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FIS011B - SMARTFISH: Selective management and retention of target fish

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SMARTFISH: Selective management and retention of target fish

FIS011 Developing and facilitating a range of possible future FIS projects in innovation in selectivity through on-net or alternative technologies

C. Tara Marshall*, Rodrigo Wiff*, Shale Rosen[+], Richard Neilson*, Ricardo Campos[^], Jenq-Neng Hwang[$] and Paul G. Fernandes*

*University of Aberdeen, UK, [+]Institute of Marine Research, Norway, [^]University of Girona, [$]University of Washington.

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Executive Summary

The landings obligation has focussed attention on the need to reduce the catch of unwanted species or sizes as part of sustainable fishing practices. To achieve this the Scottish fishing industry requires effective solutions that will enhance selectivity to better match catch composition with available quota. This report (FIS011B) outlines innovative approaches to enhancing both spatial and gear selectivity and describes a workplan for their future development.

Spatial selectivity, such as real-time area closures, has been used to avoid catching unwanted species or sizes of fish. Effective spatial selectivity requires highly resolved spatial and temporal information about catch such as that provided continuously by fishing vessels. Real-time reporting is the term used for the rapid, semi-automated collation, processing and dissemination of catch data across a group of vessels willing to share their data.

The report reviews how real-time reporting is used in Alaskan and Pacific Northwest groundfish fisheries to meet regulatory limits on bycatch. These fisheries operate under a discard ban making their experience relevant to meeting the challenges posed by the landings obligation. Data about the location and magnitude of bycatch are shared across fishing vessels belonging to the same fishing cooperative. High bycatch triggers e-mail alerts which are sent to skippers who then use the information for tactical decision making.

In Scotland, producer organisations use the elogbook database which has real-time information about the spatial location of unwanted species. However, there is no capability to capture this information for analysis or dissemination. The report includes a workplan for developing a real-time reporting system that meets the industry's information needs and their requirements for confidentiality. The workplan includes consultation with industry to design specifications for data collation, processing and presentation. Options for securing funding are identified.

Enhanced gear selectivity, using state-of-the art underwater technology, also offers considerable scope for effectively reducing bycatch. The report describes an innovative technical solution to species and selection in the trawl, referred to as Smartrawl. The Smartrawl uses stereo cameras and appropriate lighting in the trawl extension to obtain high quality images of fish as they pass by. This technology has been demonstrated by partners in the project (Scantrol & IMR) during a research cruise conducted for FIS011B by Marine Scotland Science.

The next stage in development of Smartrawl would be to conduct image analysis to identify and size each individual fish as they pass by. This requires many thousands of images to feed a machine learning algorithm as well as extensive image analysis underwater correction and image enhancement processes. These steps have been specified by a project partner with the suitable expertise (University of Girona robotics group). There is then the construction of a selective device (gate) linked to the image analysis system. Prototypes for two such gates were designed by underwater mechanical engineers from the University of Aberdeen. Each of these components are described in the report and collected as a phased approach to building Smartrawl. Costs are specified in the report and equate to approximately £970,000 over two years. Options for funding are identified.

The report concludes that a combination of enhanced spatial and gear selectivity can be used synergistically to reduce catch of unwanted species. Enabling fishing vessels to avoid areas where non-target fish are abundant will benefit the effectiveness of the Smartrawl system

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1 Introduction

This project responded to the FIS011 call *Developing and facilitating a range of possible future FIS projects in innovation in selectivity through on-net or alternative technologies*. The call recognised that the Scottish fishing industry requires innovative projects that will enhance selectivity to create a better match between catch composition and available quota. This project outlines two innovative approaches to enhanced spatial and gear selectivity. Consistent with the wording of the FIS011 call, this proposal corresponds to "Phase 1: entrepreneurial future project development and facilitation package". Securing enabling funding is the necessary precursor to actually developing the innovations for implementation in Scottish fisheries described here. This was termed by the FIS011 call as a Phase 2.

The project began under the assumption that the Landings Obligation would be applicable to UK fisheries. The validity of this assumption is somewhat in question as a result of the Brexit vote. However, in his recent address to the Scottish Parliament on December 7 2016 Fergus Ewing stated: "The outcome of these [Brexit] negotiations will be crucial to helping the fleet continue to implement the landing obligation while maintaining its approach to sustainable fishing and remaining economically viable". Thus, it would be prudent for Scottish fishing industry to assume that bycatch reduction will continue to be an important goal for the foreseeable future.

The technical drivers for innovation are also in place. The real-time reporting described in Section 2 can be viewed more broadly as an example of information and communications technology (ICT). ICT is the term used for highlighting the role of unified communications and the integration of telecommunications, computers, software, data storage, and audio-visual systems, in enabling users to access, store, transmit, and manipulate information. Currently, ICT provides skippers with real-time economic and meteorological data for tactical decision making. Examples from the Alaskan and Pacific Northwest fisheries (Section 2.2) show how ICT empowers the fishing industry to meet regulatory targets for bycatch reduction under the real constraints of a discard ban.

Underwater technology, developed for applications such as offshore oil and gas exploration, also offers greater scope for innovation in fishing gear technology. There are several systems around the world which offer the prospect of imaging fish in stereo as they pass through the extension of a trawl. These stereo images allow for the fish to be sized. At the same time image analysis techniques are being developed at a rapid pace to deal with, for example, facial recognition at various security facilities, such as passport control in airports. This technology could be applied to determine fish species. Combined with the increased capacity to develop underwater electronics and control systems, we envisage the potential to build a system which automatically links species size and species identification to a gate in the trawl to allow for the release of unwanted fish. We call this system Smartrawl and the idea is developed in Section 3.

1.1 Objective 1 Enhanced spatial selectivity - Deliverables

1.1) Review the suitability of existing electronic databases for real-time information processing and dissemination that are relevant to space/time distribution of relevant species (Section 2.1))

1.2) Engage with the Scottish fishing industry (through *inter alia* workshop) about how the current use of real-time catch information for unwanted species in the EBS walleye pollock fishery was developed and implemented with a view to fostering willingness within the Scottish industry to share information (Section 2.2);

1.3) Consult with industry and Marine Scotland to establish what is feasible and desirable for the Scottish fleet so as to allow realistic goals for future work on spatial selectivity to be defined. This will include a review of the use of observer programmes for generating relevant data (Section 2.3);

1.4) On the basis of consultations undertaken in 1.1), 1.2) and 1.3), develop a detailed set of technical requirements for implementation of spatial selectivity tools that are feasible from both government and industry perspectives (Section 2.4.2);

1.5) Identify enabling funds that would support future research and development for 1.4) and develop a plan for submitting a detailed proposal to suitable funding sources (Section 2.4.3).

1.2 Objective 2 Enhanced gear selectivity - Deliverables

2.1) Review the current progress in underwater stereo imagery, image analysis and mechanical sorting devices, to document the state of the art and determine what is required for the sizing, identification, and retention of species commonly caught in the North Sea which are subject to quota (Section 3.1-3.3);

2.2) Conduct a workshop to discuss and detail specific requirements for the Smartrawl, a species and size selective device that would be acceptable for use in the mixed demersal trawl fishery (Section 3.4-3.6);

2.3) Put together a research proposal to build the Smartrawl (Section 3.7).

1.3 Objective 3 Linking spatial and gear selectivity - Deliverables

3.1) Evaluate how the two strategies described above can be used synergistically to assist the Scottish demersal fleet in complying with the LO (Section 4).

2 Enhanced spatial selectivity

2.1 Existing data resources in Scotland

There are a number of relevant geo-referenced fisheries databases in Scotland having differing degrees of accessibility and highly variable availability in real-time. The e-logbook information (Section 3.1.1) is essentially real-time[1] and accessible by the Producer Organisations and individual skippers. The spatial resolution of the e-logbook database is reported as division, rectangle and zone as defined by the International Council for the Exploration of the Sea (ICES). In principle, the catch information in the e-logbook database could be unified with the corresponding VMS data. This has been done to a limited degree for research purposes, albeit on time scales that are nowhere near real-time. The VMS data (Section 3.1.2) are currently inaccessible in real-time although highly relevant to real-time reporting. Observer data (Section 3.1.3), as currently compiled, are less useful as a source of real-time information. However, the added value of having a source of data describing juvenile catch would be a strong incentive for improving both their availability and accessibility.

2.1.1 Logbook information

The fishing logbook is the primary method of data collection. It records data on fishing operations by individual vessels by trip, and for each day of activity within a single trip. These data are available since 1964 and include details of the catch, by species, in terms of the presentation and quantity of fish retained on board. Information is also collected on the fishing gear used and the area where the fish

[1] Real-time here is used to indicate information that is collected on very short (24 – 48 hours) which could in theory be processed and disseminated rapidly with the assistance of ICT infrastructure

were caught. Area information are reported by division, rectangle and zone as defined by the International Council for the Exploration of the Sea (ICES).

Council Regulations 1966/2006, 1006/2008 and 1224/2009 and Commission Regulations 1077/2008 and 201/2010, implemented by the Sea Fishing (EU Recording and Reporting Requirements) (Scotland) Order 2010 (SSI 2010/334), require Scottish vessels (when operating in Scottish, EU and third country waters) to record and report fishing activity data electronically. Software has been installed on board fishing vessels to record and submit data on fishing activities, with the expectation that electronic logbooks will eventually replace paper logbooks. Normally, catch data are submitted electronically to a Marine Scotland database within two hours of the haul coming on board.

All fishing activity data submitted electronically may be viewed by Marine Scotland Compliance. Primary vessel owners can also register on their systems, allowing them to view activity data for their vessels over an internet browser. The primary vessel owner can set up other users to view and administer their vessel activity data (e.g., Producer Organisations or agents). For scientific analysis of the catch data Marine Scotland Science aggregate landing data in space and time, remove any unique vessel or processor identifiers, and apply a disclosure limitation. Each aggregation must contain data from three or more vessels, and those aggregations with less than three vessels will be suppressed or, where appropriate, aggregated up to a higher spatial or temporal scale.

The electronic reporting systems operated by fishing vessels contain a limited range of validation checks to help ensure correct data are reported. In addition, to the validation processes, the information reported by fishermen is run through automatic cross-checks with other sources of information on activity available to fisheries administrations to ensure consistency and accuracy in the information reported. Landing declarations provide information on the weight and presentation of fish landed by species. Landing declarations and logbooks must be submitted to authorities within 48 hours of landing.

2.1.2 VMS data

The Vessel Monitoring System (VMS) is a form of satellite tracking using transmitters on board fishing vessels. The system is a legal requirement under EC Regulation 2244/2003 and Scottish Statutory Instrument (SI) 392/2004. A basic VMS unit consists of a GPS receiver which plots the position of the vessel coupled with a communications device which reports the position at a minimum of every two hours. The unit automatically sends the following data on a pre-determined timescale: the vessel identification, geographical position, date/time of fixing of position, course and speed

VMS data is considered personal data so access is strictly controlled. However, under the Data Protection Act vessel owners can request access to their VMS data in writing (by letter, fax or email). Vessel masters can also request VMS data for any period in which they can prove they were master of the vessel. From 2017 aggregate VMS data at the level of metiers will be available for analysis.

2.1.3 Observer data

Data from scientific observers is available from mid-90's and are available upon request from Marine Scotland. These data do not have real-time availability in the sense that the data are only available once the fishing trip finished. Observer data remove any unique vessel or processor identifiers. Between 60 and 90 trips are made annually to cover fishing operations in the North Sea and West of Scotland looking at whitefish or *Nephrops*. Observers monitor the amount of each species caught and discarded, take measurements of the size composition and, for a selected group of species including cod, haddock and whiting, collect otoliths to determine the age of the fish. Following processing, these data are then submitted to ICES and combined with similar material collected in other countries to provide overall catch information. Catch and biological data are also collected by the observer programme coordinated by the Scottish Fishermen's Federation. In 2014 and 2015 there were 144 and 135 observer trips, respectively. This data source is likely to be expanded in future.

2.2 Workshops held to evaluate systems for scientific bycatch reduction systems used in US fisheries

Two workshops were held titled *Using real-time reporting to enhance reduction of unwanted species in the Scottish demersal fleet – a discussion of experiences in Scottish and Alaskan fisheries with a view to developing tools for fishing in the future*. The first was held on Tuesday 6th September 2016 in Peterhead and aimed to discuss the topic of real-time reporting with industry. A second workshop was held on Wednesday 7th September 2016 in Aberdeen. Two experts with experience in US major demersal fisheries participated in both, giving presentations about how real-time reporting is used in Alaska (summarised in Section 2.2.1) and Northwest Pacific (summarised in Section 2.2.2). Workshop discussions are reported in Section 2.2.3.

The workshops were led by two US fisheries experts:

> **Karl Haflinger** (Sea State Inc.) began his career in fisheries as a salmon fisherman in Alaska. Based on that experience, he developed software for mapping bathymetry. Responding to industry needs for real-time reporting, he has went onto developing software that can be used to review, summarise and disseminate information to the groundfish fleet. Data sharing within fishing cooperatives is central to that effort. As a consequence of his work, he has been referred to as the inventor of "scientific bycatch reduction".
>
> **Eric Torgerson** (Chordata Ltd) is based in Alaska and has over 10 years of experience developing software for fisheries applications for the State of Alaska and the National Marine Fisheries Service. He has an in-depth understanding of integrating different types of fisheries data, including VMS data. Currently, he is developing open source software for the automated analysis of CCTV footage.

The agendas and attendees of the Peterhead and Aberdeen workshops are listed in Appendices 1 and 2, respectively.

2.2.1 Scientific bycatch reduction in Alaskan Pollock fishery

2.2.1.1 Background

Alaska was granted statehood in 1959, in part to protect their valuable fisheries. In 1976 the Magnuson-Stevens Fishery Conservation and Management Act law extended U.S. jurisdiction to 200nm and established eight regional fishery management councils, each having representation from the coastal states and fishery stakeholders. The North Pacific Management Council (NPMC) (http://www.npfmc.org/) manages the fisheries in the Alaskan EEZ including Pollock (*Gadus chalcogrammus*) in the Eastern Bering Sea (EBS). These changes stimulated an increase in capacity of the Alaskan fishing fleet and by the late 1980s there were no foreign vessels in Alaskan waters. Over the next two decades, the fishing industry assumed greater responsibility for designing systems for achieving the management targets set by the NPMC (fishing mortality and bycatch reduction). The EBS Pollock stock is widely considered to be one of the best managed fisheries in the world. In 2015 it comprised 67% of the total Alaskan groundfish catch. Currently, the Pollock fishery has approximately 120 catcher vessels that deliver shoreside for processing and that are organized into seven different fishing cooperatives. The two other fleet sectors are the catcher-processor and mothership fleets which operate at sea for extended periods.

2.2.1.2 Nature of the bycatch problem

From the outset, the NPMC was proactive on bycatch issues in the Alaskan Pollock fishery. No discarding is currently allowed and there are strict limits on bycatch. In the 1990s time and area closures were implemented to reduce the bycatch of salmon (both chub and chinook). Limits for salmon bycatch rates were set by the National Marine Fisheries Service (NMFS) and exceeding these limits could result in shutdown of the industry. The bycatch problem was deemed sufficiently intractable that the NPMC turned it over to the fishing industry to develop their own approaches to effectively reducing salmon bycatch. Industry introduced rolling hotspot (RHS) closures for chum and Chinook salmon in 2001 and 2002, respectively. The "rolling" or temporary nature of the closures allowed the industry to respond quickly to the rapid spatial and temporal dynamics of migratory salmon. To meet the information demands of defining RHS closures a comprehensive observer programme was implemented to record catches, including bycatch species, and undertake biological sampling. The NMFS Groundfish Observer Program was established in 1989 to train observers who are employed by private companies. Currently, there is 100% observer coverage of the Alaskan demersal fleet that is exclusively industry-funded.

2.2.1.3 Structure of industry

In 1998 the American Fisheries Act (AFA) effectively ended the "race for fish" in the Pollock sector. In January 1999, the Pollock Conservation Cooperative (PCC) and the High Seas Catchers' Cooperative (HSCC) signed an inter-cooperative agreement (ICA) to jointly harvest and allow the transfer of Pollock quota between cooperative members. The ICA was also designed to prevent premature closure of their fishery based on chum and Chinook salmon bycatch. The ICA effectively restructured the industry into a fully functioning fishing cooperative. Although it is not written into US fisheries legislation, the ICA is a private and contractually binding agreement for all cooperative members. The ICA allows the transfer of Pollock quota between cooperatives. Individual vessels belonging to a given cooperative are bound by the conditions of the ICA, including observance of RHS closures. Compliance with the conditions is monitored by the cooperatives themselves.

The ICA ushered in greater engagement of industry in co-management of the Pollock fisheries. To meet regulatory targets for salmon bycatch rates the ICA developed an incentive plan agreement (IPA) that was partly based on the experience with implementing RHS closures. The IPA restricts the Pollock fishing opportunities of cooperatives (in the case of chum salmon) or vessels (chinook) with poor bycatch performance while allowing cooperatives or vessels with good performance unimpeded access to the closures. The IPA therefore rewards good chinook bycatch performance with unrestricted access and penalises poor bycatch performance irrespective of Pollock or Chinook salmon abundance. The technical details of the chinook IPA can be found online at https://alaskafisheries.noaa.gov/sites/default/files/chinook_salmon_ipa_2010.pdf .

Conservations of Chinook salmon is of particular concern given its status as the king of salmon. At the start of the 2011 fishery, Amendment 91 to the Bering Sea and Aleutian Islands Groundfish Fishery Management Plan (BSAI FMP) came into effect. Amendment 91 is an innovative approach to managing chinook bycatch in that it combines a prohibited species catch (PSC) limit, or cap, on the amount of Chinook salmon that may be caught incidentally by the fishery with an incentive plan agreement (IPA) and performance-standard requirements designed to minimize bycatch to the extent practicable in all years. The total Chinook salmon PSC cap is 60,000 with a performance standard, or target, of 47,591 chinook. The IPA was adapted so as to implement Amendment 91 of the BSAI FMP in 2011.

2.2.1.4 Current management protocols

NMFS undertakes annual stock assessments for all targeted commercial species in Alaskan waters. The basic aim is to estimate total fishing mortality on all quota species. Discarding of quota species is therefore not permitted (limited discarding is permitted for non-quota species but fully documented). The observer programmes collect catch data for target and bycatch species which enables the accurate estimation of total fishing mortality.

The NPMC requires the submission of annual reports to document each cooperative's performance in meeting targets for both fishing mortality and bycatch reduction. Cooperative reports are presented by cooperative managers during the April Council meeting of NPMC (e.g., Madsen and Haflinger 2016). Real-time reporting is a term that is used here to describe the internal reporting that the fishing cooperatives undertake to monitor their use of quota as well as track the effectiveness of their bycatch reduction programmes in real-time and identify issues with high bycatch such that corrective steps can be taken. Real-time reporting thereby enables the cooperatives to be confident that they will meet their annual objectives laid out in the IPA.

Sea State, Inc. is contracted by the PCC to receive, monitor and evaluate catch and bycatch data for the chum and Chinook salmon RHS programme on behalf of the cooperative. They undertake both the real-time reporting (internal to the PCC) and reporting to external agencies including NPMC, NMFS and other stakeholder groups.

2.2.1.5 Design principles of real-time reporting in Alaskan fisheries

The EBS fishing fleet has excellent access to the internet at sea via satellite communications. Karl Haflinger initially created the software for capturing, analysing and distributing data via a protected website. The software was extensively upgraded several years ago by Eric Torgerson, Chordata Inc. The software is designed to make efficient use of bandwidth by prioritising the transfer of essential information. The software was developed according to a few basic design principles:

Catch data for target species are not shared but bycatch data are – according to the terms of the IPA, bycatch rates of individual vessels are shared within the cooperative but not across cooperatives. These bycatch rates are essentially the number or weight of salmon caught incidentally divided by the metric tonnes of Pollock caught. Further details of this calculation can be found in the IPA: https://alaskafisheries.noaa.gov/sustainablefisheries/bycatch/salmon/chinook/ipa/chinook_salmon_ipa_2010.pdf

Online analytical processing – OLAP enables users to analyse multidimensional catch data interactively from multiple perspectives, e.g. skipper, cooperative manager, analyst for third party agency responsible for compliance monitoring e.g. Sea State, Inc. Thus, the type of access a user has determines the type of data that can be viewed. This protects confidentiality of data. Individual vessels custom their own reports which can be emailed at pre-specified intervals. The particular content of reports can be customized easily. The co-operative manager can generate report showing bycatch rates for all vessels belonging to the cooperative and designate rolling bycatch hotspots.

Skippers contributing data have access to their data – this design principle aims to encourage users to engage with data and analytics. User interfaces are therefore designed to be easy and intuitive. As skippers become more knowledgeable about accessing and interpreting their own data this reduces the burden on Sea State to a minimum, e.g., assisting with initial set-up.

Access to VMS data is given to the third party analyst – Sea State is given written permission by individual skippers to access their VMS vessels from providers. VMS pings are normally every thirty minutes but can be up to 10X an hour. The software automatically combines the catch data from the observer programmes with the VMS data to allow geographic resolution of bycatch on a haul-by-haul basis.

2.2.1.6 Operational aspects of real-time reporting

The different data types used by Sea State Inc. for the real-time reporting include: observer data; VMS data; production data from shoreside plants and catcher/processors; and shoreside landings data. The observer data are uploaded to the central database (maintained by NMFS), normally within 24 to 48 hours of the haul coming onboard. Sea State automatically downloads from the NMFS data between three and four times a day. They have automated many aspects of the reporting so that information is communicated to the fleet in a timely way, independently of human effort.

If a haul with a high bycatch rate is reported then an alert (Figure 2.1a) is sent to the all vessels in the cooperative with a link to a map (Figure 2.1b) showing the geographic coordinates of the haul and basic information about the bycatch. This information is used by skippers who can use it to make tactical decisions about where and when to fish. These decisions can directly impact the vessel's bycatch performance which in turn determine access to fishing areas including the industry-defined RHS closures. After initial reluctance to share data, skippers in the Pollock fisheries quickly become "information junkies" in the sense that there is currently a very high demand for the type of high-resolution, spatio-temporal information that is being disseminated using real-time reporting.

Individual vessels can also access their own catch data and use the Sea State Inc. software to custom build reports that summarise their catch caught to date against the allocation they have for a given fishing year. They can schedule the delivery (via email) of reports according to how frequently they need to be updated.

```
This message was generated on 9/21/2015 at 2:10 AM

All high bycatch hauls:
https://acct.seastateinc.com/Seastate/Members/AfaPollockMap.aspx

AFA CP Haul 159 on 9/20/2015 has a total catch of 112 Chum Salmon. This is 1.1
x the alarm threshold of 100.
Latitude: 55 8.90 N
Longitude: 167 32.00 W
VMS track:
https://acct.seastateinc.com/Seastate/a.aspx?p=1&a=1799&h=6ef5ff0ba571b21a8188
2b50969b8c49
```

Figure 2.1a: Example of an alert sent automatically by email to cooperative members to report a haul having a high bycatch. The haul VMS track is given on a clickable link. Skippers can access this information at sea by reading their email.

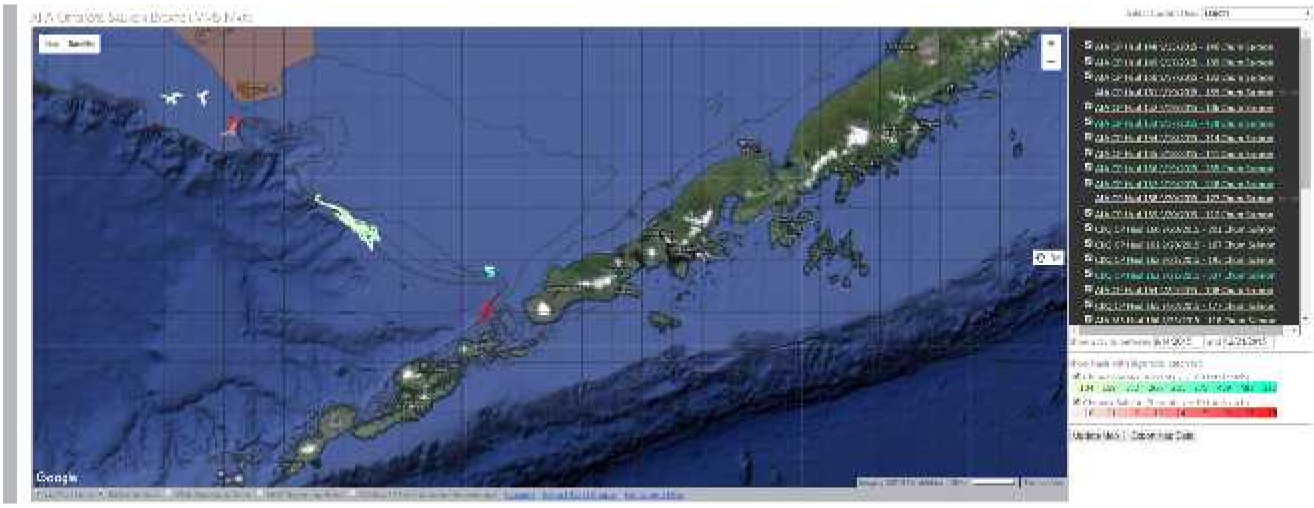

Figure 2.1b: Example of the map that is embedded in the alert message (Fig 3.1a). The VMS tracks of hauls that caught chum salmon are shown in blue and chinook in red. The darker the colour the higher the bycatch rates (scales are shown below). The individual hauls that are shown are identified on the right hand side of the image. Only high bycatch tracks from the last two weeks of the fishery are shown.

2.2.1.7 Designation and implementation of hotspots

The cooperative manager, or analyst, runs a report on Mondays and Thursdays and examines areas where bycatch is too high as well as location of current RHS closures. The analyst also examines where bycatches are low. Following consultation with others familiar with fishing patterns, a new RHS closure can be set up. Access to the closures is dependent on the cooperative's (chum) or the vessel's (chinook) ability to catch Pollock cleanly, i.e., without also catching salmon. Tier 1 cooperatives (or vessels) have access to RHS because they have a track record of catching cleanly. Tier 2 cooperatives (or vessels) are prohibited from RHS for 3 days. Tier 3 cooperatives (or vessels) are prohibited for 7 days. Sometimes Tier 2 or 3 vessels mistakenly enter RHS, for example if they misread closure notices. In this case, the cooperative manager communicates with the skipper and in some cases a fine is levied. Compliance is therefore monitored and maintained within the cooperative itself.

2.2.1.8 Performance of bycatch reduction measures

Madsen and Haflinger (2015) assessed the performance of IPA incentives for bycatch reduction of chinook salmon by comparing a number of performance measures before Amendment 91 (which introduced a hard cap of 60,000 chinook) was established in 2011 with equivalent measures post Amendment 91. Performance is expressed as number of chinook per ton of Pollock caught by catcher-processor IPA vessels. The frequency of high values of chinook bycatch rate was reduced after the implementation of Amendment 91 and the distribution shifted towards a narrower bank of low values (Figure 2.2. This provides evidence that that vessels are behaving more similarly to each other and exhibiting vessel-level accountability for their chinook bycatch.

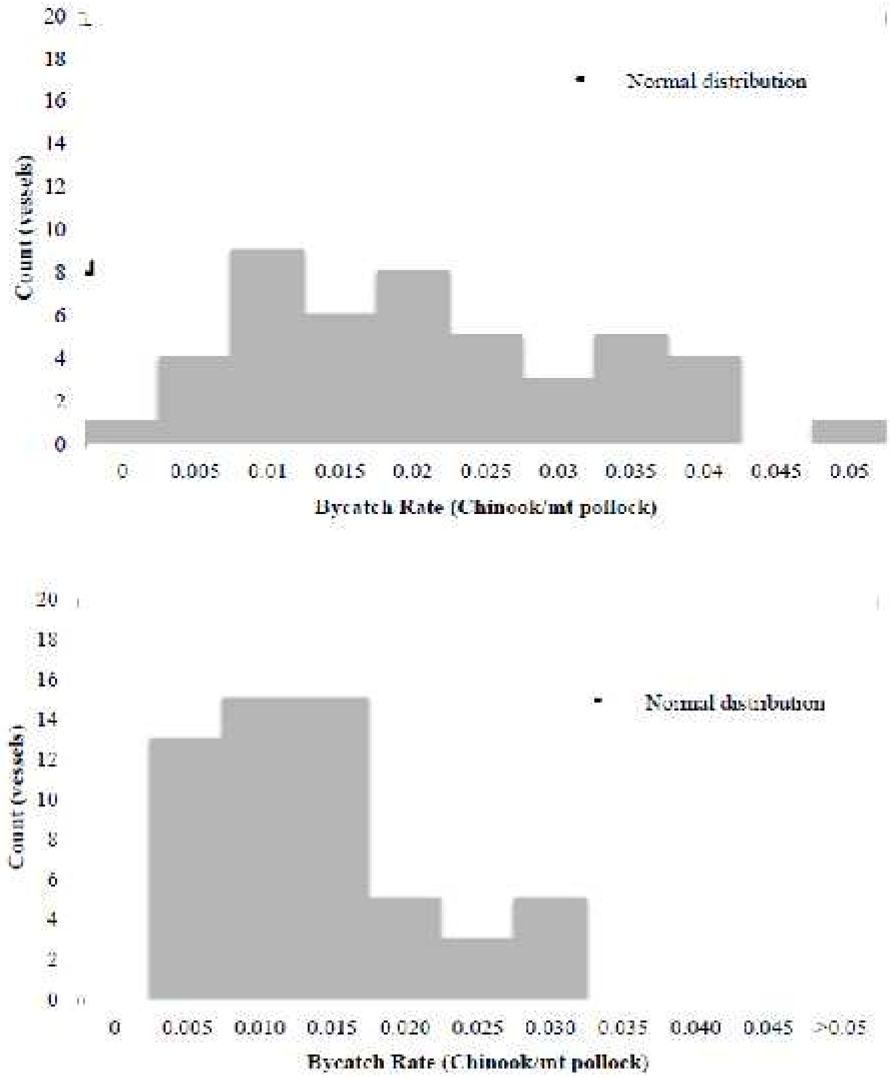

Figure 2.2. Upper panel: A-Season CP Vessel Chinook Bycatch Rate Frequency Distribution for 2008-2010. Lower panel: Distribution for 2011-2014 (from Madsen and Haflinger 2015).

2.2.2 Scientific bycatch reduction in the Pacific whiting fishery

2.2.2.1 Background

Pacific whiting (*Merluccius productus*) are one of the most important commercial fisheries off the west coast of the US. The stock was declared overfished by the US government in 2002 but was quickly declared rebuilt in 2004. Of the three recognized whiting stocks, two stocks are managed by state and local management agencies. The offshore fishery is managed by the Pacific Fishery Management Council (PFMC) (http://www.pcouncil.org/) according to Pacific Coast Groundfish Fishery Management Plan (FMP). Originally approved in 1982, the FMP currently manages over 90 different species through a number of regulatory measures, including harvest guidelines, quotas, trip and landing limits, area restrictions, seasonal closures, and gear restrictions such as minimum mesh size for nets. The US Pacific whiting fishery has four sectors: vessels that deliver to shore-based processors, vessels that deliver to at-sea processors (mother ships), vessels that both catch and process at-sea (catcher-processors) and a tribal fishery.

2.2.2.2 Nature of the bycatch problem

Prior to the rationalization of the West coast trawl sector in 2011, the PFMC managed bycatch in the Pacific whiting fishery using voluntary guidelines. Seven species of rockfish were declared overfished between 1999 and 2002, with rebuilding timelines estimated at between 24 and 112 years. This situation led to the PFMC implementing fishery-wide bycatch limits for depleted species in 2005. These limits compelled all fleet sectors of the Pacific whiting fishery to reduce their bycatch or face potential closure.

Bycatch of rockfishes is a major concern because there is limited quota available for these species due to low spawning stock biomass compared to quota for the more abundant Pacific whiting stock. Individual fishermen could reach their quota for one of these “lower-quota” (or choke) species before reaching their quota of Pacific whiting, thereby ending their fishing season with allowable harvest still left in the ocean unless additional quota can be leased or purchased from another quota holder. Acquiring additional quota for rockfishes is costly and/or difficult to obtain. Developing techniques that effectively reduced rockfish bycatch while retaining a high proportion of the Pacific whiting is therefore critical to the profitability of the industry. A further complication is that the number of potential choke species is increasing year-on-year as FMPs for more species come into effect.

2.2.2.3 Structure of industry

The history of how the Pacific whiting fishery transitioned from an Olympic-style "race for fish" into a functional harvesting cooperatives has been documented in detail (Sylvia et al. 2014). Briefly, three catcher-processor companies that held Pacific whiting harvesting rights prior to 1995 came together in 1995 to find a practicable solution to the bycatch problem. These companies had previously worked together in the EBS Pollock fishery. They recognised they faced a similar challenge for the Pacific whiting fishery: firstly, eliminate the “race for fish” and secondly, reduce bycatch of depleted rockfish and salmon species that could result in premature closure and undermine profitability. In 1996 the companies signed a cooperative agreement that allocated specific percentages of their sector’s quota allocation to the cooperative with the percentage based on the historical catch and share bycatch allocation. This cooperative agreement allowed leasing and trading of quota, and instituted a system of penalties for violating the provisions of the agreement. The agreement brought into existence the Pacific Whiting Conservation Cooperative (PWCC). With the formation of the PWCC, each company could now plan its fishing activities according to its own needs. To meet the bycatch regulations the companies collectively agreed to fund 100% observer coverage and hired Sea State to monitor catch and provide real-time reports of fishing activity within the sector.

The mothership fleet also formed a cooperative where bycatch allocations are pooled and shared among the vessels. However, other sectors of the Pacific whiting fishery are still engaged in the race for fish. These sectors have the same regulatory requirement to avoid bycatch of prohibited species, however, the competitive nature of the fishery results in weaker incentives for bycatch avoidance and greater risk of being excluded from the fishery.

2.2.2.4 Current management protocols

Management of Pacific whiting is accomplished through a bilateral agreement between the US and Canada, known as the Pacific Whiting Treaty. The Pacific Whiting Treaty established a default harvest policy, a fixed harvest allocation for each country and a joint management committee that determines the annual coast-wide total allowable catch on the basis of the best available science, the treaty's default harvest policy and input from industry advisors. The two countries jointly conduct acoustic surveys of the resource, stock assessments, stock assessment reviews and management meetings.

Regulation of the individual fisheries continue to rest within each country. The Pacific whiting fishery is currently certified by the Marine Stewardship Council as a sustainable fishery.

2.2.2.5 Real-time reporting in the Pacific whiting fishery

Because the race to catch fish is eliminated, PWCC vessels can take the time to find areas with high whiting abundance and/or move away from areas with high occurrence of bycatch. To help avoid these bycatch "hotspots," PWCC members report catch and bycatch data electronically to Sea State who collate the data and report back to PWCC vessels on a real-time basis, advising vessel captains to avoid areas in which high bycatch is likely to occur. Each PWCC vessel carries two NMFS-trained observers who monitor, record, and report all fishing activities to NMFS similar to the real-time reporting system used for Alaskan Pollock.

2.2.2.6 Risk pools

In the EBS Pollock fishery, salmon are captured by a high proportion of vessels during annual migrations of salmon to natal rivers. The Alaskan industry uses real-time reporting to track the amounts and location of salmon being caught and designate RHS closures. In the Pacific Northwest, the by-catch problem is different. The demersal industry has limited quota allocations of all species, including whiting. There are a many quota species for which it is difficult to predict their location in time and space. The term “lightning strike” refers to the possibility that one vessel will be unlucky will use up or exceed the entire bycatch allocation to the fleet in a single haul. The PWCC has self-insured against “lightning strike” hauls by forming a risk pool.

Each vessel in the PWCC puts 50% of their choke species allocation into a reserve fund. This reserve fund is held by vessels that are not actively fishing due to the regulatory requirement that quota allocations must be “associated with steel”[2]. Once an individual vessel has used up half of their own 50% allocation of choke species then it automatically gets a warning message. If a vessel has exhausted their quota allocation for a choke species but still has quota for the target species (e.g., whiting) then it will need to draw out quota for the choke species from the reserve (the risk pool) or buy quota on the open market in order to continue fishing.

2.2.2.7 Design principles of real-time reporting in Pacific Northwest fisheries

As is the case for the Alaskan Pollock fishery, real-time reporting is used for the internal monitoring of quota as well as for tracking bycatch. Companies in the PWCC can access all their observer data for PWCC vessels. Sharing of data about bycatch is done within the PWCC. Any vessel can also see VMS tracks for bycatch. Each company belonging to the PWCC has unique requirements for real-time reporting. The Sea State software is sufficiently flexible such that reporting protocols can be customized by the company itself.

2.2.2.8 Bycatch avoidance

If observer data shows a haul having a bycatch rate of a potential choke species exceeding a threshold value then an alert goes out to all PWCC vessels. Hotspot maps are disseminated showing catches of choke species. The maps indicate area closures (yellow) and forbidden areas (red). If the risk pool is

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[2] In Scotland there is a form of risk pool in operation within individual Producer Organisations. They hold dummy licenses that are not attached to an operating vessels. Rather, they are an administrative mechanism to allow Producer Organisations to hold Fixed Quota Allocations (FQA) secured from a variety of sources and for various purposes including bycatch.

depleted then yellow areas are switched to red. Some rules have been developed to ban fishing at night.

Stand down orders (to cease fishing immediately) are issued if an individual vessel fails multiple tests. For example, once they have used half of their bycatch allocation (50% is in the risk pool) in a single trip then would be required to stand down for 7 days. When a vessel has used all of their own 50% bycatch allocation then they are tested each time they go to reserves. Vessels have the option of buying quota on the open market.

Peer pressure helps to improve compliance. Because the data are shared it is possible to evaluate performance of others. Free riders, i.e., poor performers who consistently need to borrow from the risk pool, are not a feature of the industry. If it was then rules would have been developed by the cooperative to penalize this particular offense.

2.2.2.9 Performance of bycatch reduction measures

Bycatch reduction measures in the catcher-processor fleet, operating as the PWCC, have been successful in the sense that the fleet has not been shut down due to exceeding the regulatory caps on bycatch rate. Generally, the fleet shows very low rates of bycatch for both salmon and rockfishes (see Figure 2.3). Prior to the creation of the PWCC the fishing season length ranged from 18 and 34 days because vessels were fishing around the clock. Since the implementation of the PWCC, the average season length for the catcher-processor fleet has ranged between 82 and 208 days (Sylvia et al. 2014).

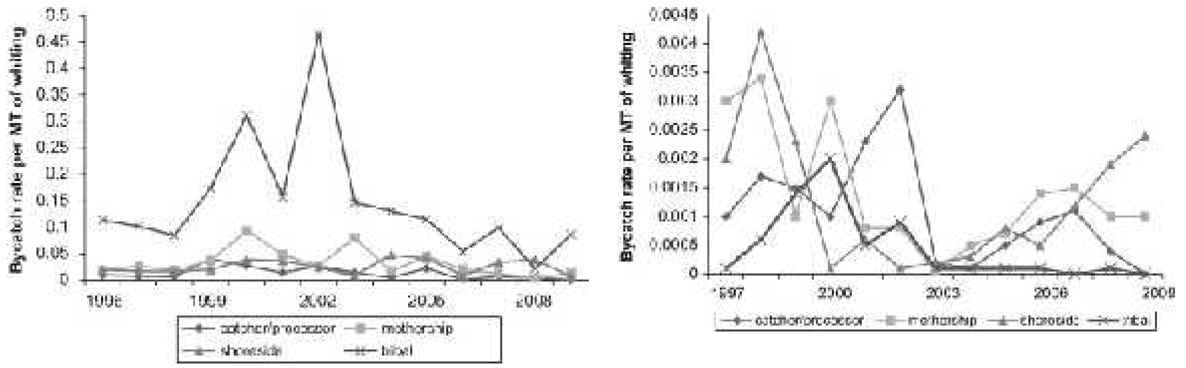

Figure 2.3: Bycatch rate for the catcher/processor fleet (PWCC) relative to other fleet sectors. Left – salmon bycatch; Right – Widow rockfish bycatch (from Sylvia et al. 2014). Note the difference in scale of the Y-axis.

2.2.3 Workshop Discussions

2.2.3.1 Peterhead

Although the event was well advertised, turnout among skippers was very disappointing (Peter Bruce, skipper MFV Budding Rose, Peterhead). This may have partly been due to Mike Park (Scottish White Fish Producers Association) being unable to attend as planned. Mr. Bruce felt some skippers would be interested in using spatial information and would communicate his experience to other skippers. Mr. Bruce thought it was essential the protocols of real-time reporting be designed by the industry. This is consistent with the US experience which has been designed by industry for the industry. K. Haflinger and E. Torgerson emphasized the industry-led design nature of their real-time reporting system.

The analogy between fishing cooperatives in the US and producer organisations in Scotland was noted during discussions. This means that the fundamental structure of Scottish fishing industry is already in place to be given similar responsibilities for scientific bycatch reduction. Two POs were in attendance (Aberdeen Fish Producer's Organisation, Mallaig & North-West Fishermen's Association Ltd). It was acknowledged that POs do not currently have the capacity, in terms of resources, to change their current reporting practices. Funding support would need to be provided. Potential sources were discussed. This discussion was subsequently followed up with a visit by K. Haflinger and E. Torgerson to Aberdeen Fish Producer's Organisation.

The use of the software to do both quota management and spatial information was thought interesting. In Scotland, the current integration of the e-logbook information with internal systems for quota management is quite poor creating an unnecessary bottleneck in the flow of information. The Sea State software does a lot of the quota tracking including allocations and transfers. So it is a well-integrated platform for "scientific bycatch reduction".

Avoiding the catch of juveniles is an important issue for the Scottish industry going forward. The e-logbook database is less relevant here as it doesn't have catch of juveniles. Observer data is relevant but the lag times uploading data are currently much longer than the US situation.

A theme to the discussion was that industry can solve bycatch problems more effectively but requires flexibility in how it achieves solutions. The creation of fishing cooperatives in the west coast of the US provides a structure for doing this by ending the race to fish and allowing them to decide when and where to fish through real-time reporting.

The main issue in Scotland is that there are problems in quota allocation such that the distribution of quota across fishing nations does not match the distribution of fishing opportunities (an outcome of the relative stability principle). This is quite similar to the experience in the Northwest Pacific. Consequently, the concept of the risk pool was of interest. The relevance of the Pacific whiting experience to Scotland has been previously noted (see http://www.gov.scot/Publications/2014/11/3252/7 for a review).

The utility of real-time reporting of the distribution of juveniles and some choke species was acknowledged. It was noted that policies of Marine Scotland would need to change considerably. Industry still fears that any information about bycatch that was shared could potentially be used against them. By contrast, compliance issues in the US fisheries are co-managed by industry and government. Compliance is monitored by the industry with fines being levied for poor bycatch performance.

Confidentiality of the database is an issue of universal concern. The US databases are designed to have selective access according to the role of the user. There is a hierarchy of users that protects confidentiality.

The Scottish experience using CCTV is another point of similarity. K. Haflinger and E. Torgerson are currently working on a project to develop open-source software for reviewing electronic video monitoring data. This discussion was subsequently followed up with a visit to Marine Scotland.

2.2.3.2 Aberdeen

The Pacific west coast fisheries have also done extensive gear development to reduce bycatch of different species. This experience has shown that gear selectivity is only part of the solution. It must be supported with enhanced spatial selectivity.

In the US, it was recognized several decades ago that NMFS cannot monitor bycatch or set-up the RHS closures rapidly enough to be of practical assistance with bycatch reduction. The job needs to be done by industry.

It is important to recognize that the rules that comprise the IPA have nothing to do with federal regulation. They were developed and are enforced by the fishing cooperatives themselves. This is very different to how European fisheries operate but more consistent with the concept of results-based management.

Risk pools were set-up to solve the problem that results when quota allocations do not match fishing opportunities. There might be analogous arrangements that are internally used by some Scottish POs.

Sharing of data was viewed as controversial when first introduced but the US industry quickly transitioned from resistance to reliance. The sharing of data occurs within a cooperative not across cooperatives. Skippers choose to become members of a cooperative and, in so doing, agree to abide by the IPA. Within a cooperative, any vessel can see the bycatch data of other vessels in the cooperative but not catch of target species. Cooperative managers can also disseminate information about the spatial distribution of "hot spots" or "cold spots". In other words, sharing of data is not industry-wide. The non-sharing fishing vessels (e.g., not belonging to a cooperative) do not have the benefit of highly resolved information about location of bycatch species and are more likely to exceed limits.

The technical problems in implementing a system for real-time reporting are entirely surmountable. The political problem are more difficult to solve.

The observer database is maintained by NMFS. Thus, the same database is used by NMFS (for compliance monitoring) and industry (for real-time reporting which has a component of compliance monitoring). This is consistent with the "with flexibility comes transparency" principle.

The ownership of CCTV data was discussed. Is it owned by government (who in Scotland would have paid for it) or the skipper of the vessel? In the US the fishing industry is adamant that CCTV footage is theirs. It has been subpoenaed in the past.

It was noted that there has been some effort towards sharing bycatch information in England related to avoidance of spurdogs.

For real-time reporting to be implemented in Scotland it would need industry buy-in from the bottom-up. Shetland was discussed as potentially pilot scheme. They have a lot of quota and function very like a cooperative. Likely choke species include hake, saithe, monk and megrim.

Wider society needs to feel confident that real-time reporting will benefit them in providing and enhancing fully documented fisheries. In other words, turning responsibility over to industry must be accompanied with assurances (e.g., via auditing) that targets are being met. Again, the principle of "with flexibility comes transparency" applies. For industry to be given the freedom to self-regulate there must be transparency in how they achieve this.

It was questioned whether there was a critical threshold to the number of vessels participating in the data sharing scheme in order for it to become useful.

It is true that species that are a choke for some vessels might be a target for others. However, it is also true that no one wants juveniles. The real-time reporting mechanism could be made flexible enough that a choke species one year might not necessarily be the choke species another year. Thus, reporting practices (and information sharing practices) would need to be adaptable.

Because fish swim, it is not really effective to set up permanent closures but rather industry needs adaptive or "rolling" closures. The e-logbook information already available in Scotland is well suited for this. Scottish experience with real-time closures is also relevant.

Some mapping of bycatch risk is already being done using historical data, for example the discard atlas for the North Sea which was published in 2014 http://www.nsrac.org/wp-content/uploads/2014/11/discardatlas_northsea_demersalfisheries_2014.pdf . These maps reflect more average (integrated over time) distributions rather than real-time distributions. This information can be used to gain an estimate of the risk of catching unwanted species.

In building something like a system for real-time reporting it is better to not try and do everything at once. Build it incrementally and learn from examples.

Summing up (by Dave Reid, Marine Institute):

- There was strong support for empowering industry to be able to use spatial information to make fishing more efficient by avoiding unwanted catch.
- Industry needs to be supported in assuming responsibility for bycatch reduction
- Risk pools are relevant to the bycatch issues in Europe. Application to fisheries here, e.g. Shetland and Ireland, deserves further consideration
- Need a pilot project to help change minds and reveal the basic operational framework for real-time reporting
- Universities can help provide technical support, possibly under Knowledge Transfer Partnership schemes (e.g., http://www.ktpscotland.org.uk/)
- Marine Scotland would need to be supportive of the goal of co-management.

2.3 Consultation with Industry

The experience with US fisheries illustrates how Producer Organisations in Scotland are central to any system of real-time reporting because their operations are responsive to rapidly changing catching opportunities under the restrictions of a discard ban. Real-time reporting is a mechanism by which they can internally monitor and manage their bycatch (Section 2.3.1.1). The US fisheries illustrated how existing databases, specifically the e-logbook database, could be used by the Producer Organisations to monitor the spatial distribution of choke species in real-time (Section 2.3.1.2). To discuss these possibilities the workshop in Peterhead was followed up by a visit to the offices of Aberdeen Fish Producer's Organisation. After attending the workshop in Aberdeen, Dr Chevonne Angus (NAFC Marine Centre) met with several Shetland-based Producer's Organisations (Section 2.3.1.3).

2.3.1 Aberdeen Fish Producer's Organisation

The Aberdeen Fish Producer's Organisation (AFPO) undertakes quota management, representation and marketing for 14 member vessels from Aberdeen to Buckie and a focus predominantly on whitefish species. A summary of discussions with David Anderson at AFPO follows.

2.3.1.1 Quota monitoring and management

AFPO currently use weekly spreadsheets produced by Marine Scotland's FIN (Fisheries Information Network), the administrative database containing information on sea fishing activity and catch details. FIN holds details of all fish landings into Scotland and landings abroad by Scottish registered vessels. Voyage and landings information are supplied by skippers who, for vessels over 10 metres, are required by EU legislation to maintain logbooks and provide landings declarations. Although this EU legislation does not require vessels of 10 metres and under to provide this information; in Scotland they provide equivalent information. Data on first sales of fish, which provides information on the value of landings, is provided by fish buyers and sellers under EU legislation and is collated and entered at port offices and then transmitted to the FIN central server. The weekly report gives the percentage uptake of the quota to date. This database is used by regulatory authorities in the EU to identify when vessels have caught more than their quota allocation. The data are eventually processed to estimate the annual landings, by country and fleet type. These reports are used in the annual stock assessment process. Further information is given here: http://www.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/SeaFishStatsDisclosure/ScottishSeaFisheriesStatisticSources

The FIN database therefore functions centrally as a tool for quota management and management. It has fixed capabilities for reporting and cannot be used for any real-time analysis of spatial distribution. It does, however, support the annual reporting of landings by country to stock assessment working groups.

2.3.1.2 Real-time reporting and spatial resolution

Within two hours of the catch being processed on board, catch weight by species are uploaded to the e-logbook system that is maintained by Marine Scotland. Catch is reported by statistical rectangle within the FAO Area, Subarea and division. The rule is once they have a reportable activity the vessel must report within two hours of the haul coming onboard. Discards are not recorded, only species for which there are quota allocations. In some cases (e.g., when an observer is on board), discards are recorded via a separate spreadsheet. These data on discards are not accessible in real-time and relatively inaccessible generally.

Access to e-logbook data are protected with the PO having access to data for all vessels in the membership of the Producer Organisation. Vessels and Producer Organisations enter the e-logbook system via http://www.fishregister.gov.uk/ The Producer Organisation has administrator access and can see all members of the Producer Organisation. Using the e-logbook data the administrator can view the catch (in kg round weight) reported by statistical rectangle. In the current configuration, the Producer Organisation cannot download the data but Marine Scotland. This has severely constrained any analysis of data. However, Marine Scotland is currently revamping the database and it may become possible in future for data to be downloadable.

2.3.2 Shetland Fisheries

Following up on the workshops held in September, Dr Chevonne Angus (NAFC Marine Centre) met with several Shetland-based stakeholders including Shetland Fish Producer's Organisation and the Shetland Fishermen's Association. In those discussions she summarised the US experience with a view to determining whether a similar means of real-time reporting could be developed locally. Industry representatives were interested in how the various data streams were used together for the real-time management they could see a lot of potential, particularly if information from the seafood auction in Shetland could be integrated in some way. They acknowledged there was merit in learning from what is being done in the Bering Sea and cherry-picking and adapting parts of what is done there for local implementation. In general, fishermen are reluctant to share any data which may give away their 'hot spots' (NB this statement applies more to target species; sharing information about choke species might be more acceptable). Concern was expressed that the information they shared could be used against them by Marine Scotland. This perception is partly based on their experience with real-time closures. Brexit is the industry's immediate priority but in future it would be helpful to embark on discussions with skippers emphasising the potential for industry to design systems that work for them and that do not expose them to risk from a compliance perspective.

2.4 Development of enhanced spatial selectivity tools

2.4.1 Opportunity for innovation

The US examples described above illustrate how "scientific bycatch reduction", including real-time reporting, has allowed the industry to meet regulatory requirements including a discard ban. It is instructive that skippers rapidly shifted from resisting the real-time reporting to relying on real-time reporting (Section 2.2.1.6). A key element of success is that the reporting systems were developed by industry, for industry.

The overarching goals of a system for real-time reporting could be to: 1) develop the information base available for improved tactical decision making at sea so as to better enable the Scottish fishing industry to match fishing opportunities to quota allocation; 2) improve the internal reporting systems for use by Producer Organisations or agents; and 3) to invest in the ICT for specific application in Scottish fisheries.

During this FIS project feedback from industry was moderately encouraging in the sense that the benefits for improved real-time reporting were clear to many. Indeed, many skippers are already using social media (e.g., WhatsApp) to disseminate information across a small network of skippers. The Shetland Producer Organisations felt that their attention is currently focussed on the implications of Brexit and thus they do not necessarily have the capacity to embark down this road. One useful suggestion was to encourage change by "drip feeding" the ideas in. Thus, a high degree of stakeholder engagement will be required to support any change.

Overall, there are several drivers for developing a functional system for enhanced spatial selectivity including:

- some form of the landings obligation will be in place;
- industry recognised that Brexit provides the industry with an opportunity to take a more active role in co-managing fishing resources. This might involve co-designing a system for real-time reporting and quota management that is bespoke for the industry.
- there are signs that the scientific capability of the industry is increasing thus creating capacity for data analytics. For example, the Scottish Fishermen's Organisation has recently hired a Scientific Advisor as has the Scottish Pelagic Fishermen's Association. This indicates the willingness of industry to assume greater responsibility for the analysis of their data;
- consumers and retailers regard discarding as an undesirable and avoidable consequence of fishing;
- government will have limited fiscal resources for developing innovative approaches to fisheries management. Results-based management, such as is used in US Alaskan and Pacific fisheries, makes considerable economic sense;
- the ICT infrastructure is already in place and will presumably improve over the medium- to long-term;
- the e-logbook database, as it currently exists, could allow Producer Organisations an excellent opportunity to analyse their own data for their own benefit;
- K. Haflinger and E. Torgerson are willing to serve in an advisory capacity. Similarly, university-based researchers are interested in supporting the development of systems that would allow for more detailed analysis of the spatial distribution of fish and fisheries.

Based on discussions with industry and Marine Scotland there are clearly obstacles including:

- individual skippers express considerable reluctant to share information even about choke species;

- Producer Organisations currently have no capacity in-house to embark on this form of development;
- whether justified or not, industry fears information will be used against them by Marine Scotland;
- Marine Scotland has limited experience with supporting the fishing industry towards a more active form of co-management although there might be greater willingness to do so in future.

2.4.2 Technical requirements

Determining where not to fish is considerably more challenging than determining where to fish. The real-time reporting in US fisheries described here illustrates the potential for catch information to inform tactical decision making in the same way that real-time information about weather and market conditions does currently. Developing a test case of real-time reporting for application to a Scottish fishery that could serve as a proof-of-concept is a logical first step in the industry-led design process.

The workplan below assumes there is enabling funding (Section 2.4.3) and that a Producer Organisation is willing to engage in the exercise (identified below as TESTPO). Timescales are not indicated here but would be developed in consultation with industry. A system for real-time reporting using only the e-logbook data could be developed in the near-term. More complex assemblages of data (e.g. combining e-logbook and VMS) would take longer time scales.

Category of activity	Task
Stakeholder engagement	Engage with Marine Scotland to discuss ongoing revamp of the e-logbook database and accessibility
	Engage with Scottish Association of Fish Producer Organisations
	Discuss design principles of real-time reporting with TESTPO
	Meet with TESTPO skippers to discuss needs including current choke species issues and future choke species
	Finalise design specification of prototype real-time reporting informed by work undertaken in previous projects (FISA 01/2015 and FIS011B)
Analytical work	Work with TESTPO to download catch data from e-logbook and plot catch of a test species by statistical rectangle for presentation to industry in preliminary discussions
	Consult with E. Torgerson regarding options for the spatial analysis and presentation of the e-logbook data (building on statistical modelling done as part of FISA 01/2015)
	Work out suitable methods for combining catch data for different sources, e.g. e-logbook data, VMS data, survey data and observer data
ICT work	Establish ICT requirements for disseminating products (quota management reporting, alerts and “hotspot” maps) by satellite communications. These requirements should be generic in the sense that it can be widely applied and is future-proof.
	Develop enabling software for analysis of the data in a GIS framework (e.g., supported by Google Earth)
	Explore options for accessing VMS in real-time, similar to how real-time reporting is undertaken in the Bering Sea

2.4.3 Enabling funding

The workplan described above is extremely ambitious and would require both substantial sources of funding and industry commitment to the overarching goals described in Section 2.4.1. Several national sources of funding exist, principally from FIS and MASTS. NERC and the US's National Science

Foundation (NSF) have agreed to work together to make it easier for world-leading environmental scientists to collaborate on discovery science projects and tackling global environmental challenges. http://www.nerc.ac.uk/funding/available/researchgrants/international/

The European Marine and Fisheries Fund is another source of funding to support activities that are supportive of the fishing industry that would be highly appropriate. Other opportunistic sources exist at the European level. There is currently an open call in the H2020 programme titled *Smart fisheries technologies for an efficient, compliant and environmentally friendly fishing sector* that is being targeted in a project led by a Norwegian firm specialising in ICT and its application to fisheries. There is also potential for funding from the Knowledge Transfer Partnership Scotland (http://www.ktpscotland.org.uk/). Knowledge Transfer Partnerships (KTP) is Europe's leading programme helping business to improve their competitiveness and productivity through the better use of knowledge, technology and skills that reside within the UK knowledge base. KTP is funded by Innovate UK with 12 other funding organisations including the Scottish Funding Council. The collaboration between industry and universities envisioned here would be eligible for support.

Given the high profile of discard bans globally, it might also be useful to explore funding sources that can support further collaborations with US scientists working in Alaska and the Pacific Northwest (e.g., NGOs such as the WWF who have been proactive on bycatch reduction issues).

3 Enhanced gear selectivity

3.1 Review of current progress in underwater stereo imagery, image analysis and mechanical sorting devices.

3.1.1 Underwater stereo imagery

Stereo imagery has been employed underwater since the 1960s for a variety of purposes including marine engineering, archaeology, and surveys of the seabed habitat. Essentially the method allows for distances between points on the image to be determined and so it used in marine biology to measure object size from [stereo] image pairs. Film camera pairs were initially deployed with a reference frame for scale and orientation, but advances in the 1980s, with pre-calibrated synchronised stable camera geometry, led to more versatility and accuracy. Measurements of mobile species lengths were then possible, which in turn led to estimates of abundance and distribution of species. Developments in portable camcorders and the proliferation and miniaturisation of consumer electronics in the 1990s made for extended applications. More recently, the advent of digital imagery and further miniaturisation has led to mass market stereo camera systems becoming available. Shortis *et al.* (2009) provide a comprehensive review of these developments and describe various applications in marine biology and ecology.

The developments in stereo image acquisition have been augmented by similar advances in the capabilities and variety of deployment platforms and image processing and analysis. In shallow water, divers continue to dominate as platforms, but the engineering requirements of the expanding exploration of offshore mineral resources have delivered systems that can be deployed in deeper and more remote waters: these systems include submersibles, remotely operated vehicles and towed systems. Finally, there has been rapid developments in underwater image processing and analysis, to characterise objects automatically. The issue of platform development is not relevant to the current application and is not discussed further. Image processing and analysis is discussed in Section 3.2. The following section reviews the general principles of stereo imagery, and provides a description of the latest developments with examples of recent applications.

3.1.2 Stereo imagery – how it works

Much like human vision, stereo systems are composed of two cameras looking at the same scene. The use of a pair of synchronised cameras, as opposed to the monocular case, provides the ability to take metric measurements of the structure of the observed scene. In order to infer the structure from the pair of images captured by the stereo system, we need to establish correspondences. A correspondence is a pair of 2D points, one from each image, which represents the projection of the same 3D point in the scene. Knowing were a point is on each camera provides the geometrical information required to reconstruct this point in 3D using triangulation (see Figure 1). In order to get the 3D position of a point, the stereo system must be calibrated. That is, we need to infer the intrinsic camera parameters of each camera, ruling its internal geometry (i.e., how a point from the world is projected onto the image plane), as well as the extrinsic parameters, i.e., the relative transformation between the two cameras[3].

[3] J. Y. Bouguet, "Camera calibration toolbox for matlab," 2008. [Online]. Available: http://www.vision.caltech.edu/bouguetj/calibdoc/.

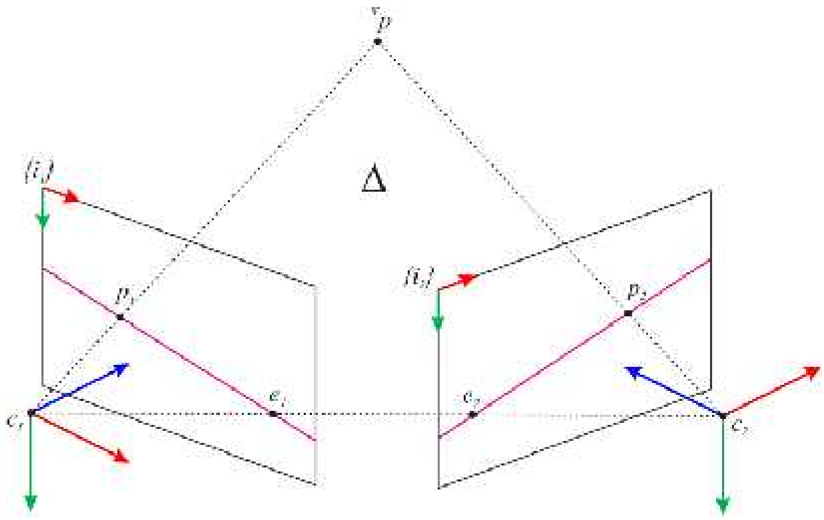

Figure 3.1. Epipolar geometry. The point ^{W}p in the world is projected to p_1 and p_2 in the first and second image of the stereo pair respectively. Epipolar geometry states that the points ^{W}p, p_1 and p_2 all lie on the same plane as the camera centres c_1 and c_2. This restricts the correspondence for both points to lie along the epipolar line (depicted in pink in the figure).

When a pair of cameras observes the same scene from different points of view, there are some relationships between the 3D points and their 2D projections that generate a series of restrictions between points and their location on the images. These restrictions are studied by the epipolar geometry (Hartley and Zisserman 2003), and we use them in order to speed up the correspondences' search process. Basically, if we have a point location in one image, its matching position in the other image will be lying along the epipolar line (see Figure 1), reducing the search space from two dimensions (all the image) to one (one line of the image). In order to speed up the search process even more, we can compute the rectified version of the pairs. The rectification process (Fusiello *et al.* 2000) consists of simulating an optimal stereo system, where the two optical axis are parallel and in the same horizontal position. When this condition is accomplished, the epipolar lines are horizontal and in the same horizontal coordinate as the point to match, making the search process much more efficient in computational terms. Several stereo matching algorithms use this configuration to provide a highly resolved 3D reconstruction of the scene (Scharstein and Szeliski 2002).

What this means for stereo images of fish is that, provided we can locate the head and tail of the animal in the image, the length of the animal can be determined almost irrespective of the orientation the animal is facing, because we can reconstruct co-ordinates of the images spaces in 3D. The locations of the head and tail are usually manually input with the aid of specific computer programs (e.g. Figure 3.2 reproduced from Harvey *et al.* (2003)). Validation of such measurements is achieved by calibrating to a known length measured at a variety of distances and orientations. Typically fish can be measured with an accuracy, root mean square (RMS) error, of around 0.9% (Harvey *et al.* 2004). Examples of such measurements are common in areas where light is not limiting and visibility is good, such as in tropical coral reefs (Shortis *et al.* 2009).

Figure 3.2. Measurement interface of the Vision Measurement System (VMS) showing the body length and span measurements of a southern bluefin tuna, reproduced from Harvey et al. *(2003).*

3.2 Image processing and analysis

3.2.1 Underwater image processing

Underwater images suffer from severe degradation due to the dense and non-uniform medium, which causes light scattering and attenuation. Typical restoration methods often rely on the so called dark channel prior, in order to counteract the effects of the water by estimating the light attenuation, and subtracting the back-scattered light influence (He *et al.* 2011). However, as a consequence of using approximate and global estimates of the back-scattering light, most existing single-image underwater de-scattering techniques perform poorly when restoring non-uniformly illuminated scenes. Some algorithms tailored to the underwater medium include e.g. Neumann *et al.* (2013). While these methods provide good results, they are computationally intensive, and thus not suitable for real-time applications. In order for these methods to work on-board underwater robotic platforms, simpler, yet effective, methods are required (Bianco *et al.* 2015).

Figure 3.3 Underwater image enhancement. Top-left areas depict the original images from a scenes affected by light attenuation and scattering, while bottom-right areas depict enhanced results [Neumann et al. 2013].

3.2.2 Underwater image analysis for the detection and classification of objects

Image classification refers to the problem of identifying regions or objects of interest in an image. Commonly, local image descriptors of different types are combined in order to characterize the information in the images. These descriptors are used in Bag-of-Words methods in several underwater applications, such as coral reef analysis, e.g. Stokes and Deane (2009). These approaches can be applied at image-level (Nicosevici and Garcia 2012), or directly on large underwater maps composed of several images, i.e., mosaics (Shihavuddin *et al.* 2013). In both cases, the main steps of the pipeline can be described as follows.

3.2.2.1 Feature Extraction

Due to the dominant presence of texture in underwater images of interest, texture information can be used to reliably solve the underwater object classification problem. The characteristics of the texture have to be defined using feature extraction and description methods.

3.2.2.2 Features Modification

The features obtained using different methods capture the core properties of the object class and are more discriminative than the raw image patch. They need to be normalized and projected onto a more compact subspace, using Kernel mapping, dimension reduction and/or normalization methods.

3.2.2.3 Segmentation

In the Cam-trawl image datasets (Williams *et al.* 2010), the underwater lighting conditions have a large difference among different fish objects. It is very difficult to use a universal threshold for segmentation. Other kinds of segmentation methods such as k-means, mean-shift, watershed, can only segment one image into many small blobs but without revealing which parts belong to the fish body. Therefore, such kinds of segmentation schemes cannot meet with our segmentation purpose. Facing with such challenges and difficulties, Chuang *et al.* (2011) developed a double local thresholding and histogram back projection scheme to perform the segmentation. For each possible candidate object, we choose two thresholds based on the Otsu method according to the local intensity. With these two thresholds, we can get two binary masks (one is large and one is small) around each fish object. Based on the intensity histograms of these two masks, we compute the ratio between the two histograms and use back projection to determine whether each pixel belongs to the fish body. This robust method, which uses adaptive thresholds for different objects, can handle different lighting conditions very well.

3.2.2.4 Detection

As we know fish is not a rigid object. They can change their poses freely. For underwater scenarios, fish can have similar colour to the background, which makes the detection more challenging. Felzenszwalb *et al.* (2010) adopted Deformable Part Models (DPM) to do the detection. It separates the object into several different parts and computes the detection score for each part. Combining all parts together we can obtain the final detection score for the whole fish body. This largely solves the challenge of the pose changing problem.

3.2.2.5 Tracking

Inspired by the DPM, Chuang *et al.* (2016) conducted fish tracking based on Deformable Multiple Kernels. First, they used different part models for each fish object and do the tracking for each part and then combine all the parts together in the next frame. This can also handle occlusions. Even if some parts of the fish are occluded, the fish can still be tracked successfully.

For some low frame rate sequences, Chuang *et al.* (2015) applied Viterbi association in the tracking. For each frame, they matched each detected object between the current frame and the next frame from both stereo cameras according to some cues, such as location information, object size, object motion direction and the histogram distance. Therefore, low-frame objects can also be tracked very well.

3.2.2.6 Learning

Given a set of training examples, and an estimated prior probability for a given texture patch to fall into any given class, several machine learning techniques can be applied to be able to discern automatically the class of a new instance. Some well-known methods such as K-nearest neighbours (KNN), Probability density weighted mean distance (PDWMD) and support vector machines (SVM) classifiers have proved useful for several underwater applications. However, depending on the complexity of the dataset, more complex solutions such as deep convolutional neural networks can be explored.

3.2.2.7 Classification

Once learning is performed, any new data can be classified (i.e. species can be recognised). After the raw classification of the texture at patch level, some spatial coherence and neighbourhood consistency can be imposed for post processing the initial classification, removing this way scattered misclassifications on large images.

Two different approaches, supervised and unsupervised, can be used in species recognition. For supervised approach, features can be extracted based on the segmentation results, like the shape/contour, colour and textures of several fish body parts. Based on such global and local features, a classifier (e.g. hierarchy classification tree) is used to predict the species. For the unsupervised approach Chuang *et al.* (2016) trained a part model which represents the discriminant parts of the fish body. For each input fish, the body was aligned with the part model and HOG features were extracted from these discriminant parts. Like a supervised approach, a classifier is then used (e.g. hierarchy classification tree) to predict the species.

Wang *et al.* (2010) used locality-constrained linear coding (LLC) for species recognition based on bag-of-features scheme. SIFT feature were extracted for different locations of the image and all the features were encoded based on a trained codebook. A Spatial Pyramid Matching was adopted in the pooling strategy.

3.3 Fish selectivity

In this section, the selectivity of the demersal trawl is considered, based on a recent publication by one of the project participants (O'Neill and Mutch 2016). It is important to note that whilst various selectivity options are available, the combination in which they are employed is largely fishery and vessel specific. Their performance will also be affected by other factors such as the nature of the specific fishery and vessel. Individual fishermen will naturally tend to tailor their gears to use whatever combination of device(s) that deliver the specific catch and quota restrictions they are faced with.

The demersal trawl has various components where fish can escape the gear: these are places where selectivity, i.e. the selection of fish species or size, can occur (**Error! Reference source not found.**).

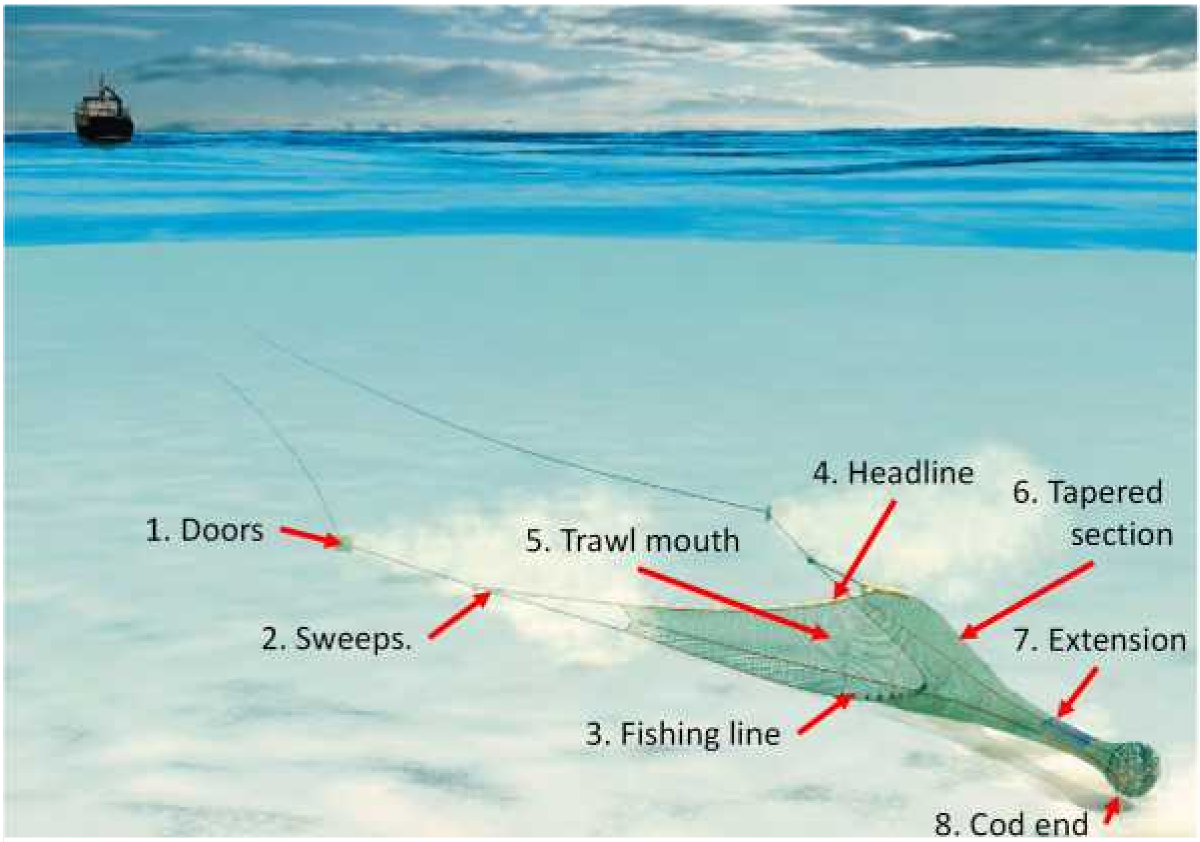

Figure 3.4. Schematic of a typical demersal trawl showing the various components (labelled) where selectivity can occur. These are numbered and (ordered by how fish encounter the component, e.g. they encounter the doors first, the cod end last.

The first component are the trawls doors. The doors themselves are large (typically larger than 1 m^2) objects, so they can therefore be seen or heard simply due to their size. The dragging of the doors along the seabed produces a sediment cloud which can also be detected. Fish can react to the doors and/or, in particular, to the sediment cloud, causing them to avoid the net or as is most often the case to be herded into the path of the net. The selectivity of the doors can be altered by raising them off the seabed, using semi-pelagic doors, so that the sediment cloud they produce is minimised. Doors can also be designed to reduce the impact on the seabed: this is not only less destructive to the seabed but reduces the sediment cloud. Such doors include high aspect doors or doors which are raised off the sea bed with skids.

The second component of the trawl that fish encounter are the sweeps. These also herd the fish into the trawl, depending on the angle, length and amount of bottom contact. Shortening the sweep length reduces the herding effect of the sweeps: this is done by taking the doors in closer to the trawl as was originally the case for these so called ‘otter trawls’ (because the doors were ‘otter boards’). Less herding results in less fish being caught which is why the sweep length was extended. Reducing the contact length of the sweeps also selects fish. This can be done by using semi –pelagic doors, by raising the sweeps with bobbins or making them from floating material.

The third component is the fishing line or footrope. Some species tend to stay close to the seabed when encountering a trawl and these may pass under the footrope depending on how much space there to allow this. The footrope can be raised to exacerbate this effect using alternative configurations and number of dropper chains. The footrope, and the net immediately above it, is typically protected from seabed impact with groundgear. There are various types and size of groundgear, ranging from simple chain to protect the footrope to large rock hoppers or bobbins, often made from old car tyres. Changes to the number, size and type of groundgear will provide opportunities for fish to escape under the footrope.

Some fish rise when they meet the net, their ability to escape the net will be affected by the fourth component they encounter, the headline. Headlines can be adapted with cutaway sections, or be of various heights in order to influence this process. How far the headline is positioned behind the footrope also affects how fish are retained. Once past this line the fish are in the trawl mouth. Selectivity from here on in depends on the mesh of the net and/or any devices that are included in the net. Increasing the mesh size in the front end of the trawl allows for certain fish, particularly those which avoid the centre of the trawl, to escape. The mesh shape can also be altered (e.g. using square mesh instead of the typical diamond). Horizontal separator panels can be introduced here to harness the vertical separation. The tapered section of the net is the sixth component the fish encounter. Many of the same principles applied at the mouth of the next apply here, in that meshes can be altered to enhance selectivity.

The extension is that section of the trawl between the taper and the cod end. It is generally made of diamond mesh which tend to close as the gear is towed due to the tension created. The further down the extension the fish pass, the more damage they are likely to incur as they encounter each other and the narrower spaces leading to collisions with the net. Several methods have been tried to provide escape opportunities in the extension, mostly in the form of panels made from alternative mesh (e.g. square), larger meshes, or escape panels. Grids can also be introduced here. These may be rigid, flexible or simple additional netting. They are typically used to deflect fish of particular size thresholds out of the trawl. Modifying flow patterns in the extension can also allow for fish to swim against the trawl direction and be allowed out of the trawl using escape hatches. Finally, the extension can be compartmentalised to grade fish into different areas from which they might be released.

The final component that fish encounter is the cod end. This is traditionally where much of the selectivity work was focussed on, because it represents simplest and last opportunity for objects to pass through the meshes of the trawl. Size selectivity has been achieved here, quite successfully, by increasing mesh sizes. The mesh size in the cod end was the distinguishing feature of fisheries in the North Sea (Holmes *et al.* 2011): with TR1 vessels having mesh sizes greater than 100 mm (finfish fishery), TR2 being those with mesh sizes between 70-100 mm (mixed finfish and prawn fishery) and TR3 being small meshes used to catch the small industrial species such as sandeel and Norway pout. The cod end can also be made of alternative mesh shapes (diamond or square), twine thickness or twin number (single or double). Double cod ends or lifting bags can also reduce selection (retain more fish).

3.3.1 Selectivity and discarding

Much of the success in reducing discards of young fish, in the North Sea in particular (Fernandes *et al.* 2011), were in line with the expected changes attributable to the minimum mesh sizes of cod ends in the demersal fleet increasing from ~80 mm in the late 1980s to 120 mm in the 2000s (Kunzlik 2003). Other technical measures introduced in the area to reduce discards include the use of square-mesh panels, limits on twine thickness, and the banning of lifting bags (Catchpole and Revill 2008). The prawn fleet has been subject to different regulations that allow the use of nets with smaller coded mesh (Graham and Ferro 2004), to allow catching of the target species (in this case, *Nephrops norvegicus*). Consequently, the discard rates have generally remained high for this fleet, though with the total raised quantities lower than those for the fleet targeting fish (Fernandes *et al.* 2011). High rates of discarding are particularly evident in the west of Scotland prawn fishery (Fernandes *et al.* 2011), where the minimum mesh size was 70 mm until the late 2000's.

To affect selectivity of larger fish it would be better to target an area further away from the cod end, because by this stage fish have experienced crowding and collisions with the net and other fish, causing stress and damage which may affect their survival even if they do escape. Two large European projects are now underway which tackle this issue: Discardless (http://www.discardless.eu/) and Minouw (http://minouw.icm.csic.es/). There are also several companies which have identified novel technical solutions to dealing, in part at least, with the selectivity issue. One of these is Scantrol Deep Vision (http://www.deepvision.no/) which is part of the current project and that system is described further below. Another, is the Star Oddi Fish Selector (see http://www.star-oddi.com/products/45/fish-sorter/default.aspx) which is a device which purports to do exactly what is proposed in this component of the FIS011b project: "This equipment is pre-programmed to select fish by specific size and species. The unwanted fish, either too small or not the right species, are automatically sorted out and released through a door into the open ocean." However, the unit is currently not for sale, and, when approached, the company were keen to develop the next version of their device at costs that were beyond the scope of what was envisaged. These two systems are, however, quite similar in scope based on what can be gleaned from the information available (being private companies they naturally keep their specific designs secret).

3.3.2 Smartrawl: the proposed solution to the discard problem

The idea for a Smartrawl, which is essentially [and coincidentally] articulated by the Star Oddi Fish Selector, originally came from a research tool called Cam trawl (Williams *et al.* 2010) which is very similar to the Deep Vision system. This research device is used to sample fish from a pelagic trawl without bringing them to the surface (Figure 3.5). A stereo camera system is used to determine the

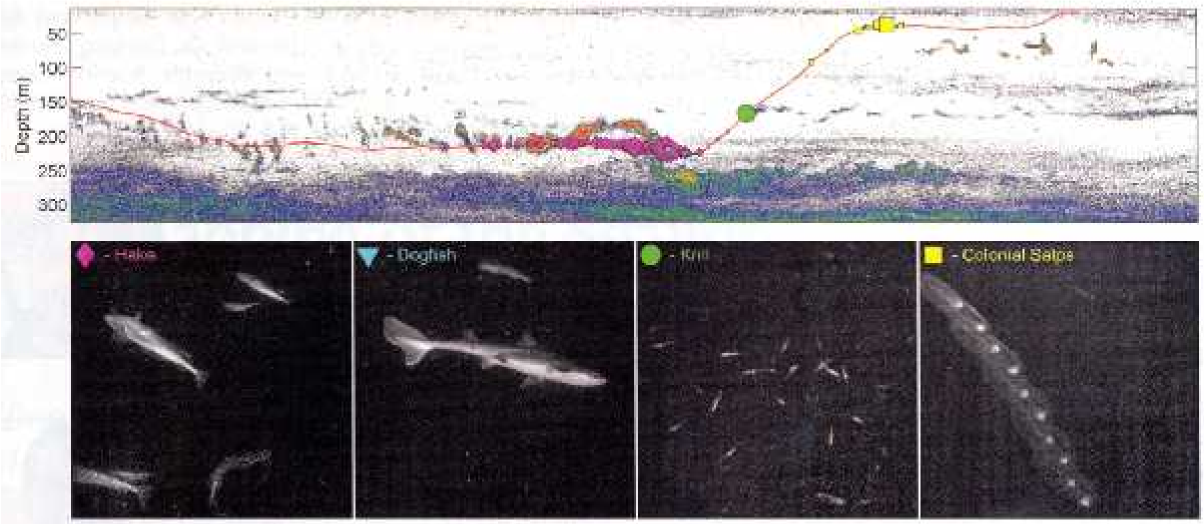

Figure 3.5. Cam trawl images (lower plates) shown with their corresponding locations on a 38-kHz echogram (upper figure, with depth along the y axis and distance on the x axis, colours indicate scattering by fish and other objects in the water column). Red line indicates the passage of a pelagic trawl, superimposed markers indicative of corresponding species in lower panels; marker size indicates the relative abundance of organisms in the images (reproduced from Williams et al 2010).

size and, later, on retrieval of the images, the species of fish as they pass the extension. The cod end can be opened so as not to catch any fish.

A similar concept has been developed by Scantrol, the DeepVision system (see (http://www.deepvision.no/). This system is described in Rosen *et al.* (2013). It consists of stereo digital colour cameras connected to a PC for control and data storage, LED strobes for lighting, all mounted in a rigid box like frame. Pressure, pitch and roll sensors provide data on depth and orientation of the device matched with a time stamp, allowing the images captured to be cross referenced to other data such as acoustic data (as per Cam Trawl). Indeed, the system was designed to capture high quality images for trawl haul verification of acoustic data (Figure 3.6, taken from (Rosen and Holst 2013).

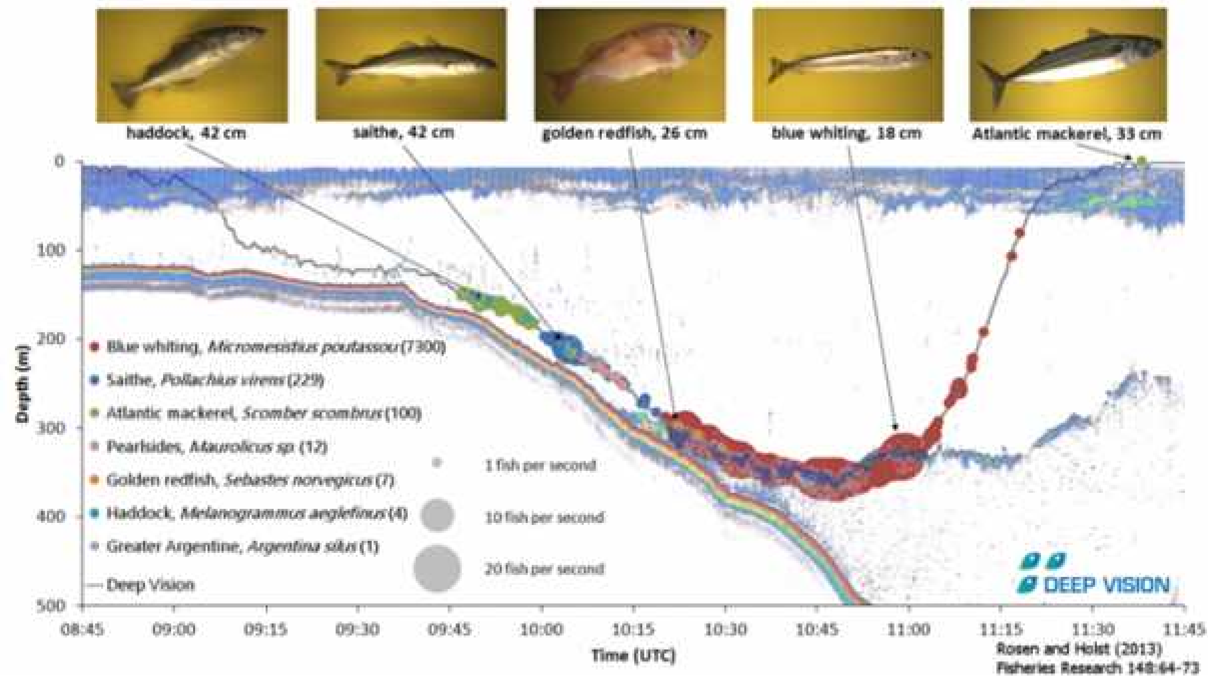

Figure 3.6. Deep vision images overlaid with their corresponding locations on an echogram (lower figure, with depth along the y axis and time on the x axis, colours indicate scattering by fish and other objects in the water column). Black line indicates the passage of a pelagic trawl, superimposed markers indicative of corresponding species in upper panels; marker size indicates the relative abundance of organisms in the images (reproduced from Rosen and Holst 2013).

The idea then follows that instead of having an open cod end, some selective gate system could be incorporated which is linked and controlled by the stereo camera system.

To explore this idea further series of workshops was arranged with appropriate stakeholders, industrial technology providers and academics. Much of the material in the preceding and following sections was derived from summaries of contributions made at these workshops.

3.4 Smartrawl workshops

3.4.1 Aberdeen, June 2016

A workshop was organised from 13-15 June 2016 to discuss a proposal to build a Smartrawl. The objectives of the workshop were as follows:

1. To review the current progress in fisheries selectivity, underwater [stereo] imagery, image analysis and mechanical sorting devices which are relevant to fisheries.
2. To discuss and detail specific requirements for the Smartrawl, a species and size selective device that would be acceptable for use in the mixed demersal trawl fishery.
3. To identify suitable funding sources and determine how to proceed with the development of the Smartrawl.

An agenda for the meeting is provided as Annex 3 along with details of the personnel involved. Several fishermen were invited to the workshop after preliminary discussions at various events earlier in the year, such as the Scottish Industry Discard Initiative (SIDI) meetings. Despite strong initial interest only one fishermen was able to attend the workshop: this was largely due to an unforeseen conflict with the Thames flotilla exercise in support of Brexit that many fishermen participated in. In the event only one active fisherman participated, and one representative from SIDI.

3.4.2 Dissemination and other activities

A video conference was held in June 2016. Participants from the University of Washington (Hwang) and the Alaska Fisheries Science Centre (Williams) were not able to join the workshop in Aberdeen. Instead, a video conference was held with these partners on Friday 17 June to discuss their ideas and participation. Their contributions are included here also. A further video conference was held with staff from the University of Girona on Monday 20 January.

A short workshop was held at the Annual Scottish Fishing Conference on 23 August 2016. The participants included Jim Portus (South West Fisheries Producer Organisation), Stewart Crichton (Orkney Sustainable Fisheries Ltd), Mark James (MASTS), Errin Todd (Lobster Pod), Ben Drakeford (University of Portsmouth), Andrew Noble (ex-fisherman) and Nick Underdown (Scottish Environment LINK). There was widespread enthusiasm for the Smartrawl idea and the fishermen present were confident that they would be able to deploy the system provided it was not much bigger than the diameter of the trawl extension.

Two presentations were given at the Scottish Discards Initiative (SIDI) meetings on 26 May and 24 June 2016. The latter was hosted at the University of Aberdeen and involved several fishermen and policy staff from Marine Scotland.

These workshops and consultations produced three major outcomes:

1. A requirement to explore options for mechanical sorting devices.
2. A desire to test a stereo camera system in a North Sea demersal trawl fishery. An opportunity to carry out tests using a modified DeepVision system was established between the project partners, on a research cruise scheduled towards the end of the project.
3. An outline project proposal for development of the Smartrawl, with a consolidated consortium of partners.

The remaining sections of this report detail these three outcomes.

3.5 A study of potential mechanical sorting devices

3.5.1 Introduction

This part of the project aims to develop concepts for a highly selective mechanism that would, in conjunction with a camera and fish identification system, deliver a “smart” trawl system by use of which bycatch and non-targeted species could be completely or largely avoided.

The camera box is placed in the narrowing of the net, ensuring that all the species detected are approaching the end of the net rather than simply passing in front of it. The purpose of this report is to outline the design of possible mechanisms which open and close the net based on input from the camera box. Several designs to serve this purpose have been considered and evaluated based on a holistic decision matrix. Two are presented as examples.

It is important to note that there are already existing mechanisms which allow bycatch of certain species, such the Turtle Excluder Device (TED). However, the mechanism designed in this project, unlike the TED, is highly selective, allowing the outlet of *any* species. The TED’s selectivity is based only on size, hence does not serve the purpose when there is an overlap in size between wanted and unwanted species.

3.5.2 Description of the problem

The aim of this part of the project was to produce some candidate designs of a fish selection mechanism which would be operated by the camera based fish recognition system. The mechanism needs a door or gate which can be moved to allow fish to enter the cod end or to close the cod end and direct the unwanted fish out of the net. This report only describes the concept designs. Additional funding will be sought for further analysis of these designs, prototyping and flume trials of scale model before embarking on a full-scale demonstrator.

The process was based on the first 4 stages of a 5-point design process:

- Requirement
- Specification
- Search for alternative solutions
- Evaluation of the solutions
- Synthesis – build

3.5.3 Requirements

This is a restatement of the problem description:

Design of a fish selection mechanism which would be operated by a camera based fish recognition system. The mechanism needs a door or gate which can be moved to allow fish to enter the cod end or to close the cod end and direct the unwanted fish out of the net.

3.5.4 Specification

Before embarking on a search for possible solutions a specification for the device was produced. The design of this selective fishing mechanism needed to meet the following requirements:

<u>Operating conditions</u>

- Must operate self-contained for the period of a trawl – up to 8 hours
- Must be robust due to potential collisions with subsea structures and with the vessel during deployment and recovery in rough seas
- Must withstand seawater
- Must be resistant to sediment suspended in the water column
- Fish must be collected until the net reaches saturation and therefore, the mechanism must not hinder access of the fish.

<u>Dimensions</u>

- Maximum dimensions similar to the dimensions of the camera box (1.5m x 1.5m x 1.5m max)

<u>Environmental conditions</u>

- Will operate underwater in typical seawater temperatures 4 - 30°C dependent on fishery
- Will operate with sediment suspended in the water column

<u>Serviceability</u>

- Must be able to be repaired/serviced by the ship's crew

<u>Reliability</u>

- The mechanism must be selective enough to avoid capture of entire shoals of the untargeted species and also avoid catching any individuals of an endangered species. Although this reliability depends highly on the accuracy of the camera box, the success of the entire system relies on the opening/closing mechanism to take relevant action.

- Ideally the default failure position should be that the net is open to catch fish

Geometry

- The system should have a geometry which matches either the camera housing (rectangular cross-section) or more ideally with the net circular cross-section of the net.

Power

- Must be self-contained with no cable

Cost

- Design will be worked to a minimum cost solution to allow uptake by commercial fisheries.

3.5.5 Possible solutions

Two of the best solutions which were generated for the mechanism are presented here as examples. Other solutions included gravity, buoyancy and drag operated gates.

3.5.5.1 Design 1: Rotating Release Window System

The system comprises two concentric cylindrical sleeves made of a frame covered with net and which have windows in them and are partially closed at the end. Each sleeve has two segments of 90° without net. These are separated by two 90° segments with net. When one sleeve is rotated relative to the other the windows can be either opened or closed. At the ends of each sleeve is a disk which is also partially covered with net. Figure 3.7, shows the configuration when the openings on the disks are aligned, while the windows are closed. In this configuration, the cod end is open for fish capture.

Rotation of the inner sleeve relative to the outer by 90° results in the windows aligning providing escape for the fish from the sides of the device, while the closed segments of the end disks block the entrance to the cod end and prevent unwanted capture. See Figure 3.8. The shape of the inner sleeve with disk 1 is

Activation of the mechanism could be by a motor rotating one sleeve relative to the other, but there may be possibilities of the fluid flow being used to rotate the sleeves, with the only actuator needed, being a solenoid release latch which would allow the flow drag to rotate the sleeve to the next 90° position.

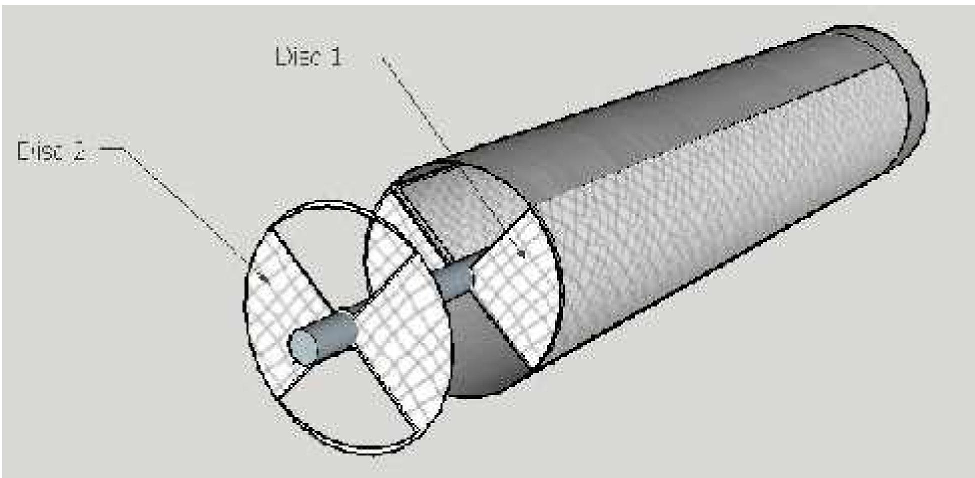

Figure 3.7. System in open configuration – openings in disks 1 and 2 allow access to the cod end, while the windows are closed.

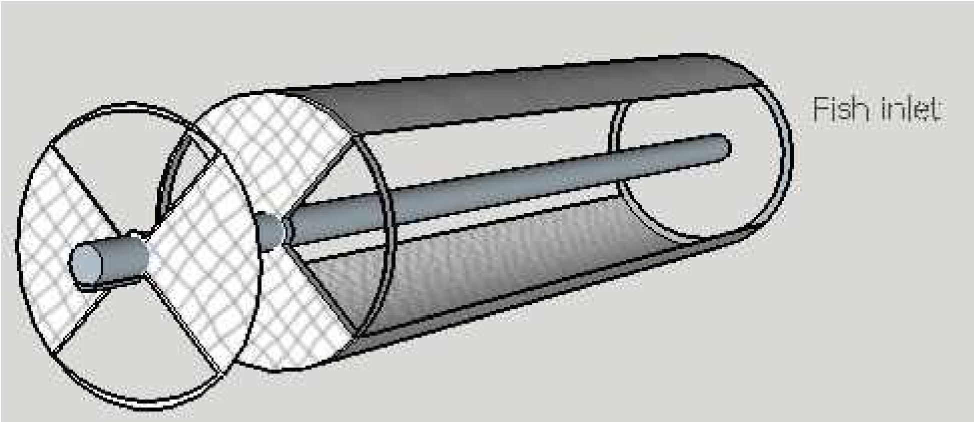

Figure 3.8.Closed configuration - after the shaft rotates 90 fish can escape through sides of the cylinder while disks 1 and 2 block access to the cod end.

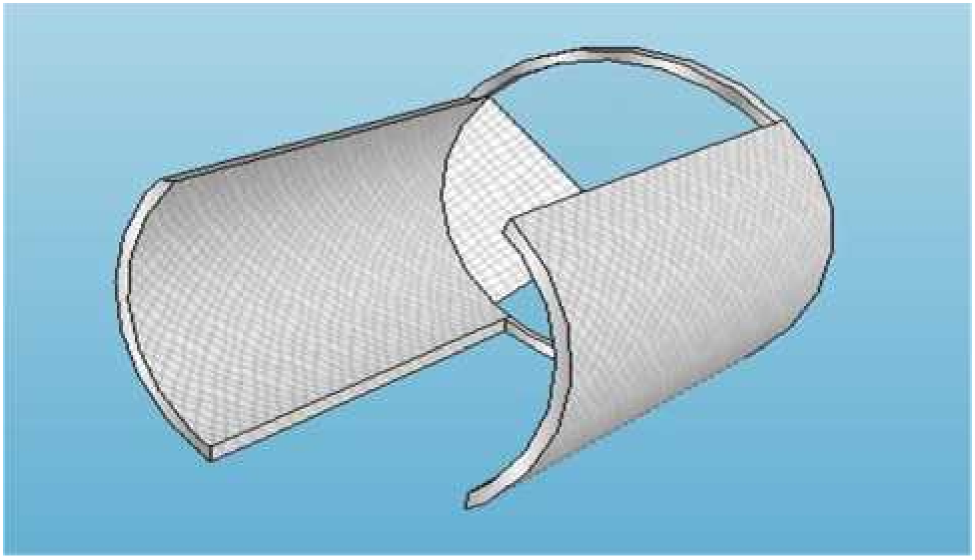

Figure 3.9. 3D model of Disc 1

There are limitations to the system. The disks at the end obscure part of the access to the cod end. These transitions could be smoothed by the use of shaped net wedges which would feed the fish towards the openings but this is a disadvantage. It is also not guaranteed that if the system failed it would be in the position where fish would still be caught. The advantage of the system is that it is cylindrical and therefore matches the geometry of the cod end cross-section. The possibility of the using fluid drag to rotate the sleeves with only a solenoid latch needed is also an advantage.

3.5.5.2 Design 2: Hinged gate

In the second design, an extension is made to the camera box. This additional box has is a frame covered in net and has a hinge attached to one of rear edges allowing one side to the acting like a gate. At the other end of this gate is a hinge and a solenoid controlled 'flap' (Figure 3.10). The gate is made of net but has a frame to keep it rigid. In the open of catch configuration, the flap is in line with the water flow, keeping the gate in line with the edges of the camera box, see figure 3.10.

When untargeted marine life is approaching, the solenoid is activated and moves the flap into the water flow inside the housing. (Figure 3.11) As the gate is free to rotate around the hinge at the back edge of the extension box the water flow pushes against the flap to move 'gate' inwards. The gate rotates inwards until its path is intercepted by the other wall of the box. This leaves an opening in the face where the gate used to be, allowing the fish to escape while blocking access to the cod end. (Figure 3.12)

Springs are included in the design and are stretched as the gate moves inwards. However, these have a stiffness designed so the sum of their forces is smaller than the magnitude of the force from the water flow pushing on the flap.

To return to the open configuration, the solenoid is deactivated and returns the flap to an orientation whereby the water flow is assisting the springs in pushing it back to its original position. A stationary plate (shown in yellow) could also be used to aid in diverting the water flow to return the gate to its original position (Figure 3.13). The water net effect of the flow's net effect along with the pulling force of the springs is enough to return the gate to its original position.

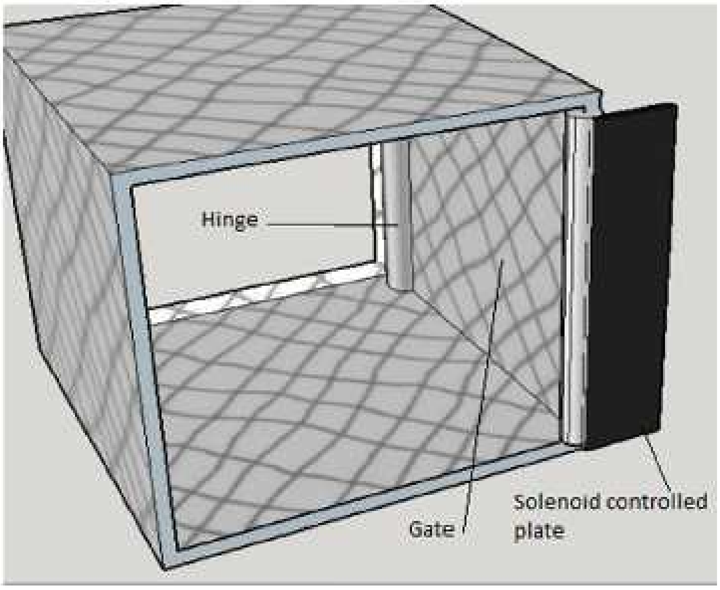

Figure 3.10. Gate extension housing

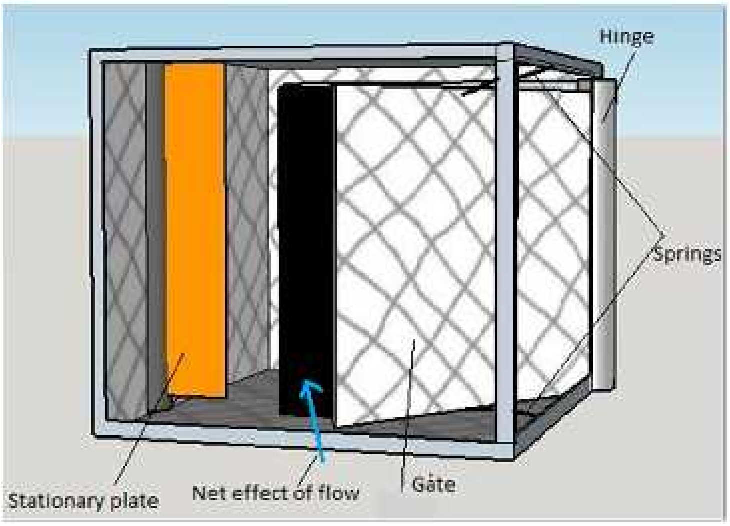

Figure 3.11. Gate extension housing showing solenoid activated and flap being deployed to open the gate and allowing fish escape.

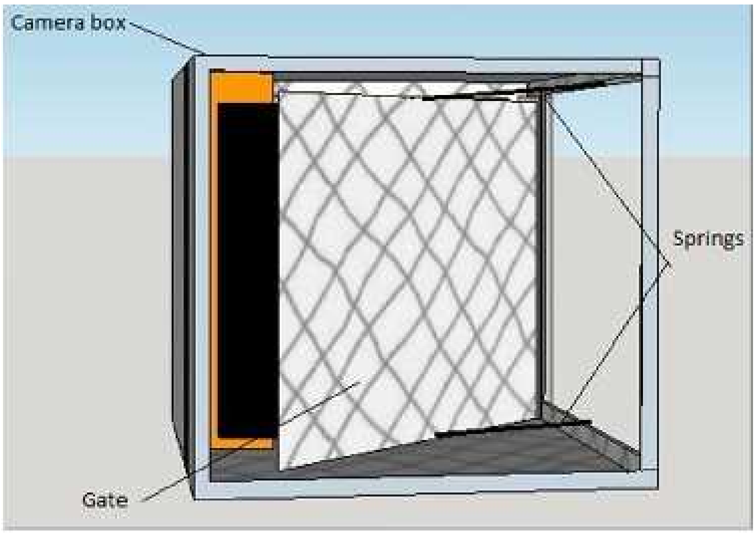

Figure 3.12. Gate extension housing showing solenoid activated and gate fully open and allowing fish escape.

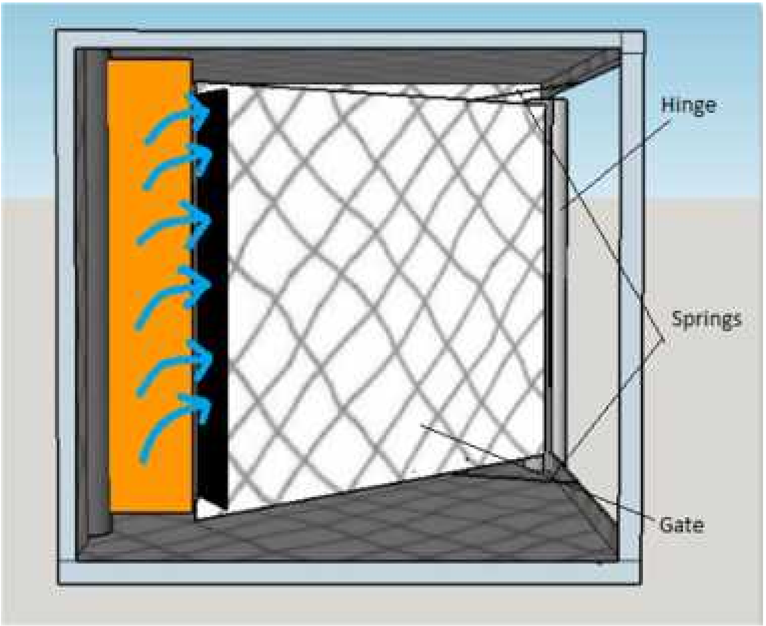

Figure 3.13. Gate extension housing showing solenoid deactivated and flap retracted to allow the gate to close under the action of the springs.

Again, there are limitations to the system. Failure of the springs would mean that the gate might stay in the position which allows fish escape. However, power failure would deactivate the solenoid which would return the door to the position in which the cod end is open and the escape is closed. An advantage of the system is that it only needs a solenoid for activation and the gate acts to close the cod end and open the escape outer simultaneously. The mechanisms is relatively simple. If required a gate could be put at both sides with the gates meeting in the middle and providing escape to both sides. Other more positive drive methods for example a screw drive with a motor are also possible with this design, but require greater weight and more parts which will be susceptible to damage under water.

3.5.6 Next Stages

The main work within this part of the project was undertaken by a student intern under Dr Neilson's supervision. The aim was not to provide detailed design but to generate and evaluate some candidate designs which could be developed into working prototypes. This has been achieved and the next stage of the work will be to undertake some further analysis of these candidate designs and to produce detailed designs of one or both them. These will then be prototyped and tested in a future project.

3.5.7 Solution assessment

The important attributes for each design were considered to evaluate their pros and cons. The attributes considered were size (small being better), cost, simplicity in repairing any parts or components, reliability and whether the system has an open configuration in case of failure. These were weighted according to the perceived importance of the attributes. The analysis indicates that Design 1 is favoured (Table 3.1).

Table 3.1. Attributes for the two design solutions for a Smartrawl gate system.

Category	**Size**	**Cost**	**Simplicity in repairing parts**	**Reliability**	**Open Configuration in case of failure?**	**Totals**
Relative weighting	**2**	**2**	**3**	**3**	**Yes/No**	**10**
Design 1: score	8	9	7	7	Yes	
Design 1: Weighted score	16	18	21	21	-	76.0%
Design 2: Score	4	7	6	7	Yes	
Design 2: Weighted score	8	14	18	21	-	61.0%

3.6 Research cruise testing stereo imagery in a demersal trawl in the North Sea

3.6.1 Introduction

This section reports on a research cruise conducted to test a simplified, compact, deployment setup of the Deep Vision in-trawl stereo camera system. It was conducted as part of the project "SMARTFISH: Selective management and retention of target fish" funded by the FIS011 call "Developing and facilitating a range of possible future FIS projects in innovation in selectivity through on-net or alternative technologies." The cruise was not initially planned as part of the FIS project, but was raised as a possibility during the June 2016 workshop to specify the Smartrawl concept (project objective 2.2) and discuss the larger research proposal. Marine Science Scotland made the Alba na Mara and staff / trawl rigging support available at no cost in conjunction with an already planned cruise. Resources to cover staff time and small equipment outlays for the Norwegian partner (Shale Rosen) were provided by the CRISP Centre for Research-based Innovation in Sustainable fish capture and Processing technology funded by the Research Council of Norway and administered by the Institute of Marine Research, Norway.

3.6.2 Goal of the investigation

The investigation had two primary goals:

- Test a prototype deployment system for the Deep Vision stereo camera system (Rosen et al. 2013) that would be appropriate for the Scottish demersal trawl fleet. The standard deployment frame is a rigid structure 150 cm in length, 110 cm in height and 120 cm in width and weighs 500 kg not including the electronics package. Despite this large size, the passage for all fish to pass through has a cross-section of just 2400 cm^2, meaning the fish are forced through an opening equal to approximately 25% of the overall cross-section of the trawl. This provides challenges both for throughflow capacity and large objects (large skates for example) which may become lodged in the channel. The rigid channel is also potentially vulnerable to damage by rocks which frequently enter demersal trawls. In this investigation, the Deep Vision cameras, lights and battery were housed in a smaller frame (115 cm in length, 80 cm in height, 30 cm wide) weighing 41 kg. A solid, light coloured background was provided by lining the trawl with a white tarpaulin.

- Test visibility and image quality in demersal trawling conditions. Most development of the Deep Vision system has been done in pelagic trawl deployments, where visibility is generally not restricted by suspended sediments. Trawling in this investigation was carried out on a series of seabed types (sand, gravel and mud) and images were captured in uncompressed "RAW" file format in order to maximize image quality for post-processing analyses, including "dehazing" techniques to extract information from images taken in turbid waters.

3.6.3 Experimental setup

The downsized Deep Vision frame was mounted inside a 275 cm long 4-panel section of 20 mm (bar length) nylon knotless square mesh (Figure 3.14). The frame was built to accommodate the camera unit; lights; and battery and protected the components against physical damage while providing a structure to secure them both relative to one another and within the trawl. It measured 115 cm in length, 80 cm in height and 30 cm in depth, weighed 40.6 kg (not including Deep Vision electronics) and was constructed of 10 mm thick HDPE sheets connected using aluminium angle. Its calculated weight in water is just over 9 kg.

The frame and 4-panel section were constructed in Norway and sent to the Marine Laboratory, Aberdeen ahead of the cruise for incorporation with the demersal survey trawl. A 2-panel 600 cm long collection bag (cod end) was produced from 45 mm (stretched length) knotted polyethylene and fitted directly behind the Deep Vision section in order to retain the catch for species identification and measuring for comparison with the Deep Vision results.


Figure 3.14. Deep Vision section during rigging in the net loft at the Marine Laboratory, Aberdeen. Left image shows the Deep Vision section, constructed of brown meshes 20 mm (bar length) nylon knotless mesh, total length = 275 cm. To the left in the image is the green 600 cm long collection bag of 45 mm (stretched length) knotted polyethylene. The Deep Vision frame is at the centre, with the access door open showing location of the battery. Right image shows Deep Vision section viewed from leading end. Frame at left contains the stereo cameras, battery and lights. It extends the entire height of the starboard trawl panel and 30 cm into the over and under panels. The white tarpaulin lining provides a solid background for the images and reflects light.

Final mounting of the frame and tarpaulin inside the trawl section, as well as testing and mounting batteries (borrowed from Marine Laboratory to spare the expense and difficulty of hazardous cargo shipping the standard Lithium-ion Deep Vision batteries from Norway) was done in the Marine Laboratory's net loft 31.10-02.11. A scale was added to the inside of the tarpaulin, marked every 5 cm in order to be able to establish the width of the field of view and to provide a target for the analysis software to calculate the tarpaulin's distance from the camera during trawling. Everything was then driven to Fraserburgh mid-afternoon 02.11 and loaded onboard R/V "Alba na Mara". The crew attached the Deep Vision section to the trawl, running lengths of spectra rope (ca. 8 mm diameter) along the trawl's laces in order to reinforce the attachment of Deep Vision to the trawl. Six 8-inch deep sea trawl floats ("Atlantic floats") were attached to the top of the Deep Vision frame, providing 14.4 kg of buoyancy and bringing the system's overall weight in water to 2 kg buoyant. With the battery at the very bottom of the frame, the frame should have a low centre of gravity and naturally maintain the desired vertical orientation.

3.6.4 Trials at sea

Trials were carried out over two days from 03-04.11.2016 in the Moray Firth just west of Fraserburgh. The cruise schedule was severely shortened due to heavy winds out of the northeast which left no sheltered areas to work. We considered steaming to Shetland for the possibility of sheltered areas, but this would have meant sacrificing the sure good days of weather (02-03.11) in transit without guarantee that we would find suitably protected fishing grounds once the gale set in. Eight hauls were conducted, five on 03.11 and three on 04.11 before weather deteriorated to the point that we had to return to port. The areas sampled, including seabed type and camera settings, are indicated in Table 3.2 and Figure 3.15, below.

Table 3.2. Summary of hauls conducted 02-03.2011 on board R/V "Alba na Mara."

	Camera settings		Bottom characteristics		
Haul ID	Exposure value	Gain	Substrate	Depth (m)	Notes
01	1	2.5	sand	30	tarpaulin not taught (folds and shadows)
02	1	1.5	sand	30	tarpaulin not taught (folds and shadows)
03	1	2	gavel	45	tarpaulin not taught (folds and shadows), tore belly of trawl
04	1	2	mud	95	tarpaulin more taught, but lots of suspended sediment
05	1	1.5	mud	130	tarpaulin variable (often folds and shadows)
06	1	1.5	mud	130	tarpaulin much more taught, but lots of suspended sediment
07	1	1.5	sand	30	tarpaulin taught, good visibility
08	1	1	sand	30	tarpaulin torn, not as taught as previous hauls, good visibility

Figure 3.15. Satellite image of the East coast of Scotland showing the cruise track (blue line) of the research vessel during the Smartfish cruise. Eight tows were conducted in four areas (red dashed ellipses) encompassing shallow sand, shallow gravel and deep mud bottom types.

In addition to the Deep Vision camera system, a monochrome video camera (Bowtech L3C-550-14) was placed 200 cm ahead of the Deep Vision section, looking aft in order to assess its shape and observe the behaviour and position of fish as they passed (including fish that passed either above or below the Deep Vision cameras' fields of view). A turbidity meter was also installed for hauls 06-08, placed on the inside of the top panel 2.8 m ahead of the Deep Vision section. The goal of this meter is to provide a quantitative measure of water clarity when assessing visibility in the Deep Vision images. Data from the turbidity meter were not yet processed at the time this report was written.

The trawl was always fished with a closed cod end in order to capture the fish imaged for comparisons of the total number of individuals captured, species composition, and length frequencies with Deep Vision results. Catches were dominated by small whiting, small haddock and flatfish. Small cephalopods were also sometimes numerous. All catch was measured and weighed following standard Marine Scotland protocols (with the exception of length, which was measured as fork length in order to be consistent with Deep Vision lengths), but results were not yet available at the time this cruise report was written.

3.6.5 Results 1: Rigging and trawling performance

After some modifications, the rigging generally worked well. The tarpaulin initially hung quite slack, creating deep folds and shadows and creating an unsatisfactory background (Figure 3.16, below). After reviewing the Deep Vision images and video from the observation camera, a float was added to the top port lace (2.4 kg buoyancy) and 3.2 kg of chain was added to the lower port lace (weight in water = 2.7 kg) in the hope that this would make the port "wall" of tarpaulin hang more vertically.

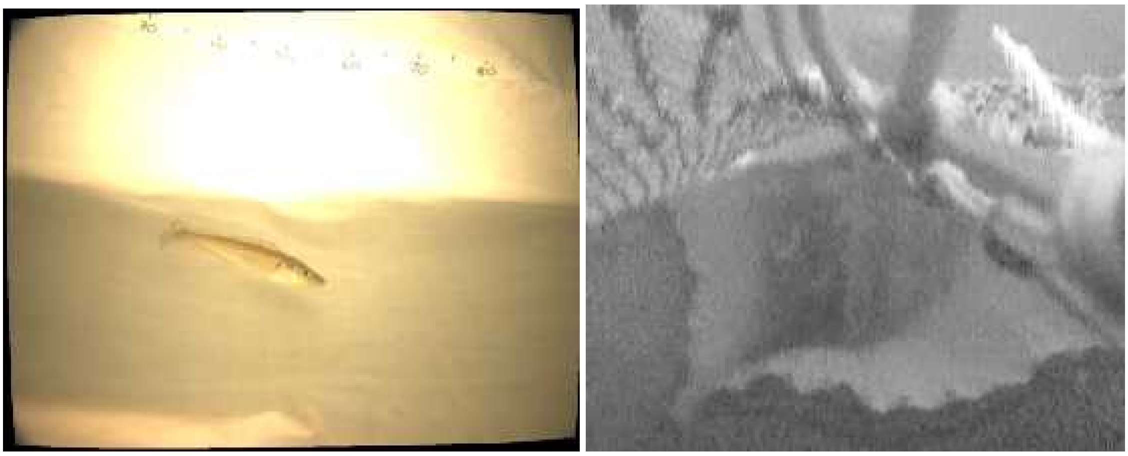

Figure 3.16. Both images from Deep Vision cameras (left, view across the trawl's cross-section) and the observation camera (right, view looking back towards cod end) showed that the tarpaulin liner was not taught with the initial rigging.

Adding the weight and floatation to the port side of the Deep Vision section improved its shape, but the improvement was inconsistent and generally best during haul-back when the combination of the vessel's forward speed and the speed at which the winches were paid in resulted in maximum trawl speed through water (Figure 3.17).

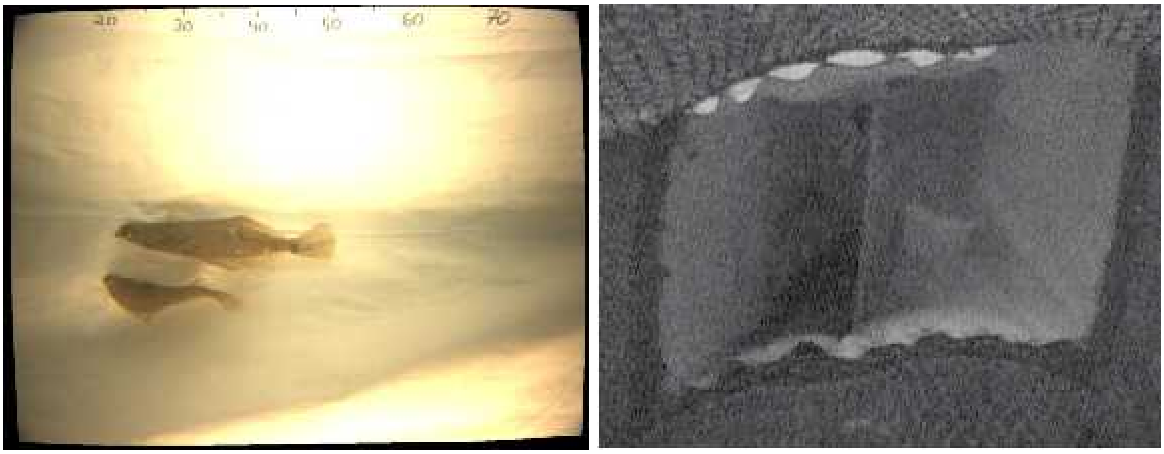

Figure 3.17. After adding weight to the lower port lace and floatation to the upper port lace the tarpaulin along the port wall often hung more vertically, but it was still not consistent and led to both shadows and overexposed regions on the background.

The fix which ultimately proved to result in a more stretched and most importantly consistent shape for the tarpaulin liner was to taper the trailing end of the tarpaulin so that it took on the shape of a sea anchor or windsock. The circumference at the trailing end was reduced by 40 cm by gathering in a triangle of tarpaulin at both the upper and lower port laces. The taper went from 10 cm per side at the trailing edge to 0 cm over a distance of 70 cm. Example images from both Deep Vision and observation cameras after introducing the taper are shown in Figure 3.18.

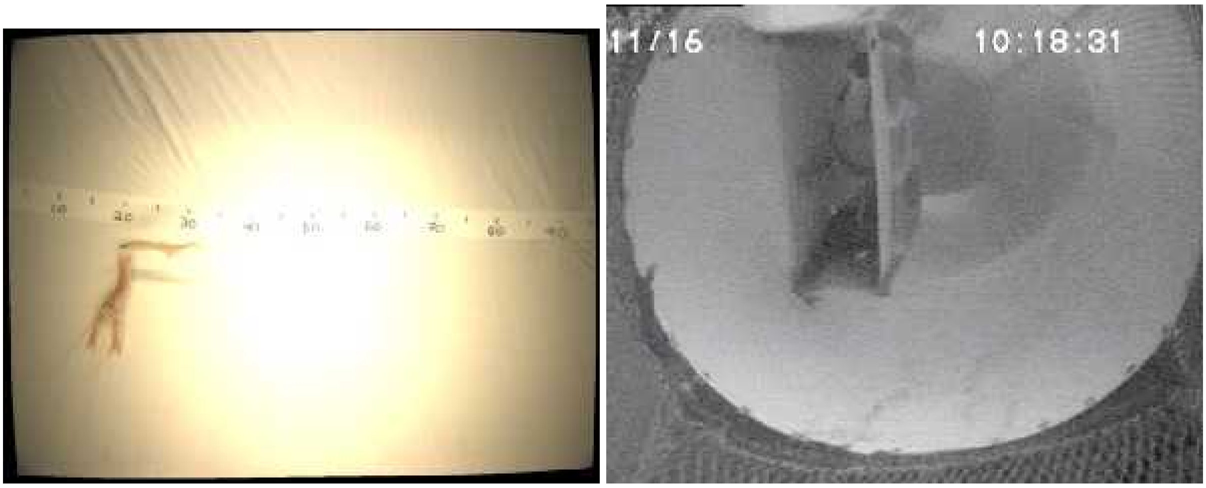

Figure 3.18. Examples from Deep Vision camera (left) and observation camera (right) after the trailing 70 cm of the tarpaulin liner were tapered achieving a slight sea anchor or windsock shape. The Deep Vision image (left) indicates the field of view is 95 cm wide at the background, at a distance of 80 cm from the focal point of the camera (approximately 70 cm from the inside wall of the frame). This represents a free cross-section in front of the frame of 4 400 cm2. The end profile of the frame is a mere 2 400 cm2, suggesting the total cross-section was [4 400 + 2 400] = 6 800 cm2. Placing the frame inside the trawl therefore reduced the cross-section by 35 %.

Handling the system proved to be unproblematic, particularly once the crew had done it several times. The frame was lifted over the transom using a crane and placed in the water (Figure 3.19). It remained at the surface, obviously nearly neutrally buoyant, and the centre of gravity kept it upright. When heaving, the crane was used again to lift the frame over the transom, and it was then lifted onto the net reel. Since it could not be run around the net reel, the cod end had to be either lifted by hand over the transom or using a stopper strop and the crane. This arrangement might be unacceptable on a commercial vessel, as it makes the process of bringing the cod end on board slower than in standard practice.

Figure 3.19. Deep Vision frame being lowered over the vessel's transom using an overhead crane (left) and floating just at the surface as the trawl was paid out (right).

The tarpaulin used (woven polyethylene, 120 g/m²) tore with an audible rip as the system was brought onto deck during heaving on the next to the last deployment (Haul 07). The tear is evident in footage from the observation camera from Haul 08 and introduced wrinkling in portion of the background within the right side of the field of view of the Deep Vision cameras (Figure 3.20). The tarpaulin served as a proof-of-concept, but future tests should be made with a more robust material which is both more puncture resistant and less prone to developing long tears. Some possible materials include very fine knotless mesh or heavy-duty PVC coated polyester.

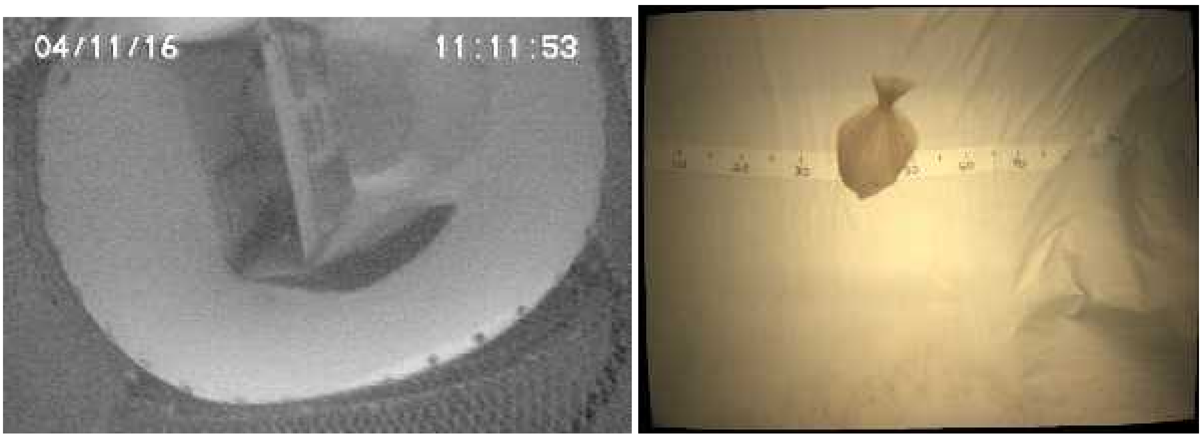

Figure 3.20. Torn tarpaulin on the final deployment (Haul 08). The tear, visible as a black ark in the lower portion of the tarpaulin at the leading edge of the frame, probably began at a pressure-point created by the corner of the frame (the corners were padded with several layers of rubber hose and tape). The tear led to slackness and folds in the right side of the field of view of the Deep Vision cameras. Right hand side: an example image of a plaice with the graduated centimetre scale in the background.

3.6.6 Results 2: Image quality and examples

Image quality was affected by a combination of how stretched the tarpaulin was (a taught background led to more even lighting and fewer shadows), seabed type (image quality was highest on sandy seabed, lowest on muddy seabed), and camera settings for exposure and gain (short exposure resulted in less motion blur but darker images unless gain was increased). Surprisingly, overall brightness of the images appears to be higher in the tarpaulin deployment than in the rigid Deep Vision frame (Figure 3.21).

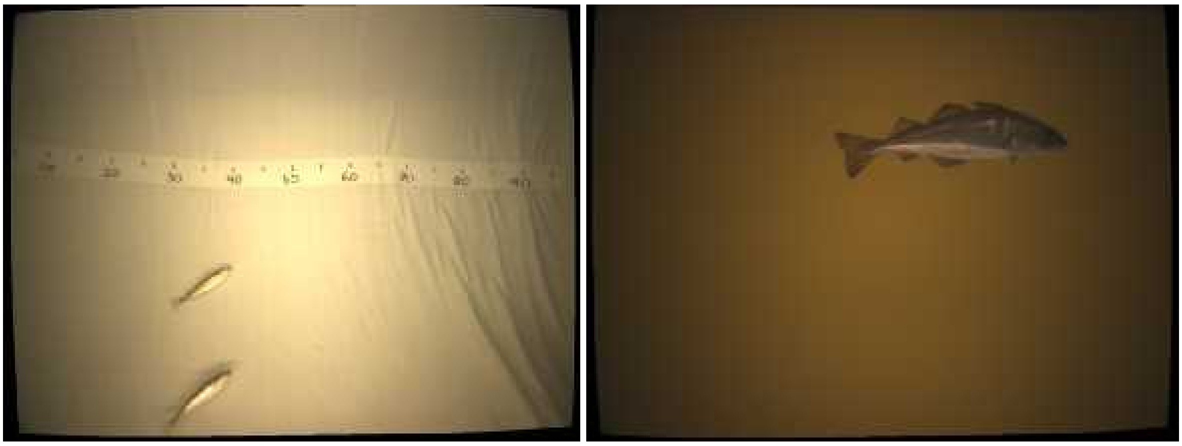

Figure 3.21. Example images taken with camera settings Exposure = 1, Gain = 1. Left image is from tarpaulin deployment onboard R/V "Alba na Mara" on sandy seabed. Right image from trawling 56 m above seabed during a follow-up cruise in Norway onboard R/V "Fangst" 15.11.2016 using the rigid Deep Vision frame. Note that the tarpaulin was white while the background in the solid frame is yellow.

Due to the limited amount of data that could be collected during the window of good weather, the full range of camera settings could not be tested on each bottom type. Exposure was kept constant at 1 (1 millisecond) while gain was varied from 1 to 2.5. The examples below illustrate both the effect of varying gain and of the different levels of suspended sediment depending on the seabed type in Figures 3.22-3.25.

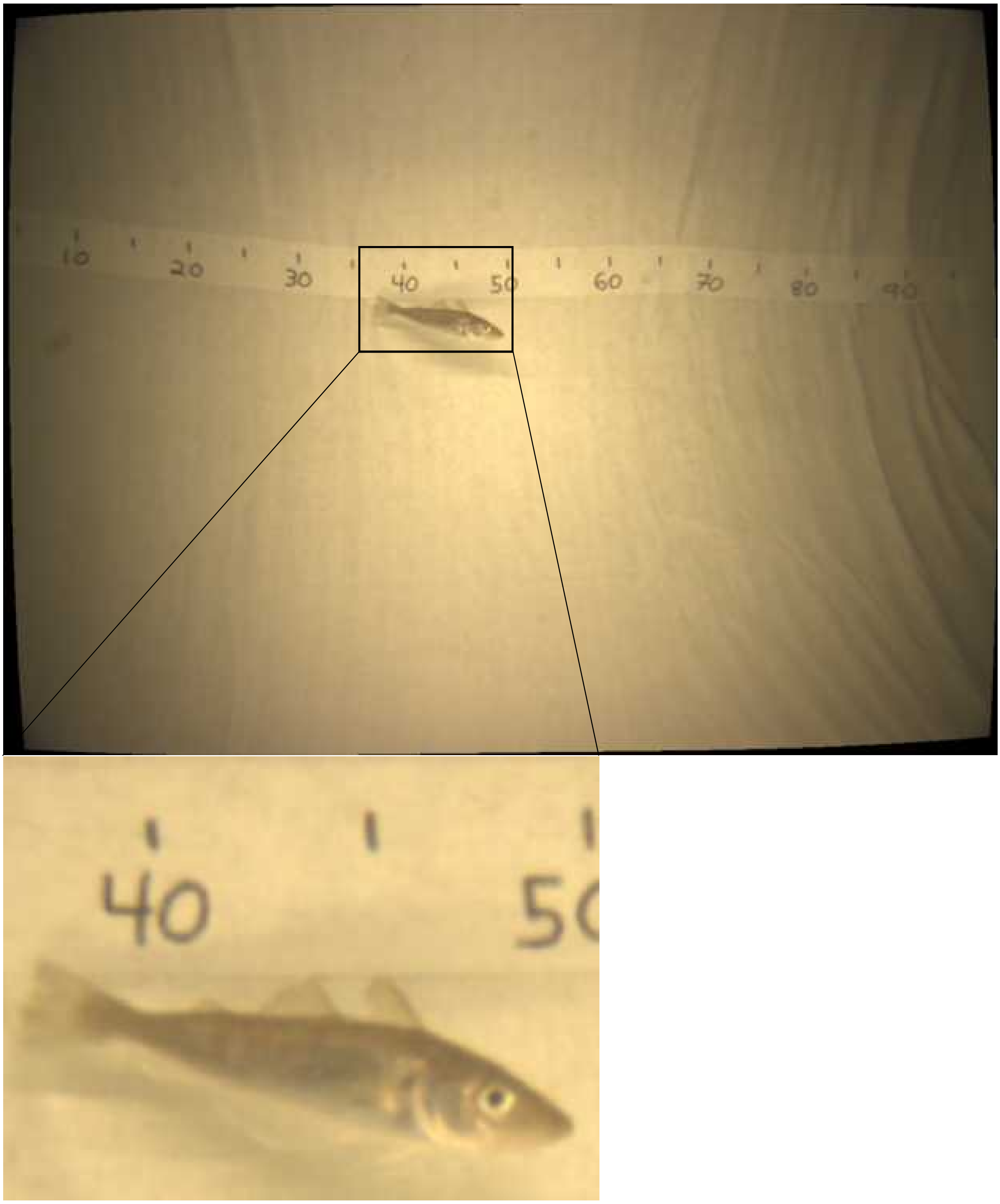

Figure 3.22. Haul 08. 15 cm whiting (Merlangius merlangus). Sand bottom, 30 m. Low level of suspended sediment. Exposure = 1, Gain = 1.

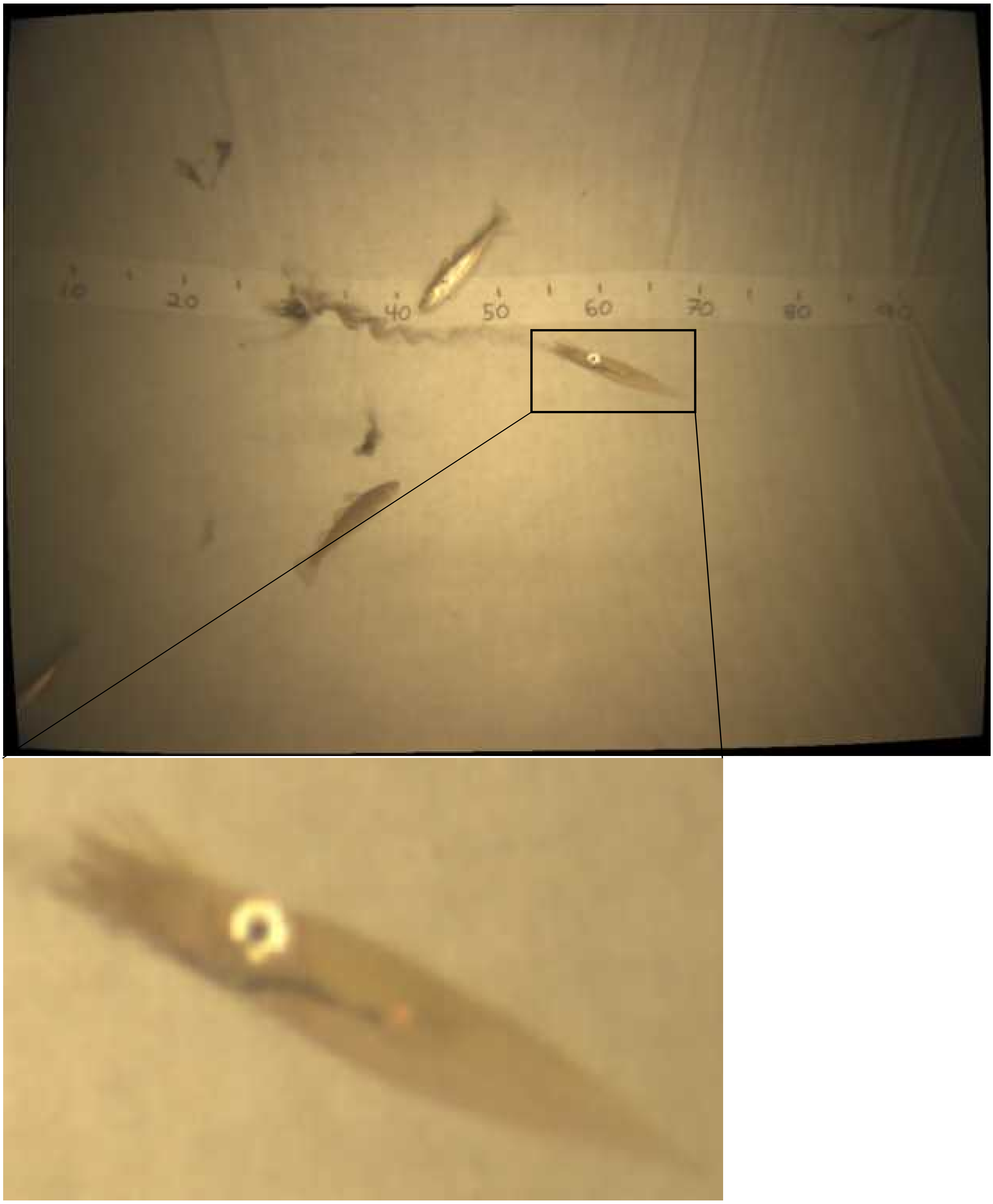

Figure 3.23. Haul 08. squid, 5 cm mantle length. Sand bottom, 30 m. Moderate level of suspended sediment. Exposure = 1, Gain = 1.

Figure 3.24. Haul 06. Mud bottom, 130 m. Moderate level of suspended sediment. Exposure = 1, Gain = 1.5. This image demonstrates how abruptly mud clouds sometimes enter and leave the field of view.

Figure 3.25. Haul 06. Mud bottom, 130 m. High level of suspended sediment. Exposure = 1, Gain = 1.5. During periods with high levels of suspended sediment it may be possible for objects to pass unobserved. Species identification is impossible. A passing fish (most likely whiting) is indicated by the red hashed oval.

The duration of periods of high levels of suspended sediment could be quickly assessed by reviewing the preview pane of thumbnail images in the Deep Vision analysis software. Figure 3.26 shows how visibility varied over 75.4 seconds of image collection (images are taken at a rate of 5 per second).

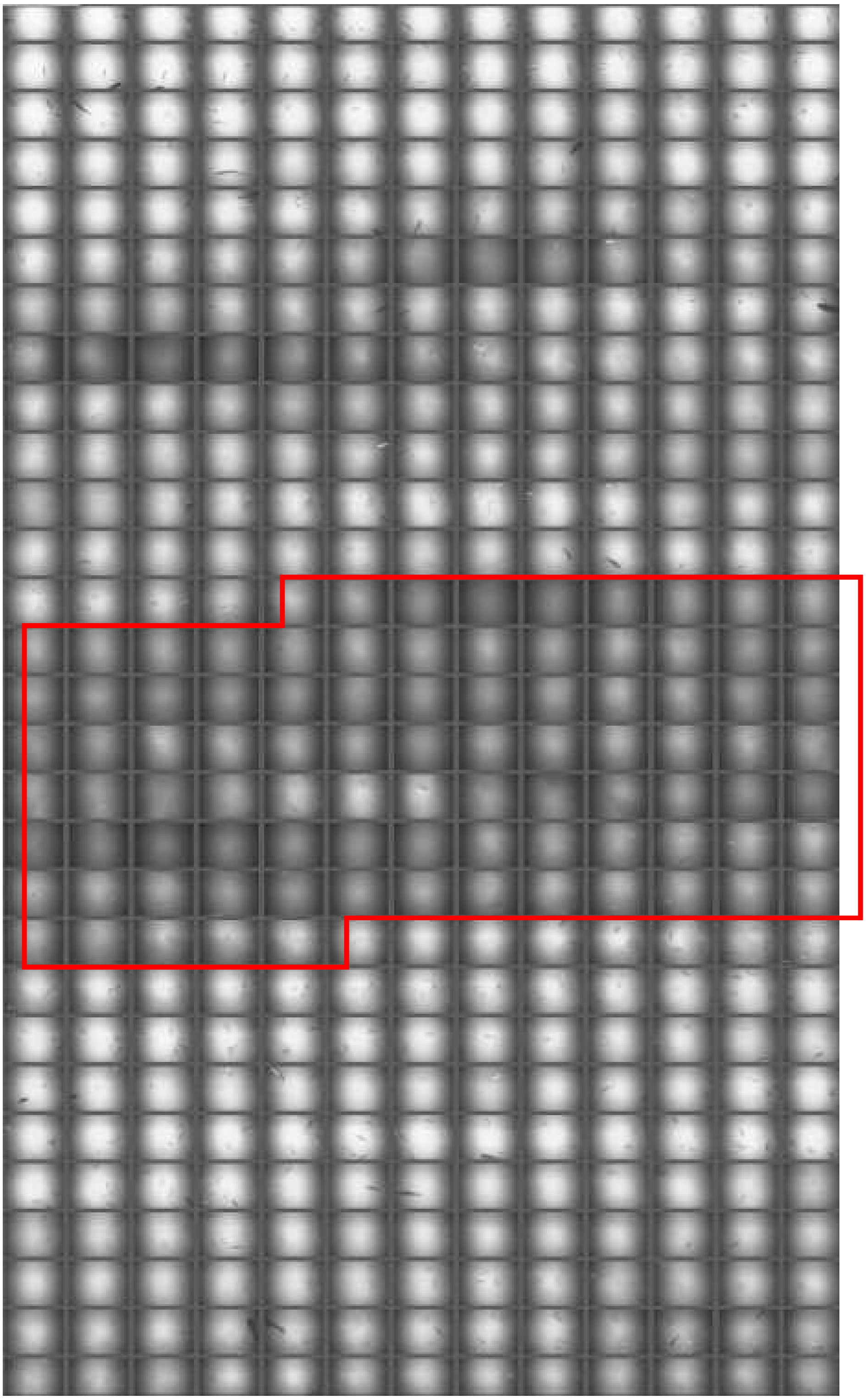

Figure 3.26. Sequential images taken over a period of 75.4 seconds. The period of high levels of suspended sediment indicated by the red outline represents 18.4 seconds

One important analysis, which has not been carried out, is to compare total counts by species in the Deep Vision images with the catch inside the cod end. While the rigid Deep Vision frame guides all catch through a trapezoidal channel that matches the field of view of the cameras, the tarpaulin design does not. Figure 3.27 gives a best estimate of the shape of the cross-section and field of view in comparison to blind zones where objects can pass unobserved. It is reasonable to believe that different species may pass in different portions of the trawl's cross-section, meaning the percentage observed is probably not simply the ratio of the area inside the field of view to the area in the blind zone and probably will vary by species.

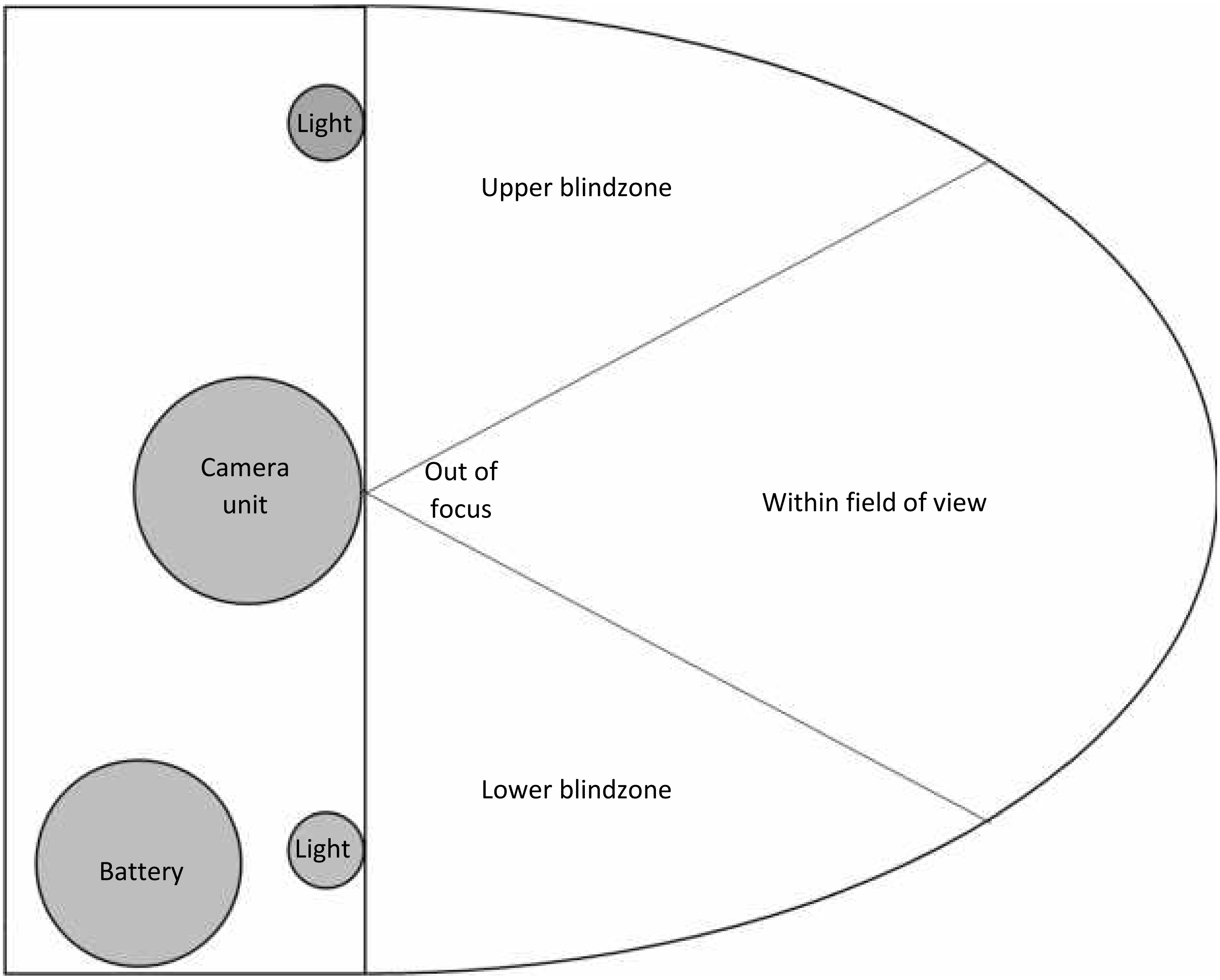

Figure 3.27. Schematic cross-section of Deep Vision section. View is from inside trawl, looking aft towards cod end. Frame, camera unit, lights and battery are at left. Open passage is represented by the arc to the right of the frame, with blind zones above and below the field of view of the camera. Any objects passing through these areas will not be recorded by the Deep Vision cameras.

Another issue is that while the camera has a wide-angle lens with significant depth of field, the focus has been optimized for > 20 cm from the front of the lens so objects passing very close to the lens will both pass through the horizontal field of view very quickly and be out of focus. It may be wise to introduce a physical barrier in order to force passing fish to keep a minimum distance from the face of the camera. This would also add an additional level of protection to prevent the camera's flat port from being scratched by passing rocks or if the frame is laid on deck with the camera side down.

3.6.7 Conclusions

Despite the short amount of time available to conduct the tests at sea, the cruise can be judged a success and demonstrated that the Deep Vision camera, lights, and prototype tarpaulin-based deployment section were capable of collecting images of sufficient quality to carry out species identification and length measurement in conditions representative of the Scottish demersal trawl fishing grounds. We did not have access to truly soft/flocculent estuarine environments (“Nephrops grounds”), but the results from the muddy substrate areas are encouraging. At times visibility was too diminished to be able to count, identify, or measure passing objects but this was a small fraction of the total bottom time.

The tarpaulin-lined extension was easy to handle on the vessel and provided light levels and a background which are certainly adequate for a human operator to identify and measure lengths of fish, shellfish and cephalopods. Tests of the segmentation routines being implemented in the Deep Vision analysis software will be required before conclusions can be made about whether the resulting images are suitable for automatic analysis. But given that this was the first test of a flexible arrangement there is scope for significant improvement both in material choice (thicker PVC coated polyester tarpaulin with a more matte finish, possibly very fine mesh knotless netting) and an improved shape with a gradual, consistent taper. Improvements in these characteristics would likely lead to a more diffused light pattern and reduced or fully eliminated wrinkling in the background.

The electronics frame, although the most compact frame tested to date, still has room for significant miniaturization. A deployment package that could be taken on and off the trawl during shooting and heaving (similar to a trawl sonar) would make the system much better suited to use during commercial fishing operations, as the trawl could be fully spooled onto the net reel during heaving in order to bring the cod end on board. This would make it faster, easier and safer to take the catch onboard and would eliminate the need for a crane or boom to guide the camera system over the transom of vessels without stern ramps.

3.6.8 Recommended next steps

It may be possible to carry out further trials onboard Marine Scotland’s R/V “Scotia” in 2017, which would provide the opportunity to test the camera on the soft/flocculent bottom types which we did not have access to on the present cruise. Any such tests should be carried out with an improved lining for the trawl, built using a more robust material and with slight, constant, taper towards the trailing end.

3.7 Outline research proposal to build the Smartrawl

3.7.1 Smartrawl specification

The vision for a Smartrawl is to build the following integrated system:

1. A stereo camera system to be mounted in the extension of a trawl. This should be as small as possible.
2. An internal net cover in part of the extension to make a contrasting foreground ahead of the camera.
3. A set of lights to illuminate the foreground.
4. The camera and lights are linked to a personal computer (PC) for control, acquisition and processing of images.
5. The entire apparatus should be housed in a robust underwater housing with communication ports for data retrieval, PC control and battery charging.

6. A set of fish detection, sizing and species recognition algorithms to determine the size and species of fish passing the camera.
7. A through the water communication device to send data on fish species and size retained from the image analysis system on the PC to the ships bridge.
8. Power (batteries) is supplied locally to all units as required.
9. A mounting frame for the camera system, lights, batteries and communication device.
10. A gate to allow individual fish to either escape or be retained in the trawl cod end.

3.7.2 Project proposal phases

This Smartrawl system is envisaged to be built in several phases. At each phase, useful components are expected to be obtained, some of which will have direct utility for discard mitigation.

1. Phase 1. Specifying stereo camera systems. The DeepVision camera system is a high quality unit that is fit for purpose as a stereo camera system. It was mounted in a frame, with a net covering ahead of it in the extension of a trawl to obtain stereo images (see Section 3.6). Other stereo camera systems may be equally suitable so this phase is purely to determine what the trade-off is between image quality and value for money of any alternative system. The accompanying lighting system should also be specified and investigated further based on the experience here (Section 3.6). Finally this phase should look to build a robust frame within which to mount the system (as per Figure 3.14). This Phase should deliver a stereo camera system, plus one spare. In total this Phase should cost of the order of £20,000 for the equipment (2 systems) and £20,000 for development & building.

2. Phase 2. Building an image library. Once a suitable stereo camera system is available (incorporating points 1-7 in the Specification above, Section 3.7.1) then the system should be deployed in the various fisheries to obtain data for the development of image processing and analysis algorithms. This exercise should be supervised by a scientist on board to:
   - 2.1. Ensure the equipment is mounted, deployed and recovered properly;
   - 2.2. Data is retrieved and the batteries recharged between hauls;
   - 2.3. The species and length composition of the catch is recorded to ensure that it tallies with the image record;
   - 2.4. Observations of deployment and recovery are made to develop more efficient operations

   This is a major undertaking as it is estimated that to develop the image analysis algorithms (see Phase 3 below) will require of the order of 10,000 images for each species. Over the course of 2 years (2008-2010, Marine Scotland observed catches), in the North Sea & west of Scotland, the demersal fish fleet caught an average of 600 cod per trip, 5000 haddock and 1000 whiting. This suggests that data would need to be acquired from at least 17 trips (to get at least 10,000 images of cod). These should be distributed across the regions (North Sea, west of Scotland), seasons (1 per quarter) and fisheries (Finfish vessels and prawn vessels). There should be minimal impact to fishing operations associated with this activity, so this could be simply a matter of funding a suitably trained observer to participate on each trip and a small amount of money or scientific quota to compensate for any additional deployment and recovery time. To deploy an observer on 20 trips (averaging 8 days at sea per trip), and then give them time to comfortably collate and label all the image data would take of the order of 2 years. This Phase should cost approximately £100,000 for staff (graduate) time and, e.g. 2 days charter per trip (£100,000) or the equivalent in scientific quota.

3. Phase 3. Image processing and analysis. The ultimate aim is to develop algorithms to size and identify certain species of fish. This algorithms will be developed through machine learning and other techniques (see Sections 3.2.2.6 and 3.2.2.7). The following steps are necessary:
   3.1. Image processing
      3.1.1. Image enhancement and correction
         3.1.1.1. Colour correction
         3.1.1.2. Dehazing
   3.2. Single fish detection
      3.2.1. Isolated fish
      3.2.2. Overlapping fish
   3.3. Single fish tracking
      3.3.1. Isolated fish
      3.3.2. Overlapping fish
      3.3.3. Not a fish (prawn, squid, or other)
   3.4. Fish counts
   3.5. Determination of fish size
      3.5.1. Estimate fish size, store to database.
      3.5.2. If fish > Minimum conservaton reference size of smallest species (e.g. 27 cm whiting in the North Sea), then proceed to next step.
   3.6. Determination of fish species ID
      3.6.1. Primary (choke) quota species > 27 cm: Cod, saithe, hake, ling, whiting.
      3.6.2. Secondary quota species > 27 cm: haddock, whiting, anglerfish, herring, mackerel, blue whiting, Norway pout, sandeel, blue ling, tusk, sprat
      3.6.3. Nephrops
      3.6.4. Flat fish (quota species): skate, turbot, halibut, dab, lemon sole, Dover sole, megrim, and plaice.
      3.6.5. Non-quota species: rays, dogfish, grey gurnard, red gurnard, John Dory, wolfish.
   3.7. Image labelling: build a database with a time reference for each frame with results of species and size for replay.

   Providing the images are made available from Phase 2, this phase requires an image analysis research group to work for what is estimated to be between 1.5 and 2 years to develop these algorithms. This would need to be a team effort and so it is envisaged that two people should be funded full time for at least 1.5 years, with adequate supervision. This should cost in the region of £200,000.

4. Phase 4. Develop an in water communication system (acoustic modem) between the camera PC and the ships bridge. Relay summary statistics from the database in real time to the bridge. This can be specified more precisely with fishing skippers, but a simple histogram of fish length for each of the major species would provide the essential information. System are available for such transfer already (e.g. Scanmar), so this should not present too great a difficulty, but it is envisaged that this would cost, including provision of a system and one spare, of the order of £50,000.

Once Phase 4 has been achieved, then a working system of significant utility will be available. This will allow skippers to, for example, to cease fishing if they receive information from the system that they are catching too much of a particular species or size. They may also be able to position their subsequent fishing hauls more precisely by examining the timeline of catch rate.

5. Phase 5. Design, test and build a fishing gate. Prototype one or both of the systems described in Section 3.5. Test these in a flume tank using a simple switch to activate the gate before connecting to the camera system. Evaluate the best design from the tank trials. Build a commercial scale

version. Undertake sea trials. Design review and modify in the light of sea trials. Costs for this element are harder to estimate, but it is envisaged that they would be in the region of £300,000 depending on how sea trials are funded.

6. Phase 6. Build the Smartrawl. Integrate the gate from Phase 5, with the camera system from Phase 1, using the algorithms from Phase 3. The system would consists of a catch selection programme, whereby the skipper would pre-programme haul specific rules, which would control the gate based on the information being processed. Once programmed there would be no requirement for the skipper to intervene. E.g. haul 1: no hake; no cod smaller than 40 cm; no saithe. The simplicity of the programme will be very dependent on the gate response time, which at the time of writing is difficult to determine. There may for example be limitations based on fish passage rates and mixtures, but these will be determined in Phase 2. The Landings Obligation de minimus rules could probably be invoked here to deal with the lack of precision of the system (i.e. not able to guarantee zero discards, but the very large majority). This requires the building of control electronics and software, all underwater housed. Envisaged cost would be of the order of £100,000 for equipment and build time.

7. Phase 7. Trial the Smartrawl on fishing vessels. Initial trials could be conducted on research vessels. Thereafter, as per Phase 2, these should take place on fishing vessels and be distributed across the regions (North Sea, west of Scotland), seasons (1 per quarter) and fisheries (Finfish vessels and prawn vessels). There is more overhead associated with this activity, so this could would require charter money or scientific quota to fund the trials. Approximate costs are estimated at £100,000.

These 7 phases should not be sequential. For example the time taken to carry our Phase 3 is extensive and does not preclude other Phases (e.g. 4 and 5), but Phase is dependent on Phase 2, so they would have to run concurrently, or lagged, with Phase 2 occurring first. The timing of the various Phases will ultimately depend on funding (see Section 3.7.3, below), but ideally they might take place as described in Table 3.2.

Table 3.2. Potential Gant chart for the development of the Smartrawl, time period cells are quarters of a year.

Year	1	1	1	1	2	2	2	2	3	3	Cost
Quarter	1	2	3	4	1	2	3	4	1	2	£'000
Phase											
1. Camera	■	■									20
2. Image library		■	■	■	■	■	■	■	■		200
3. Image analysis			■	■	■	■	■	■	■	■	200
4. Communication					■						50
5. Gate		■	■	■	■	■	■	■	■		300
6. Smartrawl							■	■	■		100
7. Sea trials									■	■	100
Total cost (£,000)											970

3.7.3 Further funding

The current proposal (FIS011B) was a precursor to allow the Smartrawl concept to be scoped out in detail for the larger funding source that would be required to achieve the phases described in Section

3.7.2. Several possible sources of suitable funding have been identified for this, each with their pros and cons:

1. European Maritime and Fisheries Fund; this requires sanction from the Scottish government and for large scale projects would require tendering, potentially across the EU. It may be envisaged that the larger elements (e.g. Phase 3, 5) could be funded through this route.
2. Scientific quota. The Scottish government can allocate a certain percentage of the national quota to vessels to support scientific activity. This may allow for part funding of Phases 2, 5 and 7.
3. European Union Horizon 2020 call H2020-SFS-2016-2017 "Smart fisheries technologies for an efficient, compliant and environmentally friendly fishing sector". This could be used to fund equipment and a scientific observer to carry out Phases 1 and 2.
4. Fisheries Innovation Scotland (FIS). The level of funding typically provided by FIS could probably fund Phase 1, 2, 4, and later Phase 6.
5. WWF. The world wide fund for nature (WWF) has expressed interest in this project, although available funding there is variable. Potentially this could fund Phase 1, and part of Phase 2.

4 Linking spatial and gear selectivity

At the European level, it has been suggested that fisheries management should move beyond the current prescriptive and detailed technical measures regulations towards a results-based approach that focusses on the outcome instead of defining technical means to achieve it. This is considered to be preferable because it would reduce the complexity of current technical measures legislation and harness the fishing industry's potential for developing innovative technology.

Experience from both US and Norwegian fisheries suggests that a combination of enhanced spatial and gear selectivity can be used to achieve clearly defined outcomes for reducing discards. These defined targets serve to incentivise the development of technologies for ICT and gear. The synergy between enhanced spatial and gear selectivity is obvious. Ensuring that fishing vessels avoid areas where non-target fish are abundant (bycatch "hotspots") will benefit the effectiveness of the Smartrawl system because the effectiveness of the system is likely to be limited by the time scales over which the non-target species can be identified and either selected or not selected. Going to places where non-target fish are at a minimum (bycatch "coldspots") would be expected to improve the performance of the Smartrawl. When deployed in coldspot areas having a high proportion of target species, the Smartrawl will help to ensure that any non-target species would not be caught.

Given that the technologies for enhancing spatial and gear selectivity described here are very much at the drawing board stage and entirely conditional on securing high levels of both funding and industry support, it would be premature to speculate further on how the synergies could best be achieved. It is worth highlighting that the two technologies can be developed in parallel and independently. This would allow them to come into operation within similar time frames.

5 Acknowledgements

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Objective 1 - Karl Haflinger and Eric Torgerson have been unfailingly generous in sharing their time and expertise. Mike Park and Kenny Coull facilitated discussions with industry. The Scottish White Fish

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Objective 2 - Marine Science Scotland made the Alba na Mara and staff / trawl rigging support available at no cost. Resources to cover staff time and small equipment outlays for the Norwegian partner (Shale Rosen, Institute of Marine Research, Norway) were provided by the CRISP Centre for Research-based Innovation in Sustainable fish capture and Processing technology funded by the Research Council of Norway, Project 203477. Special thanks to Jim Drewery and Barry O'Neill at Marine Scotland's Marine Laboratory in Aberdeen and to the captain and crew of R/V "Alba na Mara."

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7 Appendices

7.1 Appendix 1 Agenda and attendees of the workshop held in Peterhead

Using real-time reporting to enhance reduction of unwanted species in the Scottish demersal fleet

Tuesday 6th September 2016, 13.00-17.00

Buchan Braes Hotel, Peterhead

12.30 – 13.00	Coffee and registration
13.00 – 13.10	Welcome and aims for the day (Tara Marshall, University of Aberdeen)
13.10 – 15.00	Discussion of Real-time reporting in the Bering Sea fisheries Karl Haflinger Sea State Inc., Seattle Eric Torgerson Chordata Ltd, Anchorage
15.00 – 15.30	Coffee break
15.30 – 16.30	Discussion of Real-time reporting in Scotland *Does an opportunity exist?* *What are the achievable goals?* *What are appropriate incentives for real-time reporting?* *What are the technical requirements for those goals?* *What are the partnerships required?* *Is there enabling funding available?*
16.30 – 17.00	Wrap-up (Tara Marshall, University of Aberdeen, and Dave Reid, Marine Institute, Ireland)

Name	Email	Organization
Tom Bryan-Brown	mnwfa@btconnect.com	Mallaig & North-West Fishermen's Association Ltd.
Dave Reid	david.reid@marine.ie	Marine Institute (Ireland)
Julia Calderwood	julia.calderwood@marine.ie	Marine Institute (Ireland)
Adrian McClenaghan	adrianmcclenaghan@hotmail.com	Marine Institute (Ireland)
Ali McKnight	alimcknight@agroecosystems.co.uk	Agroecosystems Ltd.
Kenny Coull	k.coull@sff.co.uk	Scottish Fishermen's Federation
Peter Bruce	peter.bruce418@btinternet.com	NESFO SKIPPER
David Anderson	david@afpo.co.uk	Aberdeen Fish Producer'
Tara Marshall	c.t.marshall@abdn.ac.uk	University of Aberdeen
Rodrigo Wiff	rodrigo.wiff@abdn.ac.uk	University of Aberdeen
Karl Haflinger	karl@seastateinc.com	Sea State Inc.
Eric Torgersen	eric@chrdta.com	Chordata Ltd, Anchorage, AK

7.2 Appendix 2 Agenda and attendees of the workshop held in Aberdeen

Using real-time reporting to enhance reduction of unwanted species in the Scottish demersal fleet

Wednesday 7th September 2016, 10.00-16.00

Glen Lossie meeting room, Jurys Inn Hotel, Aberdeen (next to train station)

09:00 – 10:00	Coffee and registration
10:00 – 10:10	Welcome and aims for the day (Tara Marshall, University of Aberdeen)
10:10 – 12:30	Discussion of Real-time reporting in the Bering Sea fisheries Karl Haflinger Sea State Inc., Seattle Eric Torgerson Chordata Ltd, Anchorage
12:30 – 13:30	Lunch (Jurys Inn restaurant)
13:30 – 15:00	Discussion of Real-time reporting in Scotland *Does an opportunity exist?* *What are the achievable goals?* *What are appropriate incentives for real-time reporting?* *What are the technical requirements for those goals?* *What are the partnerships required?* *Is there enabling funding available?*
15:00 – 15:30	Coffee break
15:30 – 16:00	Wrap-up (Tara Marshall, University of Aberdeen, and Dave Reid, Marine Institute, Ireland)

Name	Email	Organization
Helen McLachlan	hmclachlan@wwf.org.uk	WWF-UK (Fisheries Governance Programme Manager)
Coby Needle	C.Needle@MARLAB.AC.UK	Marine Scotland Science
Shaun Doran	shaun.doran@cefas.co.uk	CEFAS
Stephanie Dickens	stephanie.dickens@gov.scot	Inshore Fisheries Ecologist & FISA Coordinator
Dave Reid	David.Reid@Marine.ie	Marine Institute (Ireland)
Julia Calderwood	Julia.Calderwood@Marine.ie	Marine Institute (Ireland)
Adrian McCLenaghan	adrianmcclenaghan@hotmail.com	Marine Institute (Ireland)
Kenny Coull	k.coull@sff.co.uk	Scottish Fishermen's Federation
Barry O'Neill	ONEILLB@MARLAB.AC.UK	Marine Scotland Science
James-Forbes Birnie	j.birnie@sff.co.uk	Scottish Fishermen's Federation Services LTD
Ali McKnight	alimcknight@agroecosystems.co.uk	Agroecosystems Ltd.
Chevonne Angus	chevonne.angus@uhi.ac.uk	NAFC Marine Centre
Tara Marshall	c.t.marshall@abdn.ac.uk	University of Aberdeen
Thomas Cournilier	cornulier@abdn.ac.uk	University of Aberdeen
Rodrigo Wiff	rodrigo.wiff@abdn.ac.uk	University of Aberdeen
Karl Haflinger	karl@seastateinc.com	Sea State Inc
Eric Torgersen	eric@chrdta.com	Chordata Ltd, Anchorage, AK

7.3 Appendix 3 Smartrawl workshop agenda.

Smartrawl meeting
13st – 15rd June 2016
University of Aberdeen

Chaired by
Dr Paul G. Fernandes (University of Aberdeen)

Background

SmartFish is a new Fisheries Innovation Scotland (FIS) project aiming to provide solutions to the Landings Obligation. One of the major components consists of designing a new "Smartrawl" system which has the ambitious goal of individually selecting the size and species of fish that are retained in a trawl. A summary of the project is given in Annex I. This agenda details plans for the first project meeting.

Objectives of the meeting

4. To review the current progress in fisheries selectivity, underwater [stereo] imagery, image analysis and mechanical sorting devices which are relevant to fisheries.
5. To discuss and detail specific requirements for the Smartrawl, a species and size selective device that would be acceptable for use in the mixed demersal trawl fishery.
6. To identify suitable funding sources and determine how to proceed with the development of the Smartrawl.

Logistics

Venue: Meeting room 3 – room 713, The Sir Duncan Rice Library, University of Aberdeen, Bedford Road, Aberdeen, AB24 3AA. See Annex II for directions.

Hosts: Dr Paul G Fernandes, MASTS Reader in Fisheries Science, tel: +44 1224 274166

Start Time: 13:00 13 June 2016
End Time: 13:00 15 June 2016

Lunch will be provided on all days and dinner is booked at Howies (see Annex IV and http://www.howies.uk.com/chapel-street-aberdeen/) at 19:45 on Monday 13 June.

A participant list with contact details is provided in Annex III. A list of hotels is provided in Annex V. The airport is 20 minutes from town; a taxi into town would cost around £20, but there is also a regular bus service into the train/bus station in the centre of town.

Preparation for meeting

I would ask each of you to prepare a rough presentation describing the state of the art in the designated field (see proposals in the timetable below). These presentations can be reviews of existing work or relevant initial ideas for Smartrawl. They also serve to introduce your work and expertise to the consortium.

You should also see the guidance for EMFF grants which I will attach.

Timetable

Monday 13 June 2016

Time	Item / **Person**	**Process**	**Output**
1230 – 1300		Lunch	
1300 – 1315	Housekeeping **P Fernandes**		Welcome and introductions
1315 – 1415	The Smartfish project: Smartrawl Phase 1 **P Fernandes**	Presentation	Familiarisation with the project
1415 – 1545	Review of current systems & state of the art: 1. **Barry O'Neill** – selective devices 2. **Shale Rosen** – CRISP? 3. **Coby Needle** – REM? 4. **Helge Hammersland** – DeepVision	~15 minute presentations + 5 min Q&A	Material for final report: introduction & state of the art
1545 – 1600		Coffee break	
1600 – 1720	Review of current systems & state of the art: 5. **Ricardo Campos** – UW Image analysis 6. **Paul Fernandes** – Underwater stereo imagery in fisheries 7. **Richard Neilson** – Engineering in fisheries 8. **Alastair Allen** – Underwater communication and control systems	~15 minute presentations + 5 min Q&A	Material for final report: introduction & state of the art
1720 – 1800	Brainstorming Smartrawl **P Fernandes**	Discussion	Initial ideas for next phase(s)

19:45	Dinner at Howies Restaurant (See Annex IV)		

Tuesday 14 June 2016

Time	Item / **Person**	**Process**	**Output**
0900 – 1015	Smartrawl project	Discussion	Project outline
1015 – 1045	Smartrawl project components	Discussion	Project workpackage description
1045 – 1100	Coffee		
1100 – 1300	Smartrawl project components	Discussion	Project workpackage description
1300 – 1400	Lunch		
1400 – 1530	Smartrawl project components	Discussion	Project workpackage description
1530 – 1545	Coffee break		
1615 – 1800	Funding sources 1 EMFF	Discussion	Outline text for proposal

Wednesday 15 June 2016

Time	Item / **Person**	**Process**	**Output**
0900 – 1015	Funding sources 2 H2020	Discussion	Outline text for proposal
1015 – 1045	Coffee break		
1045 – 1200	Action points & AOB	Discussion	List of action points to deliver the final report
1200 – 1300	Lunch		

Smartrawl meeting Aberdeen - participant list

	Name	**Affiliation & location**	**E-mail**
1	Paul Fernandes	University of Aberdeen	fernandespg@abdn.ac.uk
2	Richard Neilson	University of Aberdeen	r.d.neilson@abdn.ac.uk
3	Alastair Allen	University of Aberdeen	a.allen@abdn.ac.uk
4	Coby Needle	Marine Scotland Science	c.needle@marlab.ac.uk
5	Barry O'Neill	Marine Scotland Science	b.oneill@marlab.ac.uk
6	Shale Rosen	Institute of Marine Research, Norway	shale.rosen@imr.no
7	Ricardo Campos	University of Girona, Spain	rcampos@eia.udg.edu
8	Helen McLachlan	World Wide Fund for Nature, UK	HMcLachlan@wwf.org.uk
9	Helge Hammersland	Scantrol	helge@scantrol.com
10	George West	MFV Bountiful	wbountiful@aol.com
12	Elena Balestri	SIDI	elenabalestri@gmail.com

Fisheries Innovation Scotland

Scottish Charity Number SC045119

Company Number SC477579

FIS MEMBER ORGANISATIONS

marine scotland

The Scottish Government
Riaghaltas na h-Alba

SFF SERVICES LIMITED

SWFPA
The Scottish White Fish Producers Association Ltd

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

SEAFISH
the authority on seafood

Young's
SEAFOOD LIMITED

Sainsbury's