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Project MultiSEPT - Development of multirig semi-pelagic trawling

Status report January 2014

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Report

Project MultiSEPT - Development of multirig semi-pelagic trawling

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Summary

In 2013, new knowledge on semi-pelagic trawling has been created in MultiSEPT project. The achievements in the project have been possible because of extensive cooperation between the scientific and industrial partners. This report briefly describes the activities carried out in the MultiSEPT project in 2013.

Full scale tests of the semi circular spreading gear (SCSG) showed that this ground gear was easy to rig and operate, its geometry was stable during towing and it had good bottom contact. The spreading (distance between wing-ends) was approximately 7 % higher with the SCSG than with the rockhopper gear for the same gear and door spreading. The SCSG had good bottom contact and passed bottom obstacles (e.g. stones) easily. The size distribution of fish caught with the SCSG was very similar to that caught with the rockhopper. However, the number of hauls performed with the SCSG and with the rockhopper was too small to draw a clear conclusion on catch efficiency. The SCSG is a gear that is easy to rig and handle on deck, it does not require accurate adjustments, it has few control points and low weight, and the results indicate that its performance at sea is at least comparable to the rockhopper gear for given bottom conditions. Further development of the SCSG should emphasise on improving the construction materials used today in oder to reduce the wearing and increase its lifetime.

Two full scale tests were carried out in spring and autum 2013 to assess the effect of sweep length on herding of fish during semi-pelagic trawling for cod and haddock. The results showed that **sweep length can have a significant effect on the catches**. Fixing the 450-kg chain weights right in front of the ground gear captured in up to 50% less cod and up to 60% haddock (of all sizes) than when the chain weights were fixed 45 m in front of the ground gear. These results demonstrate that at least under the conditions encountered in these trials, the sweeps have a major role on the fish herding process of the gear.

The state estimator model (the core of of the Roll Royce Marine's e-Trawling system) was compared with data from small scale tests in SINTEF's test tank in Hirtshals, Denmark, carried out in July 2013. The results showed that the model apparently works well. The state estimator model is currently being validated against acoustic sensor data from full scale trials with semi-pelagic trawling carried out in November 2013.

A concept for remote control of existing trawl doors, which is based on manipulating the moment balance of the trawl doors, has been designed by SINTEF. This is achieved using control lines between points on the trawl door and external lines (warps or bridles). By tensioning such lines, the orientation of the trawl door is controlled, which again is used to control the hydrodynamic forces created by the trawl door. The energy consumption of this concept is greatly reduced by changing the rigging of the trawl door to reduce its stability. A pair of 0.6 m^2 Injector XF9 semi-pelagic doors are currently being instrumeted with actuators and will be tested in Hirtshals' flume tank in early 2014.

Semi-pelagic shrimp trawling showed approx. 6-8 % lower fuel consumption than bottom shrimp trawling. The 2.5 m^2 semi-pelagic doors tested during our trials were overdimensioned for the coastal trawler "Gullholmen", and they had to be set at the lowest angle of attack to reduce spreading force and match that of the bottom trawl doors normally used by the vessel. A set of smaller doors (approx. 2 m^2) would had been a better choice to achieve the spreading force necessary for a 1500 # shrimp trawl. This would have reduced the fuel consumption even more. Shrimp catches were too low (15 – 45 kg/hour) and very variable from haul to haul to draw any conclusion on the fishing efficiency of the gear with the different sets of doors. Further experiments with coastal shrimp trawlers are planned for winter 2014.

1 Introduction

This report is part of the research project "Development of Multirig Semi-pelagic Trawling – MultiSEPT" financed by the Research Council of Norway, The Fisheries and Aquaculture Industry Research Fund (FHF), Rolls Royce Marine AS and Mørenot Fishery AS (project no. 216423/O70).

2 Objectives

The main objective of this project is to reduce NOx- and other environmental emissions by increasing the energy efficiency of resource-intensive maritime operations in Arctic regions. The project proposes developing a multi-rig semi-pelagic trawling technology to be used for a sustainable exploitation of deep-water resources such as Northern shrimp and Northeast Arctic cod. This will be achieved by:

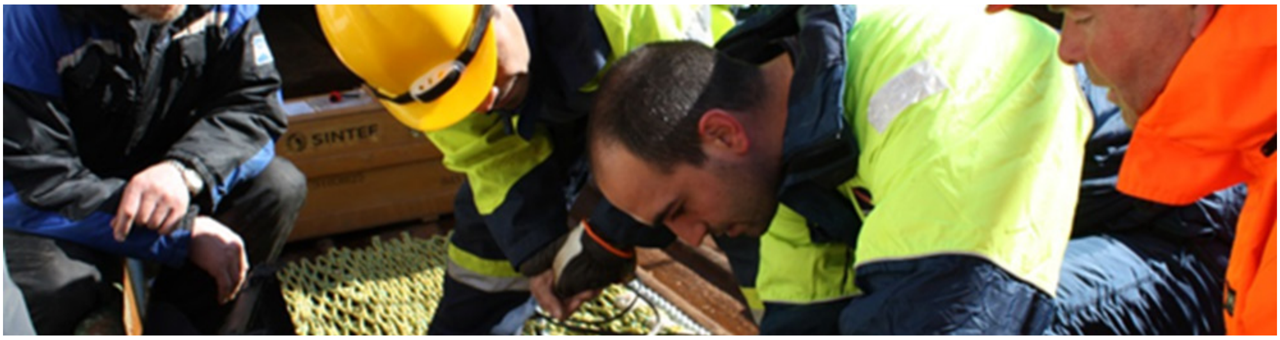
- Developing a multirig semi-pelagic trawling (twin and triple trawl) in which trawl doors, central clump(s) and sweeps have no physical contact with the seabed.
- Development of a trawl surveillance concept based on state-of the art trawl sensor technology.
- Development of trawl gear control concepts mainly via enhanced winch control and vessel maneuvering control, based on the surveillance technology.
- Developing a light ground gear based on skirt- and brush gear concepts.
- Investigating alternative solutions for herding the target species into the path of the trawl in order to compensate for the loss of herding effect when the doors and sweeps are lifted off the bottom, and in order to further enhance catch efficiency.
- Identification and elimination of safety risks (H.S.E.).

3 Research plan and scientific methods

3.1 Problem definition

Different issues have been identified as the main challenges for developing a multi-rig semi-pelagic trawling system:

- Lifting the multi-rig system (trawl doors, central clump(s), sweeps and bridles) from the sea bed without losing symmetry.
- Control and survelliance of the semi-pelagic multi-trawl system.
- Avoid the escape of fish under the ground gear.
- Loss of herding effect (on fish) when lifting the trawl doors, central clumps, sweeps and bridles from the seabed.
- Ensure that the new trawling technology does not increase the risk for occupational accidents and strain injuries when operated.



3.2 Research plan

The project is divided into five working packages (WP) that addresses the main challenges for the development of a new multirig semi pelagic trawl technology:

- WP1 Development of a semi-pelagic multi-rig system.
- WP2 Development of enhanced surveillance and control concepts for multirig semi-pelagic trawling.
- WP3 Development of a herding system for semi-pelagic trawling (Post Doc).
- WP4 Assessing the herding efficiency in semi-pelagic trawling (PostDoc).
- WP5 Evaluation of multirig semi-pelagic systems.

4 Organisation

The project runs for three years (Jan. 2012 - Dec. 2014), and include a 3-year PostDoc for Dr. Manu Sistiaga. The research team is mainly affiliated with SINTEF Fisheries and Aquaculture (SFH), the Norwegian University of Science and Technology (NTNU), the University of Tromsø (UiT), the Memorial University of Newfoundland (MUN) (Canada), and the University of Massachussets (UM) (USA). This research team is well capable of addressing the different tasks of the project (Table 1).

The project ownership is placed at The Fisheries Technology department at SINTEF Fisheries and Aquaculture in Trondheim, which is part of Scandinavia's largest independent research organization; the SINTEF group. The department is at the international forefront in hydrodynamics, design, model testing, simulation and control of fishing gear, trawl selectivity and fishing trial methodologies. Laboratory tests with multi-rig semi-pelagic trawls are planned to be conducted in the flume tank run by the department in Hirtshals, Denmark.

NTNU represents academic eminence in technology and natural sciences, and is the second-largest university in Norway. The University has given priority to six research areas where NTNU is to be among the internationally leading universities. Marine and Maritime Technology is one of these strategic areas, covering the topics Ocean Space Research, Fisheries and Aquaculture and Marine Resource Processing. The experimental facilities at NTNU are excellent, including the new and technically highly advanced research vessel R/V Gunnerus.

The University of Tromsø, through the Faculty of Biosciences, Fisheries and Economics (BFE) (former Norwegian College of Fishery Science), is a leading research and education institute specialized on arctic and marine biosciences, economy and relevant subjects relevant to fisheries and aquaculture. BFE has relevant infrastructure for fishing gear trials, including 3 research vessels. The largest of them, the 64 m RV "Helmer Hanssen", is regularly used as a platform for full scale trawl experiments. The staff inside fishing gear research has decades of experience from selectivity studies and underwater observations on various trawl techniques. The PostDoc in the project will be affiliated to BFE, University of Tromsø.

The fisheries research group at the University of Massachusetts is internationally recognized within studies of selectivity, fish behavior, catch efficiency, development of fishing gears and reduction of seabed impact of trawling.

The Centre for Sustainable Aquatic Resources (CSAR) is an applied research unit within the School of Fisheries at the Fisheries and Marine Institute of the Memorial University, in St. John's, Newfoundland and Labrador. CSAR addresses the specific needs of harvesters and fishing gear manufacturers, by undertaking industrial research and development, technology transfer, and information support on a general basis as well as on a contract or joint venture basis. The primary testing facility for CSAR is the flume tank at the Marine Institute. The Centre has a core staff in the disciplines of fishing gear technology, conservation engineering, fisheries biology, fish behavior and mechanical engineering (www.mi.mun.ca/csar).

Rolls-Royce Marine is a major supplier for both the offshore industry and the fishery industry. In relation to this project Roll-Royce Marine has developed dynamic winch control systems, whic are among the most advanced systems in the market (http://www.rolls-royce.com/marine/).

Mørenot Fishery AS is Norway's leading producer of fishing gear and equipment for the fish farming industry, and a major supplier nationally and internationally (http://www.morenot.com/).

Rosund Drift AS and Nordnes AS are two fishing companies with long experience in bottom, semi-pelagic and pelagic trawling, and are currently involved in several R&D projects.

The Fisheries and Aquaculture Industrial Research Fund (FHF) is funding industrial research and development within fisheries and aquaculture. FHF will participate in the management group of the project.

Table 1: The multidisciplinary research team.

Institution	Person	Competence
1. SINTEF Fisheries and Aquaculture	Dr. Eduardo Grimaldo	Gear technology, fish behaviour, project management
	Dr. Svein Helge Gjøsund	Gear technology, hydrodynamics
	Dr. Karl Johan Reite	Mathematical modelling, simulations, gear technology
	Sr. Scientist Kurt Hansen	Hydrodynamics, gear technology, model testing
	Dr. Manu Sistiaga	Gear technology, fish behaviour
	MSc. Lasse Rindahl	Gear technology, experimental work
	MSc. Jørgen Jensen	Mathematical modelling, simulations
	MSc. Jørgen Vollstad	Gear technology, experimental work
	Dr. Halvard Aasjord	H.S.E.
2. University of Tromsø	Prof. Roger B. Larsen	Gear technology, fish behaviour, underwater recording
	MSc. Ivan Tatone	Gear technology, experimental work
	Ing. Richarld Bovang	Instrumentation
3. NTNU	Prof. Jarle Mork	Fish behaviour, gear technology
4. Memorial University of Newfoundland	Dr. Paul Winger	Gear technology, fish behaviour
5. University of Massachussets	Dr. Pingguo He	Gear technology, fish behaviour
6. Rolls-Royce Marine AS	Per Huse	Deck machinery
7. Mørenot Fishery AS	Terje Ringstad Harald Lausund	Trawl design Trawl rigging

5 Scientific activities and results

The scientific activities in the MultiSEPT project are organized in the form of five work packages (WP) including several tasks. In 2013 the activities subprojects; the partners involved are shown in Table 2.

Table 2 Activities carried out in 2013.

Work package	Activity	Partners
WP2	• Complex model test: Validation of state estimator model with data from Qualisys measurements carried out at SINTEF's test tank in Hirtshals, Denmark (July 2013). • Full scale test for validation of state estimator model with acoustic sensor data from semi-pelagic fishing trials. The experiments were carried out om board R/V Helmer Hansen in the Barents Sea in November 2013.	SINTEF F&H Rolls Royce Marine AS University of Tromsø
WP3	• Full scale test to compare the semi-circular spreading gear (SCSG) with the rockhopper gear. The experiments were carried out in the Barents Sea in March 2013.	SINTEF F&H University of Tromsø Mørenot Fishery AS
WP4	• Full scale test to assess the effect of sweep length when semi-pelagic fishing for cod and haddock. The experiments were carried out off the coast of Troms and Finmark in March 2013. • Full scale test to assess semi-pelagic trawling for shrimps - comparison with bottom trawling. The experiments were carried out in Lyngenfjord and Ullsfjord, northern Norway in October 2013. • Full scale test to assess the effect of sweep lenght when semi-pelagic fishing for cod and haddock. The experiments were carried out in the Barents Sea in November 2013.	SINTEF F&H University of Tromsø Mørenot Fishery AS Gullholmen AS

5.1 Trawl instrumentation

MARPORT and SCANMAR trawl sensors were used to monitor the trawl- and rigging configuration. An overview of the sensors and their positions in the gear are shown in Table 3 and Figures 1 and 2.

Table 3:List of trawl sensors

Sensor	Place	Measurement
MARPORT distance/height 110kH	Trawl door	Distance between doors Depth of trawl doors
MARPORT door sonders	Trawl door	Height from seabed to trawl door
MARPORT distance/height 144kH	Wings	Distance between wings
MARPORT trawl sounde	Headline	Trawl height
SCANMAR distance sensor	Trawl door	Distance between doors Depth of trawl doors
SCANMAR trawl eye	Headline	Trawl height
SCANMAR catch sensor	Codend	Catch size
SCANMAR water speed sensor	Headline, belly, extension piece	Water flow speed

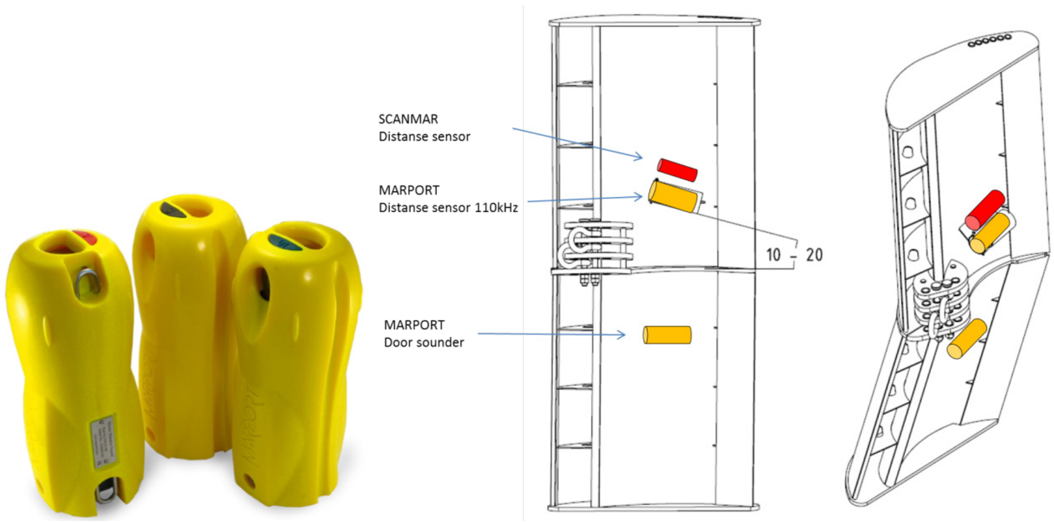


Figure 1. Sketch of the positioning of the sensors on the trawl doors.

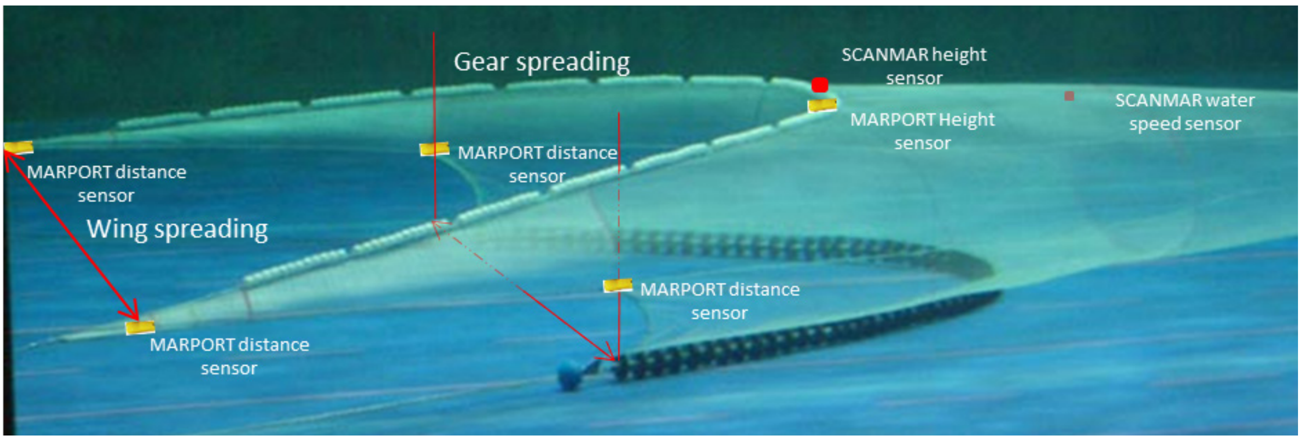


Figure 2. Sketch of the positioning of the sensors in the trawl.

5.2 New ground gear - Semi-circular spreading gear (SCSG)

Full scale tests were performed on board the research vessel R/V "Helmer Hanssen" (63.8 m LOA and 4080 HP) in the period 8–10 March, 2013. "Helmer Hanssen" is a multipurpose vessel, designed for fishery and marine biological, geological and oceanographic surveys in open and ice covered waters (1-2 m drift ice). The trawl deck is provided with double 50 m long trawl ways for bottom trawling and 4 sweep-line winches. The fishing area was off the coast of Troms (70°03'75"N / 70°06'94"N - 17°08'09"Ø / 17°11'66"Ø).

Two identical ALFREDO 3 trawls entirely built in 80 mm PE netting were rigged with two Thyborøn T2 bottom trawldoors (10m^2 and 3000 kg each), 75 m sweeps (30 m + 45 m), 108 m ground gear. The trawls had a headline of 36.5 m, a fishing line of 18.9 m and 810 meshes circumference (80 mm nominal mesh size). The foremost sections of the ground gear on both two trawls had five 21" steel bobbins (61 cm in diameter) on each side. One trawl was rigged with an 18 m long rockhopper with 21" rubber disks and 8"x

8" spacers (Figure 3), and the other with an 18 m long SCSG built in 50 cm x 50 cm HDPE pipe (Figure 4). Both trawls had identical 135 mm codends (nominal mesh size) built in 8mm Ø single twine PE netting (Euronet premium), 70 meshes long and 70 meshes in circumference. Both codends had inner-nets with 60 mm nominal mesh size (2.2 mm Ø single twine PE netting) to retain all fish over 30 cm.

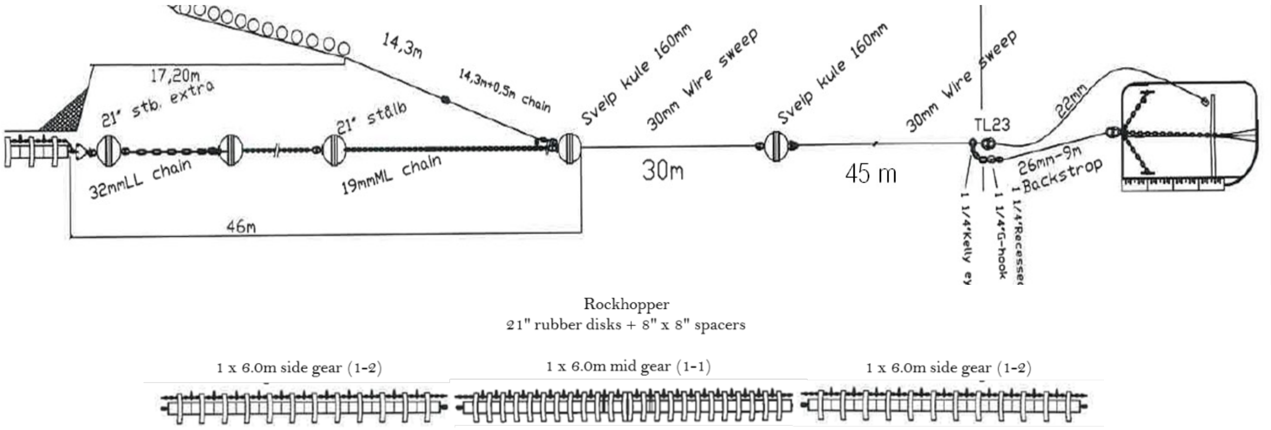


Figure 3. Rigging of trawl with rockhopper ground gear.

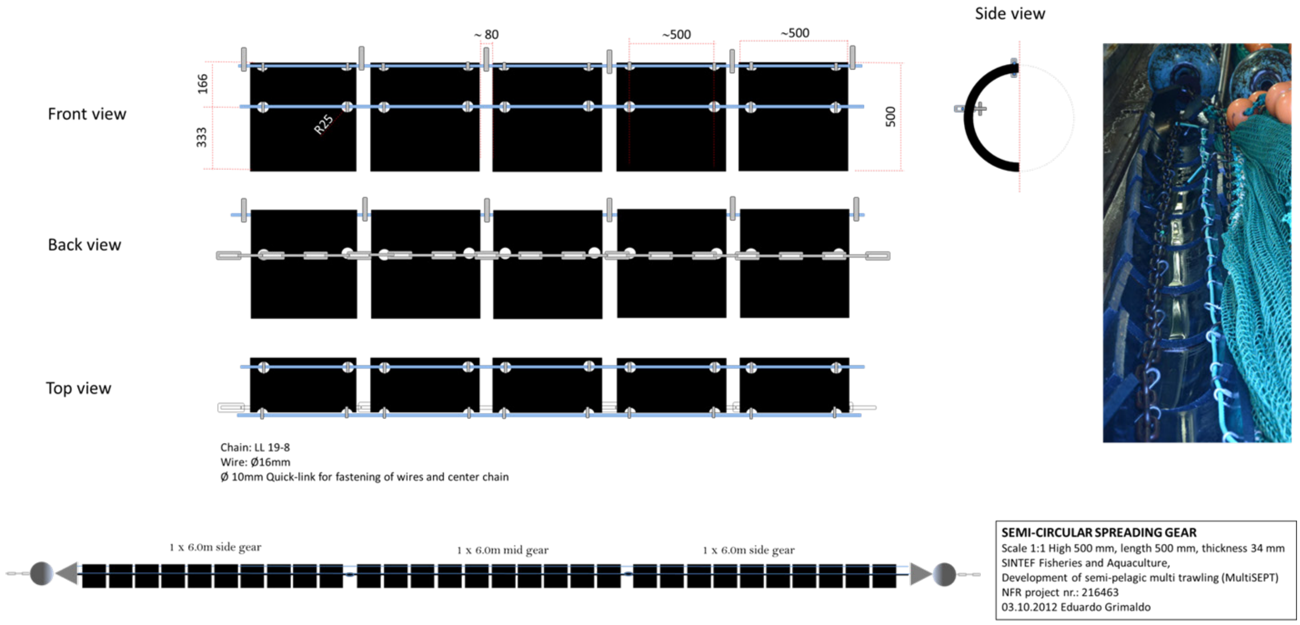


Figure 4. Semi-circular spreading gear (SCSG).

Gear performance

The SCSG in average had 7 % more spread than the rockhopper gear (16.8 m vs 15.7 m) at similar door spread (~115 m) and similar headline height (~6 m) (Table 4). The tension in the winches generally showed large variations (4.3-6.9 tons). For the SCSG the average tension was 5.85 ± 0.64 tons in the port winch and 5.80 ± 0.63 tons in the starboard winch. No significant differences in winch tension were found between the trawl with the rockhopper gear and the trawl with the SCSG.

Table 4: Average measurements of door spreading, gear spreading, headline height and tow speed.

Haul no.	Gears	Door spread	Gear spread	Headline height	Towing speed
Haul 28	Semi-circular	111.3 (± 4.9)	17.1 (± 0.5)	6.2 (± 0.3)	3.4 (± 0.2)
Haul 29	Semi-circular	117.4 (± 1.9)	16.2 (± 0.7)	6.1 (± 0.8)	3.3 (± 0.2)
Haul 30	Rockhopper	114.2 (± 3.3)	15.8 (± 0.7)	5.9 (± 0.4)	3.3 (± 0.1)
Haul 31	Rockhopper	115.7 (± 1.9)	15.6 (± 0.1)	6.0 (± 0.4)	3.4 (± 0.1)
Haul 32	Semi-circular	95.5 (± 0.7)		5.8 (± 0)	3.4 (± 0.2)
Haul 33	Semi-circular	118.3 (± 2.8)	16.9 (± 0.5)	5.6 (± 0.4)	3.7 (± 0.3)
Haul 34	Semi-circular	121.4 (± 1.7)	17.0 (± 0.4)	5.7 (± 0.3)	3.2 (± 0.1)
Mean values	Semi-circular	117.1 (± 2.8)	16.8 (± 0.5)	5.9 (± 0.4)	3.4 (± 0.2)
	Rockhopper	114.9 (± 2.6)	15.7 (± 0.4)	6.0 (± 0.0)	3.3 (± 0.1)

The video observations showed that the SCSG generally had good bottom contact throughout the entire tow, and that it easily slid over even large stones. Fish were observed swimming in front of the gear for some minutes before falling back to the trawls (Figure 5).

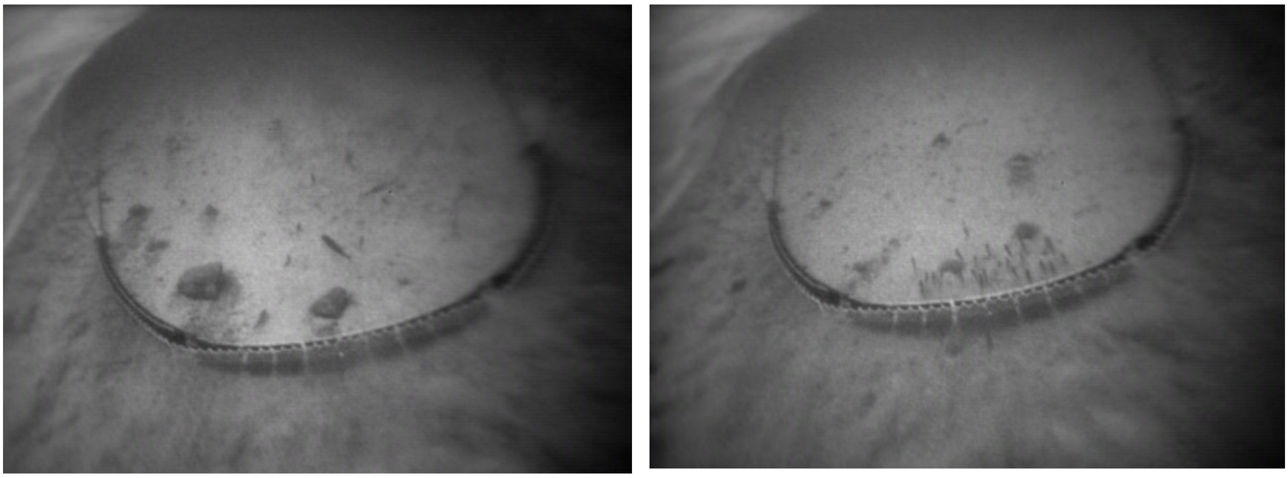


Figure 5. Underwater photographs showing the geometry of the semi-circular ground gear under operation.

The observations further revealed two openings of approximately 40 cm between the mid section and each of the side sections of the SCSG, where fish were observed escaping (Figure 6). These openings were unintentional, and can easily be avoided by changing the rigging of the groundgear (the spacing between the plates).

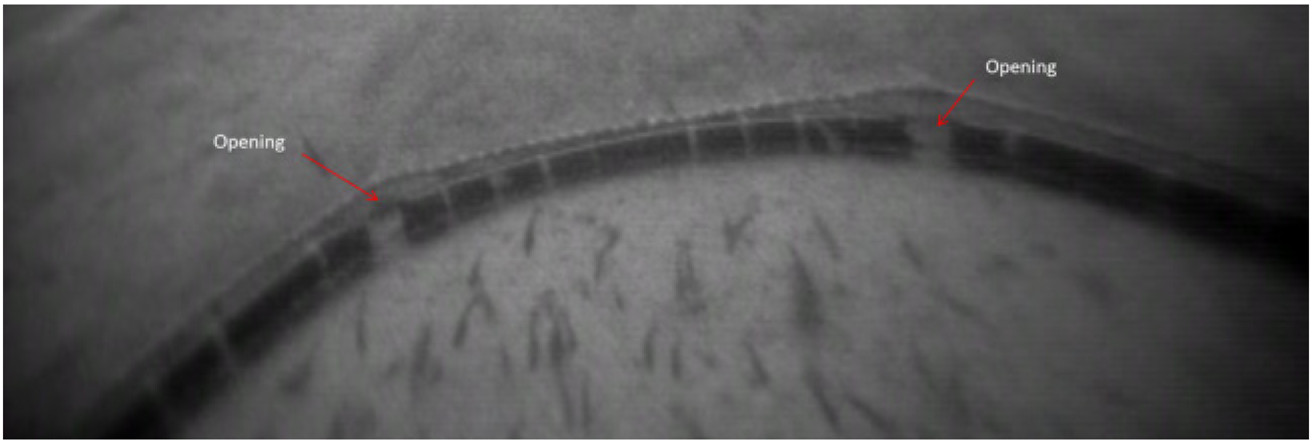


Figure 6. Underwater photograph showing the unintentional open spaces between the mid section and the side sections of the gear.

Fishing efficiency – catch comparison

The catches of cod and haddock varied considerably from haul to haul due to the variation in the availability of fish in the area. For instance, the catch ratio (number of fish caught per hour) of haddock in haul no. 29 was approximately 4.5 times higher than in the following haul. This high variability combined with the low number of hauls performed in this experiment make a standard catch comparison analysis statistically weak and unbalanced. Figure 7 shows the results obtained from the catch comparison analysis carried out on with the available data. However, as stated before, the statistical basis for these results is insufficient to draw conclusions.

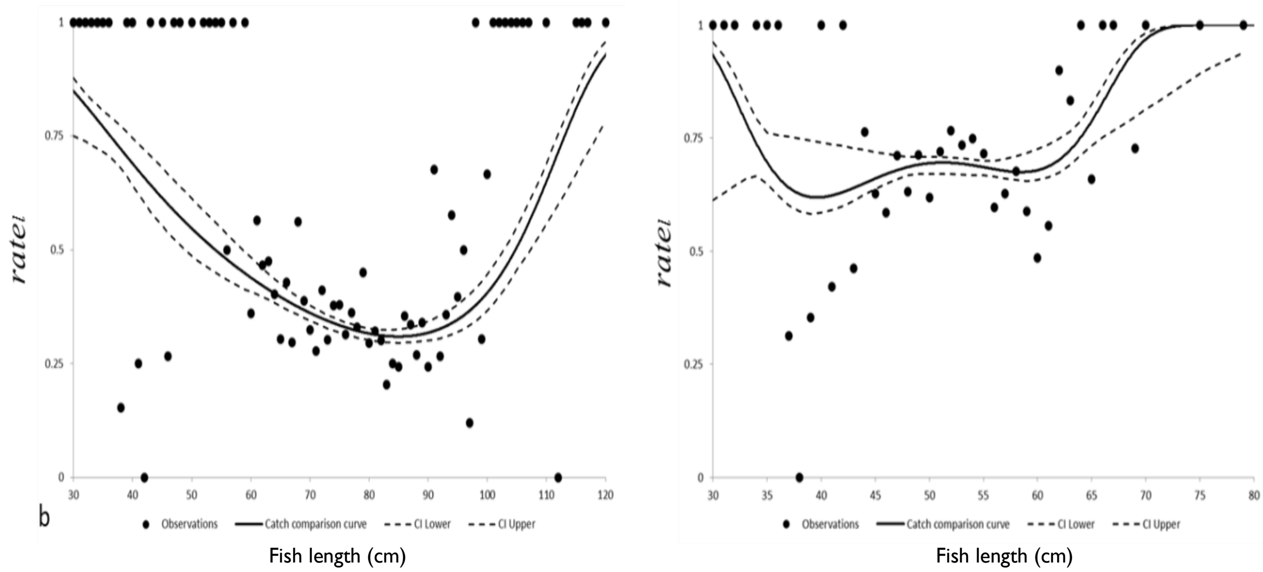


Figure 7. Catch comparison curves and 95% CI-s for cod (left) and haddock (right). When rate$_l$ = 0.5 both gears fish with the same efficiency, when rate$_l$ > 0.5 the SCSG is more efficient, and when rate$_l$ < 0.5 the rockhopper is more efficient.

5.3 Semi-pelagic trawling: Effect of sweep length on herding

Two full scale tests were performed on board the research vessel R/V "Helmer Hanssen" (63.8 m LOA and 4080 HP) off the coast of Troms (26 February – 08 March 2013), and in the banks of Hopendjupet and Bjørnøya (09 – 25 November, 2013).

Two identical ALFREDO 3 trawls entirely built in 80mm PE netting (36.5 m headline, 18.9 m fishing line, 810 meshes circumference) were rigged with two semi-pelagic Injector XF9 (6.5m² and 2200 kg each) doors, 75 m sweeps (30 m + 45 m) and 108 m ground gear. The foremost sections of the ground gear on both trawls had five 21" steel bobbins (61 cm in diameter) on each side, and an 18 m long rockhopper with 21" rubber disks and 8"x 8" spacers. Both trawls had identical 135 mm codends (nominal mesh size) built in 8mm Ø single twine PE netting (Euronet premium), 70 meshes long and 70 meshes in circumference. Both codends had inner-nets with 60 mm nominal mesh size (2.2 mm Ø single twine PE netting) to retain all fish over 30 cm. The position of the 450 kg weights were alternated from haul to haul. One position was behind the trawl doors (setup A), and the other position was in in the joint between the sweep and the ground gear (setup B)(Figure 8).

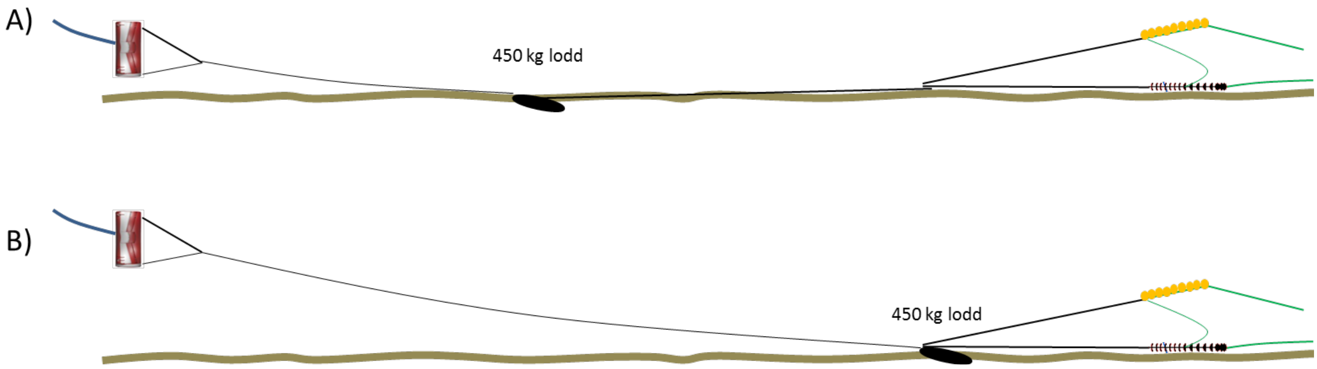


Figure 8. Sketch of the rigging of the trawl: A) The 450 kg weight is fixed behind the doors (45 m in front of the ground gear), and B) The weight is fixed in the joint between the sweep and the ground gear.

A preliminary analysis has been carried out on the cod and haddock catches of the banks of Hopendjupet and Bjørnøya in November 2013 This analysis showed that this data is statistically much stronger than the data collected during the cruise in March 2013. The dataset consisted of 32 hauls (16 comparison pairs) for cod and 14 hauls (7 comparison pairs) for haddock, and the towing time varied between 45 and 120 minutes and the catches between ca. 0.5 and 3 tonnes.

For cod, the comparison of the fish length distributions obtained with the two setups clearly show that when the sweeps are kept at the seabed (Setup A), the gear is substantially more efficient at herding fish and the catches bigger than when the sweeps are lifted (Setup B) (Figure 9). The catch comparison analysis shows that the rates differ significantly between the two setups (the upper confidence interval of the catch comparison curve (dashed blue line) does not cover the 0.5 rate value that would indicate that both setups are fishing equally efficient) (Figure 9). Further, an estimation of the catch ratio between the setups shows that the setup where the sweeps had no bottom contact captured in average 33% less fish and up to 50% less fish than the setup that kept the sweeps at the seabed.

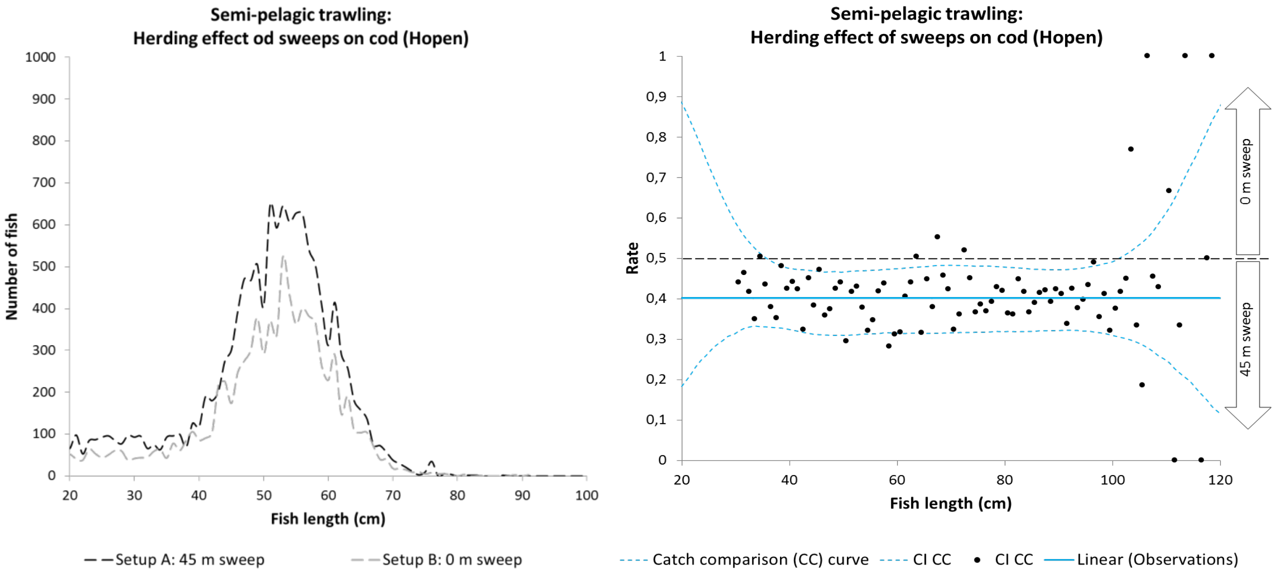


Figure 9: Herding effect of the sweeps on cod. To the left is the length distribution of fish obtained with the setup A and setup B (see figure 8). To the right is shown the catch comparison (blue line) based on the observations (black circles) with its confidence intervals (dashed blue lines). At a rate of 0.5, both gears are fishing equally efficient. Having the confidence interval under 0.5 means that setup A captured significantly more cod between 40 and 100 cm than setup B.

For haddock, the comparison of the fish length distributions and catches obtained with the two setups show similar pattern as for cod. In this case the results show some length dependency that was not detected for cod. When the sweeps are kept at the seabed, the gear is substantially more efficient at herding haddock and the catches are therefore bigger (Figures 10 and 11).

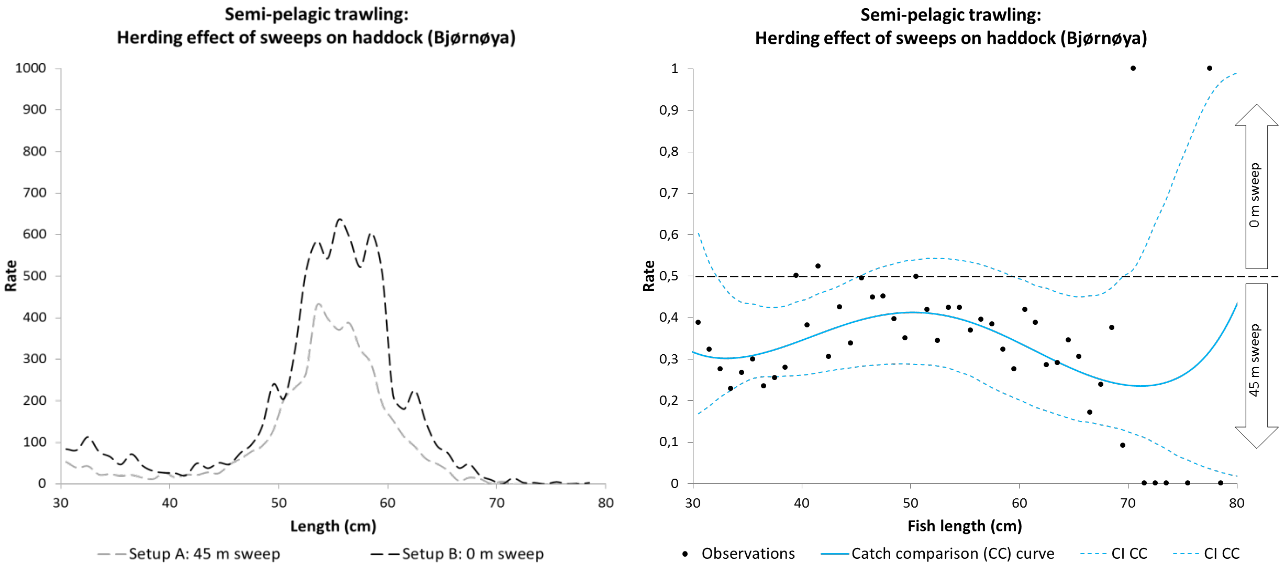


Figure 10: Herding effect of the sweeps on haddock. To the left is the length distribution of fish obtained with the setup A and setup B (see Figure 8). To the right is shown the catch comparison curve (blue line) based on the observations (black circles) with its confidence intervals (dashed blue lines). At a rate of 0.5, both gears are fishing equally efficient. Having the confidence interval under 0.5 means in this case that setup A captured significantly more haddock than setup B.

5.4 Controll and surveillance of trawl – development of state estimator

Controll and surveillance of trawl is the focus of working package 2 (WP2). Accordingly, a state estimator model (the core of the Roll Royce Marine's e-Trawling system) is being developed by SINTEF. The development plan of the SE model, which has 8 milestones, shown in Fig 11.

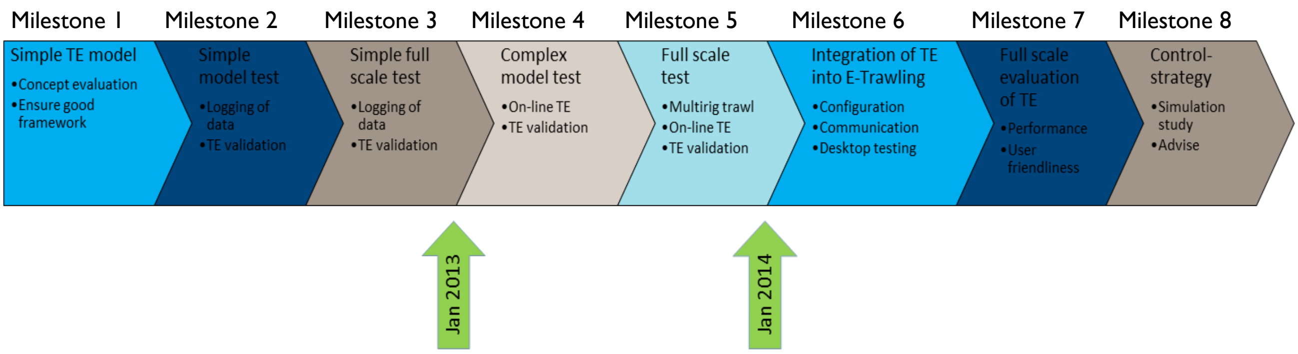
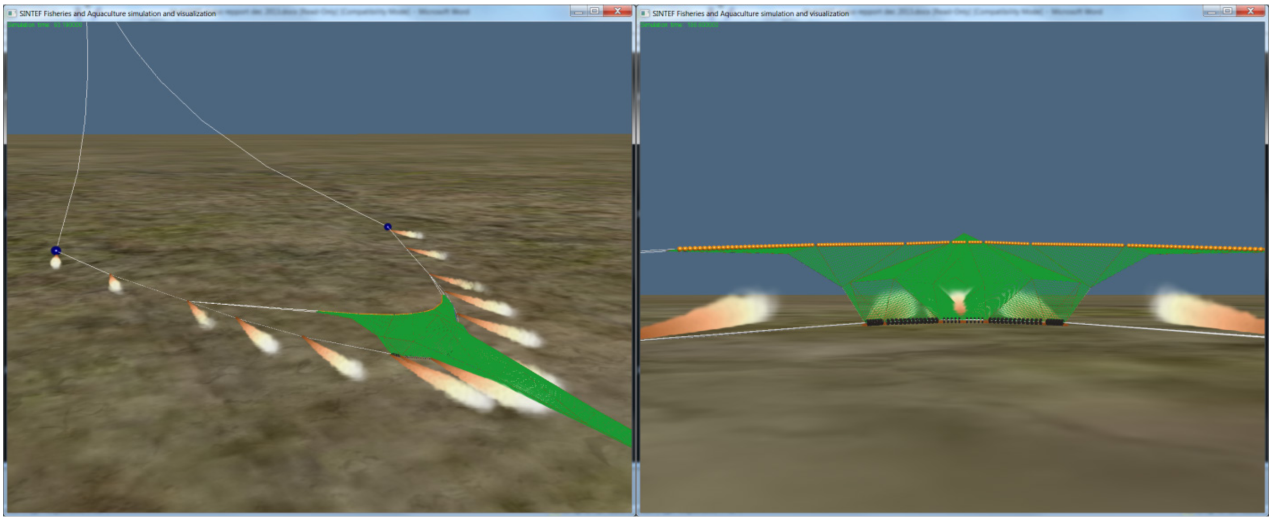


Figure 11. Progress plan. Each arrow represents a milestone.

A software framework capable of real-time state estimation of large systems has been developed, based on a nonlinear Kalman filter approach. The Kalman filter has been chosen because it allows flexibility in the system setup with regards to structure and sensor rigging.



A single-trawl model has been implemented within the framework, as well as various sensor types such as distance, depth, current, etc. In principle the framework can handle generic structures, including multirig trawls, but computation time will eventually become a limiting factor as structure complexity increases.

The first level of model verification has been to compare an estimated state against a different trawl simulation running on the same computer. Calculated sensor values from the "real" simulation are fed into the observed state simulation. The observed state simulation then tries to reconstruct the "real" simulation state based only on those sensor values.

The second level verification has been to compare the observer against model scale trials. 3D coordinates of key points on a model trawl have been logged under towing, and used to drive the state observer. Similar to the simulation-simulation comparison, the observer tries to reconstruct the position of the model scale trawl.

A full scale verification is yet to be completed. Sensor data from several trawl hauls were logged during field trials in November 2013, but are not yet processed. Due to on-site technical difficulties, full-scale online state estimation could not be performed at this instance.

The tests so far indicate that the typical minimum sensor setup of trawl door distance and depth may be insufficient to get the full benefit of the state observer. While the observer will provide an estimate that may be of some use, the variation in certain degrees of freedom will be large. Examples of different additional sensors that can be used to reduce the variation in the estimate are compass on the trawlnet or doors, global current, true position of any point on the trawl, etc. Once sufficient sensors are in place, the estimate tends to be very accurate.

5.5 Semi-pelagic shrimp trawling

An 8-day experiment (30. September – 08. October, 2013) was performed onboard the coastal shrimp trawler "Gullholmen" F-0300-M (14,09 m LOA, 400 HP main engine) in Lyngenfjord and Ullsfjord, Troms. The main objective was to compare shrimp catches and fuel consumption when fishing with a 1500 # Skjervøy shrimp trawl rigged as a bottom trawl (with 3 m^3 bottom trawl doors, Thyborøn T2), and as a semi-pelagic trawl (with 2.5 m^2 semi-pelagic doors, Injector Scorpion XF9), respectively.

On days 1, 3, 5 and 7, the trawl was rigged for bottom trawling (Figure 12) and three 3-hour tows were performed per day. On days 2, 4, 6 and 8, the trawl was rigged for semi-pelagic trawling (Fig 13) and three 3-hour tows were performed per day.

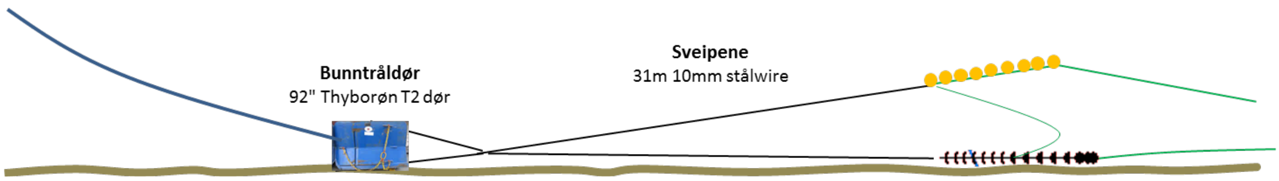


Figure 12. Sketch of the rigging for bottom trawling.

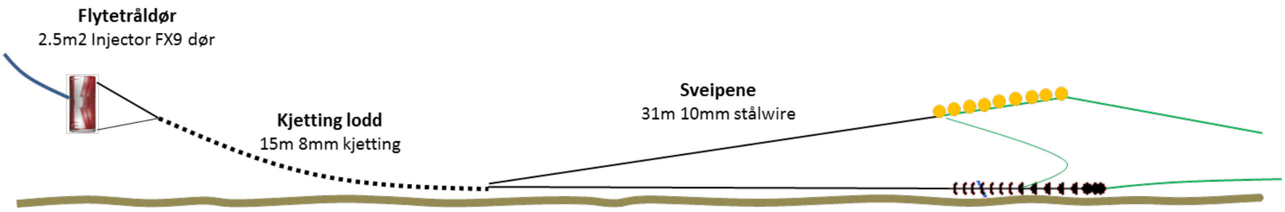


Figure 13. Sketch of the rigging for semi-pelagic trawling.

MARPORT sensors (door distance/depth, door sounders/height, and trawl eye) were used to monitor trawl configuration during trawling (Figure 14).

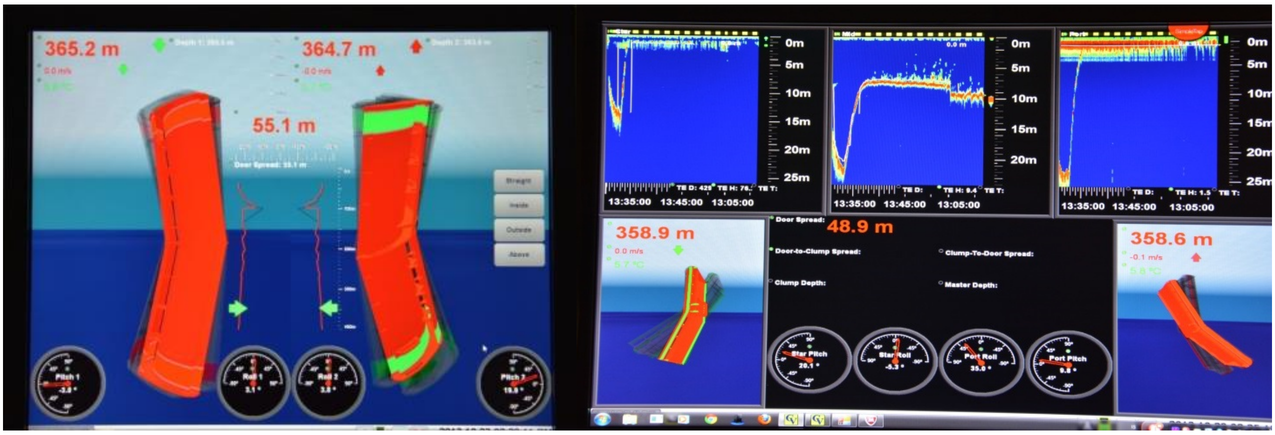


Figure 14. View of the MARPORT sensor information system. The left screen shows information on the trawl door depth, spreadning, pitch and roll. The screen to the right shows information on the trawl door depth below the sea surface, the door height above the seabed, the distance between the doors, and trawl height, pitch and roll.

Fuel consumption was approx. 6-8 % lower when trawling with the semi-pelagic doors than when using bottom trawl doors. The 2.5 m^2 semi-pelagic doors tested during our trials were overdimensioned for the coastal trawler "Gullholmen", and they had to be set at the lowest angle of attack to reduce spreading force and match that of the bottom trawl doors normally used by the vessel. A set of smaller doors (approx. 2 m^2) would had been a better choice to achieve the spreading force necessary for a 1500 # shrimp trawl. This would have reduced the fuel consumption even more. Shrimp catches were too low (15 – 45 kg/hour) and very variable from haul to haul to draw any conclusion on the fishing efficiency of the gear with the different sets of doors.

5.6 Remote controllable trawl door

A concept for remote control of existing trawl doors has been designed by SINTEF. The concept is based on manipulating the moment balance of the trawl doors, using control lines between points on the trawl door and external lines (warps or bridles). By tensioning such lines, the orientation of the trawl door is controlled, which again controls the hydrodynamic forces on the trawl door. The energyrequired to control the door can be greatly y reduced by controlling it about a point of instability.

This project focuses on developing a design which is inexpensive and easy to install on existing trawl doors. The control concept should control the roll angle of the trawl doors, while keeping the angle of attack and the angle of slip (pitch) as constant as possible. Since attaching control lines to the warp has obvious disadvantages related to handling of the door when taken in, it will be investigated how well a concept using control lines to the bridle(s) can perform.

A simulation model of the trawl door in a virtual experiment is developed. The setup is as follows: The trawl door is fastened by a warp and a bridle. The other ends of the warp and the bridle are fastened in two fixed points.

The trawl door is implemented as a 6 degrees of freedom (dof) body, and the hydrodynamic forces are calculated in all 6 dof based on the 6 dof velocity of the trawl door relative to the surrounding water. The warp and the bridle are implemented as lumped mass models. The control concept is implemented as a crow foot where the length of the individual lines can be controlled. Because of the fast dynamics of this system, its implementation is not based on elasticity in the individual lines. Instead, its steady state solution is calculated for each timestep. This is done explicitly, avoiding iterations per timestep.

The control system is comprised of a PID (proportional integrate derivate) controller and an actuator controlling the length of the control line. To evaluate the performance of the control system, the energy consumption of the actuator and the errors in orientation angles are calculated.

To develop the details of the concept and the control system, parameters of these are optimized using numerical optimisation. This is a classical multi objective optimisation problem with many separate objectives. As the number of objectives increases the computational effort required to find the optimum, one has to decide on how many (and which) of the real objectives to combine together. In this case, it was decided to use energy consumption as one objective and a function of the errors in the angles of roll, pitch and attack as another.

To evaluate a specific concept, a generic algorithm is used. The objective function is a simulation of the aforementioned system, where a desired trajectory of the roll angle is used as input to the control system. This optimisation is currently optimising 14 parameters:

- Position of the warp fastening point on the trawl door (x, y and z).
- Position of the bridle fastening point on the trawl door (x, y and z).
- Position of the control line fastening point on the trawl door (x, y and z).
- Controller parameters (proportional, derivative and integral gain).
- Controller maximum speed
- Length of the bridle base line.

6 Other collaboration

Marport Deep Sea Technologies Inc. has provided underwater acoustics products to the fishing industry worldwide since 1996 ranging from individual sensors to fully-integrated systems. Marport is an important supplier of suitable electronic equipment for field tests in this project.

VRI Finnmark has provided economical support to finance the full scale tests om bord the coastal shrimp trawler "Gullholmen" through the project "Semi-pelagic reketråling" (P2013-08).

Gullholmen AS, owners of the coastal shrimp trawler "Gullholmen", contributed to fullfillment of experiments with bottom trawling and semi-pelagic trawling for shrimps.

The Norwegian Directorate of Fisheries provided with the necesary permits for using the yearly distributed research quotas.

The conference FISHTECH 2012 proved to be an important arena for presenting and discussing the results of the MultiSEPT project with the industry and other research institutions.

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