackerel school. Left panel - Simultaneous monitoring of school and purse seine while the net is sinking. Right panel - Later stage when the net is pursed, and the rings of the purse-line can be monitored while the purse is closing, and the school is captured.

Monitoring seine geometry and performance

Monitoring and understanding the fishing gear during capture is important for controlling the capture process and for identifying potential to improve gear design or operation. In purse seine fisheries, the sinking speed is commonly monitored with a depth sensor attached to the lead-line, but little information is available on gear position in relation to the target school during capture and on purse seine performance at sea. Improved control of the seine in relation to the target school and sea bottom could potentially improve catch success and reduce contact with the seabed and therefore gear damage. The aim of this work package was to:

1. Improve the control of purse seine performance through visualization of the net in real-time during shooting, pursing and hauling.
2. Improve control of sinking speed, depth and position of the gear relative to the surrounded fish school, the sea bed and the vessel.

A real-time monitoring system for purse seines

Development of a purse seine monitoring system was initiated in another project, funded by the Norwegian Seafood Research Fund (FHF, 0900688). The seine was monitored during hauling using a Simrad fisheries sonar (SH80), which enabled a 3D reconstruction of shape and volume of the net (Tenningen et al., 2015). A Simrad HiPAP acoustic positioning system with transponders mounted in the net walls was used to validate the sonar-based net borders. In CRISP this idea was further developed with the aim of producing a system that would provide the skipper with a real time overview of the purse seine in relation to the target school during capture.

The prototype SN90 sonar was tested on “Kings Bay” in November 2014 with promising results and at the same time Kongsberg Maritime made modifications to their PX Universal catch monitoring sensor to enable use with the SN90 sonar. The modified transponder transmits an acoustic signal that is received and displayed in the SN90 sonar.

Since 2015, the system has been developed and tested in CRISP. Currently it provides accurate 3D positions of the transponders mounted on the lead-line of the gear. Several transponders can be attached to the seine (Figure 4) and these are displayed as strong echoes on the SN90 sonar screen (Figure 5). The signals from the transponders can be located as the seine is set and pursed by manually adjusting the tilt and bearing of the sonar. The latest software version includes an option for displaying transponder and school signals in the same mode by selecting the number of pings for sampling fish and the number of pings for sampling the transponder signal.

Some development work remains however before the system becomes useable by the fishing industry. The main remaining task is to automatically identify and display transponder positions in the same screen as the target fish school. This will allow the skipper to monitor the school at the same time as the purse seine position relative to the school. Smaller and lower cost transponders will also make the system more practical to use and more attractive for the fishing industry.

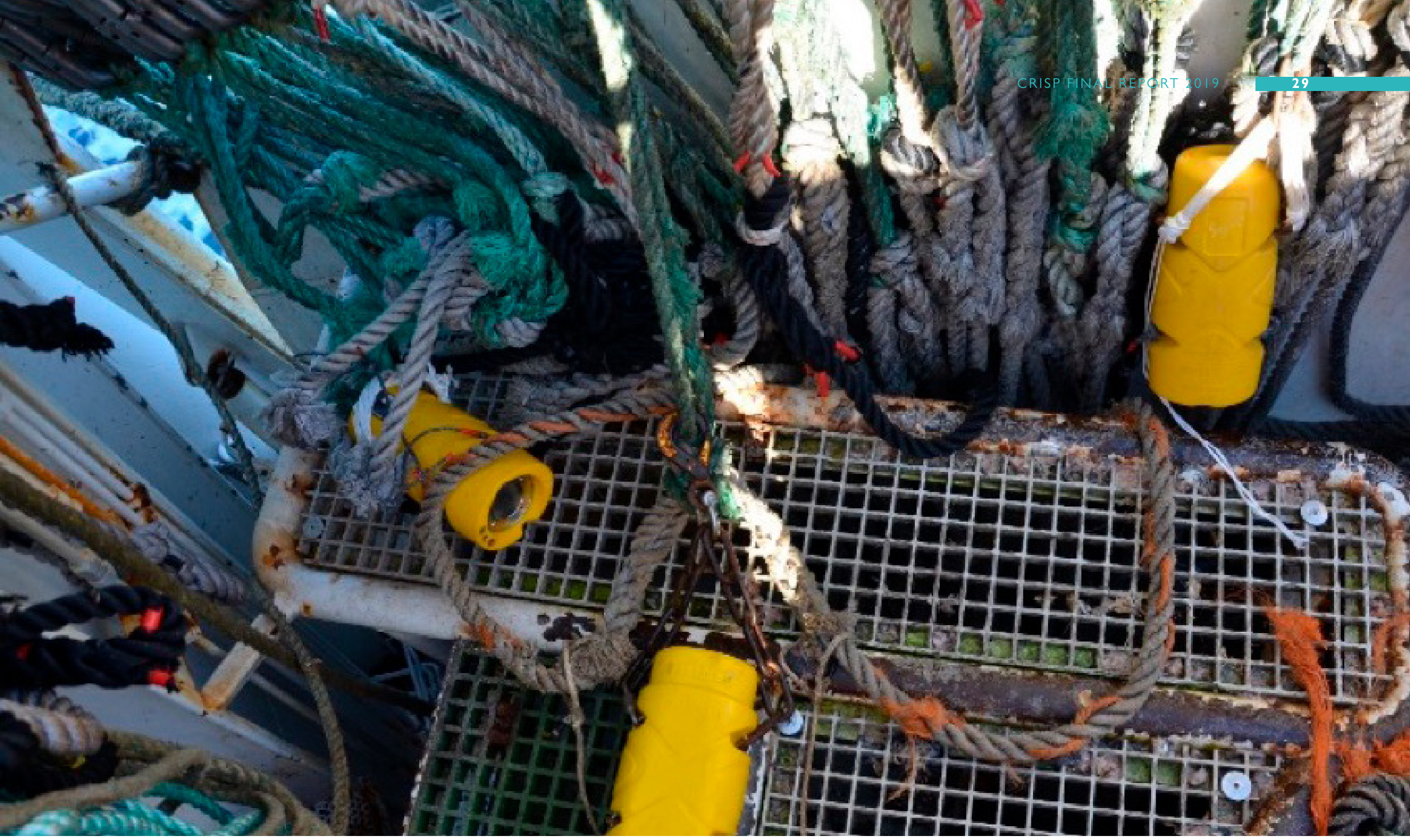


Figure 4. Three positioning transponders attached to the lead-line of a purse seine.

Estimates of purse seine geometry and volume during capture

Between 2014 and 2016, the SN90 sonar was used to monitor seine geometry and volume during commercial fishing (Figure 6). The aim was to obtain a better understanding of seine geometry and the space available for fish schools caught in the seine. It has been shown that the survival rate of fish released from a purse seine depends on fish density and duration in the seine before release (Marcalo et al., 2006; Huse and Vold, 2010; Tenningen et al., 2012). It is therefore important to have an idea of fish densities inside the seine to ensure fish are not released after fatal densities are reached. There are currently no practical methods for direct estimates of fish density in the seine, so in this work purse seine volume together with common catch sizes were used as a proxy of fish density.

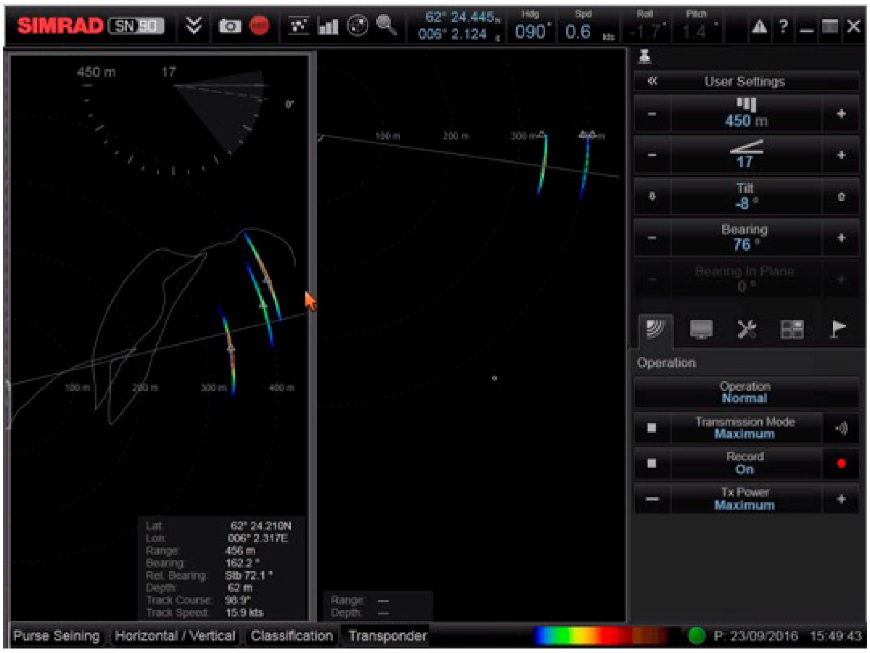


Figure 5. SN90 sonar display of three transponders mounted on the bottom line of the purse seine of FV "Brennholm". Horizontal section (left panel) shows the three transponders as coloured elongated shapes between 300 and 400 from the vessel. The vessel track is displayed during the set of the purse seine, as a white line. In the vertical section (right panel), two of the transponders are displayed at a depth of about 60 m.

In collaboration with Project RedSlip

(NFR 243885), the in-water volume of different sized seines used in the Nordic mackerel and herring fisheries were estimated and modeled as a function of the proportion of seine hauled on

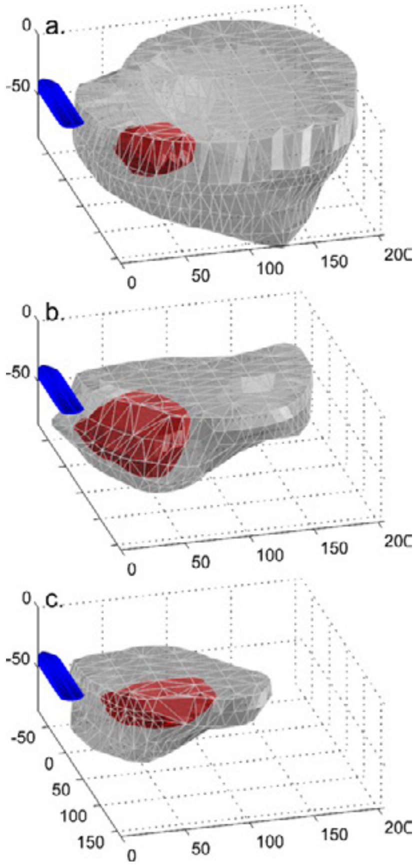


Figure 6. The reconstructed 3D net and school shape. The seine is show as the closed triangulated surface used for the volume estimates at 22, 44 and 50 % hauled net. The school is shown in red and the ship in blue.

board and seine size (Tenningen et al., In Review). The impact of seine volume on fish densities in common catch sizes was investigated. The results suggest that regulations on the release of unwanted catch from purse seines should take into consideration the effect of seine size on fish densities. Ideally, release limits should reflect real fish densities, but that will require further development of real-time catch and gear monitoring methods and instruments.

Monitoring fish behaviour and welfare status of purse seine catches

The objective of this component of WP2 has been to develop a catch monitoring platform (CMP) to monitor and characterise the catch (with respect to species composition, individual size distribution and behaviour), as well as describe environmental conditions in the net (i.e. temperature and dissolved oxygen concentrations), during the capture process in the purse seine. Being able to identify species, size or quality of a catch encircled by the seine will enable fishers to decide whether a catch should be kept or released. While having tools to monitor 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.

Early in CRISP, efforts focused on developing robust instrument pods fixed to the net walls with cabled transmission of data signals to the surface. However, while robust enough to withstand the extreme loads experienced during setting and hauling, these instruments did not encounter the catch frequently enough to be able to provide meaningful data. Focus was then shifted to developing a platform that could deploy an inte-

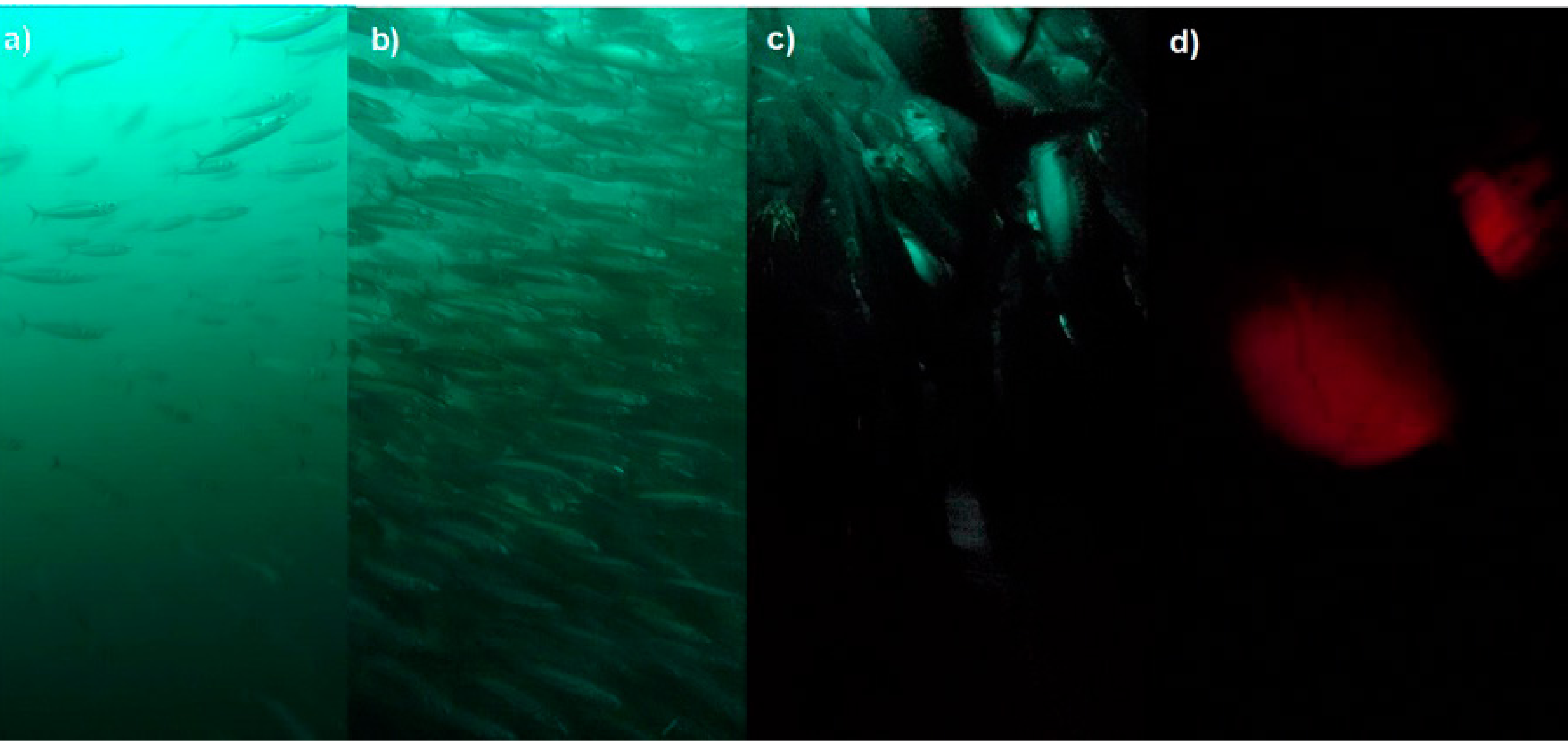


Figure 7. Catch Monitoring Probe (CMP) images of different degrees of crowding density: a) low density (score: 1); b) moderate density (score: 2); c) high density (score: 3); and d) very high density (score: 4).

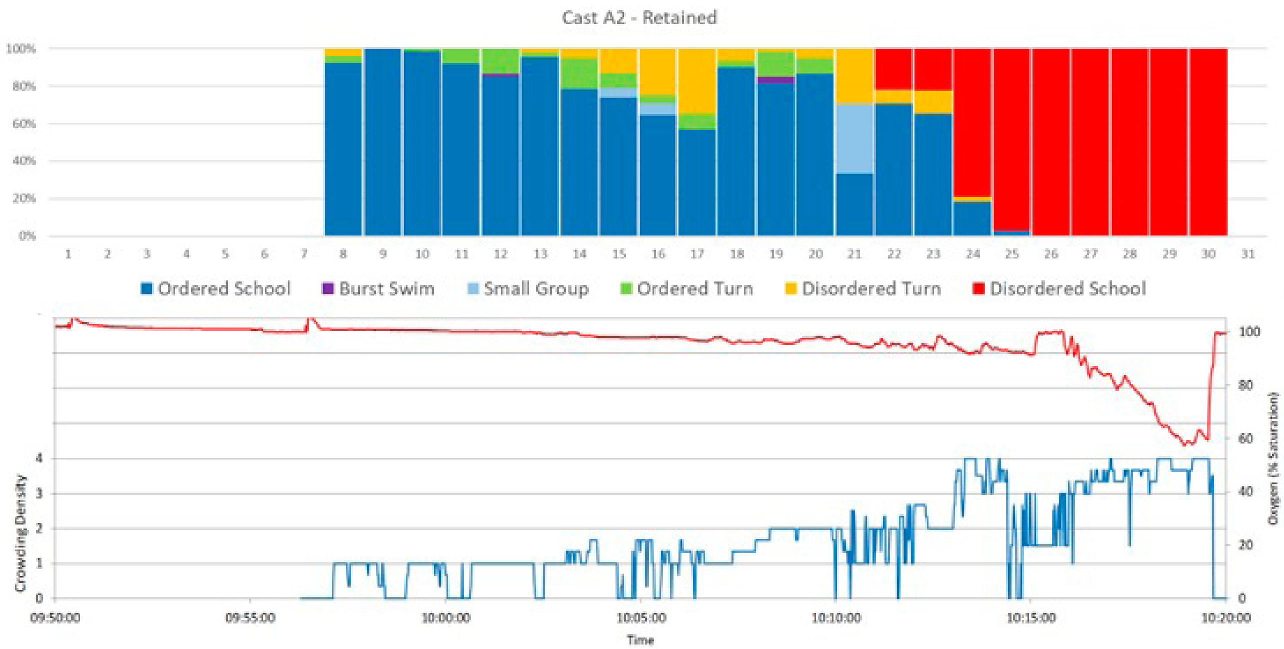


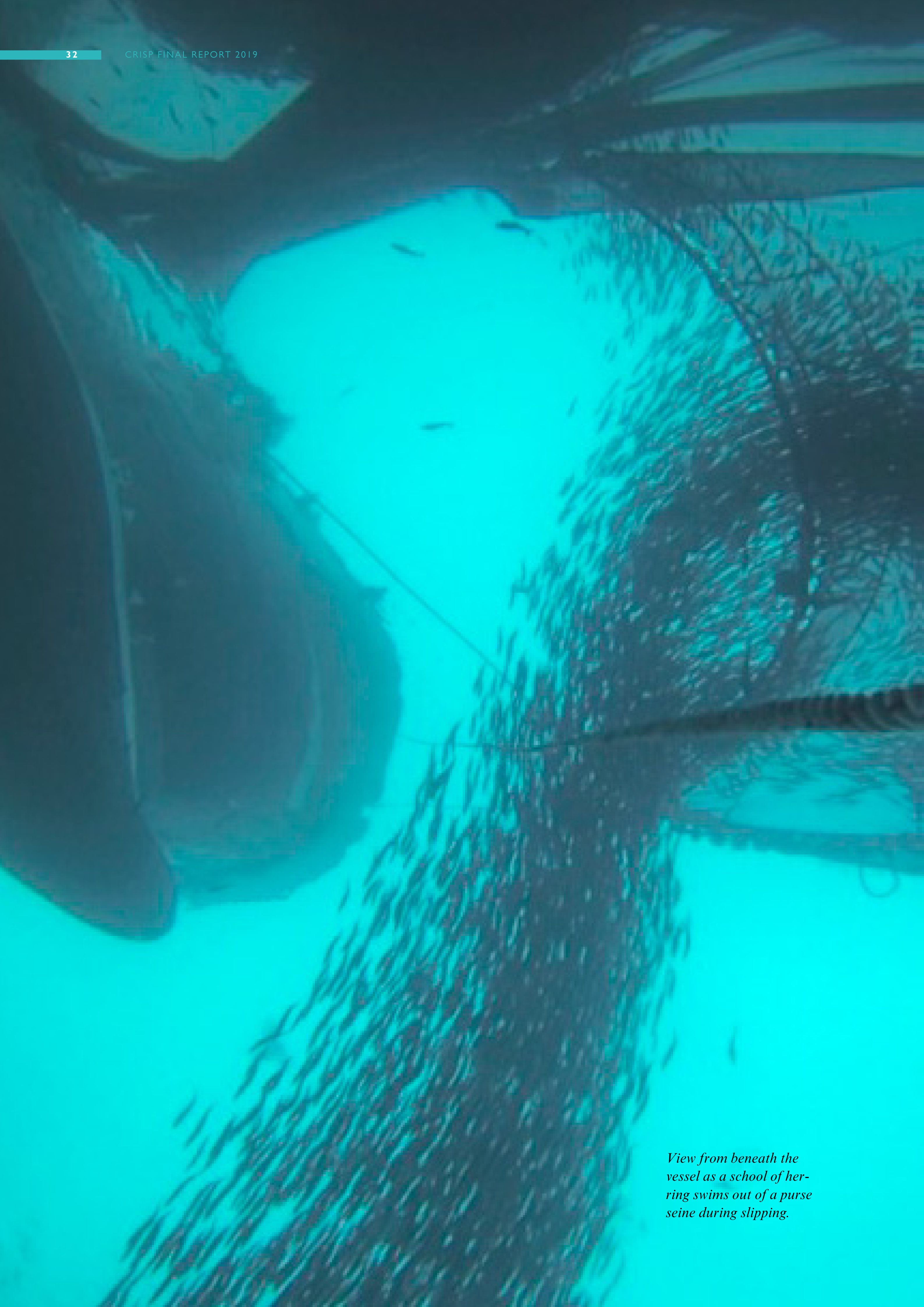
Figure 8. Catch Monitoring Probe (CMP) data from a single commercial purse seine cast showing that crowding density (blue line; ordinal score) and dissolved oxygen concentration (red line; % saturation) (top), and behaviour (below), changed over time (Behaviour summarised in 1 minute bins) (Source: Breen et al, in prep).

grated suite of monitoring instruments directly inside the catch. In 2014, a prototype instrument platform (with cameras, EK15 echo-sounder and CTD & oxygen probe) was built and successfully deployed from a small boat into the catch of a commercial purse seine. However, this mode of deployment had limited practical application; being disruptive to fishing operations and dependent on favourable conditions. Plans to deploy it from a remotely controlled surface vessel were limited by insufficient funds. Instead, in 2015, it was deployed into the seine from the fishing vessel's crane, but this again was unable to collect enough data on the catch. In 2016 and 2017, in collaboration with other projects [RedSlip (NFR 243885) & "Slipping Best Practice" (FHF 900999)], a small version of the CMP was developed that contained GoPro cameras, as well as oxygen, depth and temperature sensors (with a GoPro Camera and RINKO III logger). This was successfully deployed, using a pneumatic canon, into the catches of several commercial purse seines and provided unprecedented data on the behaviour of the catch in the net, as well as key environmental parameters (temperature and oxygen).

In collaboration with Projects "RedSlip", "Slipping: Best Practice" (FHF 900999) and, latterly, "Catch Control in Purse Seines" (FHF 901350)] several variants of the CMP have evolved to monitor different positions and phases of the later catch process: 1) in the net during hauling; 2) on the pump as the catch is pumped aboard; 3) Inside the Refrigerated Seawater (RSW) tank; 4) at the discharge opening during slipping; and 5) outside the discharge opening. In addition, one variant of the CMP is currently under development, with industry partners (Mohn Drilling), that incorporates a stereo-camera to provide accurate estimates of the size distribution in a catch before they become too crowded to safely release, if they are undersized. This variant will be tested in an ROV deployed inside a purse seine in summer 2019, as part of the Catch Control in Purse Seines project, and further funding has been sought to develop this as a commercial tool.

Among the most important results generated using these technologies has been the identification of behavioural indicators of sub-lethal stress in mackerel in the "RedSlip" Project. In controlled experiments at IMR's Austevoll facilities, the CMP and other instruments were used to collect data on sub-lethal behavioural responses of mackerel to the capture related stressors, crowding and hypoxia. These demonstrated that mackerel could tolerate moderate crowding densities (~88 kg.m^{-3} up to 1 h) and relatively low oxygen concentrations (~40% saturation) without significant mortality (as observed up to 8 days after the stressor treatment) (Handegard et al. 2017). However, during crowding the mackerel did show measurable changes in behaviour, including increased swimming activity (tail beat frequency) (Anders et al, 2019) and reduced schooling functionality (predator avoidance) (Handegard et al, 2017). Being able to monitor such responses may have utility in avoiding lethal levels of stress during the capture process of purse seining and thereby increase the survivability of released catches.

Using the CMP, descriptions of behavioural responses of mackerel during purse seine capture have been obtained in slipped and retained catches. Results indicate that as net volume is reduced, the captive school becomes progressively more crowded (Figure 7), schooling behaviour becomes more



View from beneath the vessel as a school of herring swims out of a purse seine during slipping.

disordered and dissolved oxygen levels can be reduced substantially (Figure 8). Interestingly, the severity of these behavioural changes and reduced oxygen concentrations, at higher crowding densities, was less for the slipped catches. Furthermore, descriptions of behaviour during the release (slipping) of unwanted purse seine catches under different conditions has given us an improved understanding of the drivers of disrupted behaviour, as an indicator of poor welfare (Anders et al, 2019b). This may help facilitate future science-based regulation of slipping practises (Marçalo et al, 2019).

As CRISP comes to end, the catch monitoring technology developed in this work package will continue to contribute to other projects and promote more sustainable fishing practices. For example, in "Catch Control in Purse Seines", IMR and SINTEF are integrating several data-streams from the CMPs, in addition to engineering, navigation and environmental data from the vessel (compiled and logged by SINTEF's Ratatosk system). Once compiled, NOLDUS's Observer XT will be used to conduct an integrated analysis of this data and the associated behavioural responses. By integrating data in this way, we will be able to demonstrate how changes in conditions during the capture process can affect the welfare of fish in the retained catch, as well as those released from the net.

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7.2.1 WP 3 - Capture monitoring and catch control during trawling

Work package 3 had the goal of reducing unwanted catches during commercial trawling by providing the skipper with better information on the performance of their fishing gear and the amount, type, and sizes of fish being captured in real-time. The tasks included in WP 3 evolved over the course of the CRISP project, with tasks 2.1 Trawl HUB for camera and acoustic systems and 2.2 catch and gear information system moving from WP 2 to WP 3 and task 3.3 Catch regulation in trawls moving to WP 4. For the purposes of this report, the following tasks are reported under Work Package 3:

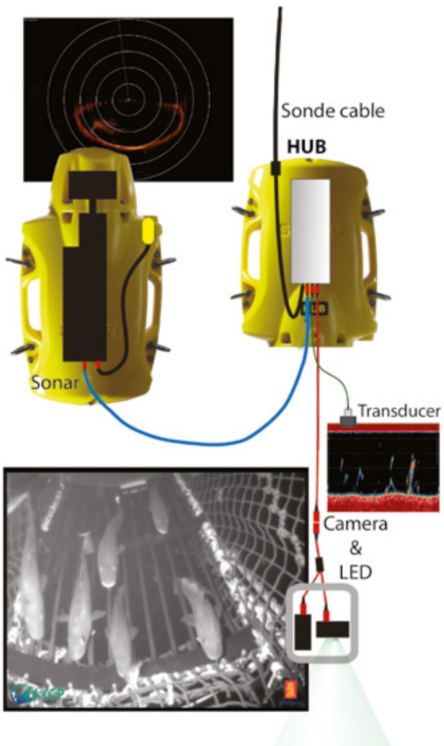
1. Trawl HUB for camera and acoustic systems
2. Catch and gear information system (for trawl)
3. Visual fish classification
4. Active device for selection in trawls

The cooperating partners in Work Package three were Kongsberg Maritime Simrad, Scantrol / Scantrol Deep Vision, IMR and UiB. Kongsberg Maritime Simrad worked on development of the Trawl Hub, catch and gear information system for trawl and one selectivity device (a remotely actuated release connected to the Trawl HUB). Scantrol (Scantrol Deep Vision after 2013) has developed the Deep Vision camera system for visual classification and worked with two prototype active selection device designed to be connected to the Deep Vision system. IMR has coordinated the work package and research cruises. UiB has contributed through supervision of PhD and MSc students working on topics under the work package.

Trawl HUB for camera and acoustic systems

The goal of the Trawl HUB was to provide Ethernet connectivity to the headrope of a fishing trawl for live two-way communication with cameras and other equipment between the vessel bridge and fishing gear. As planned, the Trawl HUB was developed by Kongsberg Maritime Simrad. A schematic diagram of the subsea components of the Trawl HUB system are shown in Figure 1. The hub is flexible in the number and types of devices which can be attached. Options include scientific echosounders (up to 2), a camera with LED light source, multiple IP cameras, scanning and multibeam trawl sonars, and a remote release device.

The Trawl HUB system, marketed as Simrad FX80, has been completed as planned and has been sold to a number of commercial fishing vessels, primarily in the Alaska pollock (*Theragra chalcogramma*) fleet where the camera is used to reduce bycatch by detecting when salmon enter the trawl. In response, the vessel slows allowing the salmon to swim through specially designed "salmon excluders."



« *Figure 1. Schematic illustration of the Simrad FX80 Catch monitoring system with trawl sonar, echosounder, and surveilance camera (left). Image at right shows the system in use detecting salmon while trawling for Alaska pollock.*

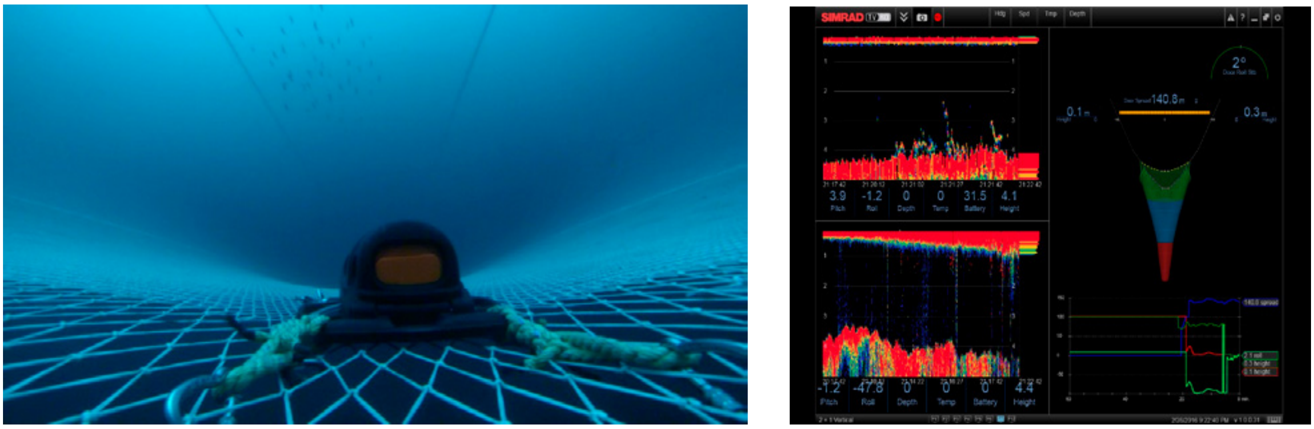


Figure 2. Simard PX Trawl eye sensor mounted on the under panel of a pelagic trawl during a CRISP cruise (left) and TV80 bridge display software (right). Echograms from two trawl eyes are displayed in the left side of the TV80 screen, door clearance above seabed, starboard door roll and door spread at right.

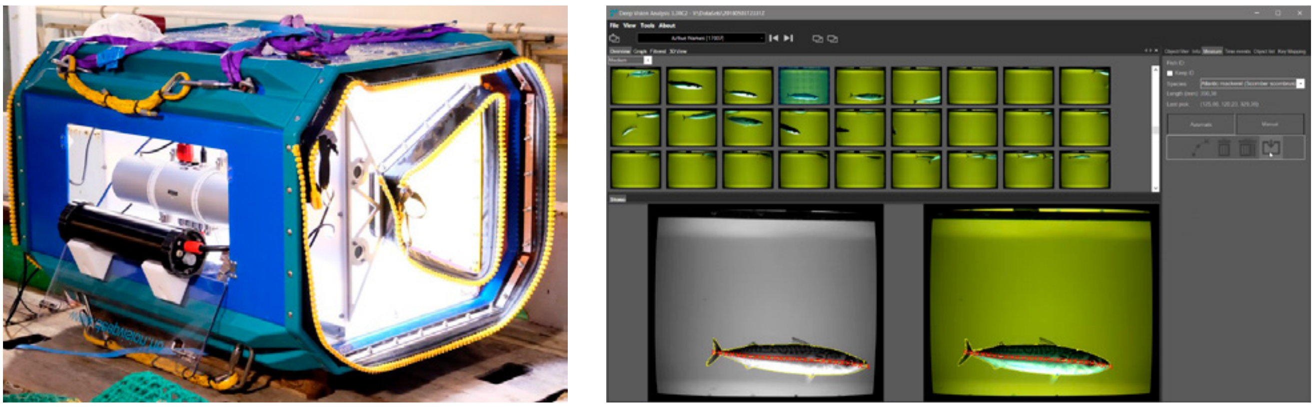
Catch and gear information system for trawl

Parallel with development of the Trawl HUB system, Kongsberg Maritime Simrad has developed and tested a new multibeam trawl sonar (FM90), a new line of multifunctional catch monitoring sensors (PX) and new bridge display software (TV80) (Figure 2). The goal of all these sensors is to improve the skipper's control over the fishing gear and what is entering the trawl. The development of sensors capable of measuring door clearance above seabed and sweep angle was critical to the seimpelagic trawling trials carried out as part of Work Package 4 *Low impact trawl*. The FM90, PX and TV80 systems are all commercially available and used by fishing vessels across the world. New types of PX trawl sensors will continue to be developed after CRISP, such as a flow sensor tested as late as the final CRISP cruise on board R/V G.O. Sars in November 2019.

Visual fish classification

Activities related to visual fish classification inside a trawl have centered around development of the Deep Vision system (commercial partner Scantrol Deep Vision). Originally planned as a system for use in commercial fisheries to avoid catches of unwanted species or sizes, development under CRISP has concentrated on a high-precision system for fisheries research which images everything passing through the trawl and provdes millimeter-scale accuracy in length measurements. Two complete Deep Vision systems have been sold in Norway, with another system ordered for delivery to Korea in autumn 2019. As the research version system is now market ready, Scantrol Deep Vision is continuing even after the end of the CRISP center to design a simpler, more compact version for use in commercial fisheries.

The research Deep Vision system consists of a deployment frame which is placed between the extension and cod end of a trawl; electronics including a stereo camera system, lights and a battery for 6 hours operation, and software for assigning species ID and measuring lengths from the stereo images (Figure 3).



Deep Vision frame and electronics (left) and analysis software used to identify and measure a 35 cm Atlantic mackerel (Scomber scombrus) (right).

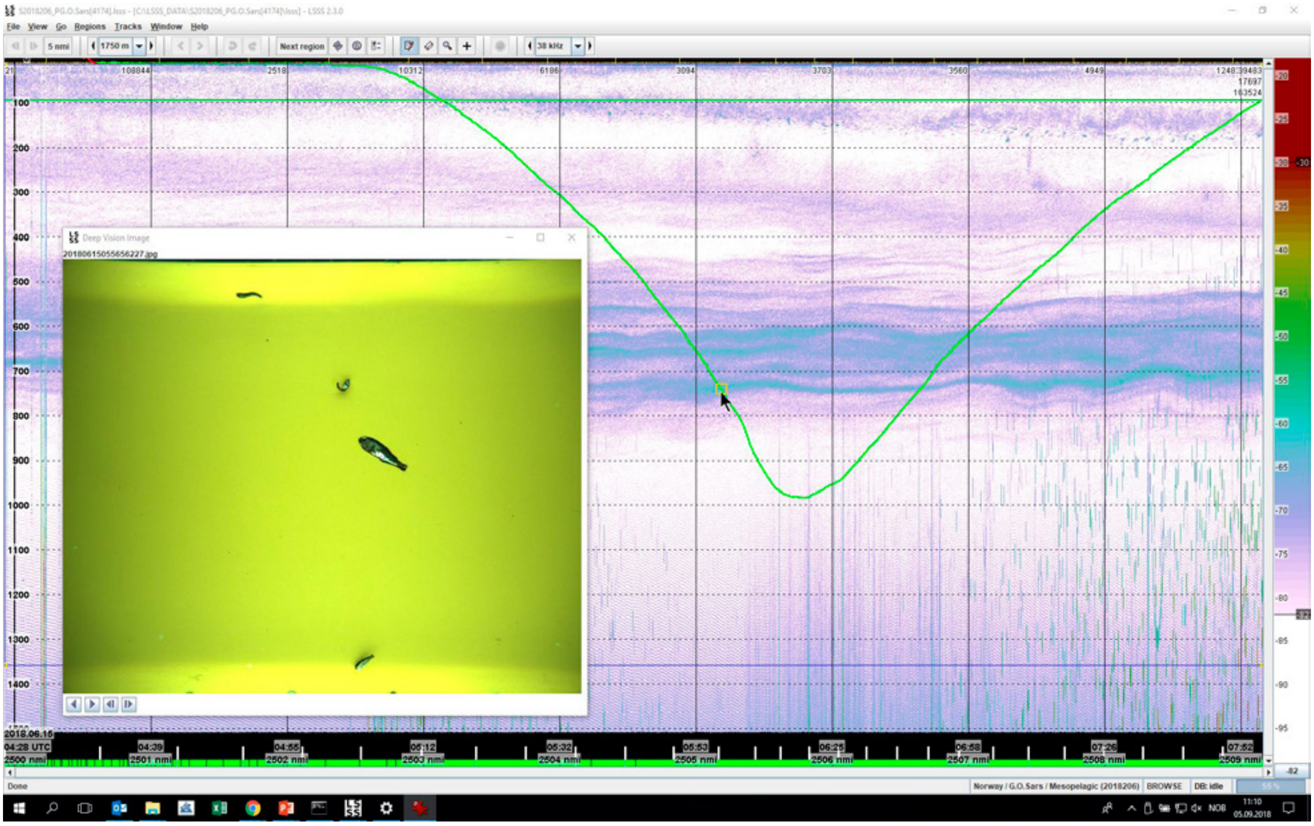
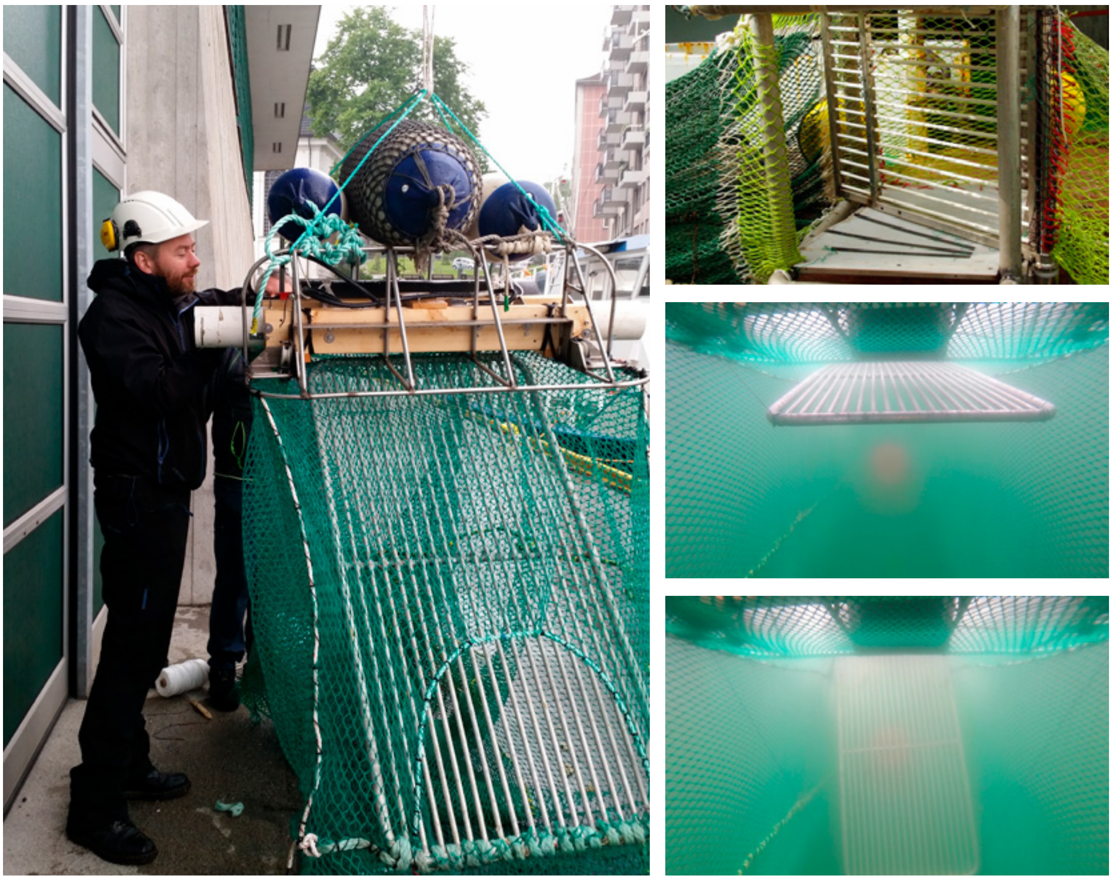


Figure 4. Trawl path and Deep Vision image integrated with LSSS software for display of acoustic data. The green line indicates the trawl's path through the water column (0 to 990 m). The arrow and small orange box indicates the position of the Deep Vision image displayed, which contains four glacier lantern fish (Benthosema glaciale) imaged at 750 m depth.



« *Figure 5. Motorized gate systems tested for active selection inside trawls as part of CRISP.*

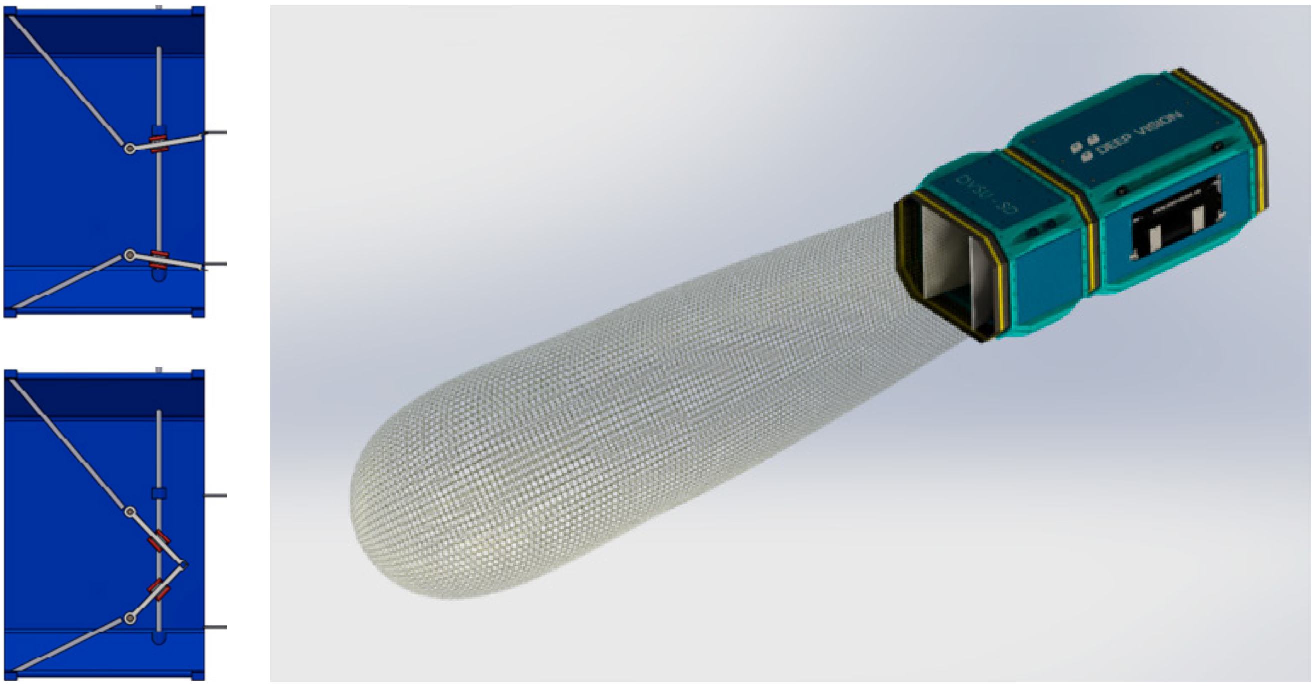


Figure 6. Design of sorting system currently under construction for direct integration with the Deep Vision frame. Top left figure is a top view of the sorting gates in position to retain catch, bottom left in position to release catch released. Illustration of the sorting mechanism placed between the Deep Vision camera frame and codend (right).

Scantrol Deep Vision and the Institute of Marine Research have cooperated to incorporate information on the trawl's position and Deep Vision images within the LSSS (Large Scale Survey System) software used to analyze acoustic data from fisheries surveys. This gives confirmation of species identity when the acoustic data are interpreted (Figure 4).

Active device for selection in trawls

Development of a device for active selection to release non-target fish from trawls was not fully realized during the CRISP project. Two prototype systems based on a moving gate were tested on CRISP cruises (Figure 5). A two-gate system for direct integration with the Deep Vision frame has been tested in benchtop scale and is presently under construction in full-scale (Figure 6).

At the request of a fishing company, Kongsberg Maritime Simrad has developed and delivered a release mechanism connected to the FX80 Trawl HUB (Figure 7). The fishing company is presently designing a system to use this release to open the codend if non-target fish are observed with the camera.

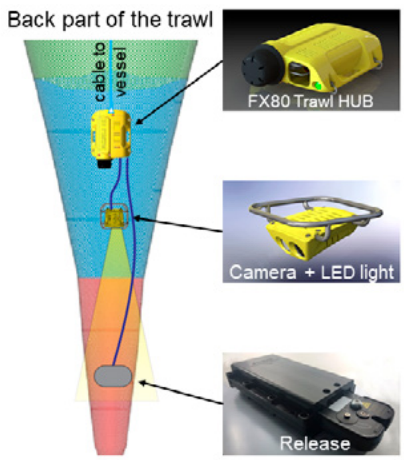


Figure 7. Codend release system based upon Simrad's FX80 Trawl HUB.

7.2.4 WP4
- Low impact trawling

Demersal trawling may have a negative impact on the benthic communities. To develop new trawl designs that minimize the environmental impact of bottom habitats fishing for cod and haddock was thus an important topic within CRISP.

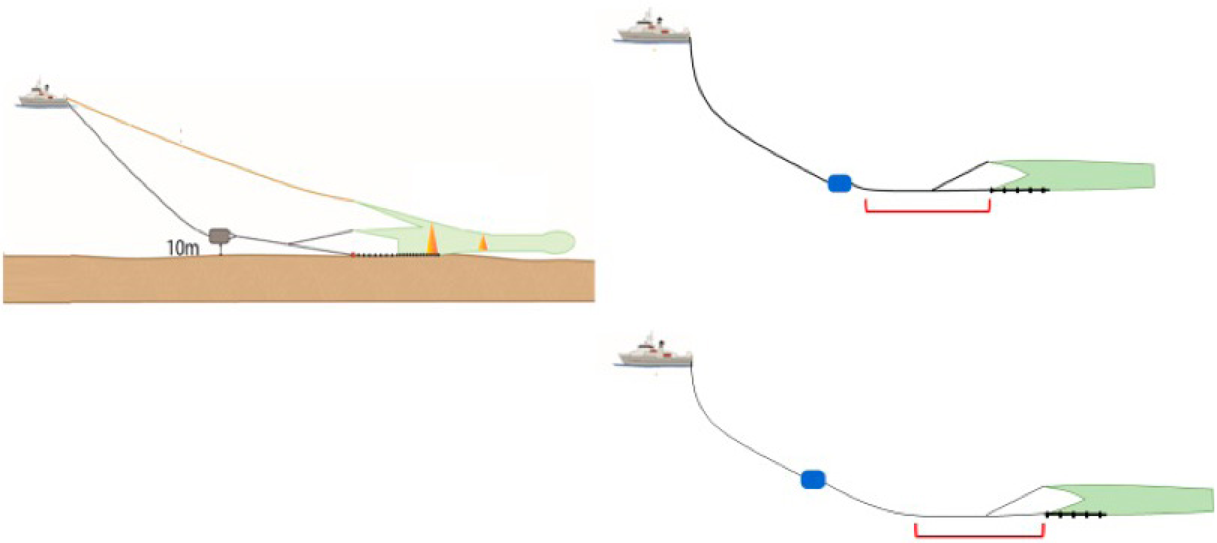
Cod and haddock are usually distributed close to seabed, but they diurnally and seasonally migrate vertically and can be found well off the seabed. Targeting cod and haddock distributed off the seabed using pelagic trawls with no parts of the trawl on the seabed, could be an option to reduce impact on seabed. Trials conducted in the Barents Sea showed that cod and haddock infrequently and unpredictably were distributed off the seabed and often in low concentrations, preventing the species to be captured efficiently with pelagic trawls. Based on these observations, it was prioritized to explore the potential of semi-pelagic trawling for cod and haddock as a way to reduce impact of trawling on the benthic community.

Development of semi-pelagic trawling techniques with the trawl doors and sweeps lifted off the seabed while keeping the trawl on the seabed, included maneuverable trawl doors. Position of the two trawl doors in equal heights above the seabed is important during semi-pelagic trawling to maintain the correct trawl geometry and thus also to maintain the catching efficiency. This cannot be done in all situation by adjusting the warps lengths.

Pelagic trawl doors with hatches above and below the towing brackets were designed and tested (Figure 1). The hatches could be opened and closed by a motor controlled though an acoustic communication system. Trials showed the trawl doors could be maneuvered both vertically and horizontally by opening and closing the upper hatch in the trawl doors. However, the acoustic communication system was found to be too unreliable to be applied commercially.

Trials have been carried out comparing the catching efficiency of cod and haddock between semi-pelagic trawling with the doors and/or the sweeps raised of the seabed (Figure 2) and demersal trawling. When the species were distributed close to the seabed, the semi-pelagic trawl caught fewer fish than the demersal trawl. This suggest that the herding

Figure 1. Maneuverable pelagic trawl doors with hatches above and below the towing brackets developed in CRISP. The hatches are opened and shut with an engine controlled over an acoustic communication system.



Figur 2. Semipelagic trawling: Experiments were carried out to compare the catching efficiency of semipelagic trawling (left) and regular bottom trawling (top right)

stimuli generated by the doors and/or the sweeps at the seabed are essential for catching of cod and haddock when fish are distributed close to the seabed. In situations when cod was shoaling at high densities above the seabed, semi-pelagic trawling provided similar catches to demersal trawling, probably due to downwards herding by the doors.

In conclusion, the current semi-pelagic rigging for cod and haddock close to seabed is not recommended. The reduced capture efficiency would require longer trawling time to obtain the same catches as traditional demersal trawling. Semi-pelagic trawling could under certain situations (high density of fish above seabed) be a viable alternative to demersal trawling for cod.

High population of cod in the Barents Sea from approximately 2010 led to excessively large trawl catches. This resulted in reduced quality when the catch exceeded the vessel production capacity, increasing risk of discarding, gear damage and safety concerns. Therefore, at the request of the industry and managers, CRISP developed a passive system to limit maximum trawl catch size. The Excess Fish Exclusion Device (Exfed) consists of a fish lock just behind a hole in the upper trawl panel covered by a mat attached only at its leading edge (Figure 3). 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 hole. As fish accumulate in the codend and fill up to the fish lock, water flow is diverted out the hole, lifting the mat and allowing excess fish to escape at the fishing depth. The Exfed is mounted at a distance from the cod line to achieve the target size catch for the vessel.

Six Norwegian vessels were given the approval by the authorities to use the system during commercial fishing in 2013. The Exfed system reduced the risk of excessively large trawl catches and has been improved based on the feedback from the commercial fleet. In 2019, 21 Norwegian trawlers have been given permission to use the system.

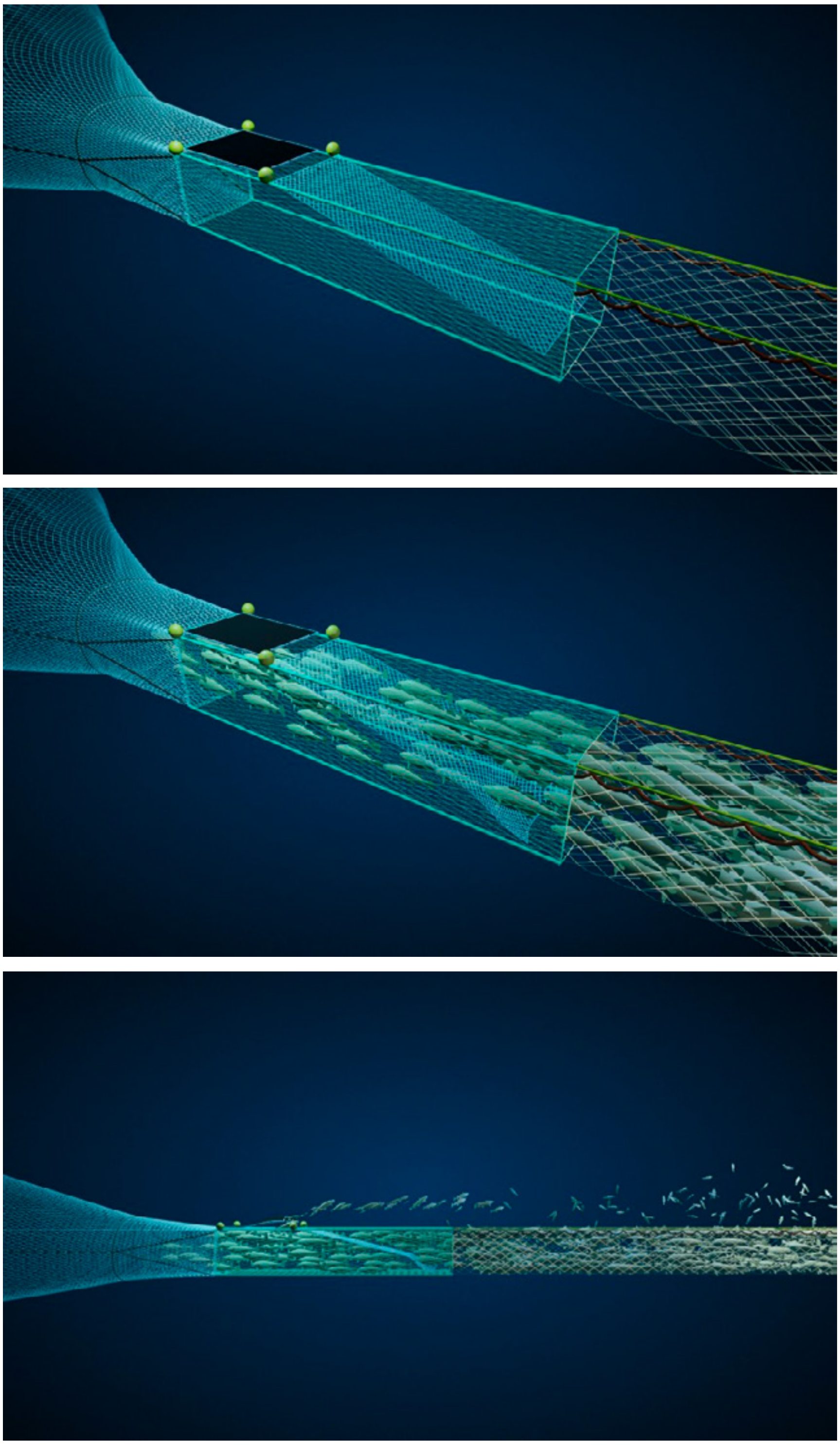


Figure 3. The catch control system (Exfed) consists of a fish lock directly behind an opening in the upper trawl panel covered by a rubber mat tied to the trawl in its foremost end (top). The fish lock prevents the desired quantity of fish to escape during hauling (middle). Initially the mat rests against the top panel, but when the catch builds up the codend, the mat is lifted by the water flow and the catch may escape at the fishing depth (below) (Graphics John Ringstad).

7.2.5 WP5 - Quality improvements

Background
The quality of fish products is influenced by a number of parameters, such as seasonal variations in feeding, temperature and spawning. The quality of the raw material is also strongly dependent on how the fish are captured. In commercial trawl fisheries, the fish are exposed to a number of stressors which may reduce the final quality of the flesh, such as swimming to exhaustion, crowding in the cod end, severe barotrauma, and lack of controlled killing and bleeding.

The hauling process is also likely to damage a substantial part of the catch due to pressure on the fish when it is being hauled towards the boat and transferred from the sea into the vessel's holding bin. The size of the catch has a direct impact on the degree of injuries when large hauls of fish are pulled up the slipway and kept in storage bins for hours before direct gutting. In traditional trawl fisheries most of the fish in the storage bin die before bleeding, resulting in insufficient exsanguination and muscle discoloration. In the CRISP project, Nergård Havfisk AS and Nofima has collaborated regarding quality improvement on board trawlers. It is however challenging to identify and measure all the various stress factors which influence fish quality during commercial fishing. To increase the knowledge about fishery generated stress, an experimental swim tunnel was built. Thus, several stressors have been investigated in controlled experimental studies in the CRISP large-scale swim tunnel/ trawl simulator.

In CRISP, our 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.

WP 5.1 Fillet quality of fish caught by commercial trawlers

Live-storage of fish on board
To study the current state of fillet quality caught by trawls, scientists joined the commercial trawler M.tr. J Bergvoll (Nergård Havfiske AS). During these cruises, stress responses of Atlantic cod and effect of live storage (0, 3 and 6 hour) on the blood-pH, -glucose, -lactate, muscle-pH and mortality were evaluated. The commercial method of direct gutting to process fish on-board, was compared to live storage of fish, which had been percussively killed and bled by throat cutting and then exsanguinated for 30 minutes prior to gutting. In addition, capture related visual quality defects on whole fish (gear marks) on fresh fish fillets (bruises, muscle discoloration and blood spots) were evaluated.

Results
The process of trawling triggers a severe stress response (changes in blood lactate, blood glucose, muscle and blood pH) in fish which is dependent on haul

Live storage of fish for 6 hours before bleeding and filleting, contributes to a whiter color of the fillet (right) than fillets treated in a traditional way (left), i.e. gutted and filleted an hour after capture (Photo: Nofima).

duration and size. These factors also strongly influenced the survival, which varied between 40-95%, with the lengthiest and largest hauls causing the highest mortality. Furthermore, we found that quality was also influenced by fishing practice and that the commercial processing method resulted in more discoloration of the muscle compared to fish that had been stored live for 6 hours. Fish, that was bled (throat cut) immediately after capture, or live stored for 6 hours prior to slaughter, obtained whiter fillets compared to fillets from fish that were processed by the commercial method. The fillets were considerably whiter and had less blood-filled veins. This implies that most of the blood was redistributed away from the muscle during on-board recovery in tanks. Keeping fish alive to recovery for more than 6 hours therefore appears to be beneficial to produce products of higher quality. Based on this result, fishing practices that secure survival on board could become essential for increasing the value of the catch.

In addition to fillet color, the development of rigor mortis was measured on fish slaughtered immediately after capture and after 6 hours of live storage and restitution. The fish that were killed immediately after capture entered rigor mortis significantly faster, than the fish that were kept alive for 6 hours. The fast onset of un-recuperated fish makes them unsuitable for pre-rigor handling as processing fish in rigor may cause the muscle to rupture, resulting in soft flesh and increased fillet gaping.

Buffer towing

Prolonged buffer towing (also called "short wiring") is a method often applied during conditions with high densities of fish, as currently encountered in the Barents Sea. Many trawlers choose to deploy the trawl directly after the catch onboard. Often the approximate desired amount of fish is caught before the catch from the previous haul is processed. Therefore, the trawl is lifted from the seabed and towed at a given depth at low speed, until the production capacity in the onboard factory is restored. The rationale for this practice is securing a continuous supply of fish to avoid any unnecessary stop in the factory onboard the vessel. However, this practice has caused some concern from the fishing industry due to indication of reduced catch quality.

Thus, it was 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 Atlantic cod. The results indicate a significant difference in the levels of glucose, bleeding, as well as fillet color. Thus, prolonged buffet towing has a negative effect on the catch quality.

Dual sequential codend

A new dual sequential codend concept was tested on board M.tr. J Bergvoll, with the aim of improving the quality of trawl-caught fish, by minimizing the severity of catch damage. During towing, the fish was retained in an anterior codend segment with the legislated mesh size. A quality improving codend segment was attached to the aft part of the first codend segment. The attached codend entrance was closed during the towing phase and opened at a predefined

Testing of the new 4-panel cod-end designed to improve catch quality. Egersund Group has designed the new cod-end in collaboration with CRISP's researchers. The bag is kept closed while towing but is opened at a certain depth to give the catch more space during the hauling. (Photo: Nofima).

depth during haul-back. The purposes of the design of the quality-improving codend segment was to reduce the water flow and avoiding the fish being packed too densely during haul-back. When comparing the quality of the cod retained in the sequential codend with cod caught in a conventional codend, the probability for catching cod without catch related damages, such as gear marks, poor exsanguination, ecchymosis, and skin abrasions, was five times higher when using the dual sequential codend.

PhD Student Ragnhild A. Svalheim performs experiments with simulated trawling in the swimming tank outside Tromsø. Here, the effect of different stress factor on fish quality and welfare was tested in controlled experiments (Photo: Nofima).

WP 5.2 Experimental testing of stressors potentially influencing fillet quality of trawled fish

During commercial fishing, there are limited opportunities for identifying, measuring and predicting the importance of the various stress factors which are known to influence fish quality. There are also limited possibilities for manipulating these factors to test if quality improvements can be made. To increase the knowledge about fishery generated stress, an experimental swim tunnel supplemented a small scale codend, where we can isolate and study the effects of the different stressors inflicted upon fish during capture and handling in controlled experimental studies was built. The studies done using the experimental swim tunnel included time-course measurements of stress and quality-determining biological parameters and has provided crucial new knowledge on these mechanisms. More specifically, the experimental swim tunnel and cod-end was used to investigate how the stress from various phases of trawl capture affects the quality in terms of residual blood, time and hardness of postmortem muscle stiffness and muscle color of cod and haddock. In addition, the effect of stress on the importance of timing of euthanasia was also addressed. The studies done in this work package is part of a doctoral thesis entitled “Stress responses influencing fillet quality of trawled Atlantic cod and haddock.

Experimental swim tunnel

The swim tunnel was custom made to provide an experimental setup for swimming trials with groups of large fish. It consisted of a collection of 0.8 m inner diameter pipes, a 3-blade propeller with an integrated 5.5 kW electrical motor secured in an 0.8 m inner diameter aluminum tube housing and a 1400 L octagonal aluminum swim chamber (2.8 m in length and 0.8 m in inner height and inner width). The swim chamber was equipped with an acrylic glass top hatch for loading of fish and a transparent side window for underwater camera observation of the fish. To minimize turbulence, a flow director made from square pipes (5 × 5 cm) of 1 m length, was placed in front of the swim chamber. Grids, preventing fish from escaping the swim chamber, were made from plastic coated stainless steel strands (SS grid) placed in the front and rear ends of the chamber. The lower half of the rear grid slanted, so that its lowest point protruded ca 0.4 m into the swim chamber. Thus, it directed exhausted fish to the upper half of the rear grid, which was attached to the lower half with hinges and could be opened to remove exhausted fish individually. A retaining box made from plastic coated stainless steel strands (SS grid) was placed behind the chamber to prevent fish from escaping further into the tank when the rear grid was opened. A small scale experimental cod-end has been attached to the tunnel. The experimental cod-end was created from net of 80 mm bar mesh size and constitutes four panels with a total length of two meters. Different crowding densities could be obtained by tightening ropes around the bag at various positions.

Results

The first phase of trawl capture that was chosen to study was the herding of fish in front of the trawl mouth. Two experiments were conducted to address this issue. The first one involved exhaustive swimming of cod, and the second critical swimming speed of haddock. These studies showed that exhaustive swimming causes a moderate stress response that takes longer than 6 hours to recover from and that exercise has a short-lasting effect on muscle texture, but little or no effect on muscle coloration. It was concluded that other stages of trawl capture have a higher impact on muscle quality.

The second phase of trawl capture under investigation was how swimming and subsequent crowding would affect the physiology and muscle quality of cod.

Researcher Stein Harris Olsen and PhD student Ragnhild A. Svalheim evaluate the fillet quality after a trial (Photo: Nofima).

Findings from this study showed that crowding caused a severe stress response and that fish probably became hypoxic due to inability to move their opercula and not because of low oxygen levels in the water. In addition, quality was significantly reduced due to increased amount of blood in the muscle. None of the effects of crowding were reversed by recuperation time of 6 hours.

The last stage of trawl capture process, i.e. the effect of air exposure on deck, was also studied. Fish was stressed by gentle crowding and then exposed to air for 15 or 30 minutes or directly euthanised by terminal blow to the head and then left in air for 0, 15 or 30 minutes before exsanguination. We found that the stressed/crowded fish had a stronger response to this air exposure by faster increase in residual muscle blood, which resulted in lower fillet quality. However, direct euthanasia prevented blood flow into the muscle and the quality was significantly better.

Based on the experimental studies done in WP 5.2, we found that it the high pressure during crowding in the cod-end and improper handling of fish on board the fishing vessels are important stages where quality degradation occur during trawl fishing. Crowding and air-exposure cause an increase in fillet redness and blood in the muscle that was not seen for exercised fish. We suggested that the accumulation of residual blood in the white muscles of crowded fish may be the result of insufficient emptying of segmental veins due to the static condition of the muscles during crowding and air exposure in holding bins.

Measures that may secure top quality fish from trawlers, include reducing crowding in the cod-end and implementing immediate slaughter after capture. Recuperation may have beneficial effects on fillet quality by reducing air exposure time and gaining control on slaughter time.

Conclusions

In WP 5 intrinsic and extrinsic factors influencing the quality of trawl caught white fish (Atlantic cod, saithe and haddock) have been studied both on board research vessels, commercial trawlers and experimentally under controlled conditions. The overall conclusion from WP 5, is that gentle handling of fish is the key to a high-quality fish product.

The experimental studies in WP 5.2 showed that crowding and air exposure is highly detrimental to quality. However, as shown from the studies from WP 5.1., these problems can be tackled by keeping towing time as short as possible, implement new gear technology that allow the fish more space during hauling, and by keeping the fish alive on board the vessel to gain control over slaughter time.

The knowledge produced in WP 5 has been noticed by the industry, and several have decided to implement new technology for live storage of the catch on board their new fishing vessels.

7.2.6 WP6 - Value adding

This work package has focused on measuring the added value and sustainability of the new technologies developed through the research done at CRISP. The main focus has been on the vessel categories cod trawlers and purse seiners. An economic assessment of these vessel categories was made at the start of the project. Changes have then been monitored throughout the duration of the project. This has provided a basis for measuring the impact of the new technologies developed through CRISP. Within this, we have developed models to study how technological innovations affect environmental impacts and economic added value by lowering fuel consumption and raising quality.

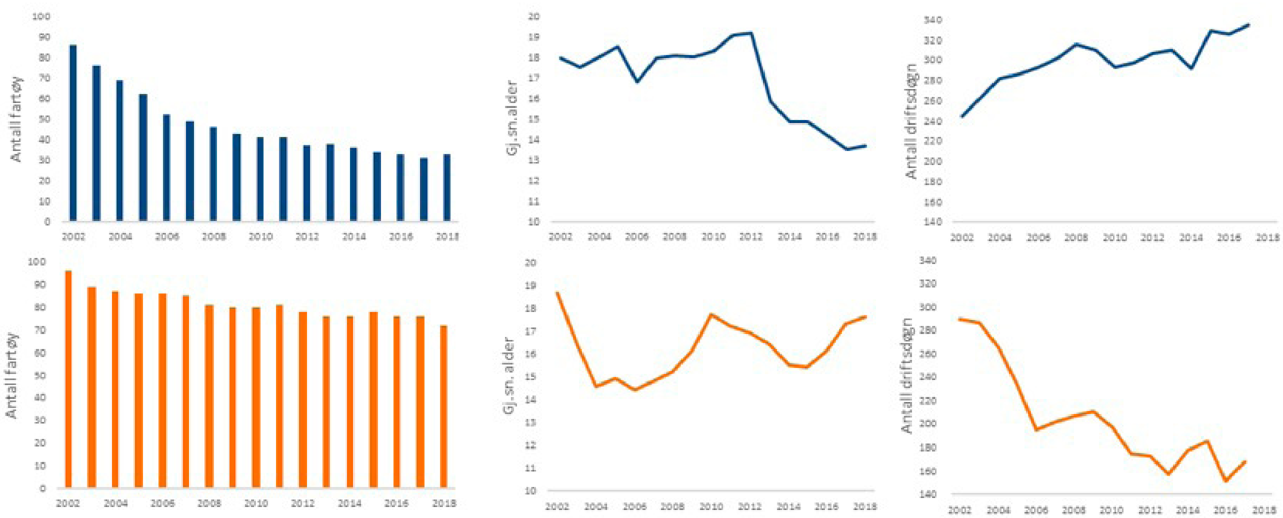
Initial economics of the industry

At the start of the project, we focused our attention on producing status reports for the vessel categories purse seiners and cod trawlers. This resulted in a report on the cod trawler category entitled "Norwegian cod trawlers – structure and profitability", published in 2012. The report examined traditional economic parameters such as changes in capacity, the age structure of the fleet, fishing patterns, profitability, catch value, harvesting costs and fuel consumption. It found that the structure of the fleet was changing and that there were large variations in catch rates, fishing days, fuel consumption and added value within the fleet. An equivalent assessment was done for purse seiners, which resulted in the report "Purse seiners: structure and profitability", published in 2013. A large number of vessels were being replaced, leading to a newer, more modern fleet. The purse seiner fleet had been strongly profitable over an extended period, with an operating margin of around 25-30%, enabling it to replace older vessels. The new vessels were bigger than the ones they were replacing. In spite of the modernisation of the fleet, plenty of room for improvement was found.

What both vessel categories had in common was their strong profitability, but both were highly heterogeneous in terms of their vessels' fuel consumption and added value. There is greater potential to reduce the fuel consumption of cod trawlers, since they are more energy-intensive than purse seiners. The prices they achieve for the fish they harvest are also significantly lower than those achieved by autolining, for example. The two vessel categories target species with different patterns of availability. For example, the purse seiner fleet has highly intensive seasonal fisheries targeting both Norwegian spring-spawning herring and mackerel. The biology of the species therefore plays an important role in the vessels' choice of fishing strategy. Technological innovations that make it possible to focus very narrowly on the part of the biomass with the highest market value will help them to add more value. For both purse seine and trawl fisheries, technology developed through CRISP will help to reduce fuel consumption, increase targeting of the most valuable parts of the stocks and improve catch handling.

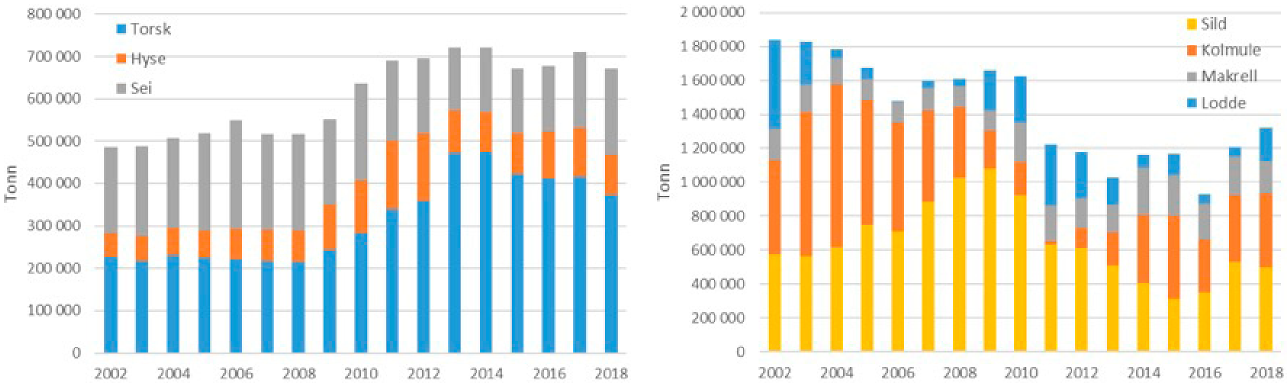
Management regimes affect restructuring

The type of management regime affects how useful the technological innovations developed through CRISP are. It can influence the ability of vessels to implement new technology and the environmental impacts of fishing fleets. It is therefore important to understand how management regimes affect the use and impact of new technology within the two vessel categories. The change in the rules that introduced transferable quotas made it possible for a single vessel to harvest a higher proportion of the total quota[1], and this has had a big impact on structural changes in these vessel categories. Historical events in the



Changes in the number of vessels, average age and fishing days for cod trawlers (blue, top) and purse seiners (orange, bottom) over the period 2002-2018

[1]On the other hand, there are both quota ceilings and other rules that limit the concentration of fishing rights within these vessel categories.

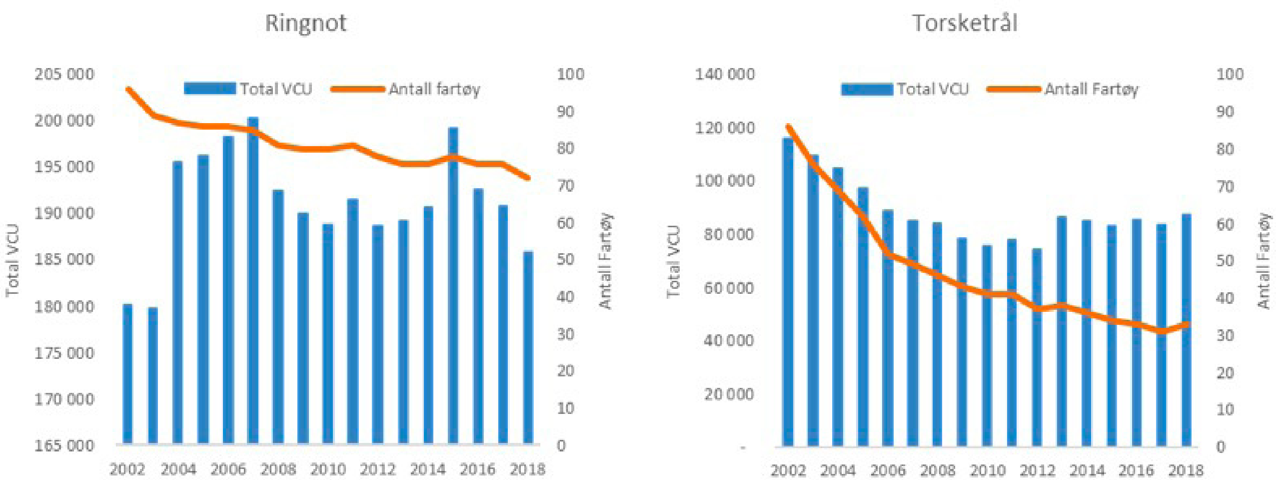


Annual Norwegian catches of cod, saithe and haddock (left) and of herring, blue whiting, mackerel and capelin (right) over the period 2002-2018

fisheries, such as the collapse in the Norwegian spring-spawning herring fishery in the 1970s, the cod crisis at the end of the 80s and the introduction of various restrictions on capacity, must also be assumed to have had an impact.

The bar charts on the left above show a reduction in the number of active vessels in both categories. The reduction in the number of active cod trawlers is most pronounced over the period shown. The cod trawlers have made much greater use of the restructuring opportunities than the purse seiners. In 2018, the proportion of transferable quotas was 62% for cod trawlers and 21% for purse seiners. That is probably related to fishing rights being much less concentrated amongst the purse seiners than the cod trawlers. That fact has allowed most of the restructuring of the trawler fleet to take place at shipowners who own several vessels.

The line graphs in the centre show changes in average vessel age over the period 2002-2018. It is important to note that if no vessels are replaced, the average age will increase each year. The average age of the cod trawlers remained relatively stable from 2002 to 2012, but in the following years more new vessels were brought into the fleet. As a result, the average age has fallen by around five years since 2012, to roughly 13 years in 2018. The purse seine fleet has seen periods when many new vessels have entered service, interspersed with periods with few new vessels. The average age of the vessels in 2018 was 17 years, two years less than in 2002, due to the introduction of many new vessels in the period 2013-2015. The average vessel age is assumed to be an indicator of how technologically advanced the fleet is. For example, innovations arising from CRISP may have been implemented in new vessels during the analysis period. The line graphs on the right show trends in the average number of fishing days per vessel. For cod trawlers, the number of fishing days rose from 244 days in 2002 to 335 days in 2017, whereas for purse seiners the number of fishing days fell over that period, from 290 days to 168 days. On average, the operating parameters for the remaining cod trawlers have improved over the period, whereas the reverse is true for the purse seiners. The differences in the levels of activity must be viewed in the context of



Numbers of vessels and Vessel Capacity Units (VCUs) for purse seiners (left) and trawlers (right), 2002–2018 restructuring, changes in quotas and the renewal of the fleets.

The bar charts above show trends in catches of the most important species for the two vessel categories. On the left we can see changes in catch volumes of the species that are the most important for cod trawlers. On the right we can see the equivalent data for purse seiners. The figures show that the trends have been different for the two categories, which reflects the TAC[2]: any increase/reduction in the TAC for the species will, all other things being equal, increase/reduce activity levels in the category.

The figures above show a reduction in the number of active vessels in both categories. The number of cod trawlers fell from 86 vessels in 2002 to 33 vessels in 2018 (-62%). However, the number of vessels is a poor measure of changes in capacity. As there isn't an equivalent reduction in the category's total capacity measured in VCUs[3], capacity appears to be roughly unchanged since the start of CRISP. The reduction in the number of active vessels means that the remaining modern vessels make better use of their capacity. The purse seiner fleet has exploited the potential for restructuring much less. The reduction in the number of active vessels was only 25% over the period in question. For this vessel category, if we measure capacity in VCUs, capacity has increased since 2002.

Energy consumption

Over the period 2002-2017, for cod trawlers we can observe a reduction in fuel consumption per kg of landed fish. It falls from 0.72 l/kg to 0.39 l/kg, but that must be seen in the context of changes in quotas and an increase in the availability of cod. The most important reason is probably that the number of vessels has fallen sharply, leaving the remaining vessels with far more fishing days and higher quotas. This, combined with the higher loading capacity of the new trawlers, has pushed down the energy consumption per landed kg. We have also found that trawlers sometimes gave up the chance to engage in shrimp trawling during the period analysed. Shrimp trawling is considered significantly more energy intensive than trawling for other species and therefore has a bigger impact on fuel consumption.

In spite of the improvements in the fuel consumption of the trawlers, the purse seiners and their fishery are far more energy efficient. This is primarily due to the fact that purse seines are an energy efficient type of fishing gear. This, combined with intensive fishing with high catch rates over short periods and the use of new vessels with high loading capacities operating near the coast, means that this vessel category is energy-friendly.

Adding value

At the start of CRISP, we uncovered large variations in the prices achieved within each vessel category. Over the course of the project, one important goal has been to raise catch values through gentle and quality-enhancing capture and handling procedures. The innovations that have been developed through CRISP have a positive impact on the quality of the fish landed. Although there has been no discernible reduction in variability in quality, the next generation of trawlers is expected to improve quality significantly. It is particularly pleasing to see that new trawlers are being built with seawater-fed receiving bins designed to keep the fish alive until they are slaughtered. CRISP may thus help to raise the quality of trawl-caught fish to a level previously only attained by autolining.

A study looking at the quality of fish harvested by the purse seiner fleet found room for improvement in parts of the fleet. Technology developed through CRISP that provides more accurate information about the size of schools and the size distribution of the fish within them will facilitate more precise targeting of the parts of the stock with the highest market value, both for purse seiners and cod trawlers. Through CRISP, a new understanding has been built up of the stress levels of fish during capture and storage prior to slaughter. Stress levels affect the quality of the end product. CRISP has therefore used this knowledge to develop improvements to fishing gear technology and the procedures for catch handling.

CRISP's analyses show that vessels choose different strategies for achieving profitability. Some vessels prioritise speed and efficiency. This often has a negative impact on quality. Meanwhile, others prioritise gentle handling of the catch. This often has a negative impact on efficiency. An important challenge for the management authorities is therefore to ensure an efficient first-hand market that rewards good quality and penalises poor quality. That is a fundamental prerequisite if vessels are to introduce the quality-enhancing technology and processes developed through CRISP.

Studies carried out within CRISP show little systematic improvement in catch quality and energy efficiency in the new vessels that have entered service in the two vessel categories. This is probably linked to the fact that older vessels can also implement some of the new technology that has been developed. Moreover, it often takes time for innovations to become available and for all of their impacts to become apparent in the performance of the vessels.

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[2] Total Allowable Catch: The total amount that the fleet is allowed to catch of a particular species.

[3] Vessel capacity units: $VCU=\sum_{-(i=1)} lengde_i \times bredde_i + 0{,}45 \times motorkraft\ (i\ kW)_i$

7.3 HIGHLIGHTS

7.3.1 More accurate catch information with better sonar systems

More precise data on both the total quantity of fish and the size of individuals in schools of pelagic fish like herring, mackerel and capelin makes it easier for captains to target the right school.

Since the 1980s, marine scientist Egil Ona has been working on acoustic methods for measuring the size of fish stocks. During the eight-year-long CRISP programme, he led a work package on developing these methods so that sonar can be used to directly measure the size of schools.

"The project covered methodologies for both calibrating instruments and actually calculating the size of the school. This included physical verification, as the schools were caught with a purse seine after being measured with the instruments", says Ona.

He has been supported by researchers from the Institute of Marine Research and Simrad (Kongsberg Maritime), the PhD student Sindre Vatnehol and, last but not least, several highly experienced fishers and captains.

– If the captain has a better idea of the size of a school and perhaps even of the size of the fish in it, the industry can harvest its quota without harming fish stocks by targeting the wrong schools and causing bycatch mortality during capture.

Accurate estimates depend on experience

Captains of purse seiners use sonar to help choose a suitable school to target. Vessels have fixed quotas and it is important to maximise their value. Captains must therefore make use of all available observation tools combined, of course, with their personal experience to estimate the actual size of the school.

"Traditional sonars have limitations. They mainly tell us the biomass of the school. The margins of error are also often pretty big. How accurately the information is interpreted then comes down to experience", says Ona.

Sources of error include smearing effects affecting the school size, inadequate information about density and acoustic attenuation of the signals transmitted through the school. In addition, swim bladder status and fish behaviour also have an impact on the extent to which herring reflect the sonar signal.

"A dot on the sonar can easily be anywhere between half and three times the size of what you would expect. In CRISP, we have tried to compensate for some of the most important sources of error and calibrate systems to make them comparable between vessels."

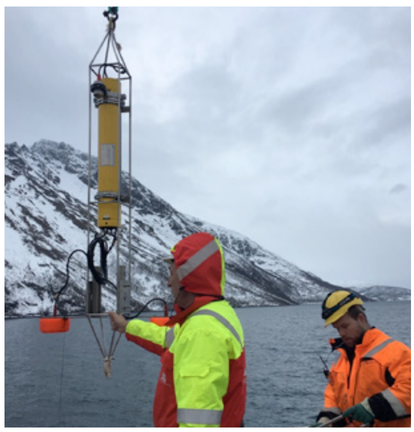
Better hardware and software

The project in CRISP has sought to develop systems that give captains more precise data for estimating school size, and the research has included a number of verification catches taken by both research vessels and fishing vessels.

The work has been done in close cooperation with our industrial partner Simrad, which continuously implements new methodologies into the software of the equipment that it supplies to the fishing industry and researchers.

"Our algorithms are being built into future sonar models, so captains will get figures and data that in principle should be much more reliable", concludes Egil Ona.

Senior researcher Egil Ona, IMR, in activity on a research cruise (Photo: IMR)



Senior researcher Egil Ona, IMR, inspecting fish schools onboard a fishing vessel (Photo: IMR)

FACT SHEET:

Shale Rosen (born 1976) is originally from the United States, but having come to Norway in 2007 to do a Master's degree in fisheries management, he is now a Norwegian citizen. In 2013 Rosen defended his PhD thesis on "Giving eyes to pelagic trawls. Acoustic and optical techniques to measure behaviour, species, and sizes of fish in situ", and he has been involved with CRISP since the start of the programme in 2011.

7.3.2 Nine years with Deep Vision

For the duration of CRISP, researcher Shale Rosen's main task has been working on the development of Scantrol's innovative Deep Vision camera system.

Photo; Scientist Shale Pettit Rosen, Institute of Marine Research (Photo: IMR)

From 2009 to 2013, Rosen was a research scholar through the NFR's Industrial PhD scheme. His employer was Scantrol Deep Vision, and he was assigned to work package 3. For the period 2014-2016, Rosen continued his involvement in work package 3 as a postdoc affiliated to the Institute of Marine Research. He is now permanently employed as a researcher at the Institute of Marine Research, and his duties have included leading scientific surveys for CRISP on G.O. Sars.

Great opportunities

Throughout the period, Shale Rosen's most important task has been developing the stereoscopic camera system Deep Vision, which he started working on right back in 2009.

Deep Vision is a tool designed to improve fisheries research, give more accurate stock estimates and, last but not least, allow far more selective targeting when the technology is transferred to commercial fishing vessels.

– As opposed to traditional systems such as echo sounders and sonar, the Deep Vision cameras give direct visual information about the distribution of species and fish sizes while the fish are still in the sea. This will make it easier for captains to decide whether to go ahead with or abort setting the net, explains Rosen.

Can control fish selection

The plan is also to use the species and length information from the Deep Vision system to remotely control a mechanism that releases fish of the wrong species or size.

– This minimises the risk of catching the wrong species or undersized fish and allows vessels to make the best possible use of their quotas. The data and photos provided by Deep Vision, both on caught and uncaught fish, can also easily be made available to researchers. All of these things will be of benefit to future fisheries management, says Shale Rosen.

FACT SHEET:

Ólafur Arnar Ingólfsson (born 1970) is from Isafjördur on Iceland. In 2006 he defended his PhD thesis on "Size selectivity and escape mortality of gadoid fish in the Barents Sea trawl fishery". Ingólfsson has led the CRISP project looking at how to limit catch sizes to the production capacities of fishing vessels.

Scientist Olafur Arnar Ingolfsson, IMR, inspecting the trawl net on deck in cooperation with gear technician Liz Kvalvik (Photo: IMR)

7.3.3 Catch control is a key factor for raising product quality

Very large catches are a problem for the fishing industry. To ensure that fish for human consumption is of the highest quality, it should be processed before rigor mortis sets in. The longer the processing time, the greater the number of fish that go through rigor mortis, causing an overall decline in the quality of the end product.

Marine scientist Ólafur Arnar Ingólfsson has led a CRISP project to develop new passive mechanical systems that allow excess fish to escape from trawls down at the sea bottom. The project was originally led by Arill Engås, but Ingólfsson took over in 2015.

One of these mechanical systems consisted of an escape hole surrounded by a steel frame, a rubber mat over the hole and a "fish lock" right at the back. The system showed significant promise, particularly when used ahead of the codend without a sorting grid in the trawl net.

In 2013, the Directorate of Fisheries gave six trawlers permission to use and test the catch control device in order to gain practical experience. The following year permission was also granted to test a similar device fitted behind a size-selective sorting grid, but this version of the system wasn't equally effective.

Incremental improvements

In order to improve the catch control system, further tests were subsequently carried out on fishing vessels, supplemented by underwater observations from the research vessel G.O. Sars.

– Based on these tests, improvements were made to the system. The steel frame around the hole proved unnecessary, so it was eliminated. In addition, improvements were made to the shape and buoyancy of the system", says Ingólfsson.

The latest design has worked as intended and makes it possible to avoid excessively large catches, although it still has a limited ability to exclude fish in the event of really big catches. In those cases, the trawl system requires the crew to intervene in the process. The use of mandatory sorting grids in combination with the catch control device also creates sporadic problems. Fish often gather around the grid and some have been observed being "washed out" at the water surface.

Propose specific measures

An alternative concept was therefore also designed and tested as part of the project:

– A four-panel codend with short lastridge ropes to maximise the opening of the mesh was compared against a sorting grid. This significantly improved size selection and so it has the potential to safeguard fish stocks by ensuring that fewer juvenile fish are caught. Our proposed solution for limiting catch sizes is therefore a combination of the catch control device and a suitable four-panel codend, concludes Ólafur Arnar Ingólfsson.

Stein Harris Olsen, Nofima, one of the senior researchers working in WP5 (Foto Nofima)

7.3.4 Handling fish gently brings rewards

Trawling is a highly efficient fishing technique and potentially very profitable, but it is a well-known fact that the quality of trawl-caught fish is variable. The aim of work package 5 has been to improve the quality of trawl-caught fish, partly drawing inspiration from methods and technologies used at modern fish farms and salmon slaughterhouses.

Capturing and hauling in fish as gently as possible, as well as keeping them alive until the moment they are slaughtered, are some of the things that can be done to improve the quality of fish caught in a trawl.

The participants in this work package were Nofima, UiT The Arctic University of Norway, Nergård Havfiske and the Institute of Marine Research.

Want to match the quality of line-caught fish

– In work package 5 we tested methods that can help to reduce the stress and injuries to trawl-caught fish. We also established procedures and techniques for keeping the catch alive on board until it has recovered, says researcher Torbjørn Tobiassen.

We also tested slaughter methods used in the salmon farming industry. Gentle handling and controlled slaughter of the fish improves the chances of getting beautiful white fillets, of an equivalent quality to line-caught fish. Customers consider this to be synonymous with high quality, which makes it good marketing for demanding higher prices.

– The colour of the fillet is therefore an important quality indicator, and in work package 5 the fillet colour was visually assessed and measured with instruments.

Experiments in swim tunnels and on boats

In addition to extensive testing on commercial fishing vessels, studies were also performed in a large, experimental swim tunnel at the aquaculture research station in Tromsø. The tunnel makes it possible to simulate the stress that fish experience during trawling under controlled conditions.

The combined results of these experiments have provided information that helps both researchers and fishers to understand the physiological mechanisms in live fish that affect the quality of the end product.

– In CRISP, technology and methods have been developed that make it possible to keep the fish alive both during capture and on board the fishing vessel. Improved handling of the catch and controlled slaughter, resulting in higher product quality, will in the future be important considerations for trawlers, concludes Torbjørn Tobiassen, a researcher at Nofima.

Researcher Torbjørn Tobiassen, Nofima, inspecting the quality of cod (Foto, Nofima)

7.3.5 The big picture

Nofima's main objective in work package 6 of CRISP has been to analyse and measure the impact of new technologies and methods on the added value and sustainability of the fishing industry.

Nofima's economic researchers have had overall responsibility for the work package, but the contributions of the other work packages and the industrial partners have also been important. The results and models that have been developed provide a basis for making fisheries more sustainable, as well as for catch regulations and technology that can reduce fuel consumption and improve product quality.

Monitored throughout the period
The focus was on the vessel categories cod trawlers and purse seiners. These fishing gears are efficient and profitable, but the quality of their catch is variable.

– These two fishing gears – trawls and purse seines – face different challenges in terms of energy consumption and fish quality. The type of species being targeted – whether it is demersal or pelagic – also influences the harvesting strategy chosen, explains Nofima's Research Director Bent Magne Dreyer.

Economic analyses were carried out at the start of CRISP to ascertain the position before the programme got underway. The analysis covered traditional economic parameters such as changes in capacity, the age structure of the fleet, fishing patterns, profitability, harvesting costs and fuel consumption. Nofima then monitored how the vessel categories performed throughout the eight-year-long programme.

Senior researcher Bent Magne Dreyer, Nofima (Photo Petri Suuronen)

More sustainable harvesting
The reason for monitoring how these parameters changed at the fleet level was to analyse whether the fisheries became more sustainable – environmentally, financially and socially.

– Our focus has been on measuring whether value added has increased, whether the market potential of the limited fishery resources is being exploited better and whether the energy consumption of the two fleets has fallen. One of our priorities has been studying how gentle capture of the most valuable parts of the stocks helps to increase value added throughout the value chain, says Dreyer.

Building models and practical consequences
"As a result of CRISP, Nofima has developed models to explain the links between harvesting patterns, fishing gear technology and value added. These models also incorporate government measures and catch regulations. One of the key goals has been to document how technological innovations in the two fleets have affected added value and environmental impacts.

– Nofima has therefore reviewed the technological products developed through CRISP, their stage of development, the challenges they may help overcome and their overall financial and environmental impacts, concludes Research Director Bent Magne Dreyer.

7.4 TECHNOLOGY DEVELOPED - OVERVIEW

During the program, several technologies have been developed/modified in CRISP. The below listed technologies are at various stages of development. Some of the technologies are for scientific use, whereas others 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), increasing catch efficiency, 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. Verification catches on three species: herring, mackerel and capelin.

2. Calibration of the fisheries sonars: Development of equipment and procedures to calibrate the fisheries sonars with an accuracy of 2-3 % for the Simrad SU90 and Simrad SN90 sonars.

3. Echo sounder system: Development of a new broad band echo sounder system and methods to measure the size of individual fish inside a school (Simrad EK80 and Dabgraf projects)

4. Development of methods for measuring Target strength of single targets in situ in lateral aspect for converting backscattering measured by sonar to biomass. (Probe and WBAT measurements).

5. Development of methods to correct for acoustic extinction (shadowing) in large herring and capelin schools.

WP2 - Gear and catch monitoring systems in purse seine

6. 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.

7. Sonar: Development of a new sonar, Simrad SN90, for use inside a seine

8. Catch Monitoring Probe: development of technology and protocols for monitoring the behaviour and welfare of fish during capture in purse-seines, incorporating 360 camera, stereo-camera and oxygen/temperature sensors.

WP3 - Methods for capture monitoring and catch control during trawling

9. Operationalized Deep Vision in-trawl camera system: Development of in-trawl camera system for species identification and sizing of fish

10. 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

11. Simrad PX MultiSensor trawl door sensor and TVI topside interface

WP4 - Low impact trawl

12. Trawl doors: Developed trawl doors, which can adjust the spread and position in the water column.

13. Catch regulation device: Developed and implemented a catch regulation device for trawls that releases excess fish at fishing depth

WP5 - Quality improvement

14. CRISP trawl simulator: Developed as a scientific tool to simulate trawling conditions in small scale, which `produce trawl-caught fish in the laboratory`.

15. Live fish technology: Development of knowledge and a prototype tank for live storage of cod on board trawlers

16. Vacuum pumping from cod-end: Test vacuum pumping onboard a commercial trawler to improve the landing of fish from the cod-end

17. Stunning and bleeding machines: Tested a modified stunning and bleeding machine (Baader- SI7) on a commercial fishing vessel

18. Sequential codend: Development of a new codend concept, designed to improve the quality of fish without compromising size selectivity.

19. Hydrostatic catch releaser: Development of a hydrostatic catch releaser, which opens the entrance of the quality improving codend segment of the sequential codend during haul-back. Also tested/applied in demersal seines.

7.5 AWARDS

Nor-Fishing awarded its innovation prize for 2016 to Scantrol Deep Vision AS for its development of Deep Vision. From left, Director of Fisheries Liv Holmefjord, Minister of Fisheries Per Sandberg, Business Development Manager at Scantrol Deep Vision Hege Hammersland-White and engineer Håvard Vågstøl (photo: Nor-Fishing).

In 2016, Scantrol Deep Vision AS won the Nor-Fishing fair's innovation prize for its development of the Deep Vision system. The prize was awarded by Director of Fisheries Liv Holmefjord during the fair, which was held in Trondheim in August. Minister of Fisheries Per Sandberg was also in attendance. The award was based on Deep Vision's potential to revolutionise both marine research and commercial fishing.

For CRISP it was particularly pleasing that the Institute of Marine Research, represented by one of its researchers affiliated to CRISP, Olafur Arnar Ingolfsson, was also nominated for the prize for its development of a catch control device for Danish and Scottish seines.

AS THE JURY SAID:

***Scantrol Deep Vision AS, Bergen: Deep Vision** is being developed as an alternative, supplementary method for monitoring catches, and uses stereographic images from the trawl, as opposed to current methods based on acoustics and experience. 3D modelling of the fish makes it possible to determine the species and fish length, which in turn enables sorting of the catch in the trawl and more efficient fishing based on market prices, controls and quotas, with less bycatch. The technology can give an important contribution to more ethical fishing practice as well as an environmentally sustainable management of marine resources. The system is expected to be of great importance to international marine research as well as to commercial fishing."*

Figure 3. HRH Prince Charles and King Harald chatting to the former Programme Director of CRISP, John Willy Valdemarsen, the IMR's former Managing Director, Tore Nepstad, and the head of the Norwegian Herring Sales Association, Johannes Nakken, on board the purse seiner Brennholm (Photo: IMR).

The Institute of Marine Research, represented by Olafur Arnar Ingolfsson (far right), was also one of the three finalists for Nor-Fishing's innovation prize for 2016 for his development of a catch control system for Danish and Scottish seines (photo: Nor-Fishing).

Group photo from the Ny-Ålesund Symposium 2016, where the participants included HRH Crown Prince Håkon and former Minister of Fisheries Per Sandberg. Aud Vold, the Programme Director of CRISP, was invited to give a presentation on the CRISP centre at the symposium (Photo: Ny-Ålesund Symposium).

We are also proud that Bent Dreyer of Nofima, a senior researcher affiliated to CRISP, has been invited to be an expert adviser to the FAO on two occasions: autumn 2015 and spring 2017. During his time there he held the seminar **"THE COMPLEXITY OF SUSTAINABILITY IN THE SEAFOOD INDUSTRY,** Capture based aquaculture of Arctic cod – state of the art."

In 2012, CRISP was presented to HRH Prince Charles and King Harald on board the purse seiner *Brennholm* when they visited Bergen and the Institute of Marine Research. Prince Charles had specially requested that an introduction to marine and fisheries management be included in the programme. Some of our leading researchers told the royals about CRISP's research work. We are also very proud of the fact that CRISP, represented by its Programme Director Aud Vold, was invited to present the centre's vision and innovations at the Ny-Ålesund Symposium "Planet Ocean" in September 2016. This symposium is an annual event that brings together international and Norwegian decision-makers, researchers, key business leaders and other high-level participants. The theme in 2016 was global challenges related to the oceans and climate.

8. INTERNATIONAL COOPERATION

CRISP has cooperated with international research institutions where this has been useful for joint development activities and for promoting sustainable fishing gear technology beyond Norway's borders. The industrial partners in CRISP are Norwegian-owned companies, and all of their production takes place in Norway. They have therefore been somewhat reluctant to involve foreign partners who may share their knowledge of the products with potential international competitors.

Nevertheless, it has been important to spread CRISP's vision of ensuring a profitable fishing industry by developing technology to make it more sustainable. This has been done through researchers affiliated to CRISP attending scientific meetings and symposiums. There is a great deal of international interest in the technology that has been developed through CRISP. This is particularly true of the innovations in fish-finding equipment like sonar and echo sounders, catch and fishing gear monitoring systems like FX80 and Deep Vision, and handling methods to improve the quality of trawl-caught fish.

For example, in recent years scientists from a number of countries have attended a course, held on the research vessel "G.O. Sars", on how to use a broadband acoustic system developed through CRISP to measure the size of schools. Hector Peña, a researcher at the IMR, has also held courses on how to use sonar technology at research institutions in Spain, Argentina and the United States.

Hector Peña, senior researcher at the IMR, training researchers at the Argentinian National Institute of Fisheries Research and Development (INIDEP) in the use of sonar technology in 2017.

Researcher Pyungkwan Kim of The National Institute of Fisheries Science, South Korea, examines Deep Vision's underwater unit on RV "G.O. Sars" in late autumn 2018 (photo: Tim Petter Hansen).

The Russian researcher Alexander Pavlenko of PINRO in Murmansk went on a survey with RV "G.O. Sars" in 2012.

Several researchers affiliated to CRISP have been key players in the Horizon 2020 project MINOUW: Science, Technology, and Society Initiative to Minimize Unwanted Catches (Grant Agreement number: 634495 - MINOUW - H2020-SFS-2014-2015). This project aims to gradually eliminate discards from European fisheries. Equipment, instruments and methods developed under the umbrella of CRISP, such as the Deep Vision technology and low-impact slipping technology for purse seines, have been presented as ways to reach goals on reducing bycatches and fish mortality. CRISP also takes part in the INTPART project PRIMA LEARNING ("Connecting hands-on-practice and innovative marine ecological sampling methods and analysis tools for enhancing student learning of ocean science"), led by the University of Bergen. The aim of this project is to develop students from South Africa into highly qualified fisheries research scientists.

Researcher Shale Rosen of the IMR, who is affiliated to CRISP, also participates in the Nansen Programme and has taken part in missions on the research vessel "Dr. Fridtjof Nansen". This vessel is operated by the FAO and sails under a UN flag. Our most important activity has been implementing the Deep Vision technology as a tool for fish stock monitoring, particularly for mesopelagic fish. The National Institute of Fisheries Science, South Korea, has purchased the Deep Vision system for use in its national fish stock surveys. The Korean researcher Pyungkwan Kim has therefore attended surveys with *G.O. Sars* to gain experience of using this kind of technology.

9. TRAINING AND RECRUITING RESEARCHERS

In its original project plan, CRISP aimed to train 6 PhD students, one in each work package. In total 7 PhD students were taken on, one more than planned, because UiT The Arctic University of Norway decided to employ and fund an extra student who was assigned to package 5. For personal reasons, one of the research students chose to drop out before completing their PhD, so we ended up with the originally planned number. Four of them have submitted and defended their theses, one is planning to submit it during the autumn of 2019, while the final student will take a bit longer on account of taking parental leave. In addition, CRISP has financed two postdoc positions, and trained 16 Master's students.

CRISP's field of work, fishing technology, has traditionally been a highly male-dominated area, both in the research community and industry. We are therefore very proud that half of our PhD and Master's students are women. The candidates who have completed their PhDs have all immediately been employed in research positions at Nofima, the Institute of Marine Research and the UiT The Arctic University of Norway. Our Master's students have entered a wide range of careers, e.g. the fishing gear industry, fisheries management and further research.

TABLE 1
EMPLOYMENT STATUS OF STUDENTS WHO HAVE COMPLETED THEIR PHD

At a research institute	At a university	Not yet completed	Withdrew	Total
3	1	2	1	7

9.1 PHD-STUDENTS

9.1.1 Computer correction of sonar images

Multi-beam sonars are important tools for fishers when searching for schools of pelagic fish like mackerel, herring and capelin. With better information about the size of the school, it may be possible to avoid catching ones that are too big.

This was the core area that Sindre Vatnehol investigated during the early phases of the project he was assigned to, and people like researchers Hector Peña and Arne Johannes Holmin took up the baton when Vatnehol completed his PhD in 2016.

As a research scholar, Vatnehol was affiliated to the Institute of Marine Research and University of Bergen, and after completing his PhD he was given a postdoc position in the Institute of Marine Research's project on Reduced Uncertainty in Stock Assessments (REDUS). Sindre Vatnehol has since 2018 been employed as a researcher in the Institute of Marine Research's pelagic fish research group.

Correcting for "smearing effects"
In his work on his PhD, Vatnehol studied some of the most important improvements needed to increase the accuracy of sonar measurements of school sizes. The biggest job was enabling the sonar to perform quantitative measurements, i.e. developing calibration methodologies. He also did simulations of how to correct calculations of the volume of fish schools for "smearing effects".

"Essentially you need to estimate two parameters: school volume and school density. The volume is calculated by measuring the horizontal and vertical cross-sectional areas of the school. These areas must then be computer corrected for the 'smearing effects' of the school, as the volume of the school shown on the computer is significantly bigger than it is in real life."

FACT SHEET:

Sindre Vatnehol (born 1986) is from Ålesund. He has a Master's degree in physics from the University of Bergen (2012) and from 2012 to 2016 he was a research scholar at the Institute of Marine Research. In 2016 he defended his PhD thesis on "Increasing the biomass estimation accuracy of a single fish school using a cylindrical multi-beam fishery sonar".

Avoiding schools that are too big
The density estimate for the school is based on the strength of the echo, and for this value to be correct, the sonar must be properly calibrated. In addition, the school echo is strongest when you observe migrating schools from the side.

"By circling around the school several times, like fishing vessels do when targeting schools, we were able to show that it is best to use the strongest echoes when converting the school echoes into actual fish densities", concludes Sindre Vatnehol.

In the future this research may lead to more accurate measurements of school sizes, which will make it easier for fishers to avoid ending up with schools that are far too big in their nets.

Sindre Vatnehol, former PhD-student in CRISP, is presently employed as researcher at IMR (Photo: IMR).

FACT SHEET

Melanie J. Underwood (born 1980) grew up in Australia. She took a Master's degree in cognitive and behavioural ecology at the Memorial University of Newfoundland in 2012. Later that year she joined the Institute of Marine Research and University of Bergen as a research scholar. This led to her obtaining a PhD from the University of Bergen in 2018. Underwood is now working as a postdoc at the Institute of Marine Research.

9.1.2 Alternatives to bottom trawling

It is important to understand fish behaviour and the complex interaction between the fish and the trawl gear before trying to design better trawls. This requires a good understanding of how the trawl works and observations of how fish come into contact with the various parts of the fishing gear.

In CRISP's work package 4, Melanie J. Underwood's main task was investigating whether semi-pelagic trawling is a realistic alternative to bottom trawling in cod fisheries. This involved studying the catching efficiency for cod and using hydroacoustics to understand the reaction of cod to the two different trawling techniques. Underwood also used cameras mounted at the front of the Deep Vision system to observe whether fish stopped or passed rapidly on when they reached the Deep Vision channel.

Methodological challenges

Part of the research she did for CRISP formed the basis for Melanie J. Underwood's PhD thesis on "Understanding interactions between fish and trawl gear in order to improve catching efficiency and scientific sampling, with focus on methodological challenges". The thesis focused on solving methodological challenges and improving our understanding of how fish react to bottom trawling, semi-pelagic trawling and pelagic trawling respectively.

– Studying how fish interact with trawl gear poses methodological challenges. New camera systems and advanced hydroacoustics are important tools, but there are still gaps in our knowledge, says Underwood.

Better understanding of behaviour results in better fishing gear

The results highlight the complexity of multi-species studies and suggest possible ways of improving the current methodology. A better understanding of fish behaviour may lead to changes to fishing gear that increase the efficiency of bottom trawling.

In addition, under certain conditions it is possible to profitably trawl for cod using fishing gear with a lower impact on the sea bottom.

– The potential benefits arising from the research include higher catching efficiency and lower environmental impacts in fisheries, as well as adaptations to trawls to make them work better for scientific sampling, says Melanie J. Underwood.

Melanie Underwood, former PhD-student in CRISP. She is presently a postdoc at IMR (Photo: IMR).

Ragnhild Aven Svalheim, former PhD-student i CRISP. Ragnhild is now employed as researcher at Nofima in Tromsø (Photo: Nofima).

9.1.3 Gentle handling improves quality

By studying the physiology of fish over the course of the whole capture process, we can learn about the relationship between fish welfare and the quality of the end product.

The most important question for Ragnhild Aven Svalheim in relation to work package 5 was which parts of the trawling process have the biggest impact on deterioration in the quality of fresh cod fillets.

– We also looked at whether there is a link between fish stress levels and fillet quality, and found that it's not just about stress levels: the manner in which the fish are stressed also plays a key role. Gentle handling of the fish always produces the highest quality!

Affiliated to Nofima

Svalheim has a Master's degree in fisheries biology and management from the University of Bergen and completed her PhD at Nofima and UiT in 2018. She now works as a researcher at Nofima in Tromsø.

This research institute, which focuses on commercially useful research, played a key role in work packages 5 and 6 in CRISP.

– Being able to clarify which parts of the trawling process have the biggest impact on deterioration in quality and why provides a basis for developing new technologies that can help to improve the quality of trawl-caught fish, says Ragnhild Aven Svalheim.

FACT SHEET:

Ragnhild Aven Svalheim (born 1988) is a Norwegian citizen. She was assigned to CRISP work package 5 during the period 2013-2019.

The researcher: Jesse Vallevik Brinkhof (28) is a Dutch citizen affiliated to UiT The Arctic University of Norway/Norwegian College of Fishery Science, who contributed to work packages 4 and 5 of CRISP. He was employed as a research scholar until he defended his thesis on 14 February 2019.

9.1.4 Catch quality and size selectivity during bottom trawling for cod

Buffer towing lowers the catch quality and fish survival rate while using a gentler codend quintuples the probability of catching fish without any visible injuries.

These are some of the conclusions of Jesse Vallevik Brinkhof's PhD project "Catch quality and size selectivity in the Barents Sea bottom trawl fishery – effect of codend design and trawling practice".

The most important aspect of the project was investigating how trawling practice and trawl design affects catch quality and size selectivity. These questions are important both in terms of enabling fishers to achieve higher prices and making bottom trawl fisheries more sustainable.

Better catch quality and fish welfare
"My research interests lie in fishing gear technology, and I wish to develop and facilitate technologies that benefit both the resource users and the resources. The background to my thesis is the growing interest in catch quality and fish welfare, both within the fishing industry and amongst consumers", says Jesse Vallevik Brinkhof.

The first two studies in the thesis document the impact of buffer towing on catch quality and size selectivity. Buffer towing is performed when the trawl catches a sufficient quantity of fish before the previous haul has been fully processed. In those circumstances, fishers may choose to raise the trawl off the bottom and tow it through open waters until they can haul the catch onto their vessel.

– This practice has a negative impact on catch quality by causing pressure injuries and skin abrasions. It is also suspected that some fish escape during buffer towing. The survival chances of those escaped fish are unclear.

Newly developed sequential codend
The third and fourth studies look at a newly developed dual sequential codend, also known as the "snuggle bag". The concept consists of two segments, the first of which performs the size selectivity needed to avoid catching undersized fish. The second segment is closed during fishing, and opens after the catch is hauled onto the vessel, so the fish have more space and suffer fewer pressure injuries. It also retains some water when the trawl is being hauled aboard, which is good for fish welfare. Compared with a traditional codend, the catch quality improved. In fact, the probability of catching fish without any visible injuries quintupled.

– The sequential codend didn't have any negative impact on size selection either, says Jesse Vallevik Brinkhof.

All of the studies required data to be collected from tests performed on trawlers. This was done using the research vessel "Helmer Hanssen", which belongs to UiT The Arctic University of Norway, and the trawler "J. Bergvoll", which belongs to Nergård AS.

Jesse Brinkhof, former PhD-student in CRISP, is presently employed as researcher at UiT (Photo: Nofima).

FACT SHEET

Neil Anders (born 1986) is a research scholar who was assigned to work package 2 of CRISP. He is a British citizen who works for the Institute of Marine Research. He plans to defend his PhD thesis on fish welfare during purse seining for mackerel in December 2019. After that, Neil Anders wants to continue with his research on fishing gear as a postdoc or in an equivalent research position.

PhD-student Neil Anders is assigned to work package 2 of CRISP. He works for the Institute of Marine Research and is expected to defend his thesis at the end of 2019.

9.1.5 How to reduce injuries to mackerel

In the purse seine fishery for mackerel, "slipping" an unwanted catch is legal under certain circumstances, both in Norway and the EU, but it remains unclear to what extent the fish survive the stress associated with this. Moreover, the rules are somewhat unclear and difficult to enforce.

Fish injuries and stress obviously have a negative impact both on catch quality and the survival rate in conjunction with slipping, i.e. releasing an unwanted catch before hauling it aboard. Neil Anders' PhD project aims to improve our understanding of how the stress experienced by mackerel during purse seining affects their survival chances if they are released. His research has also looked at how stress influences product quality for mackerel that are landed.

The project has involved collaboration with Mike Breen (IMR/CRISP researcher), Jostein Saltskår (IMR/CRISP technician), Bjørn Totland (IMR/CRISP technician), Jan Tore Øvredal (IMR/CRISP technician) and Aud Vold (IMR researcher and CRISP Programme Director).

Schools mustn't break up

Neil Anders has focused particularly on the mackerel's schooling behaviour prior to slipping. If the school breaks up before slipping, this is a strong indicator of excessive stress levels, which can lead to high mortality rates.

The research has involved a combination of fieldwork on the fishing vessels "Fiskebas" and "Sjarmør" and laboratory experiments. On the vessels, GoPro cameras were used to record videos inside the seine, and the results showed that small schools of fish that swim out of the net early on manage to maintain their school structure. In big hauls, on the other hand, the fish density is very high. Fish are then often squeezed out of the seine and the schooling behaviour becomes chaotic.

This can increase the mortality rate compared with if the fish have been subject to less stress and have been released in an intact school.

Current procedures are a good starting point

As part of his work, Neil Anders has also looked at the swimming behaviour of fish that are released using the current "best practice" slipping method. Research shows that with this slipping method there is a low frequency of abnormal behaviour in the released fish, so mortality rates should be low if everything goes to plan. The new knowledge provided by Anders' research is the importance of avoiding schools breaking up and of not catching excessively big schools.

There remains, therefore, a need to develop new methods and to learn more about what causes schools to break up in order to further improve survival rates. A better understanding of the mackerel's ability to withstand stress factors during capture, including crowding, a lack of oxygen and a breakdown in the school structure, will enable us to develop more effective countermeasures to limit the harm caused. These measures could include adjusting the size of the discharge opening and the proportion of the school that is released.

Improved procedures would also help to maximise the quality of the part of the catch that is kept. Neil Anders' PhD therefore makes a direct contribution to improving the sustainability and profitability of the Norwegian fishing industry.

9.2 POSTDOC-POSITIONS

9.2.1 Fish in the cod family cope well with exhaustion

Former postdoc Anders Karlsson-Drangsholt (Photo: Maya Boutroue Vedeld)

FACT SHEET:

Anders Karlsson-Drangsholt (born 1982) was assigned to work package 5 of CRISP and affiliated to UiT The Arctic University of Norway for the period June 2012–June 2015. He is now a senior adviser at the environmental group Bellona.

Are fillets from cod and haddock that have to swim hard prior to slaughter of lower quality? Is there any difference in how well species cope with this? Swim tunnel research makes it possible to introduce targeted measures to improve the quality of trawl-caught fish.

In a series of experiments, wild-caught cod and haddock of the typical size for consumption were put in the swim tunnel in Tromsø, where the fish had to swim to exhaustion.

The project was led by Anders Karlsson-Drangsholt. Ragnhild Aven Svalheim, Øyvind Aas-Hansen, Stein Harris Olsen, Kjell Øivind Midling, Michael Breen, Endre Grimsbø and Helge K. Johnsen also helped with the experiments and are listed as co-authors of the two resulting reports.

Cod are robust

The project aimed to replicate the typical situation during trawling where fish often try to swim towards the mouth of the trawl until they become exhausted or lose interest in escaping. We investigated whether this exhaustive exercise affected the quality of the fillets, and to what extent "convalescence" periods of varying durations could return the fish to their normal, unstressed and rested state.

The results of the experiments showed that swimming to exhaustion increased the level of muscle stiffness in cod during rigor mortis, but it didn't alter the time until maximum stiffness or result in noticeable discolouration of the fillets. Lactic acid and cortisol levels also increased after swimming, but then fell gradually over the recovery periods. The pH level of the muscle fibres of exhausted cod typically returned to normal after four hours.

The data suggest that exhaustive swimming has a moderate and rapidly reversible effect on fillet quality. During trawling, fish are also exposed to other factors such as crowding in the trawl, rapid pressure changes and suffocation on deck. Those kinds of stresses are likely to be far more important causes of reduced catch quality than simply exhaustion.

Haddock are more vulnerable to exhaustion

Identical swim tunnel experiments with haddock produced somewhat different results, suggesting that haddock are slightly more vulnerable to exhaustion. For some of the parameters, such as glucose and lactic acid levels, a six-hour convalescence period was insufficient. On the other hand, exhaustive swimming had no significant impact on the pH values of muscle fibres, and there was no abnormal discolouration of the fillets after the experiments in the swim tunnel.

The final reports conclude that even if the impact on haddock is slightly greater than on cod, the consequences of exhaustion are still moderate and reversible. In the same way as for cod, other physical stresses probably have more impact on any deterioration in quality.

10. COMMUNICATION

When the programme started in 2011, it was important to raise the profile of CRISP at the Institute of Marine Research and Nofima. The centre was organised as a separate research programme at the IMR. This was later changed. In order to give CRISP a distinctive profile, it was given its own logo, symbolising a fish in a trawl. Dedicated CRISP roller banners were also created, which all of the partners took to events like Nor-Fishing in Trondheim to make it clear that they were affiliated to CRISP.

Researchers at CRISP have attended a wide range of national and international meetings, seminars and conferences where they have presented the scientific output of CRISP. CRISP's message and innovations have also been presented to the fishing industry and the general public in a variety of contexts, including at the biennial Nor-Fishing fair in Trondheim and at the annual meetings of trade bodies for the fishing industry. The Ministry of Trade, Industry and Fisheries and the Directorate of Fisheries have shown an interest in and have been kept informed about CRISP's innovations, particularly those with potential applications in supervising and monitoring fishing activities and fish stocks.

Researchers at the IMR publish most of their work as reports in Rapport fra Havforskningen, while employees at Nofima publish in the Nofima report series. News of many of CRISP's highlights has been published through short presentations in the pamphlet "Marine Research News". By the time CRISP ended, 40 peer-reviewed articles had been published.

CRISP has also on several occasions been presented on the radio and TV, both in Norway and overseas. Fiskeribladet, Intrafish and Tekfish are three major publications aimed at CRISP's target audience that have played an important role in disseminating our research.


Aftenposten Onsdag 13. april 2016

Meninger 11

sørge for sakens opplysning. Det er noe helt annet enn det Thune skriver, som bekrefter et inntrykk av for passiv dommerinnsats med mulige svake/gale dommer som følge. Etter min oppfatning viser Thunes artikkel og et alminnelig inntrykk ellers at det er behov for at staten gjennomgår muligheten for kvalitetssikring av dommerarbeid.

Jens A. Sunde
høyesterettsadvokat (p)

Demokratiet som sviktet

Oslos demokratiske system har sviktet beboerne på Nedre Grefsen. En sterkt inngripende omregulering av en veletablert småhusbydel kom som lyn fra klar himmel på de berørte. Skal dette være mulig i vårt demokrati?

Det er behov for økt antall boliger i Oslo, og fortetting er et godt virkemiddel. Våre politikere har sikkert diskutert fordeler og ulemper med de aktuelle alternativene før de besluttet å sanere Nedre Grefsen. Oslos ledelse har utvilsomt sitt på det tørre når det gjelder det juridiske. Men er det god moral å fatte en slik dypt inngripende beslutning over hodene på beboerne?

Fiskerinæringen. Teknologiutviklingen har sørget for mer effektiv produksjon og store fiskefangster. Men kvaliteten på fisken har fått unngjelde.

Kunnskapsløs teknologiutvikling

Debatt

Stein Harris Olsen
forsker, Nofima

Ved å dreie oppmerksomheten fra kvantitet til kvalitet, kan mer av fisken gå til godt betalende ferskfiskmarkeder.

Bedre fangstteknologi, større fartøykvoter og effektiv produksjon har bidratt til en kraftig reduksjon i antall fartøyer og fiskere de siste ti årene. Blant

Effektive fiskeredskaper har bidratt til gode fangstresultater. Denne utviklingen har gått på bekostning av kvaliteten til hvitfisk, mens pelagisk sektor har klart å håndtere kvalitetsutfordringene, skriver Stein Harris Olsen. FOTO: OLE MATHISMOEN

11. THE EFFECT OF THE CENTRE FOR THE PARTNERS

11.1 "CRISP PAVES THE WAY FOR NEW APPROACHES TO MONITORING FISH STOCKS"

As CRISP draws to a close, Research Director Geir Huse looks back with satisfaction at the Institute of Marine Research's multi-year involvement in a multitude of projects that may help guide the fishing industry into a new, even more technology-driven future.

FACT SHEET:

Geir Huse (born 1969), Research Director for marine ecosystems and resources at the Institute of Marine Research is originally from Austevoll. Huse completed his PhD on the "Spatial distribution of capelin" at the University of Bergen in 1998.

– As I see it, CRISP has offered a useful and very interesting model for better cooperation between the research community, fishers and technology developers, not least because the project has paved the way for alternatives to the traditional approaches to monitoring fish stocks, says Huse.

CRISP is leading the way towards a future where technology and smarter fishing techniques both reduce waste and increase prices by ensuring that the products which reach consumers are of a higher quality.

Sustainability is the key

"Sustainability" in the broadest sense has been a common denominator for the work packages in CRISP, but it is when sustainability is also good for revenues that it becomes really attractive to professional fishers, who constantly have to keep an eye on their profitability.

"I think this work basically started back in the mid-1980s, when Gro Harlem Brundtland led the UN's World Commission on Environment and Development. After experiencing some collapses in fish stocks, Norway had by then already introduced resource-friendly quota systems. But the quotas were designed to ensure that stocks were harvested sustainably and focused less on the quality of the end product. Now new sustainable harvesting technologies are available to us.

New technology in place

The recent development of increasingly advanced sonar and video systems, combined with powerful computers, means that technology can now really help both to make fishing more sustainable and to increase returns for fishers. By handling fish more gently during capture, identifying the amount, species and size of fish in schools before setting trawls, reducing the need for bottom trawling and, of course, minimising the bycatch, better use can be made of quotas through improving the quality of the end product and reducing waste.

Technological progress

In other words, developing new technology has been at the heart of the many activities within CRISP. But as well as developing new products and methods, CRISP has also resulted in a number of PhDs.

Like other research institutions, the Institute of Marine Research finds that funding is hard to come by for new research projects. The significant financial resources put into CRISP, together with the excellent opportunities for practical research on vessels and at partner institutions, have made it possible for many new researchers to undertake ambitious projects.

– It is clearly useful to collaborate with both technology developers and the fishing industry on specific research tasks, says Huse.

Not forgetting basic research

Conversely, the projects in CRISP have provided less of a platform for basic research, but Huse stresses that this area is not neglected by the Institute of Marine Research or other research institutions.

– Basic research is naturally important, and the Research Council of Norway offers good schemes for funding it, but

we should bear in mind that the Institute of Marine Research, as I see it, has always been a research institution with a practical focus. For us, CRISP therefore represents a natural continuation of our longstanding traditions. However, the scope of CRISP is definitely new, so it's great to be able to conclude that eight years of really hard work has been so successful. We've worked well with our partners, and I'm really pleased with the number of PhDs to have come out of CRISP. It has undoubtedly provided great opportunities for students and researchers alike, concludes Research Director Geir Huse.

FACT

Simrad was originally an abbreviation for Simonsen Radio AS, which was established based on the experience Willy Chr. Simonsen made as radio developer for the Allies under World war II. For more than 70 years, the company has been a leading provider of maritime communication systems and marine electronics such as sonars and echo sounders. Simrad is currently a brand name used on all fisheries-related products from the large group Kongsberg Maritime AS.

11.2 DEEP INVOLVEMENT THROUGHOUT THE CRISP PERIOD

SIMRAD

KONGSBERG

With Simrad in place as a business partner right from the start, CRISP has benefited from having had one of the country's strongest technology development environments as a partner.

Simrad's central role is emphasised by managing director Olav Vittersø also has been chairman of CRISP - and after eight years the time has come for summing up:

– This has been a long race that we have now stood out completely. I can conclude that the cooperation in CRISP has worked as intended. As chairman of CRISP, I have experienced that the processes have been agile and well-functioning, and as a corporate leader, I see that Simrad has brought new products and new technology together with new partners, delivered to new customers, says Olav Vittersø.

Simrad is one of four business partners in CRISP and just like the other partners Simrad has funded their own efforts. All Simrad's projects are fully supported under CRISP's main goal of developing more environmentally friendly and resource-saving capture techniques that also allow fishermen to deliver better quality catch, thereby achieving better prices.

New Products and Technologies

In CRISP, Simrad has been working on developing acoustic instruments for more precise measurements of total volume and individual sizes in schools of pelagic fish. This gives the skipper better tools to choose the right school before setting his gear and to monitor the catch inside the net. Simrad has also developed the wired video and sonar system FX80, which monitors the catch inside a trawl. A number of these systems are sold to American hake and shrimp fishermen who has to avoid bycatch of wild salmon.

In addition, Simrad has received much attention around the collaboration with Scantrol on the Deep Vision system, but this much-discussed camera system is not the only project in which the company has played a key role.

The Nofima cooperation, according to Olav Vittersø, has been very important, and also the cooperation with Egersund Trawl on the possible remote control of adjustable trawl doors which has involved Simrad's development teams. Simrad has further tested the use of water flow meters and an ADCP sonar (Acoustic Doppler current profilers) for use inside the trawl.

Practical testing and development

The Commercial part of Simrad's CRISP commitment was to develop new products that improves the fisheries sector's environmental profile and profitability, but the combination of research and extensive testing in the field is often difficult to achieve, both for practical and economic reasons.

In addition, researchers and businesses often meet the classic conflict between the goal of open research and the companies needs to protect their own technology for competitive purposes.

– CRISP has managed to combine these considerations. The cooperation has also taken place on the premises of the industry, and the well-functioning overlap between research and the companies' product development plans has been an important success criterion. The collaborative projects we have initiated will now continue after the formal project is closed. Both Scantrol and Egersund Trawl are obvious partners for further work, concludes managing director Olav Vittersø.

QUICK FACTS:

Scantrol Deep Vision AS was established in 2014 as a sister company of Scantrol AS. The company's main task within CRISP has been developing the camera system Deep Vision. Both Scantrol companies are based in Sandviken, close to Bergen city centre, and they share an international distribution and customer service network.

11.3. SCANTROL DEEP VISION AS: A CAMERA IN THE TRAWL PAVES THE WAY FOR AUTOMATIC SORTING

One CRISP project that has caused a stir beyond purely academic circles is the underwater camera system Deep Vision, developed by Scantrol Deep Vision AS.

Deep Vision is a powerful tool in our efforts to develop more sustainable fishing gear technology for trawling. The Bergen company behind the system has been working on it for over ten years and now it has begun on the commercialisation of the product. The first orders came from the Institute of Marine Research, but international customers have also ordered Deep Vision over the past year.

"A lot of the development of Deep Vision has taken place through CRISP. Successful cooperation is needed to develop ground-breaking technology and products, and CRISP gave us a unique opportunity for that", explains Business Development Manager Hege Hammersland-White.

The camera system is attached to the trawl and takes photos of all of the fish that swim in. The photos are analysed for species and fish length, and that information makes it easier for the captain to decide whether or not to haul the catch aboard.

May be automated in the future

– Eventually Deep Vision will also be able to control a sorting mechanism that enables trawlers to select which fish they want to keep and let the rest swim out of the codend. Because the technology is constantly being developed, and within a few years Deep Vision will be ready to act as a sorting system for commercial fishing vessels.

Hammersland-White also stresses that the good cooperation within CRISP has been important driver of the development project. The centre has given the company invaluable access to expertise, both from the research community and from the other participating companies.

– The researchers haven't just contributed their expertise and given feedback on the system, they have also become our first customers. Other industrial partners have also contributed expertise and technology, including Simrad, which supplies an acoustic link for the system. CRISP has also helped us to raise the profile of the technology through presentations at various forums.

Tested in practice on joint scientific surveys

The joint scientific surveys were an important element of CRISP that gave Scantrol Deep Vision AS a chance to test its technology. This practical testing would have been very time-consuming and expensive if the company had needed to go it alone.

– The scientific surveys have provided a good testing ground where good and bad ideas have succeeded or been rejected, depending on how they have performed in the sea. The surveys and annual get-togethers have also been offered an important opportunity to meet other people and discuss the development of our technology and possible synergies with other technology developed at the centre, concludes Business Development Manager Hege Hammersland-White of Scantrol Deep Vision.

QUICK FACTS:

Egersund Trawl AS is part of the Egersund Group. The company was founded in 1952 and is now an important supplier of trawl gear, cages for fish farms and various other products for the fishing fleet, aquaculture industry and offshore industry. The Egersund Group also manufactures oil spill equipment and ice management systems.

11.4 SUCCESSFUL DEVELOPMENT OF ADJUSTABLE TRAWL DOORS

The fishing gear manufacturer Egersund Trål AS has been one of CRISP's industrial partners right since the programme started in 2011. Its main project has been the development and practical testing of a new type of adjustable trawl door within work package 4: low impact trawl.

The adjustable trawl door is primarily designed for pelagic trawling. The difference between this kind of trawling and bottom trawling is that the trawl operates at varying heights above the sea bottom. The adjustable hatches above and below the towing bracket makes it easy for the crew to adjust the depth and spread of the trawl without changing the speed of the vessel. This is also useful when trawling in the presence of challenging currents, changing course and trawling on slopes.

The adjustable trawl doors also make it possible to reduce the trawl's spreading force by up to 40 percent. This means that the same set of trawl doors can be used for pelagic trawling, which requires less spreading force, and for bottom trawling, which requires a lot of spreading force.

Practical testing on FV "Fangst"

The company started the development project with two adjustable half-scale trawl doors made of aluminium. The practical testing started on the vessel "Fangst", where the doors were used to open a pelagic trawl with a circumference of 230 metres.

The results were positive, and work continued through a number of experiments to ascertain how the trawl doors behaved with different opening areas and rigging arrangements.

Catch control applications have also been tested through trawl-mounted systems that allow the fish to swim freely out of the trawl when the codend is full.

Egersund Trawl AS also wants it to be possible to adjust the hatches remotely. This can be done by sending a signal directly from the bridge to the trawl doors. In partnership with Simrad, motor and battery packs were developed that were fixed to the trawl doors and tested during trawling. However, it proved very difficult to send and receive signals through seawater over such relatively long distances, so the remote control technology has not yet reached a level that allows it to work sufficiently well for real-world use.

The "snuggle bag"

One experiment that did, conversely, produce rapid positive results is what has been called the "snuggle bag". In order to improve the quality of trawl-caught fish, the company tried fitting an extra codend with a fine mesh behind the original one. As the net was hauled in, the "snuggle bag" was opened to give the fish more space and hence reduce crowding.

The extra codend has a fine mesh which means that a lot of water is also hauled in. This helps to protect the catch against injury and increases the probability of the fish staying alive while being hauled in. This is important, because many boats supply live cod to the market.

QUICK FACTS:

The shipowner Nergård Havfiske AS, formerly Ytre Rolløya AS, currently owns and operates four trawlers. The shipowner, which recently moved its main base from Harstad to Tromsø, is a wholly-owned subsidiary of the large fishing conglomerate Nergård AS.

Samarbeid ombord på Nergårds tråler «J Bergvoll». Fra venstre skipper Torgeir Mannvik, PhD-student Ragnhild A. Svalheim, Nofima-forsker Stein Harris Olsen og daglig leder i Nergård Havfiske Kjell Larsen

11.5 NERGÅRD HAVFISKE AS WILL USE SYSTEMS DEVELOPED THROUGH CRISP ON A NEW VESSEL

NERGÅRD

The shipowner Nergård Havfiske AS has already started implementing what it has learned by participating in CRISP. It will even start using brand new technology on a newbuild that will be delivered in 2020.

– At times when there is a lot of fish, we use catch control systems developed through the CRISP partnership, and some of the experience we gained from CRISP has been integrated into the new vessel. For example, this vessel will have seawater-fed receiving bins. This means that fish are kept in fresh, oxygen-rich water right until they are slaughtered. This keeps the fish alive for longer and reduces the length of time between when they die and are processed. This raises the quality of the end product", says Nergård Havfiske AS's Managing Director Kjell Larssen.

The shipowner's parent, Nergård AS, is a vertically integrated group involved in harvesting, processing and marketing, and Larssen stresses that all of those levels of the organisation want harvesting to be sustainable and for the end products to be of a consistent, high quality:

– The object of CRISP was to develop methods to reduce environmental impacts and improve quality. That's why we chose to participate.

Introducing new methods

Over the course of the partnership, Nergård Havfiske has made suggestions in relation to developing new methods, and the company's boats having been used for practical activities such as testing catch control systems, studying fish recovery, pumping fish onto vessels and testing a codend that is gentler on fish during their capture.

The catch control equipment was quite soon introduced on a number of boats, but there is not currently space on trawlers for pumping fish and live storage.

– That is probably because those methods result in higher investment and operating costs. It is unclear whether the market is willing to pay for the improvement in quality. Nevertheless, the results of the experiments were so good that we are continuing to build on their principles. I believe that live storage will gradually be introduced on boats over the coming years.

Have become more innovative

Larssen states that participating in CRISP has helped to make the company more innovative:

– Within the company, CRISP has undoubtedly helped to put the spotlight on new ways of improving quality. The staff who have been involved in CRISP have made a very positive contribution, not to mention the fact that they've appreciated meeting so many excellent researchers.

And the many contacts that have been built up with the research and development communities are one of the things that he emphasises as being very positive.

– We will draw on them for future development activities, both in relation to our existing boats and the new boat that is about to be delivered, says Nergård Havfiske AS's Managing Director Kjell Larssen.

12. WHERE NEXT?

Right from the start, CRISP has worked on research and development in areas related to the seafood industry.

Marine-based industries have always been one of Norway's most important sectors, and it appears that their significance will only grow in the coming years. The Norwegian government has, for instance, launched an ocean strategy to promote sustainable growth and employment in the ocean industries. Science and technology will play a vital role in unleashing the potential for added value in the ocean industries and ensuring sustainable growth. The strategy explains that in order to reach the main objective, the government will work on three main tracks, the last two of which are highly relevant to the work done at CRISP:

- The development of knowledge and technology in the ocean industries will be facilitated through research, innovation, education, and competence. This will be done by improving our fundamental understanding of the ocean, furthering and strengthening the development of knowledge and technology in current ocean industries, strengthening collaboration across industries and academic communities, ensuring a good and relevant education system which helps cover the ocean industries' need for skills, and promoting recruitment to maritime research, training and professions.

- The international competitiveness of the Norwegian ocean industries will be strengthened by supporting efforts to improve market access, internationalization, and marketing of the ocean industries, helping more businesses step out into the world and succeed, and making sure that Norway consolidates its leading global position as a hub for the development of ocean-based technology.

This shows that the principles that have guided our efforts at CRISP will live on beyond 2019. CRISP's philosophy must be carried forward even after its work draws to a close, albeit in somewhat different ways.

All of the topics that CRISP has worked on could be grouped under the umbrella of **"Sustainability sciences"**, i.e. sustainable ways of obtaining food for the world's growing population. This includes the whole value chain from good fisheries management (including technology for monitoring and managing fish stocks, developing and implementing good management regimes, etc.), through responsible fishing and capture (including vessels, fish-finding equipment, low-impact fishing gear), to proper handling (to ensure quality) and marketing. The industry's potential must be exploited through sustainable growth, with management regimes, the industry and technology being developed in a way that reflects biological processes.

Technology for monitoring the oceans and its resources

Innovative technologies were developed through CRISP that can be used for stock management, such as new sonar technology and Deep Vision. These technologies are already being introduced to monitor fish stocks, but it should be possible to expand their areas of application. Over the coming years, the companies involved and other high-tech companies in Norway will undoubtedly expand their range of marine monitoring products, not just for the fishing industry but also for other maritime industries. The partners in the CRISP consortium will continue to develop marine monitoring systems in new projects, both in Norway and overseas.

Fishing gear and catch monitoring technology

There is a constant need to make fisheries and fishing gear more selective, less energy intensive and more reliable, and to reduce their environmental footprint. The goal is still to develop tools, fishing techniques and energy solutions that have as little impact as possible on the environment. In CRISP, the focus was on the high-tech segments of the Norwegian fishing fleet, namely ocean-going trawlers and purse seiners. There are also challenges associated with developing smart solutions for other segments of the Norwegian fishing fleet.

Globally, the majority of fisheries are of a completely different size and at a completely different level of technological development than the ones that CRISP focused on. Nevertheless, the challenges involved in developing responsible harvesting techniques are at least as big at a global level. One key question is therefore how we can downscale the CRISP innovations into smaller products that are less capital-intensive and therefore suitable for use across a higher proportion of the world's oceans.

Food and food quality

Some of the world's growing need for food can be met by increasing production of marine resources. Future sustainable development of the fishing and aquaculture industries must be based on production environments that give us safe and healthy seafood. In order to maximise the economic potential of marine resources, it is important to focus on quality, provided that higher quality commands a higher price. Another key consideration is consumer power. As well as wanting high quality, consumers want evidence that the food they are eating comes from a well-managed fish stock that is harvested sustainably and in a way that guarantees animal welfare. A lot of research still needs to be done in these areas.

13. CONCLUSION

The government's ocean strategy states that the development of knowledge and technology is the key to unleashing the potential for added value in the ocean industries and ensuring sustainable growth. The aim is to improve our basic understanding of the oceans and strengthen the development of knowledge and technology in current ocean industries. There is also a desire for Norway to consolidate its leading global position as a hub for the development of ocean-based technology.

This is very much in line with CRISP's objective, which was to reinforce the position of Norwegian companies in fishing-related industries as leading suppliers of equipment and seafood to a global market by developing sustainable technology for trawling and purse seining. CRISP has worked towards developing a profitable fishing industry by focusing on "smart" and "green" technology.

We believe that we have largely met our goals. A number of new "smart" technologies have been developed as a result of the CRISP partnership. Some of these innovations are already being used by the Norwegian fishing industry or in Norwegian and international fisheries research, while several other innovations are still under development and will be taken further after CRISP.

The biggest reason for CRISP's success is that it is a partnership between industry and the research community. The focus of the projects has largely been driven by the industrial partners, with the research partners giving their input and helping to facilitate the testing of the innovations.

The long-term funding available to a Centre for Research-Based Innovation (CRI) is clearly a very important success factor, particularly for the research partners. For a few of the companies, the eight-year duration of CRISP was perhaps a bit on the long side. However, that long-term horizon made it possible to build up the centre's research capacity both in terms of human and technological resources. It also helped to build up mutual trust between the partners, which is something that future collaborative projects will benefit from. Another contributing factor to our success has been the close cooperation between the research institutions and the industrial partners on board research and fishing vessels. There they have worked side by side on the practical testing and development of innovations. It was also important that the industrial partners in CRISP had complementary business interests that made it easy for them to cooperate without any sense of competition between them.

CRISP has been very successful in terms of innovation, as was confirmed in our mid-programme assessment and by our Scientific Advisory Committee. Although scientific success measured by the number of articles published has improved over the lifetime of the centre, and while the centre's researchers have contributed to a large number of scientific forums, the centre scored less well for pure science than it did for innovation. For the centre it has been something of a paradox that the evaluation of the performance of CRIs, which in principle are supposed to focus on innovation, is so strongly based on their scientific output rather than their degree of innovation.

The annual event that has brought together everyone affiliated to CRISP to present the latest progress and discuss future challenges has also been important to the centre's success. In addition, the centre has trained a number of Master's and PhD students. As representatives of a traditionally very male-dominated industry, we are particularly proud that half of our recruits were women, and that most of them have continued to work in fishing technology research or at technology companies.

APPENDIX I STATEMENT OF ACCOUNTS FOR THE COMPLETE PERIOD OF CENTRE FINANCING

Funding

Activity/Item	RCN	HOST - Havforskningsinstituttet	Partner 1 - NOFIMA	Partner 2 Kongsberg Maritime	Partner 3 Scantrol Deep Vision AS	Partner 4 Egersund Group	Partner 5 Nergård	Partner 6 Universitetet i Bergen	Partner 7 - Universitetet i Tromsø	Sponsor Norges Sildesalgslag	Sponsor Norges Råfisklag	**Total cost**
WP 1	11 637	37 374	-	39 307	-	-	-	-	-	600	-	88 918
WP 2	9 064	16 244	-	8 900	-	-	-	-	-	-	-	34 208
WP 3	12 115	11 210	-	339	9 843	-	-	-	-	-	-	33 507
WP 4	8 115	16 091	-	113	242	10 686	-	-	-	-	-	35 247
WP 5	15 526	142	5 137	-		-	7 843	-	5 118	-	200	33 966
WP 6	9 156	-	5 718	-		-	220	-	-	-	600	15 694
SFI Equipment												-
WP 7	14 387	7 649						2 612		200		24 848
Total budget	**80 000**	**88 710**	**10 855**	**48 659**	**10 085**	**10 686**	**8 063**	**2 612**	**5 118**	**800**	**800**	**266 388**

Cost

Activity/Item	HOST - Havforskningsinstituttet	Partner 1 - NOFIMA	Partner 2 Kongsberg Maritime	Partner 3 Scantrol Deep Vision AS	Partner 4 Egersund Group	Partner 5 Nergård	Partner 6 Universitetet i Bergen	Partner 7 - Universitetet i Tromsø	Sponsor Norges Sildesalgslag	Sponsor Norges Råfisklag	Total funding
WP 1	49 611	0	39 307	0	0	0	0	0			88 918
WP 2	25 308	0	8 900	0	0	0	0	0			34 208
WP 3	23 325	0	339	9 843	0	0	0	0			33 507
WP 4	24 206	0	113	242	10 686	0	0	0			35 247
WP 5	321	16 434	0	0	0	7 843	0	9 368			33 966
WP 6	0	15 474	0	0	0	220	0	0			15 694
SFI Equipment											0
WP 7	18 791						6 057				24 848
Total budget	**141 562**	**31 908**	**48 659**	**10 085**	**10 686**	**8 063**	**6 057**	**9 368**	**0**	**0**	**266 388**

** Cost for 2019 are estimated in the reporting*

APPENDIX 2 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
Geir Sogn GRUNDVÅG	Nofima	Value adding	M
Øyvind AAS-HANSEN	Nofima	Quality improvement	M
Arill ENGÅS	IMR	Low impact trawling/Instrumentation	M
John Willy VALDEMARSEN	IMR	Low impact trawling/administration	M
Shale ROSEN	IMR	Low impact trawling/Instrumentation	M
Olafur A. INGOLFSSON	IMR	Low impact trawling/Instrumentation	M
Terje JØRGENSEN	IMR	Low impact trawling/Instrumentation	M
Egil ONA	IMR	Sonar technology and instrumentation	M
Gavin MACAULEY	IMR	Sonar technology and instrumentation	M
Hector PENA	IMR	Sonar technology and 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
Helge K. JOHNSEN	UiT	Researcher training, recruitment	M
Arne JOHANNESSEN	UiB	Researcher training, recruitment	M
Anders FERNØ	UiB	Researcher training, recruitment	M

Key technicians, research institutes

Name	Institution	Main research area	Sex
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
Asbjørn AASEN	IMR	Trawl technology	M
Jostein SALTSKÅR	IMR	Engineering, instrument development	M
Liz B.K. KVALVIK	IMR	Engineering, instrument development	F
Anne Britt TYSSELAND	IMR	Engineering, instrument development	F
Bjørn TOTLAND	IMR	Engineering, instrument development	M
Ronald PEDERSEN	IMR	Sonar Technology and Fisheries Instrumentation	M
Tor H. EVENSEN	Nofima	Quality improvement	M
Kathryn DONELLY	Nofima	Information logistics	F
Ronny JAKOBSEN	Nofima	Quality improvement	M

Key personell, industry partners

Name	Institution	Main research area	Sex
Ole Bernt GAMMELSÆTER	Kongsberg Group		
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	Sonar technology and fisheries instrumentation	M
Thor BÆRHAUGEN	Kongsberg Group	Management, Board leader	M
Jon Even CORNELIUSSEN	Kongsberg Group	Monitoring fish and gear	M
Roger KOTENG	Kongsberg Group	Monitoring fish and gear	M
Øivind HANTHO	Kongsberg Group	Sonar technology and fisheries instrumentation	M
Anita P VIK	Kongsberg Group	Sonar technology and fisheries instrumentation	M
Toan Thanh PHAM	Kongsberg Group	Sonar technology and fisheries instrumentation	F
Helge HAMMERSLAND	Scantrol Deep Vision AS	Visual fish classification/Management	M
Kristoffer LØVALL	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
Boweng TONG	Scantorl Deep Vison AS	Visual fish classification	M
Arvid SÆSTAD	Egersund Group	Low impact trawling	M
Trond NEDREBØ	Egersund Group	Low impact trawling	M
Wenche H VIGRESTAD	Egersund Group	Low impact trawling	F
Bjørn HAVSØ	Egersund Group	Low impact trawling/Management	M
Vidar KNOTTEN	Egersund Group	Low impact trawling	M
Roy SKULEVOLD	Egersund Group	Low impact trawling	M

Name	Institution	Main research area	Sex
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	Universitetet 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	07.05.2012-10.04.2018	F	Capture behaviour
Sindre VATNEHOL	Norwegian	01.09.2012-03.03.2016	M	Sonar Technology
Ragnhild A. SVALHEIM	Norwegian	15.04.2013-31.03.2018	F	Fish Quality
Jesse BRINKHOF	Norwegian	14.03.2016-13.03.2019	M	Fish Quality/Capture behaviour
Helene JENSEN	Norwegian	01.09.2016-31.08.2018	F	Value adding
Neil R. ANDERS	Great Britain	01.01.2016-31.12.2019	M	Fish Welfare & Quality in Purse seine
Tonje K. BJØRVIG	Norwegian	31.03.2017-31.03.2021	F	Fish Quality in Trawl (funded by UIT)

Master students

Name	Nationality	Period	Sex	Topic
Alexandre J D GREVE	French	2018-19	M	Fish behavior and welfare
Thomas RIEDINGER	German	2018-19	M	Fish behavior and welfare
Kjetil G THORVALDSEN	Norwegian	2017-18	M	Acoustic of mesopelagic registrations
Kirsten HOWARTH	UK	2015-16	F	Fish welfare
Bård AARBAKKE	Norwegian	2015-16	M	Fish behavior
Helene JENSEN	Norwegian	2015-16	F	Value adding
Eugene KITSIOS	Greece	2014-15	M	Fish quality
Jacub TICHY	Slovakian	2014-15	F	Fish quality
Tonje JENSEN	Norwegian	2013-14	F	Fish quality
Wenche H VIGRESTAD	Norwegian	2013-14	F	Fish behaviour
Rachael MORGAN	UK	2013-14	F	Fish behaviour
Jan Tore DIDRIKSEN	Norwegian	2012-13	M	Quality improvement
Didrik VARTDAL	Norwegian	2011-12	M	Fisheries biology
Sindre VATNEHOL	Norwegian	2011-12	M	Sonar technology

APPENDIX 3 PUBLICATIONS

PUBLICATIONS IN PEER REVIEW JOURNALS

2019

- Anders, Neil; Breen, Michael; Saltskår, Jostein; Totland, Bjørn; Øvredal, Jan Tore; Vold, Aud. Behavioural and welfare implications of a new slipping methodology for purse seine fisheries in Norwegian waters. PLoS ONE 2019doi.org/10.1371/journal.pone.0213031.

- Anders, Neil; Howarth, Kirsten; Totland, Bjørn; Handegard, Nils Olav; Tenningen, Maria; Breen, Michael. Effects on individual level behaviour in mackerel (Scomber scombrus) of sub-lethal capture related stressors: Crowding and hypoxia. PLoS ONE 2019 doi.org/10.1371/journal.pone.0213709.

- Bertheussen, Bernt Arne; Dreyer, Bent. Is the Norwegian cod industry locked into a value-destructive volume logic? Marine Policy 2019, Volum 103: 113-120.

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