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**A review of possible mitigation measures for reducing mortality caused by slipping from purse-seine fisheries**

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## Abstract
The release or "slipping" of schooling species like mackerel (*Scomber scombrus*) and herring (*Clupea harengus*) in the later phases of hauling during purse-seine fishing has been shown to induce high mortality among the released fish. Unsuitable catches, with respect to species, fish size and/or quality, or excessively large catches are the main reasons for slipping in these fisheries. In 2011, Norway introduced regulations banning the deliberate release of fish in the later stages of the purse seine haul in an attempt to minimise the unaccounted or collateral mortality from these fisheries. A mitigation program has been launched in Norway that aims to provide fishermen with tools that will minimise the need for slipping and, where slipping is unavoidable, maximise the survival of "slipped" fish. The program focuses on three main areas of development: 1) acoustic instrumentation for improved pre-catch identification of fish schools (in terms of species, quantity and fish size) to prevent catching unwanted fish; 2) methods and equipment to estimate the catch volume, fish size and quality at an early stage of pursing while slipping is still acceptable; 3) seine net designs and techniques that minimise the mortality associated with slipping. Where purse-seine gears used today are designed to maximise catch, new designs should consider the welfare of the catch and aim to minimise potentially fatal stressors and, physical injuries to the fish during the capture process

Key words: North Atlantic, purse-seine, mitigation, mortality

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## 1.0 Introduction
Purse seines have been the single most productive fishing gear globally for the past five decades, accounting for approximately one third of the global catch (by weight)(Watson et al., 2004; Watson et al, 2006; Watson et al, 2004 & 2006). Norwegian purse-seine fisheries catch about 500 000 tonnes of Northeast Atlantic herring and 180 000 t of mackerel annually, making them among the largest and most profitable fisheries in Norway (Fiskeridirektoratet 2012). Single catches may be very large, over 1000 metric tonnes, and highly valuable (~7 million NOK; ~€1 million). The price of the catch is, however, dependent

on the individual size and quality of the fish, thus the motivation to catch the most valuable fish is strong. Despite advances in sonar technology and highly experienced fishermen, it is currently difficult to determine a reliable quantity and a size-range for the fish before the catch has been densely crowded at the end of the haul. It is also difficult to control the catch size, and excessively large catches may exceed the quota or the hold capacity of the vessel. "Slipping", the release of the entire catch or portions of the catch from the purse-seine, is a common method of regulating the size and quality of the catch.

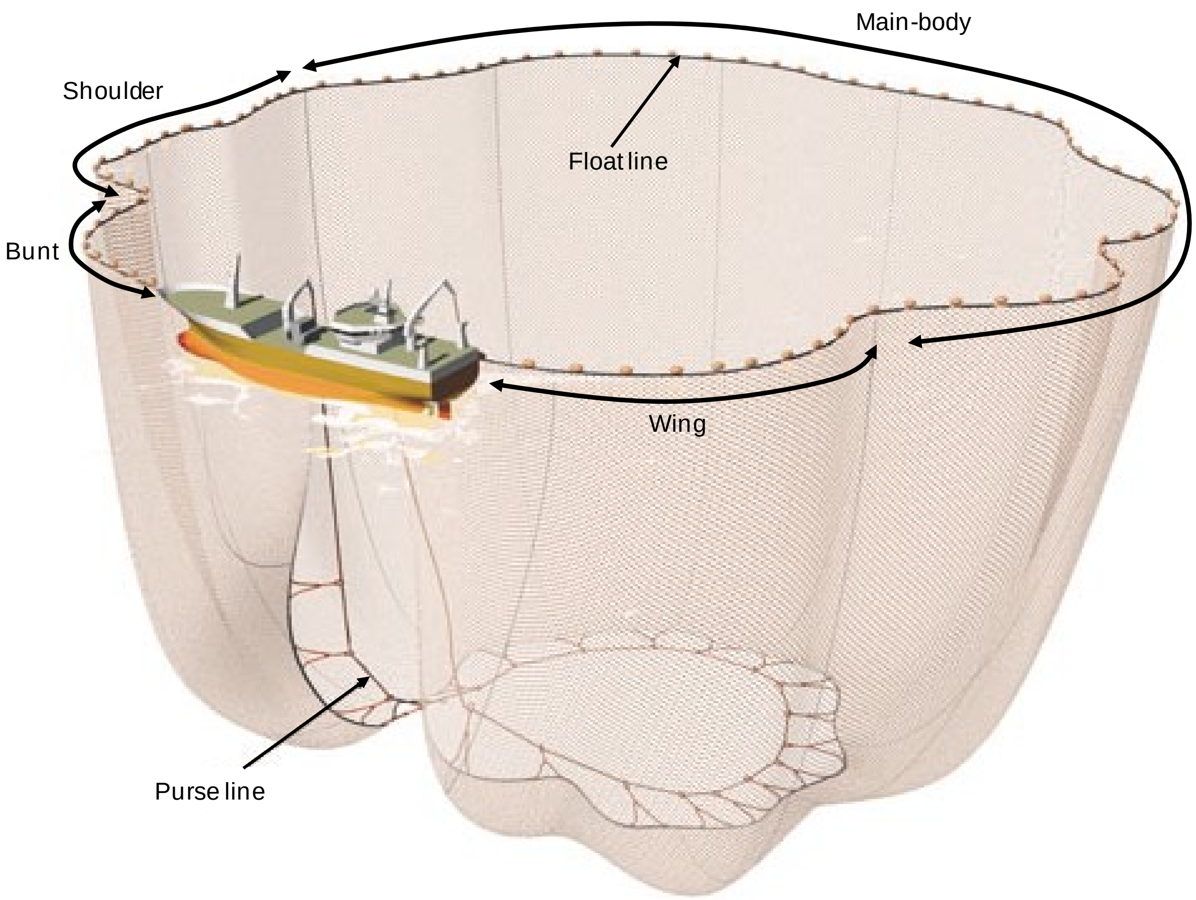


Figure 1: Annotated diagram of a purse seine (see figure 2 for further information on the component parts of the seine net). (Adapted from Galbraith et al, 2004)

The purse-seine is a highly efficient fishing gear; the largest seines can be over 1000m long and 200m deep (figure 1), which are capable of surrounding and catching an entire school of pelagic fish. Once a potential target school has been identified and the vessel manoeuvred into a favourable position, the seine net is shot, bunt first, by deploying a dan and/or sea anchor and bridle (figure 2). The vessel follows a course around the school, attempting to encircle it with the seine net that is drawn/cast out of the net pond at the aft end of the vessel. With the net fully cast and assuming the school has not evaded capture, the bridles to the bunt and wing are hauled in to close the seine around the school. Simultaneously the purse line is hauled in to close the seine net beneath the school. Once the seine net has been completely closed, it is heaved aboard the vessel wing first. This progressively reduces the volume of water contained within the net and concentrates the catch at the bunt end of the net. The bunt can contain catches in excess of 1000 tonnes, in the largest nets, and is thus specifically reinforced to handle the associated loads while the catch is loaded aboard the vessel, typically using a pump system.

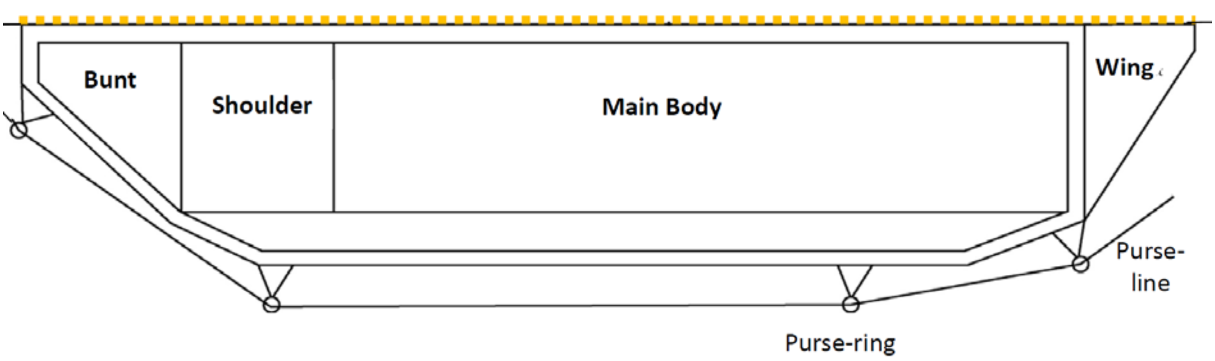


Figure 2 - Principle components of a purse seine

During this final phase of the capture process, the catch can become highly concentrated, with densities exceeding 250 kg.m$^{-3}$ for example(Tenningen et al. 2012), and can be exposed to potentially fatal stressors, including oxygen depletion, exhaustion and physical injury from contact with the net and catch. Unfortunately, it is typically not until this phase of the haul that the fishermen have sufficient information on which to decide whether to retain or release the catch. Experiments have demonstrated that the release or "slipping" of schooling species like mackerel (Lockwood et al. 1983; Huse & Vold 2010), herring (Tenningen et al. 2012), sardine (Marçalo et al. 2006; Marçalo et al. 2010) and sardinops (*Sardinops sagax*)(Mitchell et al. 2002) may lead to unacceptably high rates of unaccounted or collateral fishing mortality. Moreover, the mortality of slipped fish is directly related to their treatment within the net, with mortality increasing with increasing crowding densities and crowding time (Figure 3)(Lockwood et al. 1983; Tenningen et al. 2012). Slipping in the later phases of hauling, when the crowding densities are highest, is therefore unacceptable, and according to Norwegian legislation (Marine Resources Act, 2008) it is illegal to release dead or dying fish. However, the same experiments show that slipping at an earlier phase in the haul, when the crowding densities are lower, could induce far lower and more acceptable levels of mortality (figure 1).

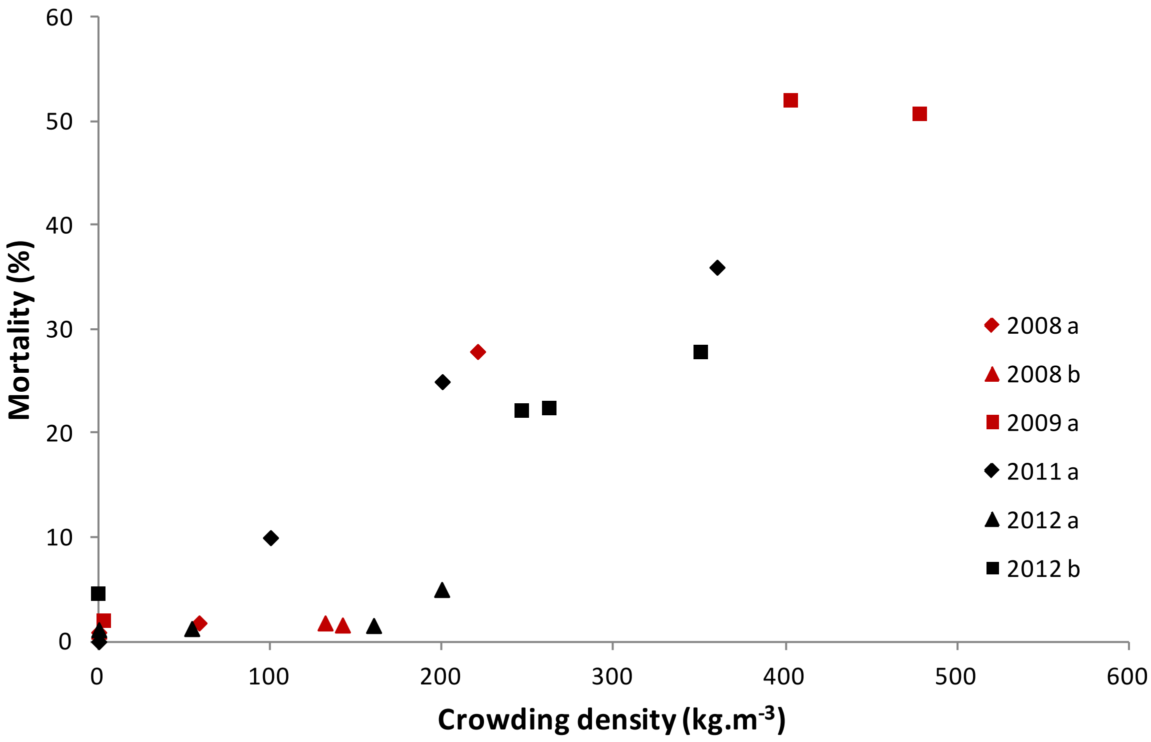


Figure 3 - The relationship between crowding density and mortality in North Sea herring (red) and Norwegian spring spawning herring (Blue) (adapted from Tenningen et al. 2012).

In response to new regulations in Norway (Fishing practice regulations §48), which ban the deliberate release of fish in the later stages of the purse seine haul, an extensive mitigation program has been launched in Norway that aims to provide fishermen with tools to minimise the need for slipping and, where slipping is unavoidable, maximise the survival of "slipped" fish. This program is funded through the Norwegian Research Council's "Centre for Research based Innovation in Sustainable Fish capture and Pre-processing Technology" (CRISP) based in IMR, together with funds from The Norwegian Fisheries and Aquaculture Industry Research Fund (FHF). The program focuses on three main areas of development (Figure 4): 1) **pre-catch identification** of fish schools (with respect to species, quantity and fish size) using acoustic techniques, to prevent catching unwanted fish; 2) **monitoring the catch and net** during the haul to provide information on the catch volume, fish size and quality at an early stage in the haul, while slipping is still acceptable; 3) **purse seine design and techniques** may be modified to promote the survival of deliberately slipped fish and minimised the accidental release of fish during the final phase of the haul.

This paper will review a range of potential technical solutions, including a new generation of acoustic and optical instrumentation, as well as new fishing gear designs, and will highlighted a Norwegian funded mitigation programme supporting the development of these innovations.

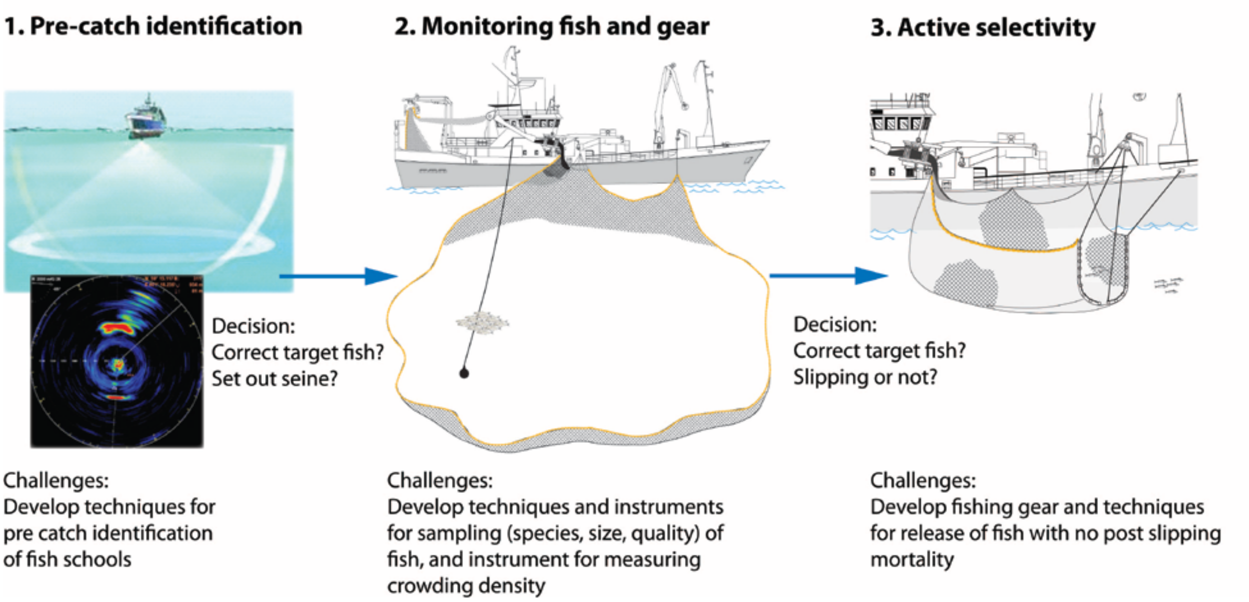


Figure 4 - Overview of the mitigation program for minimizing fish mortality caused by slipping.

## 2.0 Key Parameters in the selection of a suitable catch

Before discussing how to mitigate for "slipping" from purse seines, it will be useful to consider what parameters are, or could be, used when deciding whether a catch is suitable or not – and hence determine whether a catch is slipped. Rational decisions about the suitability of a catch could be made prior to and during the deployment of the net, if the fishermen can obtain an accurate, real-time description of the target school in terms of the following parameters:

**2.1 Fish species:** It is crucial for the fishermen to be able to identify the target species pre-shooting in order not to waste time by setting the net on an unwanted species. This is also important from a management point of view, as slipping fish of the "wrong" species may lead to unaccounted/collateral mortality among the released fish.

**2.2 Quantity:** Information on the volume of the target school pre-shooting, and the quantity of fish encircled by the net at an early stage of hauling is essential for the fishermen. The catch should not exceed the vessel's holding capacity or the remaining vessel quota. It must also comply with market demands.

**2.3 Quality:** There are many different parameters that can determine the perceived quality of a catch (e.g. size, meat and fat content, as well as the time delay in landing the catch). In some fisheries the price differences between fish of different qualities can be substantial. One well-known example is in the North Sea herring fisheries (in May/June) where the price of "matjes" grade herring (i.e. with specific fat and stomach content) can fetch a price several times higher than paid otherwise. Whereas, in the sprat fisheries for "sardine" production, fish with empty guts are preferred.

**2.4 Fish size:** this is typically the most important factor determining quality and, as such, should be considered separately. The price often differs considerably between size groups. For example, large mackerel normally fetch a better price than smaller ones, while in the North Sea herring fisheries "matjes" quality fish should not become too large (i.e. preferably 150-180g).

**2.5 Welfare status:** Now that the survival of fish after "slipping" has become an important management issue in the purse seine fisheries, it is likely that some measure of the catch's welfare will need to be considered before an unsuitable catch could be "slipped". Which parameters best estimate the post-release survival of fish, and can be practically measured during the capture process, are uncertain at present (see section 3.2.2 for further discussion).

## 3.0 Mitigation Measures

In following with the strategy described in section 1.0, three broad/tactical approaches have been adopted to address the slippage issue in the purse seine fisheries:

1. Develop technologies for remotely/indirectly providing estimates of key selection parameters (section 3.1);
2. Develop techniques for directly obtaining data on key selection parameters about the target school and its welfare (section 3.2); and
3. Modify the purse seining gear and technique to minimise mortality following the deliberate or accidental release of fish from the net (section 3.3).

The following section will give an overview of potential techniques and technologies for providing data on key selection parameters (see section 2.0) during purse seine fishing. Some methods, like acoustic technology, has been in commercial use for fish finding for decades, but are under continuous development to improve their accuracy for quantification, sizing and species identification. Other methods, like optical technologies, are still in the initial phases of development, while still others are at the conceptual phase (e.g., measuring metabolic products). It is unlikely that in the near future any one technique/technology will satisfy all measurement requirements for the purse-seine fleet, and therefore it is likely that a range of instrumentation and techniques will be required in order to fully identify the composition of the catch. However, all instruments that are developed for purse-seine fishing must be practical to handle and operate in order to be acceptable to the fleet. Also any instrument fitted on the seine net has to be robust enough to withstand the great physical forces created during the deployment and recovery of the net, but particularly while being dragged through the Triplex (triple power block).

With respect to minimizing unaccounted mortality, pre-catch identification methods are clearly preferable, as all risk of damage to the target fish, and indeed the crew and gear, is removed if the gear is not shot unnecessarily. However, if a catch is encircled by the net, and the full details of the catch suitability parameters are not yet available, it is crucial to obtain the additional information as soon as possible, while it is still acceptable to release unwanted fish.

### 3.1. Remote or Indirect measurement of target school

#### 3.1.1 Acoustic Techniques

The acoustic techniques currently used by the purse-seine fleet are sophisticated instruments giving a wide range of outputs which experienced fishermen may interpret to give quite accurate information about the fish schools being hunted, i.e. its position and depth, as well as direction and velocity of movement. However, these instruments cannot, at this stage, always provide the information necessary to decide whether the target school is a suitable catch or not (see section 2.0). Presently, there is a development programme within the CRISP Centre, where scientists at IMR are cooperating with a fishing technology company (Kongsberg Maritime AS - Simrad) to improve the precision and functionality of existing sonars, as well as to develop new acoustic instrumentation for pre- and early catch monitoring of fish schools.

<u>Pre-catch information</u>

At present, the acoustic pre-catch monitoring of a pelagic fish school using sonar and echo sounders is limited in the quantitative data it can provide about the target school, particularly with respect to volume and density. As part of the CRISP programme, work is underway to develop multi-beam sonar techniques to provide improved measurement of the target school volume and density, and hence estimates of the potential mass of catch. This includes using element data from the transducer to create multiple vertical beams for a 3D representation of the school at short range during the inspection phase of the haul.

These techniques must overcome the problem of variable target strength, due to the different horizontal aspect of individual fish within the school (Pedersen et al. 2009). This will be achieved by integrating information from different the sonar frequencies to measure and account for variations in horizontal target strength. To date, the work in this area has focused on the development of new calibration methodology and equipment capable of calibrating individual beams, as demonstrated in the Simrad MS70 scientific sonar (Ona et al. 2009), as well as post-processing software for school detection and estimation (Vatnehol 2012).

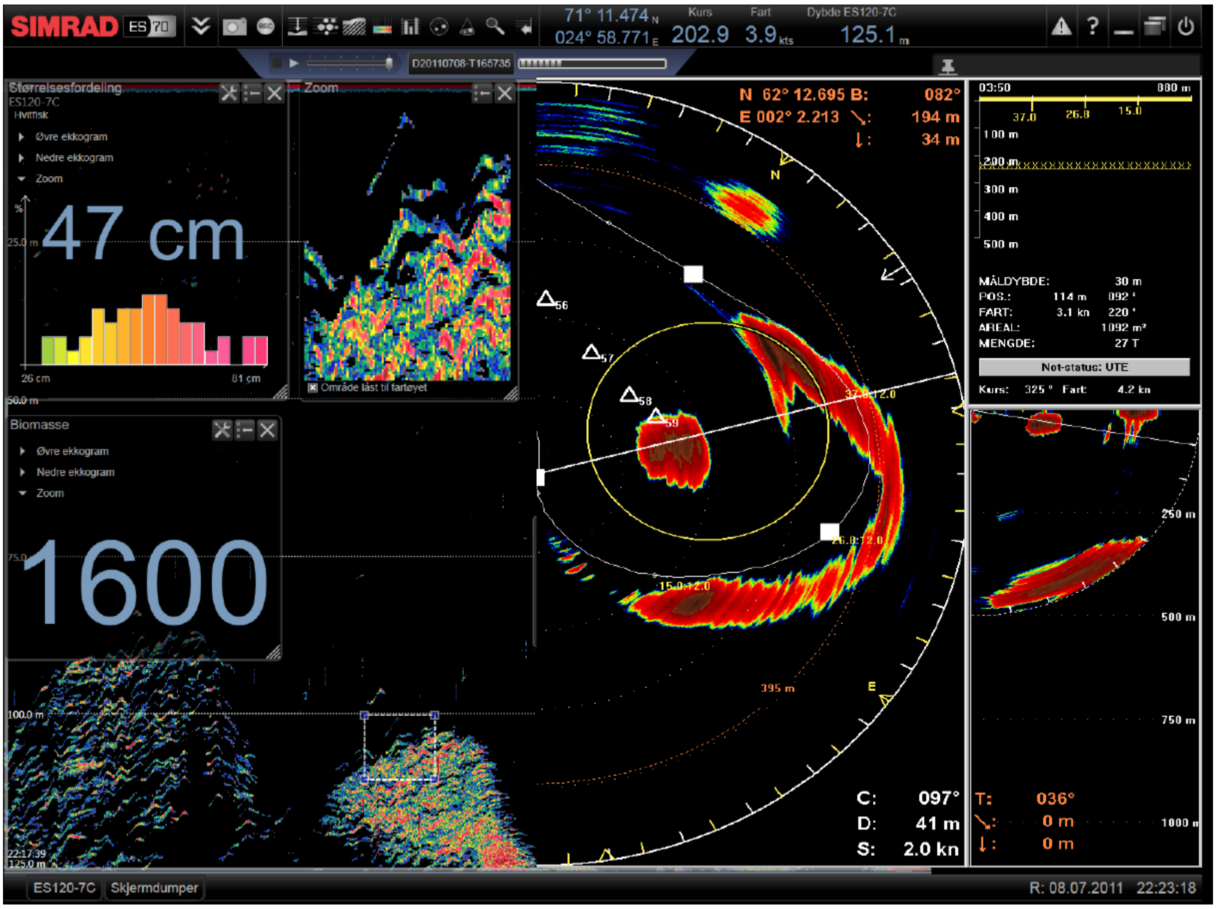


Figure 5 – The prototype Simrad SN90 “In-Seine” sonar system display, showing integrated information on the size, structure and density of the target school, as well as single target information (i.e. fish species and size)(Image from Kongsberg Maritime AS – Simrad).

## Early catch information

Acoustic techniques have not been considered particularly useful after the purse seine has been set, as the fishing operation itself generates a bubble cloud surrounding the vessel and acoustic attenuation becomes a major problem. As part of the CRISP programme, an integrated suite of acoustic and optical instruments is being developed to tackle this problem and provide information on school volume, density and fish size before the fish are crowded to unacceptable densities.

New transducer mountings are currently under development to help reduce the effects of bubble noise. Also, instrument drop-keels and alternative transducer positioning may further reduce this problem, provided they can protrude below the bubble cloud without impeding or entangling with the net. With this new observation platform, it may be possible to monitor the catch inside the net using a range of both acoustic and optical instrumentation.

At the dense concentrations likely to be observed in fish schools within the seine, acoustic signal attenuation can become problematic. Work is planned, through experiments and comparative trials, to measure and correct for these shadowing effects, thus allowing more precise biomass estimates to be made with calibrated instrumentation.

The size of individual fish can be measured using broadband split-beam echo-sounders (Cutter & Demer 2007) and work is currently underway with the Simrad EK80 in controlled net-pen experiments to develop this system. The EK80 echo sounder will be modified by using more and narrower beams, and determining how these can be arranged in side-view modes. This will enable split-beam target tracking on the outer edges of dense schools, thus it may be possible to monitor the behaviour and activity of fish on the outer edge of the school (e.g. Handegard et al. 2009).

One interesting development by Kongsberg Maritime (Simrad) is the SN90 "In-Seine" sonar system. This system aims to combine the functionality of a multi-beam sonar with a split-beam echo-sounder. Using a forward blister-mounted transducer, in an attempt to avoid bubble noise, it will simultaneously transmit over three discrete frequency bands, and receive in a horizontal swath, a vertical cross-sectional beam and a directionally controllable split-beam (figure 6). The objective is to have an integrated system that will provide information on the three dimensional size, structure and density of the target school, as well as single target information (i.e. fish species and size).

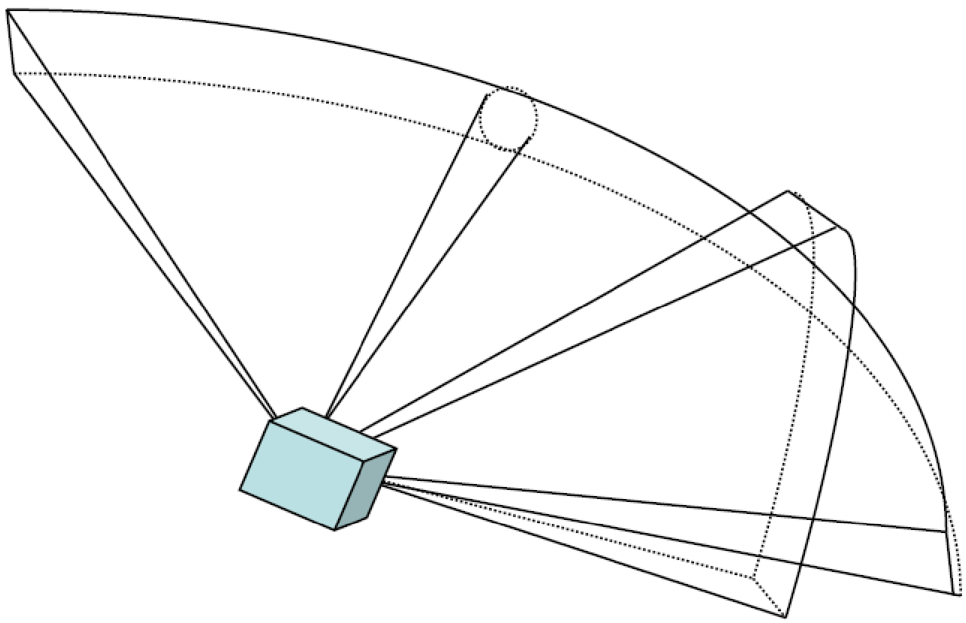

Figure 6 - The Simrad SN90 will simultaneously transmit over three discrete frequency bands, and receive in a horizontal swath, a vertical cross-sectional beam and a directionally controllable split-beam (Image from Kongsberg Maritime AS – Simrad).

Finally, a method for integrating sonar and echo-sounder information with positional data from acoustically activated transponders (e.g. HiPaP) is currently being developed, by researchers at IMR, to describe the three dimensional geometry of the purse-seine ( Tenningen & Pena 2012). This system will not only be informative for the fishermen during the deployment and recovery of the net, but will also provide valuable information about the volume of water in which the target school is held, thus allowing more accurate estimates of crowding density to be made (see section 3.2).

High Resolution Imaging Sonar/"Acoustic cameras"

Sonar operating at very high frequencies (>1Mhz) can be used to produce high resolution images of objects, at relatively short range (<30m), but independently of light and turbidity conditions. These systems have the potential to be used to identify and measure individual fish, as well as provide point estimates of school/crowding density and observations of fish behaviour (Boswell et al. 2008; Graham et al. 2004; Moursund et al. 2003; Handegard & Williams 2008; Holmes et al. 2006). But the resolution of the image must be balanced against the range, and is also dependent on the operational frequency and size of the acoustic array (Svardal et al. 2012). Examples of "acoustic cameras" include: SoundMetric's Aris and Didson ranges of cameras, as well as the CodaOctupus Echoscope and BlueView systems. Apart from the very high cost of these systems and limited effective range, their main disadvantages are their current size/weight and susceptibility to damage, which make them impractical to use in commercial purse seining operations at the present time.

Passive acoustics

Hydrophones can be used to monitor pressure waves emitted from moving fish and hence assess the level of activity (i.e. the tail beat frequency), interaction with the netting or other sounds generated by the swimming activity. Several studies have shown measurements of sound from swimming fish and shoals including Shiskova (1958, horse mackerel), Moulton (1960) and Gray & Denton (1991, herring, sprat and whiting). Strategically placed hydrophones/echo-sounders on the netting wall would also be able to detect large concentrations of fish in close proximity or in physical contact with the netting wall. This approach is unlikely to be able provide sufficient warning of unacceptable crowding densities before it is too late to slip. However, it could be used to trigger a device (e.g. a strobe light) to stimulate the fish to move away from the netting, hence avoiding injury, or alternately into the field of view of a short-range observational instrument, i.e. an acoustic or optical camera.

### 3.1.2 Optical Techniques

The ultra short wavelength of visible light means that optical or photographic techniques can provide images with much higher resolution than acoustic methods; thus enabling species identification and size estimation, as well as monitoring the behaviour and activity of the target fish down to the level of the individual. Moreover, the human observer generally finds it easier to interpret photographic images, which is likely to make this technology more appealing to the fishing industry. However, the very short wavelengths also mean that light is quickly attenuated and scattered in water, thus limiting traditional photographic techniques for such applications to relatively short ranges (typically <20m) in even the clearest waters with optimal lighting conditions.

Recent advances in optical technology have provided many potential solutions to these limitations, for example:

> **Optical sensors:** there is now a wide range of sensors available with different properties (e.g. CMOS, CCD, ICCD, EB-CCD and EM-CCD), which have greatly improved the sensitivity of cameras and increased the range of natural underwater lighting condition where they can be used. Key properties to consider are pixel resolution, spectral response, sensitivity and signal/noise ratio; where there is generally a trade off between light sensitivity & cost with resolution & signal noise (Svardal et al. 2012).
>
> **Lighting Method:** There are now various technologies that make the use of artificial light in fishing operations like purse seining more practical and energy efficient; e.g. LEDs and fibre optic cables. If it is necessary to use artificial light sources, the choice of method will greatly influence the resolution of the image, as well as contrast and range. To minimise backscatter from suspended particles in the water, it is best to maintain an optimal angle between the camera and light source; however this will reduce both the contrast and range, through attenuation and scattering of the light due to the increased light path. Other techniques exist that further improve the range, e.g. range grating (Jaffe et al. 2001) and synchronised laser scanning (Narasimhan et al. 2005); although these are costly and unlikely to be sufficiently robust for practical application in a purse seine fishery (Svardal et al. 2012).
>
> **Spectral & Polarising Filtration:** In some lighting conditions, particularly in turbid waters, the use of spectral (colour) and polarising filters can be used to significantly reduce unwanted light and increase contrast and range. Further improvements can be made with post-processing of the images (eg. Schechner et al. 2004).

Therefore, it is conceivable that, with sufficient development investment and using optimal lighting methods and spectral/polarization filtering, in combination with range-gating techniques, it may even be possible to capture informative images of the target school with a camera mounted on the ship’s bridge (Svardal et al. 2012).

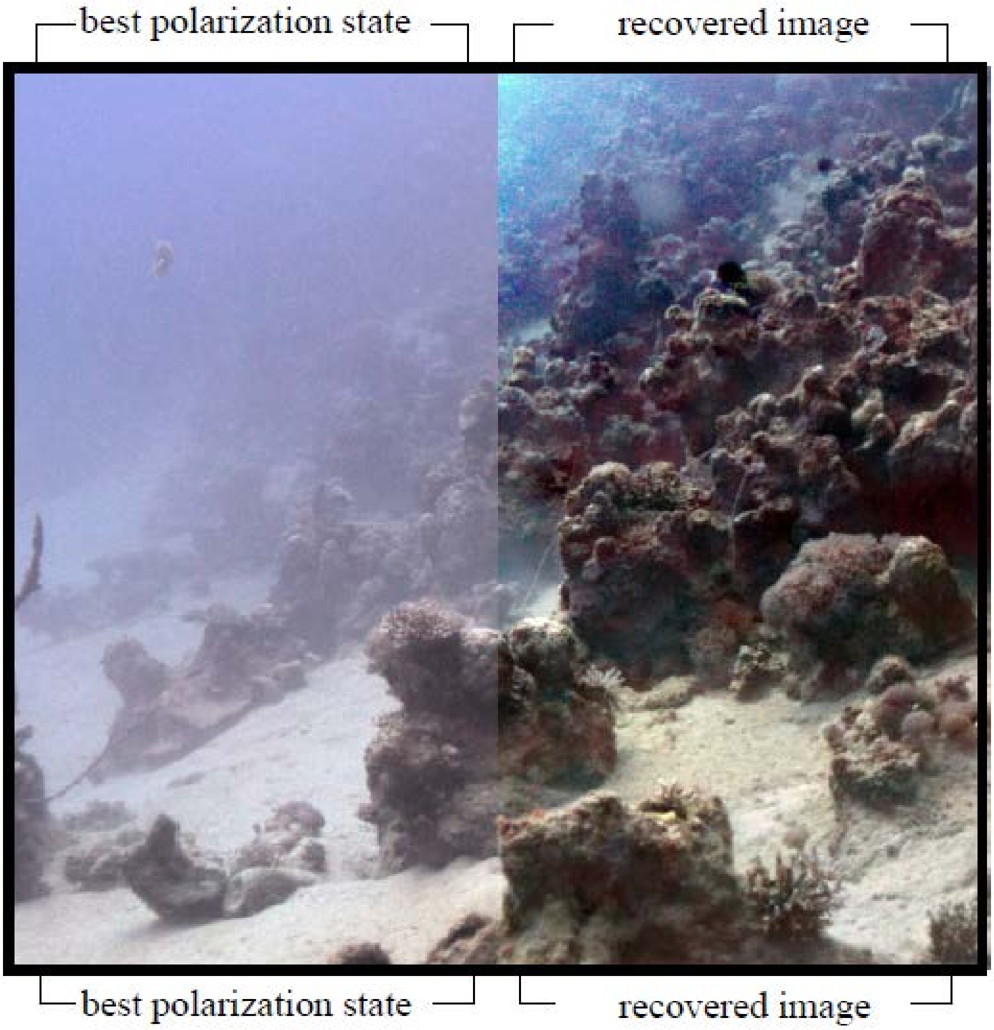


Figure 7 - Demonstration of the effects of polarised filters and image processing on a photograph from the Red Sea, 26m depth (from Schechner and Karpel, 2004)

To be able to estimate the size of individual fish from an optical image, it is essential to know the scale or perspective of the image. One of the most promising techniques for this application is stereo photography. This technique has already been developed, by Scantrol AS working with the CRISP Centre, for species identification and fish sizing in trawls (Valdemarsen et al. 2012), and it is feasible that a similar technique may well be applicable in purse-seines.

However, to make any optical instrument useful for this particular fishery, an extensive development of hardware for protecting, powering and operating the camera systems in this extreme environment will be required. This is particularly true if the cameras are to be mounted on the fishing gear, where it will also be necessary to provide solutions for stabilising the image in this dynamic environment, as well communicating and processing the large volumes of data produced. Also the user interface must be customized for the purse-seine fleet's needs.


Figure 8 - Fish size and species (herring) identified in situ by stereo-optic measurements (Photo: Scantrol AS).

## 3.2. Direct measurement of the target school

**3.2.1 Sampling Methods:** While quantity, size and species may be determined using remote measuring techniques, fish quality can, at present, only be determined by physically examining a specimen from the catch. In order to be able to get a fish sample from a seine at an earliest possible stage of hauling, it is necessary to develop sampling methods to capture fish inside the seine. Several methods are currently already used by some vessels (e.g. hand-lining & trolling for mackerel and dip-netting for capelin). However, these techniques are often limited in their application and there is a clear need to develop more generally applicable techniques.

One approach was to fit bags of different sizes to the shoulder end of the bunt, on the assumption that fish would be caught in these bags during hauling, thus providing a sample of fish for examination before the catch became too crowded. The method work but could not be relied upon to provide samples every haul. Trials with larger sampling net, of transparent netting, with an opening of 5 x 5 meter - where it was hoped that some herring would attempt to escape through the apparent opening - did not prove successful either.
Another, more promising approach, is a small pelagic trawl (figure 9), which is kept open by kites while it is towed through the school encircled within the seine. The sampling trawl is

deployed across the net using a compressed air gun and then rapidly hauled back to the vessel. The initial experiments have shown that this method has the potential for being used for sampling fish. Further studies are needed however to optimise the deployment and operation of the sampling trawl, as well as establish how well this sampling method describes the target school.

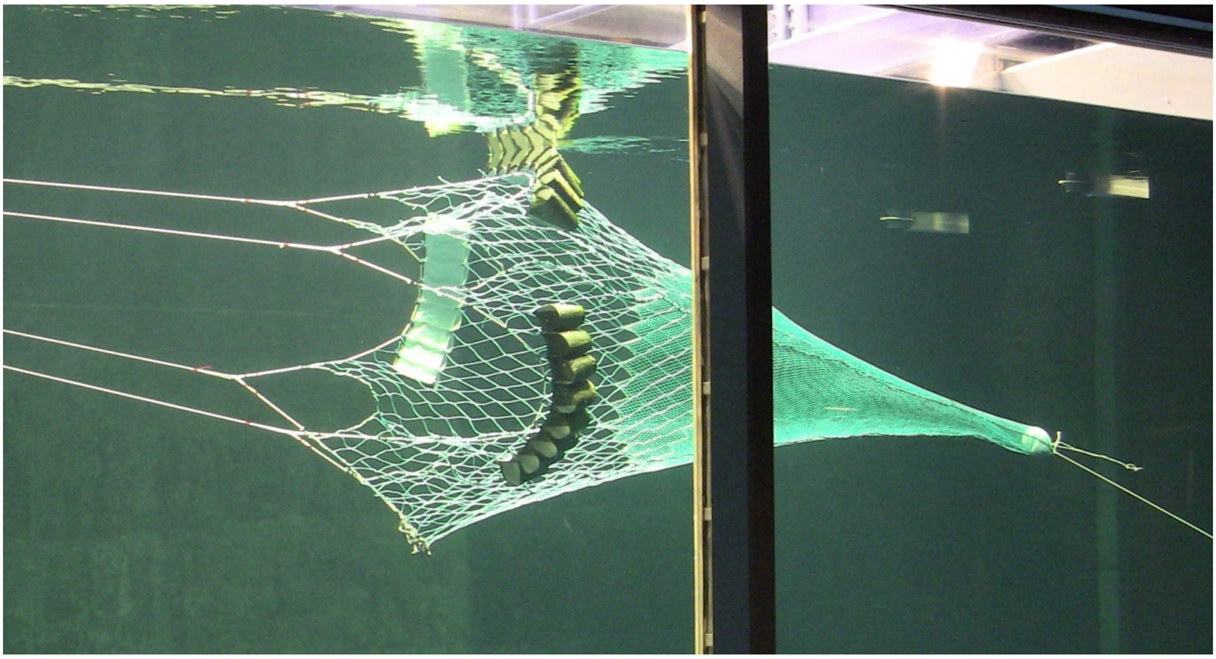

Figure 9 - a model of a prototype sampling trawl during trials in a flume tank

**3.2.2 Monitoring welfare status:** The mortality of “slipped” fish has been shown to be proportional to the crowding density (Tenningen et al. 2012). This may prove to be a useful indicator, if it can be accurately estimated; where a crowding density, or “point of no return”, could be defined in fishing regulations after which the fishermen are no longer allowed to release fish. Thus will not only require estimates of the size of the target school (section 3.1), but will also require accurate descriptions of the net geometry (Tenningen & Pena 2012).

It is well established that the behaviour of fish, both individually and in groups, is an important indicator of their welfare status (eg. Huntingford et al. 2006). It would therefore be informative to describe changes in the behaviour of the target species (using both acoustic and optical techniques) throughout the capture process, but in particular when crowded. From this it may be possible to identify behavioural indicators that could be used as a threshold for the safe release of fish from the purse seine.

While the fish are encircled by the net and the volume gradually decreased and the fish density increases, metabolites from the fish’s physiological processes starts to accumulate in the water, while the oxygen level will decrease as the fish used the dissolved oxygen for its metabolism. Measuring the level of physical metabolites and oxygen in the water may give an indication of the quantity of fish, but in particular of fish density, within the net. However, this would need a considerable effort in fundamental biological research to learn the significance of these metabolites. Even more relevant is that the concentration of metabolites and decrease in oxygen level will probably only be measurable at very late stages of crowding, probably too late to conduct a responsible release of fish.

## 3.3. Modifying fishing practices

Two distinct areas were identified in which the mortality of fish being released from purse seines could be reduced:

a) Minimising the risk of physical injury and stress during the release; and
b) Minimising the unintentional release of fish from the catch.

<u>a) Minimising physical injury & stress</u>

The purse-seine gears used today are designed primarily to maximise the catch, however, now that the survival of fish after "slipping" has become an important management issue, new fishing gear designs and practices should also aim to minimize unnecessary stress and physical injury to released fish. This is not a new concept however, as the transfer of pelagic fish from purse seines into floating storage pens was once common practice in the Norwegian coastal fisheries; enabling small vessels to take catches much larger than their hold capacity or to delay harvesting to improve the quality and/or value of the catch. Clearly, it was a priority in these fisheries to maximise the survival potential of the fish following their transfer from the purse seine. So valuable insights into methods for minimising injury and stress can be learned from studying the practices and gears from these coastal fisheries.

If 'slipping' is unavoidable, it is essential to minimize crowding and physical contact with the gear in order to minimise stress, injury and mortality. To facilitate this, the release opening should be made as large as possible to encourage the fish to escape, or conversely, not present a visible obstruction and hence stimulate them to turn back into the seine. The opening must also be easily and rapidly opened and closed. This can be achieved with relatively simple modifications of the terminal end of the bunt (bunt-end) and associated strops. In modern purse seine designs the hanging ratio of the bunt netting onto the float-line and bunt-end is set (at typically 42-45%) to maximise the surface area of netting and hence the volume that can be contained within the bunt. This makes the pursed bunt quite bulky, while the round-strop at the end of the bunt constricts the opening during slipping, thus severely limiting the opening for slipping the catch. By decreasing the hanging ratio of the bunt-end from 42% to 25%, the same amount of netting will almost double in length, making it less likely to bunch up and restrict the opening. At the same time, the roundstrops at the bunt-end can be replaced with a single strop secured at one end, which is less likely to constrict the opening in the bunt during the release (Figures 10 & 11). These modifications have recently been successfully tested on a commercial purse seine as part of the mitigation program. Interestingly, one Norwegian word used by the coastal fishermen for the bunt-end of the purse seine is “geil” which means “corridor”; highlighting the concept behind its design.

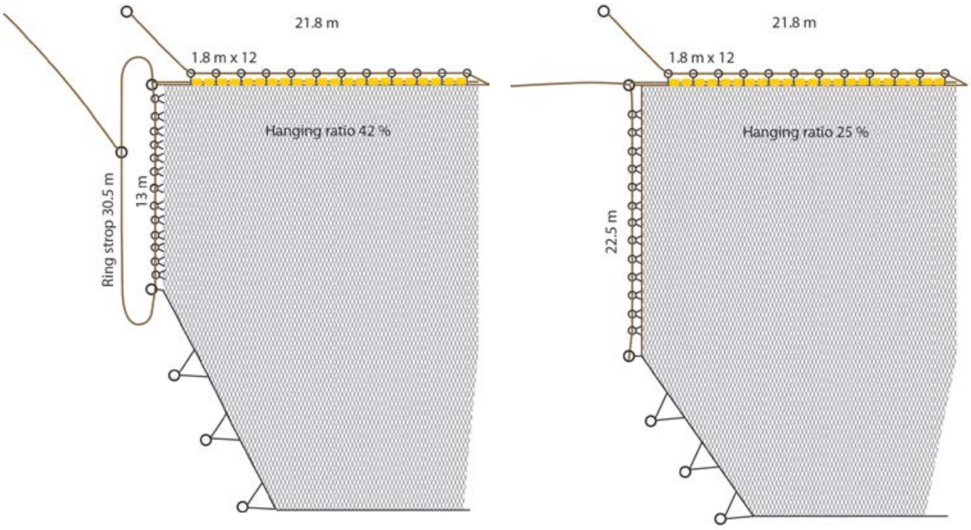


Figure 10 a) the normal rigging of the bunt of a Norwegian purse seine. A hanging ratio of 42% makes the pursed bunt quite bulky, while the round-strop at the end of the bunt constricts the opening during slipping. b) By decreasing the hanging ratio of the bunt-end to 25% and replacing the round-strop with a single rope can increase the release opening in this example to ~7m deep and ~14m wide, facilitating fish escape.

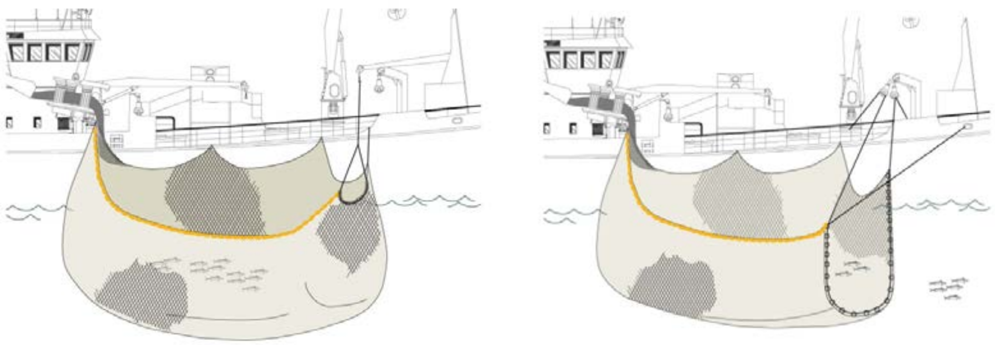

Figure 11 - An illustration of how modifications to the rigging of the bunt end of the seine (see figure 10) can increase the opening available for slipping unwanted catch (right).

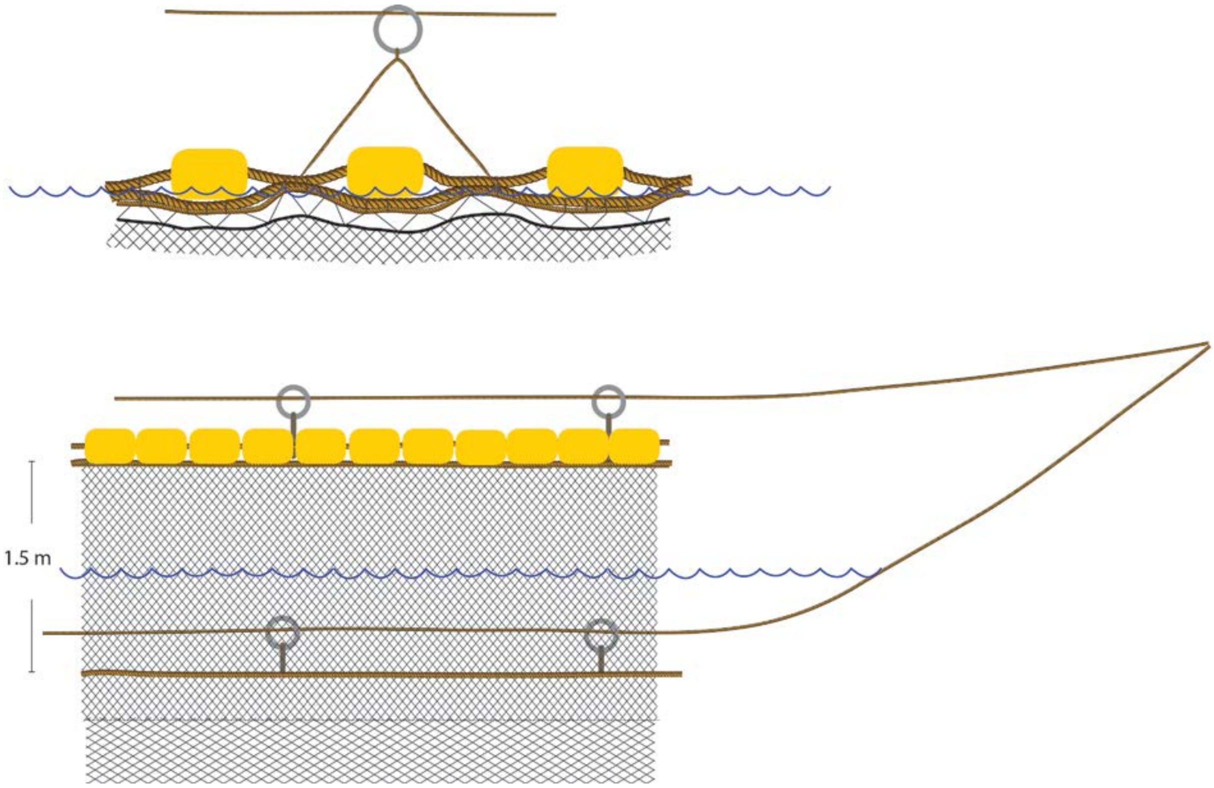


Figure 12 A new type of float line is developed to prevent fish from escaping above the line.

b) Minimising accidental release from the catch

During late stages of hauling the weight of the catch in the bunt can often drag the float-line beneath the surface, inadvertently releasing fish from the seine. As these fish have been released during the most crowded phase of the fishing operation, their survival is likely to be low (Tenningen et al. 2012). This accidental release of catch can be remedied however by modifying the float-line; where an additional line is added below the float-line, to support the weight of the catch, while the section of netting above acts as a skirt to prevent accidental loss of the catch (figure 12). This modification has recently been successfully tested on a commercial purse seine.

## Summary & Conclusions

Research has shown that pelagic schooling species, like mackerel and herring, experience elevated levels of stress and considerable mortality after dense crowding in purse seine nets (Huse & Vold 2010; Tenningen et al. 2012). Slipping from purse seines in the late stages of hauling may therefore produce unacceptably high rates of unaccounted fishing mortality. However, the fishing industry has no desire to contribute to this unnecessary wastage and the associated detrimental impacts upon the status and management of the stock (ICES 2005). It is therefore important that the fishing industry, the suppliers of fishing gears and instrumentation, and scientists work together to develop solutions to this problem. This paper has reviewed a range of potential technical solutions, including a new generation of acoustic and optical instrumentation, as well as new fishing gear designs, and has highlighted a Norwegian funded mitigation programme supporting the development of these innovations. The work of this programme indicates that by relatively simple modifications to the purse seine net, inspired by traditional fishing practices, the survival of the slipped fish may be improved. Also the acoustic, optical and physical sampling techniques show promising results that may ultimately lead to the development of an integrated suite of technologies that provide fishermen with the information they need to make rational decisions about the selection of their catch before they have any detrimental impact upon the target school.

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