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DiscardLess

Strategies for the gradual elimination of discards in European fisheries

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Report on meta-analyses of gear selectivity data in terms of gear design parameters, and of the vertical distribution of fish as they enter trawls; sensitivity analysis of predictive methods to estimate selectivity for data poor species, and economic model to evaluate impact of selective gears at vessel level

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Executive Summary

Box 1: Report Highlights

- codend selection depends on codend mesh size, the number of open meshes around the circumference and twine diameter
- panel selection depends on panel mesh size
- For gadoids, panel contact probability depends on where the panel is positioned and the time of year when fishing takes place
- the relationship of L50 with number of meshes in circumference and twine thickness can be opposite between roundfish and flatfish
- it should be possible to separate the three categories of (i) haddock, whiting and saithe, (ii) cod, plaice and lemon sole and (iii) monkfish and *Nephrops* using vertical separation.
- A Best Practice Guideline and an Excel toolkit assessing the economic implications of selective gears are being developed

Box 2: The methods/approaches followed

- Review of published scientific literature
- Compilation and meta-analysis of a large number of existing data from historical selectivity trials
- Best Practice Guidelines and Toolkit for the Economic analyses of selectivity scenarios

Box 3: How these results can be used and by who?

- Gear selectivity knowledge can be used by fishers and net makers to pre-select the likely most appropriate changes in gear design to reduce unwanted catches, through e.g. low headline trawls, coverless trawls and trawls with raised footropes
- Guidelines and the toolkit will be useful for fishers, scientists and managers to assess the validity and the economic consequences of future selective gears to be developed and experimented by the fishing industry

Selection by the codend has been the subject of much research over the past thirty years, with trials in artisanal and industrial fisheries around the world. These studies typically test only a few gears, partly for logistic and/or economic reasons and partly to ensure there are sufficient hauls to estimate the selection of each gear with reasonable precision. To explore a broad range of selective gear options for use in a fishery, and to understand better the relative influence of the important variables related to gear design, it is necessary to develop models that predict selection across all of these variables. Such empirical models are best constructed in meta-analyses that combine the data from many trials. There are, however, few meta-analyses in the size-selection literature and these usually only consider the effect of codend mesh size. In order to make best use of existing selectivity data we review the meta-analyses that have taken place and extend these studies to investigate the vertical distribution of fish at the mouth of trawl to estimate selectivity for data poor species. These analyses advance our understanding of the potential of using selective gears to reduce discards and will be of particular importance in relation to potential 'choke species' which may not have had much attention in the past.

We also describe the development of an Excel toolkit that will provide best practice guidance on collecting the required data and methods to evaluate economic implications of trial fishing gear. This is the result of a technical workshop with 25 contributors including vessel operators, policy makers, scientists, fishing gear manufacturers and gear technologists the purpose of which was to prepare a Best Practice Guidance document on how to undertake such gear trials and to develop an excel workbook with embedded formulae intended to be a practical aide for vessel operators or scientists trialling new fishing gear.

Part A : Meta-analyses of gear selectivity data

1 A review of meta-analyses of codend selection

The codend is the rearmost part of a trawl gear. It is where the catch accumulates in demersal and mid-water otter trawls, beam trawls and single, pair and Danish seines, and is the area which offers fish a final opportunity to escape. Accordingly, selection by the codend has been the subject of much research over the past thirty years, with trials in artisanal and industrial fisheries around the world. Although many of these trials are species (and possibly fishery) specific, they have led to a better general understanding of the selection process and have identified many of the variables that influence codend selection. These include codend mesh size (Perez Comas and Pikitch, 1994; Kunjipalu et al., 2001; Madsen, 2007, Queirolo et al., 2012), codend twine diameter (Lowry and Robertson, 1996; Kynoch et al., 1999; Sala et al., 2007), codend twine material (Tokaç et al., 2004), the number of open meshes around the circumference of the codend (Galbraith et al., 1994; O'Neill et al., 2008; Broadhurst and Millar, 2009), and the use of attachments such as lifting and strengthening bags (Kynoch et al., 2004). Selection by the codend can be augmented by the presence and position of additional selection devices such as grids and square mesh panels (Tokai et al., 1996; Graham et al, 2003; Jørgensen et al., 2006; Eayrs et al., 2007; Grimaldo et al., 2008,; Silva et al., 2011). Selection is also affected by uncontrolled variables such as the codend catch (O'Neill and Kynoch, 1996), season and fish condition (Özbilgin et al., 2006, 2007) and weather and sea state (O'Neill et al., 2003).

These studies typically test only a few gears, partly for logistic and economic reasons and partly to ensure there are sufficient hauls to estimate the selection of each gear with reasonable precision. To explore a broad range of selective gear options for use in a fishery, and to understand better the relative influence of the important variables related to gear design, it is necessary to develop models that predict selection across all of these variables. Such empirical models are best constructed in meta-analyses that combine the data from many trials. There are, however, few meta-analyses in the size-selection literature and these usually only consider the effect of codend mesh size. For example, Perez Comas and Pikitch (1994) regress estimates of the 50% retention length (L50) for 12 gadoid species from 689 experiments against codend mesh size. Similarly, Madsen (2007), in a review of the selection of Baltic cod, regresses against codend mesh size for different types of codend design. A more wide-ranging analysis of *Nephrops* (Nephrops norvegicus) selection found that codend selection depended on codend mesh size and shape (diamond or square) and the presence / absence of a lifting bag (ICES, 2007).

More recently Fryer et al (2016) presented a meta-analysis of haddock (Melanogrammus aeglefinus) size-selection data collected by Marine Scotland Science (formerly Fisheries Research Services) since 1991. Their meta-analysis is based on size-selection data from 614 hauls collected on 24 vessels over 21 trials investigating diamond mesh codend selection and 19 trials investigating the combined selection of a diamond mesh codend and a square mesh panel in the upper sheet of the codend or extension. Combining the data from so many trials provided sufficient information to give separate models of panel and codend selection, something that is rarely possible with data from a single trial. Gear selection was then estimated by combining the estimates of panel and codend selection. The analysis shows that codend selection depends on codend mesh size, the number of open meshes around the circumference and twine diameter, that panel selection depends on panel mesh size and that the panel contact probability depends on where the panel is positioned and the time of year when fishing takes place.

The results are consistent with those for other gadoids and provide a basis for understanding and improving the selection of all trawl fishing gears.

More specifically they show that the 50% retention length of the codend

- increases by 3.39 (se 0.20) cm for each 10 mm increase in codend mesh size
- decreases by 1.27 (se 0.18) cm for each extra 10 codend meshes around
- decreases by 1.40 (se 0.28) cm for each 1 mm increase in codend twine diameter

and that the log codend selection range

- increases by 0.104 (se 0.017) for each 10 mm increase in codend mesh size
- decreases by 0.080 (se 0.030) for each 1 mm increase in codend twine diameter

Back-transforming, these equate to an 11% increase and 8% reduction in codend selection range respectively. The panel 50% retention length increases by 3.79 (se 0.58) for each 10 mm increase in panel mesh size.

The effects of month and panel position on panel contact probability are illustrated in Figure 1. Panel contact probability increases between June and December and then decreases again. The log-odds of contacting the panel decreases by 0.072 (se 0.027) for every 1 m further the panel is placed from the codline (Table 3). In December, this equates to a reduction in contact probability from an estimated 0.84 when the panel is 1 m from the codline to 0.60 when 18 m from the codline; in June, the corresponding reduction is from 0.27 to 0.10. These periods broadly coincide with peak haddock condition, before spawning and after summer / autumn feeding, and their poorest condition, post-spawning, when they are spent. They are also approximately out of phase with the timing of the lowest and highest water temperatures (February and August, respectively) suggesting that for haddock in the waters around Scotland changes in fish condition influence swimming performance more than the variation of water temperature.

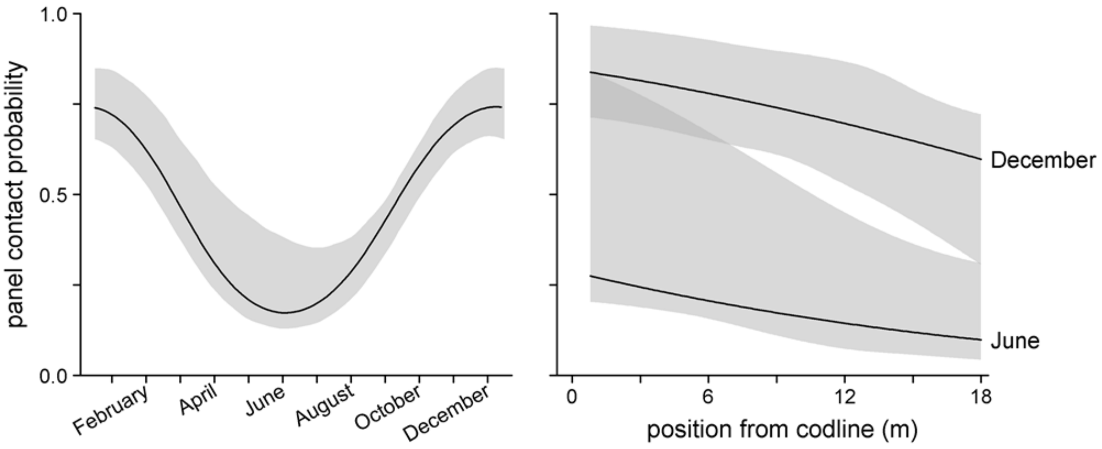

Fig. 1. The estimated panel contact probability with pointwise 95% likelihood bands (left) at different times of year when the panel is placed 9 m from the codline and (right) as panel position varies in December and June.

Figure 2 illustrates how panel mesh size and position affect retention in December, September and June when the codend has a 50% retention length of 34.5 cm and a SR of 5.6 cm (typical of a Scottish trawler targeting haddock with a codend made with 120 mm mesh, 5 mm double twine and 100 meshes around). In December, the panel contact probability is high and the panel is most effective. However, the panel only has a marked effect on gear once the panel L50 exceeds the codend L50. For example, inserting a panel with an L50 of 32.9 cm (100 mm mesh) increases the gear L50 to no more than 35.8 cm, regardless of panel position, whereas a panel with an L50 of 44.3 cm (130 mm mesh) increases the 50% retention length to 41.3 and 43.6 cm when the panel is 18 and 1 m from the codline respectively. In September, the panel contact probability is lower, but a panel with an L50 of 44.3 cm can still increase gear L50 to over 40 cm if the panel is close to the codline. In June, the same panel increases gear L50 to no more than 36.5 cm, regardless of panel position, because less than 50% of haddock contact the panel.

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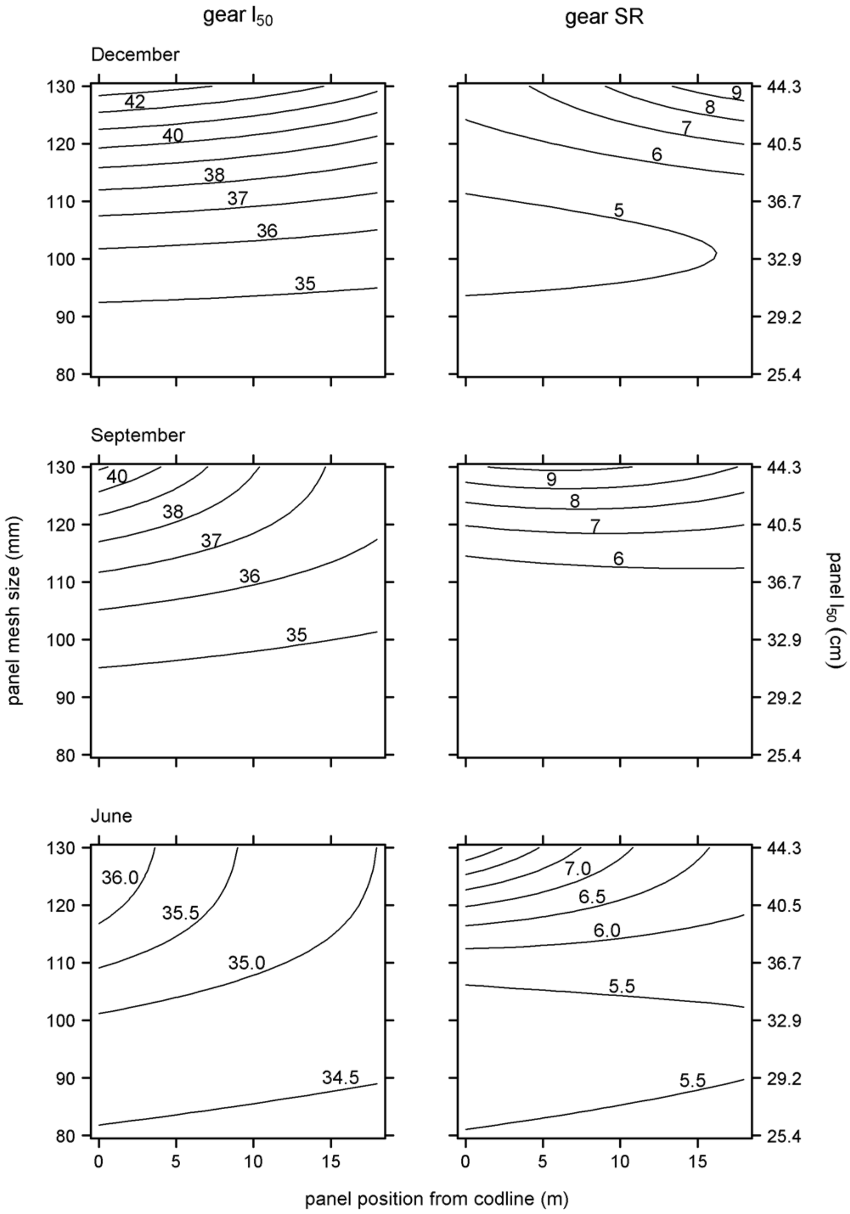

Fig. 2. The effect of panel mesh size and position on gear (left) and SR (right) for a typical Scottish trawler targeting white fish in December (top), September (middle) and June (bottom).

2 Meta-analysis of vertical separator data

This chapter summarises the findings of the study published as

R.J. Fryer, K. Summerbell, F.G. O'Neill, 2017. A meta-analysis of vertical stratification in demersal trawl gears Canadian Journal of Fisheries and Aquatic Sciences, https://doi.org/10.1139/cjfas-2016-0391

Differences in the behavioural reaction of fish to towed fishing gears, from when they first become aware of its approach and their interaction with the doors, sweeps and trawl mouth, to their possible entry into the net and passage to the codend, has led to the development of many selective trawl designs (Winger et al, 2010; Ryer, 2008; Wardle, 1993). There are trawls with raised doors and sweeps to reduce the herding of some species into the path of the trawl mouth, and trawls with raised footropes or fishing lines and low headline and coverless trawls which exploit differences in how fish behave at the trawl mouth and as they enter a gear (Krag et al., 2015; Bayse et al, 2016; Rose et al., 2010; Chosid et al., 2011; He et al., 2015). There are gears with large mesh panels in the forward or centre sections of the trawl (Kynoch et al., 2011; Campbell et al., 2010; Thomsen, 1993; Madsen et al., 2006; and Beutel et al., 2008; Holst and Revill, 2009) and with selective devices such as square mesh panels and rigid, flexible and netting grids (Drewery et al, 2010; Catchpole and Revill, 2008; Valentinsson and Ulmestrand, 2008; Isaksen et al., 1992) in the extension (or straight) section or in the codend. There has also been research of how mesh penetration and selectivity are influenced by netting material properties, such as twine colour and contrast, twine thickness and mesh size and mesh shape and by codend attachments and lifting bags (Glass et al., 1993; O'Neill et al., 2016; Herrmann et al., 2013; Tokaç et al., 2004; Sala et al., 2007; Kynoch et al. 2004).

Many of the insights of how fish behave during the capture process, and which have been used to develop these types of selective gears, have come from visual observations by divers (Main and Sangster, 1981), footage from underwater cameras (Jones et al., 2008; Reid at al., 2007; Bryan et al., 2014), laboratory experiments (Winger et al., 2004; Glass et al., 1995; Breen et al; 2004) and from experimental fishing trials at sea (Main and Sangster, 1985; Engås et al, 1998; Ingolfsson and Jørgensen, 2006; Ryer et al., 2010).

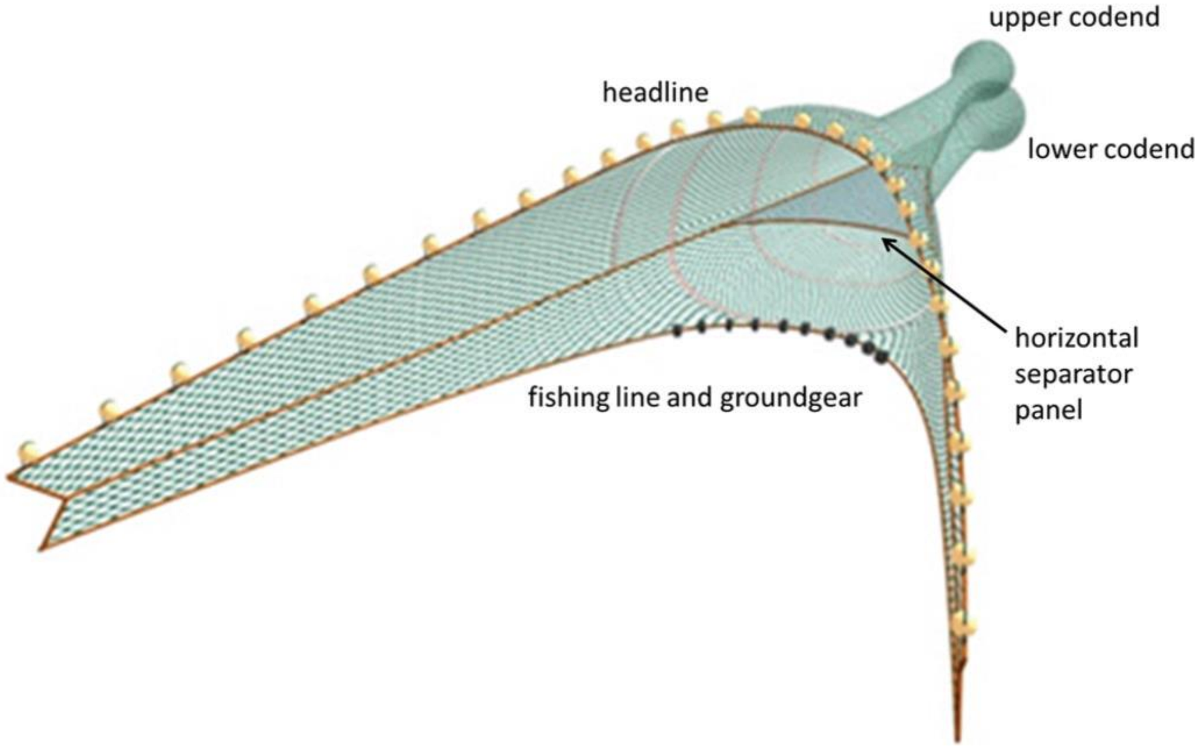

Fig. 3. Demersal trawl fitted with a horizontal separator panel that directs fish that go above the panel to the upper codend and fish that go below the panel to the lower codend.

Here, we consider experimental fishing trials that have used trawl gears with horizontal separator panels to assess and quantify the behavioural reaction of fish as they pass through a gear. The first report of such trials was by Dickson (1960) who fished two trawls, one above the other, to investigate the influence of increasing headline height. The first trials that we are aware of which fitted horizontal panels into existing trawls and directed fish that go above / below the panel into different codends are those of Symonds and Simpson (1971), who examined whiting and Nephrops behaviour with a horizontal panel in the codend of a Nephrops trawl, and Strzysewski (1972), who fitted a horizontal separator panel 1.5 m above the footrope of a demersal herring trawl (Figure 3). Subsequently there have been many attempts to develop species selective trawls using horizontal separator panels (Main and Sangster, 1985; Stone and Bublitz, 1995; Hickey and Brothers, 1998; Engås et al. 1998). Trials have investigated gears where the panel has been fitted at different heights and positioned as far forward as the fishing line or as far back as the codend. Other trials have explicitly investigated the influence of panel position and the time at which trawling took place on separation (Main and Sangster, 1982a; Main and Sangster, 1982b; Valdemarsen et al., 1985; Ferro et al., 2007) or examined ways of modifying separation by using inclined netting sheets and rising ropes ahead of the panel (Graham, 2010).

We carry out a meta-analysis of separation data from 20 of these trials that were conducted in the North Sea, the Grand Banks, the Barents Sea, the Baltic Sea and the Skagerrak between 1970 and 2015. We consider the effect of explanatory variables such as the height of the panel, the distance of the panel from the ground gear, and the time of day at which trawling took place on the separation and vertical distribution of fish at the leading edge of the panel. Results are presented for eight species: the gadoids cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*) and whiting (*Merlangius merlangus*), the flatfish lemon sole (*Microstomus kitt*) and plaice (*Pleuronectes platessa*), and monkfish (*Lophius piscatorius*) and *Nephrops* (*Nephops norvegicus*) (Figure 4).

The results show that for six of the eight species, the proportion of fish that rise above the separator panel decreases as the height of the leading edge of the panel increases (as would be expected). The species can be broadly characterised into three categories. Haddock, whiting and saithe behave in a similar way and almost all go above panels that are less than 1 m height. Cod, lemon sole and plaice can also be grouped, with about half swimming above panels that are 0.2 m high, but very few swimming over panels more than 1.5 m high. Only monkfish and Nephrops have no significant dependency on panel height; whilst, in some trials, individuals enter the upper codend when the separator height is low, in general most do not go above panels more than 0.2 m high.

Cod is the only species for which separation depends on the horizontal distance of the leading edge of the panel from the ground gear, with the proportion of cod going above the panel increasing the further the panel is from the ground gear. There is a suggestion that plaice behave similarly, but the relationship is not significant ($p = 0.063$). The time of day at which the trials were carried out only affected the separation of plaice ($p = 0.006$), with a greater proportion of plaice going above the panel at night than during the day ($p = 0.003$). (There was no significant difference between the mixed category and either day or night.) Again, there is a suggestion that time of day had a similar effect on lemon sole, but the relationship is non-significant ($p = 0.069$).

These results will be useful in designing species selective fishing gears, which are becoming increasingly important as more jurisdictions prohibit discarding. In European Union fisheries, for example, there are concerns that, as the land-all obligation is applied to more species, fishermen are more likely to catch fish which they are not allowed to discard and for which they have no quota. In such circumstances, if species selective gears are not available, the only options may be to change fishing ground or to stop fishing altogether. Our meta-analysis quantifies the vertical distribution of a range of commercially important North Atlantic species as they enter and pass through a demersal trawl gear and hence can be used to develop and adapt gears such as low headline trawls, coverless trawls and trawls with raised footropes which have already been shown to be effective in a number of fisheries (Krag et al., 2015; Bayse et al, 2016; Chosid et al., 2011). Our analysis suggests that, in the first instance, it should be possible to separate the three categories of (i) haddock, whiting and saithe, (ii) cod, plaice and lemon sole and (iii) monkfish and nephrops. If these species can be directed to different parts of the gear it may then be possible to further select on a size or species basis. Furthermore, if such selection can take place during the early stages of the capture process, the fish will be less likely to be exhausted or to suffer physical damage while passing through the netting meshes and be more likely to survive (Breen et al., 2004; Suuronen and Erickson; 2010).

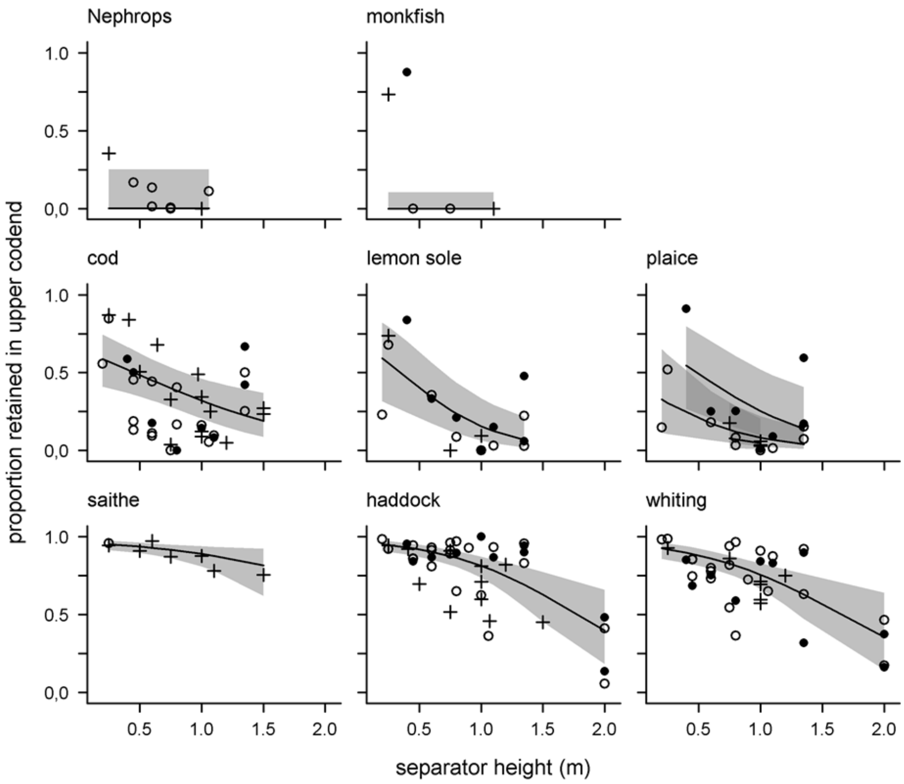

Fig. 4. Proportion of fish retained in the upper codend plotted against separator height with the fitted relationship (solid line) and pointwise 95% confidence bands (grey shaded area). The species have been ordered from bottom left to top right by decreasing median proportion retained. The plotting symbol indicates the time of day: day (open circles), night (solid circles), and mixed (plus signs). The proportions are those used for modelling, so for saithe, monkfish, and Nephrops, the data have been aggregated across time of day with a plus sign indicating that day and night hauls were combined. For cod, the fitted values are standardised to a distance from ground gear of 1.6 m, the median of the nonzero values in the data set. For plaice, the three lines correspond to the three time of day categories: night (upper line), day (middle line), and mixed (lower line). For monkfish and Nephrops, there was no significant relationship with separator height and the (back-transformed) intercept is shown: the very low values arise because the estimation is on the logistic scale and there are some trials with no fish retained in the upper codend. (From Fryer et al., 2017)

3 Estimating selectivity for data poor species

To consider estimating the selectivity of data poor species we carry out a meta-analysis of plaice trawl codend selectivity data. A literature search only revealed data from 7 studies which provided data from 9 trips, 26 gears and 185 hauls, however, in many of these hauls very few plaice were caught. The covered codend method was used to investigate 24 gears and the twin trawl method was used for the other 2 gears. (Frandsen et al, 2009; 2010; 2011; Herrmann et al, 2013; 2015; O'Neill et al, 2016; Mieske et al, submitted)

The range of explanatory variables that are considered in these studies are

- mesh: codend mesh size (range 89 – 143 mm)
- nAround: number of meshes around the codend circumference (range 44 – 120)
- twine: codend twine diameter (range 1.6 – 6.0 mm)
- logCatch: log of the catch bulk (range 20 – 1488 kg)
- SMP: presence of a square mesh panel (only 4 gears, of which 3 have the panel on the bottom of the extension)

In a preliminary analysis, we modelled the covered codend data (which form the bulk of the data). The numbers at length retained in the test codend were modelled using a generalised linear mixed model assuming binomial errors and a logistic link. We began by fitting a 'full' model with fixed effects of the form:

proportion retained ~ 1 + mesh + nAround + twine + logCatch + SMP + length + length:(mesh + nAround + twine + logCatch + SMP)

and random effects:

~ (length | gear) + (length | haul) + (1 | haul:length)

accounting for between-gear variation, between-haul varation and overdispersion. The fixed effects model was then simplified in a backwards stepwise procedure with model selection based on AIC. The final model was

proportion retained ~ 1 + mesh + nAround + twine + length + length:nAround

The parameter estimates are given below (although note that the variables have been centred for numerical stability, so the intercept should be interpreted with care).

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-0.9428	0.4492	-2.099	< 0.05	*

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length	0.8187	0.0368	22.256	<0.001	***
mesh	-0.1674	0.0166	-10.065	< 0.001	***
nAround	-0.0327	0.0183	-1.793	< 0.1	.
twine	-0.7461	0.2654	-2.812	< 0.01	**
length:nAround	0.0046	0.0015	3.135	< 0.01	**

The effects of mesh size, number of meshes around and twine diameter on L50 and selection range are illustrated in Figures 5 and 6. In each plot the other variables are held constant at values typical of a Scottish whitefish boat: a mesh size of 120 mm, 100 meshes around and 5 mm double twine.

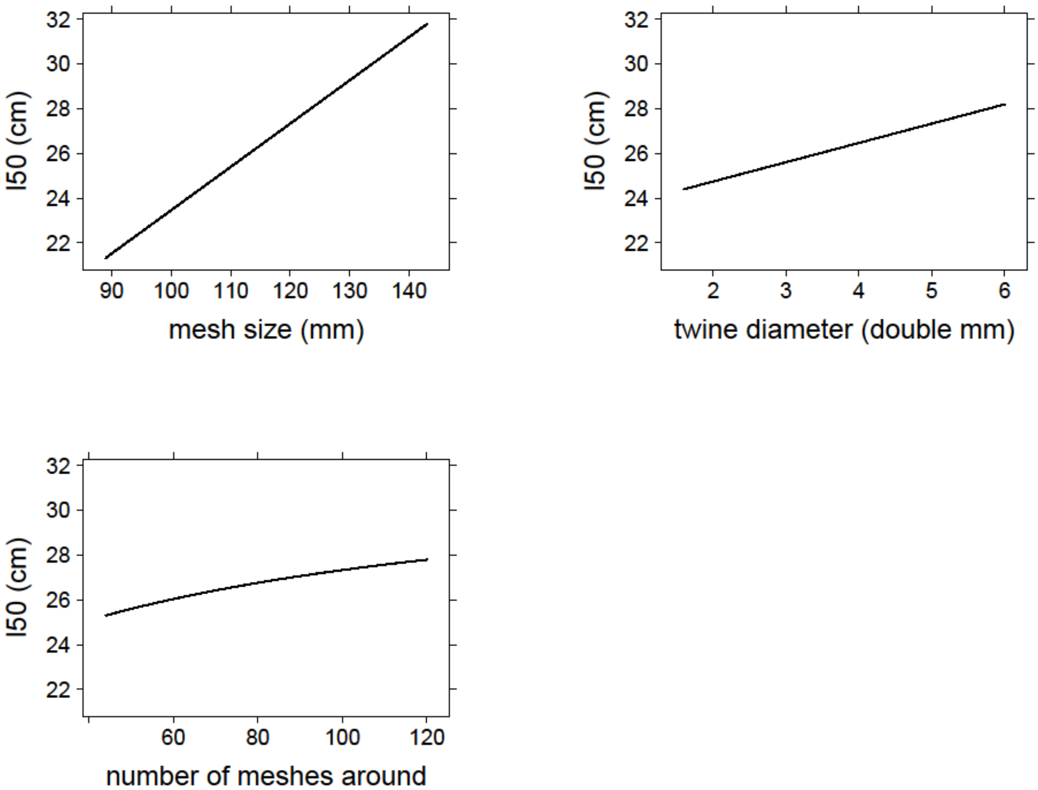

Fig. 5. The dependence of plaice L50 on codend mesh size, twine diameter and number of meshes around the circumference.

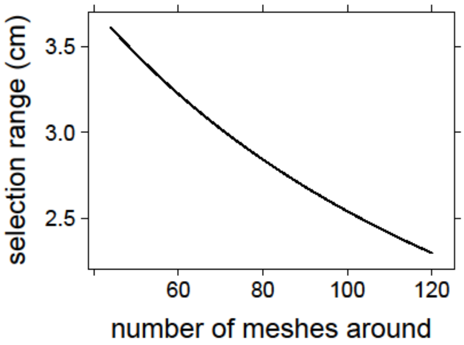

Fig. 6. The dependence of plaice selection range on the number of meshes around the circumference.

These results are very interesting as they highlight the relationship between the lateral opening of a mesh and fish cross-sectional geometry which has been used by many authors to explain (i) between-species differences in the selective performance of a given codend and (ii) differences in the selective performance of different codends for a given species. As expected L50 increases with mesh sizes. However, the relationship of L50 with number of meshes in circumference and twine thickness is the opposite of what has been found for roundfish. Presumably the increase of plaice L50 with increases of these two parameters is because both will lead to an decrease in the lateral mesh opening which serves to facilitate the escape of the laterally compressed plaice.

More generally, this study has demonstrated that it is possible to carry out a meta-analysis of data poor species such as plaice. Thus it improves our ability to identify and design selective gears to reduce of 'choke species' which may not have had much attention in the past and for which there are few data.

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Part B: Best practice guidance for assessing the economic and financial implications of selective fishing gear

1 Project Overview

Fishing gear technology to increase selectivity is integral to fishing successfully and sustainably under the Landing Obligation. Here we describe the development of an Excel toolkit that will provide best practice guidance on collecting the required data and methods to evaluate economic implications of trial fishing gear.

The project has involved so far:

- Review of the literature on the economic implications of gear trials to identify key methods, data requirements and measures to be considered in the Best Practice Guidance (BPG).
- A technical workshop with 23 contributors (not including the organiser, Seafish) was held in Edinburgh May 4 2017. The participants represented all sectors of the fishing industry including vessel operators, policy makers, scientists, fishing gear manufacturers and gear technologists. The purpose of the workshop was to discuss and agree content, methods and text for the final Best Practice Guidance report and other outputs.

The following outputs are currently being drafted for review by the workshop participants and other stakeholders who have agreed to contribute to the project however were unable to attend the event. There will be two versions of outputs 1 to reflect two broad categories of gear trial - DIY trials undertaken by the vessel operator alone and scientific trials with an independent observer.

1. Best Practice Guidance document – outlining best practice on how to undertake an economic assessment of gear trials. Including, what data to collect, key economic and financial measures and methods to undertake the analysis.
2. Excel tool – reflecting the best practice guidance, this will be an excel workbook with embedded formulae intended to be a practical aide for vessel operators or scientists trialling new fishing gear.
3. Business assessment template report – a template to enable findings to be reported in a standardised format for different trials. This could also be used as an example of results to collect and incorporate into the thinking at the beginning of fishing gear trials rather than incorporating an assessment of the economic implications as an additional exercise after the trial is complete.

Goals of selective fishing gear

These outputs are due to be published at the end of August 2017. Vessel operators are currently being identified to test the best practice guidance, excel tool and template report to identify improvements that can be made for a future iteration of these resources. Several vessel operators undertaking fishing gear trials after publication have confirmed a willingness to test the guidance.

Vessel operators may have different motivations and objectives of trialling new fishing gear. Although, these objectives might have similar outcomes of reducing costs and increasing revenues. Table 1 below outlines the key objectives of trialling new fishing gear for vessel operators.

This best practice guidance (BPG) is concerned with assessing trials of experimental fishing gear, however in a broader sense of innovation, this BPG could be adapted to assess other different working practices such as, new systems of on-board catch handling and processing. The same principles would apply.

Table1: Vessel operator aims and objectives of trialling new fishing gear

Aim or Objective	Description
Eliminate discards	Limiting the amount of low quality target species caught and how much of the quota is caught per trip. Lowering of eliminating non-marketable or low value by-catch.
Increase value of catch (box)	Increasing the value of each catch per box or tonne/ kg.
Productivity	Increase catch (kg) per litre of fuel used either through: • Decreasing the time taken to catch and sort fish worth a specific £ per tonne or kg. • Decreasing the energy usage of trawl whilst fishing. • Increasing the trawl size whilst keeping the drag consistent with benchmark or traditional fishing gear.
Reduce vessel costs	Operating costs such as fuel, bait,
Increase size or quality of catch	Increase the average size or noticeable quality (undamaged, etc.) of catch per tonne or kg.
Return on Investment within x months	New gear earns additional revenue to have a predicted return on investment of x many months.
Avoid choke point	Phasing the catch of quota species to avoid choking at the wrong time.
Expand or change quota	Change of species focus or seeking to expand current quota.
Demonstrate sustainability of fishing activity	Ensure and demonstrate sustainable practices which could increase demand for fish landed.
Reduction of bottom impact	Reducing the impact of the gear in terms of the area affected and degree of impact.

Environmental impact	Reduction in pollutions levels – greenhouse gas emissions, noise and light pollution.
Feedback to legislation governing fishing gear use	Gather evidence to feedback and influence key legislation governing permissible gear types.

The outcome measures to report the economic implications of gear trials need to reflect the goals of the trial being undertaken and the potential for the goals of vessel operators to differ.

2 Data Requirements and Collection

2.1 Type of Trial

The data requirements and collection will depend upon the type of trial being undertaken. The technical workshop identified two broad types of trail which are undertaken.

1. **DIY Trial** – undertaken by the vessel operator to test or modify gear, involves a less detailed level of data collection. Depending upon the type of vessel gears may be directly comparable on the same trip (trawl) or be tested on separate trips. The difference in testing will impact upon the calculation method and robustness or results. This type of trial can be part of a one-off assessment (one trip) of gear effectiveness to inform skippers or be part of a series of trials modifying the gear perhaps for several months. The length of trial can influence how the results can be compared, used and interpreted. Often time longer trials modifying the gear might involve at an appropriate stage verification through an independent observer.
2. **Scientific Trial**– involves a more detailed data collection process and data are evaluated in more depth due to the involvement of independent observers. This type of trial is also often supported by additional funds which increases the robustness of the resulting measurement of gear effectiveness. The trial is usually undertaken over one to three trips due to the high cost involved.

Depending upon the vessel and trial methods employed will influence the results. For example, trialling fishing gear at the same time on the same vessel or making two trips each trialling out the different gear respectively. There will be differences in data quality and variability which will have a knock-on effect on the confidence in the results of an assessment of the economic implications. The assessment method will therefore have to distinguish between these differences in data but be applicable to both types of trial.

2.2 Data Requirements

A summary of data requirements is presented in the table below. These requirements are wide ranging and reflect the best possible scenario. The variables included have either been identified through the technical workshop or a review of literature.

Table 1: Overview of data requirements for the assessment of the economic implications of fishing gear trials

Data required	Description or reason for requirement	All or scientific trial only
Vessel details		
Name	Name of vessel(s) involved.	All
Vessel profile and dimensions	Type of vessel, length, breadth and depth.	All
Engine Type	Type of engine and manufacturer for comparison across different trials and control for factors influencing fuel consumption.	All
Engine Power (Kw)	Power of engine.	All
Context		
Key fishing seasons and average number of trips per season	Average number of trips per season in order to estimate annual impacts of changes in catch per trip.	All
Target species and quota	List of target species and vessel quota for those species.	All
Fishing gear (both benchmark gear and trial gear)		
Gear type	Details of the benchmark gear and the key differences of the gear being trialled.	All
Manufacturer	Company manufacturing or modifying the trialled gear.	All
Additional fishing gear employed	Monitoring equipment in use and other types of information systems.	All
Headline length/ height (m)	To profile specific gear and modifications made.	All
Wing-end spread (m)	To profile specific gear and modifications made.	All
Footrope length (m)	To profile specific gear and modifications made.	All
Fishing-circle (meshes × mm)	To profile specific gear and modifications made.	All
Sweep length (m)	To profile specific gear and modifications made.	All
Warp diameter (mm)	To profile specific gear and modifications made.	All
Door weight (kg)	To profile specific gear and modifications made.	All
Gear drag per Kw	If possible and appropriate to understand any fuel savings whilst fishing.	ST
Gear spread (area)	To profile specific gear and modifications made.	All
Gear purchase cost (£)	Cost of purchasing the two gears respectively.	All
Estimated gear annual maintenance cost (£)	Estimated or expected cost of maintaining gear (advised by the manufacturer).	All
Gear modification cost (£)	Cost and time taken to fit and modify fishing gear.	All
Gear rental cost (£) (if applicable)	Cost of renting the gear for the trial.	All
Expected lifetime of the gear	Number of years the fishing gear is expected to last before being replaced.	All
Finance cost (if applicable)	Any financial costs of investing in the new gear or trialling the gear borne by the vessel.	All
Goals of trial		
Primary Goals	The main measurable goal(s) for the vessel operator of trialling the new gear and/ or the expected outcome(s) of the new gear for vessel	All

	operator, independent observer or other stakeholder.	
Secondary Goals	Secondary goal(s) and/or expected outcome(s).	All
Fishing Grounds		
Fishery name	To enable overview of stock in the waters vessel is operating in, how its catch composition compares and to potentially derive other context.	All
Shallow or deep water	Different fishing gear may be more or less effective in different conditions. For example, light may be more effective in shallow water but less so in deeper.	ST
Co-ordinates of haul	Longitude and latitude. In order to keep consistency between trips and comparison with future trials.	All
ICES area	To enable overview of stock in the waters vessel is operating in, how its catch composition compares and to potentially derive other context.	ST
Trial Details		
Date	Control for time of year (seasonality of stocks).	All
Length of trip (days)	To control for fuel cost and revenue per time at sea.	All
Day or night and weather conditions at time of trial	Control for conditions when the gear is trialled therefore comparison between different trials.	All
Crew number and wages	To account for labour costs for the trial.	All
Number of independent observers and cost of observers	The number of independent observers and cost of observer time.	ST
Number of crew required and time taken to sort catch for both benchmark and trial gear.	The cost of sorting the catch from the benchmarked gear compared with the trial gear.	ST
Fuel cost	Cost of fuel per kw of travel and fishing and total fuel cost per trip.	All
Training time	Time taken to train	ST
Extra equipment cost	Any additional equipment required for the trial such as rental of vessel or monitoring equipment.	All
Funding of trial	Breakdown of how the trial is funded – for example, 100% vessel, 100% supplier, 50% vessel and 50% UK grant funding, etc.	All
Catch composition		
Catch composition	Quantity (kg) each gear caught of target species, marketable by-catch and non-marketable by-catch.	All
Size of catch	For each target species the quantity caught of small, medium and large fish and the average size of fish caught on each haul.	All
Quality of catch	In the absence of a formal approach to assessing quality – rate target species and marketable by-catch through assigning as close as possible to the following score: 1. = lower quality of catch than benchmark gear 2. = equal quality of catch to benchmark gear 3. = minor improvement in condition and	All

	quality of catch than benchmark gear 4. = 75%+ of catch undamaged and major improvement on benchmark gear 5. = 75%+ of catch undamaged and alive. In addition, if applicable, make a note of the price premium for the better quality caught.	
Opportunity cost of trial	Average catch composition per trip of vessel under business as usual conditions.	All
Value of catch		
Monthly average price per species per size and quality for each target and marketable by-catch species	Average sale price for the month of each species of the catch from the benchmark gear and catch from the trial gear. This helps control for daily variation in prices. It may be difficult to capture differences in quality of catch using monthly prices.	All
Revenue from sale of catch per species per size for each target and marketable by-catch species	The revenue gained from the catch from both fishing gears when sold, broken down by species, weight, size and quality.	All

2.3 Standards for the collection and entry of data requirements

It is recommended that data should be collected for a minimum of six fishing trips to improve the robustness of the resulting average difference between the benchmark gear and trial gear. This should help account for any variation in the reported results of individual trials. However, it is not always possible to do this. Therefore, differences in the reliability of the data should be reflected in the interpretation of results.

The way the data is collected and entered needs to be completed in a standardised format which minimises errors. In addition to recording the number of trials and data values, the following should also be stated where appropriate:

- Whether the values entered were exact, approximate or calculated/ derived. If the values entered are approximations then this is arguably less reliable than exact entered values. If values are calculated or derived then the calculation steps should be easily identifiable or stated in order to understand the basis for the value.
- Whether the assessment is undertaken as an add-on after the trial is complete or has been considered and built into the trial from the beginning. It is recommended that the assessment is built in from the beginning and the business assessment report template and excel tool could help facilitate consideration of economic implications at this early stage.
- It is important to collect data from the benchmark gear and trial gear consistently (same methods for same data requirement) and report separately.

3 Approach and Methods

The proposed method for assessment is a three-step process. Firstly, to assess the difference in key outcome measures between the benchmark gear and the experimental gear for the trial. Secondly, estimating the annual implications of adopting the experimental gear based on results from the trial. Thirdly, indicate whether the trial gear has met specific targets or goals for the vessel operator.

The method focuses on short to medium term implications of gear change for the vessel operator rather than long-term implications for the vessel operator, fleet, fishery and stocks. It is designed to allow comparison between different trialled fishing gears.

Table 1: Key direct outcome measures and calculations

Measure	Description
Total cost of new fishing gear	Sum of purchase cost of new gear (including associated financial costs), vessel modification, annual maintenance cost for x many years of fishing gear lifetime.
Cost of trial	These costs include the trial gear, modifications to the vessel, training time, cost of lost catch through fishing gear experimentation, cost of other gear and personnel.
Cost of Switching	Cost of new gear minus cost of benchmark gear per annum.
Fuel cost savings	Sum of the total fuel cost per day/ trip of benchmark gear minus fuel cost per day/ trip of trial gear.
Additional revenue from sale of catch	Revenue gained from trial gear catch per kg minus revenue gained from benchmark gear catch per kg.
Total additional revenue	Sum of fuel savings and additional revenue from sale of catch.
Opportunity cost of investment	What could be earned by the investment if it was spent on an alternative purpose. Such as the benchmark gear plus any extra cost of trial gear invested in savings at y% per annum rate of return.
Return on Investment (RoI)	The 1) amount of time it takes for additional revenue earned to pay back cost of trial gear; and 2) annual rate of return on investment.
Avoided choke point	Through reduction in low value by-catch using more selective gear should enable choke points to be avoided.
Discard reduction	The extent to which the new gear achieves reduction or elimination of discards of low value catch and unmarketable by-catch.

Generalisation of the key measures in the table above on a per annum basis for the vessel operator is dependent upon a number of assumptions. Some assumptions are partly captured if both gears are trialled at the same time and trip - for example, weather, fishing ground, time, trial details such as trawl speed. Other variables are not as well captured and assumptions must be made:

- Seasonality - depending upon the season results from the two gears may differ due to, for example, spawning.
- Fuel price - the price of fuel may dictate the percentage of the boat costs it makes up. A lower price during particular years may artificially lower the cost of fuel as a percentage of the overall vessel operating costs and diminish any percentage difference in efficiency between fishing gears.
- Fishing tactics - a vessel operator may change her or his fishing tactics as a result of the new gear and the composition of catch she or he can now target.
- Changing fish price - changes in the price of certain types or sizes of fish can affect the value of switching to the trial fishing gear.

Estimating the annual economic and financial implications involves assuming the extra total revenue over an annual timeframe. These estimations would take the form of scenarios to help inform decision making of vessel operators under conditions of imperfect knowledge. For example, five scenarios could be generated for a successful trial:

Scenario 1 - additional revenue and savings gained through trial gear is multiplied by number of trips per season for the vessel operator and summed annually. Point in year quota is reached is captured. Price of purchasing additional quota is then factored in to the costs for the remainder of the year and subtracted from the additional value generated by the trial gear.

Scenario 2 - assume the vessel operator only gains 75% of the additional value of catch produced from the trial gear. Apply this in the same way as scenario 1 and determine the annual value of switching gear.

Scenario 3 - assume the vessel operator gains 125% of the additional value of catch produced from the trial gear. Apply this in the same way as scenario 1 and determine the annual value of switching gear.

Scenario 4 - assume the cost of fuel changes up or down by 25% and determine the value of the trial gear under these conditions.

These scenarios an help 'stress test' the trial results for the vessel operator when trying to understand the estimated annual value of switching gear and the return on investment from that gear.

3.1 Key wider outcome measures and assessment

Labour costs and crew retention: The labour cost of sorting the catch may be significantly quicker with more selective fishing gear and therefore lower number of species caught. This will lower vessel costs. However, if a vessel becomes more efficient and spends less time at sea then it may struggle to maintain crew (if paid not as a proportion of the catch value).

Feedback to customers and environmental credentials: becoming more selective or attempting to be more selective could improve the image of the vessel and thus increase demand for or gain a premium price per kg caught. Although, this is too difficult to capture quantitatively through this guidance it is worth outlining as a potential outcome from the gear trial.

Feedback to policy and legislation: the vessel may be gathering evidence to feed back to the policy or legislation to gain permissions to use the gear and demonstrate the benefits of using the gear.

3.2 Rating the gear

The success of the trial for the new fishing gear being economically viable and meeting key goals set by the vessel operator can be indicated by a rating system. This rating system could be designed to automatically tell the vessel operator when the choke point on the current quota would be with the trial gear, economic viability of the vessel adopting the trial gear and the % reduction in unwanted catch of a low size or unmarketable by-catch. The fishing gear can be rated on all the key measures for the vessel and a rating of the gear (without giving away any detail of the actual resulting value) could be produced to share with the fleet on existing fishing gear databases.

4 Interpreting the Results

There are a number of limitations of this method which should be taken account of when interpreting results

- Confidence in results – depending upon type of trial, timing of trial, and quality of data collected this can influence results. Due to the lack, in the case of DIY trials, of independent verification and the pressure due to the cost of the trial itself on the vessel operator this can lead to errors. Assumption made when estimating annual returns have been discussed.
- Trial time period can place limits on the interpretation and generalisations of results.
- The comparison of different trials and gears between vessels to identify generally superior fishing gear can be practically challenging due to differences in the make-up of vessels, available quota, fishing grounds and species targeted.

5 Guidance for future actions or next steps after the initial trial

Re-testing and monitoring: After the initial assessment of the fishing gear, monitoring results against the trial results or annual scenarios may inform the vessel operator of any further improvements or adjustments to make to the gear.

Developing the fishing gear over time: Logging any modifications made to the gear over time along with the economic implications of those changes may inform the vessel operator of the effectiveness of change being made.

Confirmation of results: Comparison of results between DIY trial and scientific trial via the business assessment template report would be possible as conformation of the outcomes produced by fishing vessels.

6 Policy Implications

There are a number of policy implications for the application of an approach standardising the assessment of the economic implications of fishing gear trials and encouraging the consideration of the economic implications as a central component of trials.

- Discards - improved uptake of selective fishing gear over time may improve the health of the fishery and support the industries compliance with the discard ban. Evidence gathered through the voluntary submission of data could feed into models for the fishery and longer term bio-economic modelling of the fishing stocks and financial health of the industry.
- Legislation - feeding back evidence of economically viable selective fishing gear potentially appropriate for sections of the fleet fishing particular stocks could lead to a more flexible or responsive mechanism to allow adoption of gears currently not legal. Lowering a barrier to fishing gear adoption.
- Quota system - Changes to selective fishing gear may lead to circulation of fishing quota and encourage effective market mechanisms for the transaction of quota or focus on under-valued quota or non-quota stocks.
- Supplement and support existing government or industry funded fishing gear trial projects. Such as GITAG.
- Barriers to technology adoption - this work may highlight some of the barriers facing vessel operators to the adoption of new fishing gear. Such as lack of access to finance and the tendency of industry to undersupply level of R&D to meet socially optimal levels. This might lead to a revision of government policy in this area for the fishing industry.
- Environmental benefits - this work could help to highlight the environmental benefits of more selective gear such as lower environmental impact from bottom trawling, lower fuel emissions and improving fish stocks. This could help advocate for greater support for vessel operators to undertake gear trials and, where appropriate, encourage policy makers to find ways to communicate effective technologies with the rest of the industry.

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