Fisheries Innovation Scotland

FIS011A - Developing and facilitating a range of possible future FIS projects in innovation in selectivity through on-net or alternative technologies

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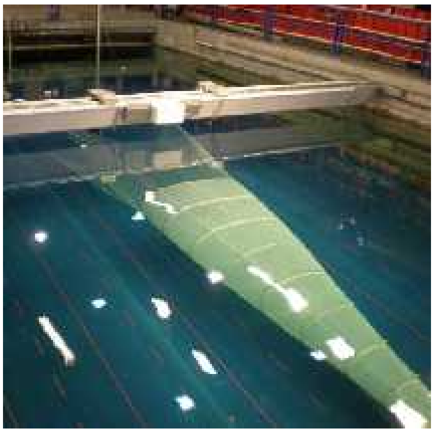

Developing and facilitating a range of possible future FIS projects in innovation in selectivity through on-net or alternative technologies

FIS11 A

Fisheries Innovation Scotland

Final report

28th November 2016

MRAG

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Acronyms

CFP	Common Fisheries Policy
EMFF	European Maritime and Fisheries Fund
ETP	Endangered, threatened or protected [species]
EU	European Union
EUR	Euro
FAO	Food and Agricultural Organisation of the United Nations
FIS	Fisheries Innovation Scotland
GITAG	Gear Innovation and Technology Advisory Group
ICES	International Council for the Exploration of the Sea
NERC	Natural Environment Research Council
TAC	Total Allowable Catch
USD	United States Dollar

1 Introduction

1.1 Purpose of the project

The issue of discards continues to be a hot topic in the fishing industry. The discarding of unwanted catches by fishermen constitutes a substantial economic waste that challenges the financial viability of fisheries and is at odds with the sustainable exploitation of marine resources. In recent years, public opinion has been building up against the wasteful practice of discarding, and, with the reform of the European Union (EU) Common Fisheries Policy (CFP), an obligation to land all catches is being introduced gradually on a fisheries-by-fisheries basis. (This obligation is expected to remain, in some form, once the UK has left the EU). The landing obligation has increased pressure on fishers to fish more selectively in order to avoid catches of unwanted fish, which previously would have been discarded. Fishers in Scotland, and around the world, have trialled and implemented a range of initiatives aimed at reducing the catch of unwanted fish, mainly through modifications to fishing gears or use of new technology, although these initiatives are still too scattered to fully eliminate the practice. Therefore, in many Scottish fisheries there is still a need to find solutions for reducing unwanted catch by improving selectivity in the broadest sense.

1.2 Project objectives

To understand how the use of selective fishing gears and practices may be increased in order to reduce the catches of unwanted fish, there needs to be a directed drive to progress innovation in this area. Responding to this challenge, this project had five objectives:

1. To provide a concise review of the state of knowledge and advances in selectivity, including a typology of selective gears, devices and practices in use worldwide;
2. To identify and scope novel ideas and innovations, inspired from other disciplines and sectors, that may be relevant to improving selectivity;
3. To chart the pathway to developing selective gears and practices and to identify roadblocks to the development and uptake stages;
4. To provide a strategic plan for future multidisciplinary initiatives aimed at improving selectivity in Scottish fisheries; and
5. To identify possible funding sources to support future selectivity research projects and initiatives.

The outputs of the project, which are presented in this report, are intended to benefit FIS by providing a clear framework for future work, in particular drawing fresh ideas and initiatives from beyond the fisheries sector. In turn, the products of this future work are expected to support Scottish fishers with respect to adapting to EU and possible future UK discard policies by bringing about improvements in selectivity.

1.3 Overview of study methods

This project involved literature review and consultation with fisheries and gear experts to investigate the state of knowledge and potential for innovation in selectivity. The project ran for 6 months and was completed in November 2016.

2 Review of improving selectivity in fisheries

2.1 Defining unwanted catch

The term ‘discards’ refers to the part of the catch that is returned to the sea. There may be a number or combination of reasons why a fisher may want to discard some part or all of the catch, including:

- Fish are of the wrong species, e.g. not the target species for the particular operation, there is no quota for the species or it has already been reached, it is a prohibited species or it has been caught at the wrong time, area or by the wrong gear;
- Fish are of the wrong size (too small or too large) and either command too low a price on the market to be worth landing or are outside the limits imposed by management for that particular species;
- Fish are damaged through impact by the gear, predation or mis-handling on board, meaning they may not be marketable or may cause damage to the rest of the catch; and
- There is a lack of storage space on board, usually meaning that higher quality fish of the target species take precedence over lower value or non-target species.

In seeking to reduce the practice of discarding, there are a number of ways to reduce each of these reasons for unwanted fish. For instance, in the case of catching fish of the wrong species or the wrong size, a fisher can reduce the need to discard by fishing more selectively to reduce the number of unwanted fish in the catch. Or, in order to reduce the number of damaged fish, a fisher can make changes to gear design, fishing practices and on board handling techniques.

This study focuses on the reduction of unwanted catch though improvement in the selectivity of fishing gears and practices.

2.2 A brief history of selective gears and practices

Over recent years the fishing industry has been under increasing pressure to improve the size and species selectivity of commercial fishing gears in order to reduce the catch of unwanted fish. Selectivity is defined here as the capacity of any method or gear type to capture certain fractions or sections of the fish population whether grouped by species, age, size or behaviour, and to exclude others (MacLennan 1992).

Changing the selectivity of fishing was once relatively straightforward, although in modern fisheries has become substantially more of a challenge (Thomson & Ben-Yami 1984). During the development of industrial fisheries in the UK in the first half of the 20th century (ca. 1900-1940), most commercial fishermen had a market for only a few species of fish, in particular herring and cod. The types of gear and the practices used were relatively selective compared to modern standards, both as to species and the size of fish taken. Most fishing vessels at that time were single-purpose and fished almost exclusively for one species and for fish above a certain size within that species. In this situation it was relatively easy to control fishing effort because, for most vessels, their gear could not be used economically to catch species other than the one it was designed to target. Thus, in these early industrial fisheries it was fairly easily to control the size of fish caught by regulating a minimum mesh size for drift nets and trawls, or minimum hook size for long lines. These gear design modifications were amongst the earliest efforts to modify the selectivity of fishing, and remained effective until fisheries began to increase in diversity and complexity in the mid-20th century.

Over the past 30 years or so, two types of fishing gear have accounted for the bulk of the fish catch in the UK and Scotland: trawl net, including with and without otter boards, and purse seine. There exists a multitude of variations within these two gear types, each of which are used to target different species and complexes in different types of marine habitat (although we do not attempt to summarise that diversity here). Importantly, however, the proportion of different species and size classes caught in any given operation varies as a result of the net design, the techniques used and the grounds fished, which complicates efforts to make changes to selectivity across the entire fishing industry.

Owing to this complexity in gear types and catch compositions, much of the work done to improve fishing selectivity since the 1970s has been focused on modifying the design, structure and shape of fishing gear. These design changes have been informed largely by underwater observation of fish behaviour in nets, through which the mechanisms of capture and selection have been gradually understood. This knowledge of fish reaction and escape behaviour initially led to the development of novel cod-ends with more open meshes. This subject was examined in depth at a seminal EU Workshop in 1990, and many novel methods of increasing mesh opening and improving size selection were subsequently devised and tested, including square and diamond mesh shapes. As an integral part of this work, techniques for the measurement of cod-end size selection were improved and new approaches to data analysis developed to give more reliable estimates of the selection parameters.

Mixed species fisheries in particular have presented a challenge for selectivity work. In mixed species fisheries, a major driver for improving selectivity is that unwanted species are often caught and discarded. However, differences in behaviour offer opportunities for separation and release of the non-target catch and many different ways to achieve species separation have been trialled, including horizontal separator panels, sorting grids and different mesh shapes in the cod-end. Sorting grids, which were originally developed for species separation in shrimp fisheries to reduce the fish bycatch, have proven to be particularly effective in certain situations and continue to be developed and tested today.

Improving selectivity is not simply about developing new gear designs or devices. Since the 1990s the diversity of approaches used to change fishing selectivity has increased considerably. During an expert workshop held in 2012, twelve commonly-used methods for mitigating discards were identified and classified into five categories: total allowable catch (TAC) and quotas; fishing effort and capacity; technical measures; social initiatives and market actions (Sigurðardóttir et al. 2015). Whilst each of these have the potential to modify fishing selectivity to a greater or lesser extent, spatial restrictions, selective gears and methods and society awareness of discard issues are particularly relevant approaches for improving selectivity. Another critical aspect of selectivity work is engaging with fishers and ensuring selective gear and practices are used by them. This has involved knowledge sharing, awareness campaigns and training fishers in how to use selective gears. There has also been social research directed at the challenge of achieving wide scale uptake of selective gears and practices by fishers.

2.3 Typology of selective gears and practices

Fishing selectivity has often been viewed only in the very narrow sense of gear selectivity. In fact, the selectivity of fishing can be modified through a variety of gear modifications, fishing behaviours and regulatory measures applied at almost all stages of the fishing operation. A typology summarising the various selectivity measures that have either been implemented or experimentally trialled in Scotland or elsewhere in recent years is summarised below and presented in Table 1. In this exercise we have also considered devices or practices that are used to improve the quality of retained catch, although we frame these in the context of improving selectivity (i.e. the ability to sort and release unwanted fish). In considering regulatory measures, we have not included those that require specific gears or modifications (which are covered individually), prohibited species, limits on catches or sizes, or the EU landing obligation.

Generally speaking, the selectivity of fishing can be modified at three main stages of the capture operation:

1. Unwanted fish can be avoided pre-capture, such as by adopting certain fishing behaviours, restricting where fishing is allowed, using deterrents or by modifying the profile of a gear. Pre-capture avoidance methods are usually based on ecological knowledge of the fish, such as its spatial distribution, its response to stimuli or its swimming behaviour when disturbed by fishing gear. Avoiding fish at this stage has the advantage of minimising or avoiding entirely the interaction between fish and fishing gear.
2. Unwanted fish can be allowed to escape from fishing gear post-capture by incorporating design features in the gear such as square mesh panels, escape holes, sorting grids and artificial light. These post-capture methods generally work by exploiting variation in size or swimming behaviour between wanted and unwanted fish to sort them within the gear. In trawl gear the escape of unwanted fish usually occurs before they reach the cod end, although the process of escaping can result in injury or mortality.
3. Unwanted fish can be sorted and/or graded post-harvest and returned alive to the sea, using manual or automatic methods. The sorting of fish at this stage of the operation is most commonly associated with the discarding of fish that a fisher cannot or does not want to land or store on board. This is not an ideal stage for applying selectivity methods, as fish have passed through the full fishing operation and, depending on the method of fishing, may be in poor condition or already dead. However, the practice of sorting and release at this stage may be an effective selectivity method for certain resilient species[1] or in situations where fish are maintained in a near-pristine condition until the point of sorting.

Regarding the latter two stages, escaped or released fish must be in good enough physical condition to survive in the long term for any of selective measures, devices or practices to be considered as genuinely modifying selectivity.

[1] The EU landing obligation includes an exemption for species for which a high post-release survival rate can be demonstrated.

Table 1 Typology of selective gears and practices. Selectivity measures are grouped into those that are applied pre-capture (before fish enter the gear), post-capture (when fish are in the gear) or post-harvest (during or after the gear is hauled). These measures are collated from fisheries around the world, although use of these methods in Scottish fisheries is indicated wherever known.

Sub-category	Fishery type	Region(s)	Description	Examples
Pre-capture				
Alterations to the profile of the net	Applicable in trawl fisheries	Scotland and worldwide	Trawl gears designed in such a way as to reduce the chance of a certain species of size class from entering the net. Designs typically exploit variation in swimming behaviour between target and non-target species.	**Coverless trawl**.[2] In the coverless trawl, the headline and footrope are approximately the same length so that the top and lower panels are directly above one another when the net is being towed. This allows fish to escape upwards and over the headline without ever being caught by the net. Used in *Nephrops* fisheries in the UK **Eliminator trawl**.[3] Designed to reduce catch of cod and other unwanted species whilst targeting haddock by allowing fish to escape through large mesh holes at the front of the lower panel of the trawl. This exploits the tendency for haddock to swim upward and cod to swim downwards when escaping from a trawl net. Initially designed in the US and has since been trialled in the UK
Deterrents	Applicable mainly in gill and tangle nets, but also in pelagic trawl	Scotland and worldwide	Devices attached to a fishing gear that aim to deter certain species from approaching and becoming captured or entangled, or to prevent depredation of fish captured in gear or in fish cages. Most commonly used to deter cetaceans (and to a lesser extent, seals) from netting, but devices exist to scare birds from interacting with longline gears in some areas (e.g. Tori lines).	**Acoustic deterrents (pingers)**.[4] These devices use sound to deter cetaceans and/or seals from approaching nets and fish cages. This is achieved by using sharp, loud noises or 'pings' that result in acoustic stress. Acoustic deterrents are used widely in Scottish farms to reduce depredation, and in some pair trawl and gillnet fisheries in the UK to avoid cetacean bycatch (e.g. Celtic sea gill net fishery, UK sea bass pelagic pair trawl)
Fixed spatial closures (no-take areas or reserves)	Applicable to all fishery types	Commonly used worldwide	The total closure of certain areas from fishing in order to protect vulnerable habitats, nursery areas, spawning aggregations etc. No-take areas are often considered as being necessary where other measures to alter the	**Scotland's Nature Conservation MPA network**.[5] This network consists of 30 MPAs: 17 MPAs under the Marine (Scotland) Act 2010 in Scottish territorial waters and 13 MPAs under the Marine and Coastal Access Act 2009, which have been recommended by Scottish Natural Heritage and the Joint Nature Conservation Committee to protect

[2] http://www.seafish.org/geardb/device/coverless-trawls/.

[3] http://assets.worldwildlife.org/publications/668/files/original/2007_winners.pdf?1392737742.

[4] http://www.gov.scot/Publications/2014/10/8271/4.

[5] http://www.gov.scot/Topics/marine/marine-environment/mpanetwork/developing/DesignationOrders

Sub-category	Fishery type	Region(s)	Description	Examples
			selectivity of fisheries (usually regarding non-target species or interaction with seafloor habitat) are not feasible or have failed.	benthic species and habitats such as maerl beds and common skate.
Temporary moratoria and closures	Applicable to all fishery types	Commonly used worldwide	Alterations in the timing of fishing operations in order to better target or avoid certain species. This might involve fishing at a different time of day or night due to specific fish behaviour, or be implemented on a broader scale with non-permanent closures in order to avoid, for example, breeding seasons, fish migrations or aggregations of juvenile fish.	**Real time closures (RTCs).** [6] These short-term area closures represent a more dynamic and flexible selectivity method compared to fixed spatial closures which may not sufficiently take account of variations within highly dynamic fisheries. Real time information is used to determine whether fishing should be closed in a certain area, using variables such as percentage of catch, bycatch or juvenile catch. RTCs may have a pre-determined time period before expiry, or might require assessment of the fishing area before being lifted. Scotland has operated a system of RTCs since 2007 designed to help the continuing recovery of cod stocks.
Depth restrictions	Applicable mainly to demersal trawl and bottom set gears	Commonly used worldwide	The imposition of minimum or maximum depth limits in accordance with the known ecology of target/likely bycatch species, thereby taking steps to reduce risk of unwanted catches.	**NAFO depth restrictions**.[7] NAFO rules restrict the Greenland halibut fishery to grounds greater than 700m depth in order to reduce the bycatch of juvenile fish of the target and non-target species. Similarly, restriction of the NAFO shrimp fisheries to fish in areas less than 200m depth is intended to reduce catches of juveniles of a range of non-target fish species.
Behavioural practices	Applicable to all fishery types	Commonly used worldwide	Fishers can adopt certain practices, techniques or tactics that reduce the chance of capturing unwanted species. Decision making may be supported by experience, communication with other fishers or technology, such as fishing suitability maps, remote sensing data, real time catch reports, echo-sounders etc.	**Avoidance of certain areas.** Fishers may temporarily or permanently choose to avoid areas associated with high bycatch, spawning aggregations, nursery areas etc. This approach is especially applicable in trawl fisheries. **Avoidance of specific species or size classes.**[8] Fishers can use echo-sounder technology to discriminate the species or size composition of a target fish shoal, and choose to avoid it as necessary. The use of this technology in this way is undergoing development and has been trialled in the Scottish pelagic mackerel

[6] http://www.gov.scot/Topics/marine/Sea-Fisheries/management/restrictions/closures

[7] NAFO Conservation and Enforcement Measures 2016 available at: https://www.nafo.int/Portals/0/PDFs/fc/2016/fcdoc16-01.pdf?ver=2016-05-09-121749-753

[8] FIS004 report available at: http://www.fiscot.org/media/1256/fis004.pdf

Sub-category	Fishery type	Region(s)	Description	Examples
				fishery by the University of Aberdeen as part of a previous FIS project in 2015. Its use in demersal fisheries has been proposed by not trialled.
Post-capture				
Alterations to mesh size, shape or orientation	Applicable in a variety trawl fisheries, and also some seine fisheries	Commonly used in Scotland and worldwide	Changes in the size, shape or orientation of mesh in netting. The purpose is typically to select for a larger size of the target species, allowing smaller fish to escape the net. Mesh modifications can be made to various parts of the net including the front, belly, top and cod end, according to the needs of the fishery	**Square mesh panels.**[9] A panel made from square-shaped mesh is fitted in the net before the cod end. Square mesh keeps its shape and size when under tow, which increases the opportunity for small fish to escape before reaching the cod end. Used extensively in UK and European trawl fisheries **T90 cod end configuration.**[10] Conventional diamond mesh is turned through 90 degrees in the cod end to enable the meshes to remain open to a greater extent while the gear is being towed. This increases the opportunity for small fish to escape from the cod end. This alteration has been trialled as part of the CEFAS 50% project on some beam trawlers in southwest England
Separator panels and devices (including artificial light systems)	Applicable mainly in trawl fisheries	Limited use in Scotland (mainly *Nephrops* trawl) but wider use worldwide	Redesign of the internal structure of gear or the addition of a device intended to separate species within the net according to size, body shape or behavioural response. The purpose is to facilitate the escape of unwanted species or size of fish (or other animal). A wide diversity of such designs and devices exist, including but not limited to separating panels, flexible or rigid grids, escape windows, guiding panels, multiple cod ends and belly windows. More recently the use of artificial lights to separate fish within the net and/or facilitate their	**Inclined grid.**[11] A flexible grid device is fitted in the trawl at an angle so that it allows certain species to pass through and into the cod end and directs other species or size of fish out through an escape hole in the top of the trawl. The flexibility of the grid helps in setting and hauling the gear. **'Flip flap' netting grid trawl.**[12] A specific trawl configuration that includes separator panel and escape panels, along with square mesh panel. This design was experimentally trialled in Scotland in 2012, specifically to reduce fish bycatch in *Nephrops* trawls **LED light rings.**[13] Artificial lights are placed on the trawl mesh to stimulate fish in certain ways in order to improve their chances of escape. These devices are intended to be used in combination with other selectivity devices, e.g. square mesh panel. This technology is

[9] http://www.seafish.org/geardb/device/cod-end-configuration-square-mesh-cod-ends/.

[10] http://www.seafish.org/geardb/device/cod-end-configurations-t90-cod-ends/.

[11] http://www.seafish.org/geardb/device/inclined-grids/.

[12] Results of a Marine Scotland comparison trial available at: http://www.gov.scot/resource/0039/00391333.pdf.

[13] http://sntech.co.uk/problems-solutions.

Sub-category	Fishery type	Region(s)	Description	Examples
			escape has been explored. At least two automated, camera-based sorting devices have been developed and are in use in both research and commercial situations (see examples).	still in development but has been trialled in a UK *Nephrops* fishery in 2016 **Deep Vision automatic sorting system**.[14] Deep Vision is a camera-based fish sorting system that can automatically measure and classify different species in the net during a tow and transmit information about the mix of species in the gear in real-time to the vessel. The system, which is under continuous development, is currently aimed at research applications, e.g. survey cruises. However, developers anticipate that if combined with a sorting mechanism it will be possible to program the system for desired species and size classes and automatically sort the fish in the trawl based on this information. **The Fish Selector**.[15] This device is similar to the Deep Vision system, with the addition that unwanted fish are automatically released through an escape door in the sorting chamber.
Behavioural practices	Applicable to all fishery types	Commonly used worldwide	Fishers can adopt certain practices, techniques or tactics that increase that chances of unwanted fish escaping the gear. Decision making is mainly supported by experience or technology, such as cameras deployed in the gear.	**Reduced setting time**. A reduction in the amount of time the net is set in the water before hauling, which can promote the escape of certain species or reduce the overall number of unwanted fish are caught. **Reduced vessel speed**. The speed at which a trawl is dragged across the seabed can be varied in order to increase opportunities for unwanted or undersized fish to escape the net.
Post-harvest				
Sorting and grading living fish	Applicable in all fisheries	Not widely used as a selectivity measure *per se* in any regions. Most relevant examples in Australia,	Unwanted fish can be sorted and/or graded post-harvest and returned alive to the sea, using manual or automatic methods. The sorting of fish at this stage of the operation is most commonly associated with the discarding of fish that a fisher cannot or does not want to land or store on board. This is not an ideal	**Precision Seafood Harvesting**.[16] This new technique is an alternative to traditional trawl nets. Instead, fish are captured and contained inside a large flexible PVC liner where they are able to continue swim when hauled on board. Escape holes in the PVC liner allow small fish to escape during the tow and the catch can be further sorted (manually) for the correct size and species after the gear, which retains seawater, has been brought on board

[14] http://www.deepvision.no/deep-vision/deep-vision

[15] http://www.star-oddi.com/products/45/fish-sorter/default.aspx

[16] http://www.sanford.co.nz/sustainability/precision-seafood-harvesting/

Sub-category	Fishery type	Region(s)	Description	Examples
		Norway and Antarctica.	stage for applying selectivity methods, as fish have passed through the full fishing operation and, depending on the method of fishing, may be in poor condition or already dead. However, the practice of sorting and release may be an effective selectivity method for certain resilient species or in situations where fish are maintained in a near-pristine condition until the point of sorting.	the fishing vessel. Damage to the hauled fish is negligible and therefore post-release mortality of discarded fish is expected to be very low. **Vacuum pumping from the cod end.**[17] Research is ongoing in Norway to develop a vacuum system that pumps cod from the trawl net to the vessel before it is hauled on board. This is aimed primarily at ensuring quality of captured fish, although could in theory be adapted to sort unwanted fish and release them with high chance of survival. A similar system is in place in the Antarctic krill fishery to avoid the damage caused to the krill when hauling the net.[18]

[17] https://nofima.no/en/nyhet/2014/08/trawl-caught-cod-survive-with-vacuum-pumping/

[18] https://www.ccamlr.org/en/fisheries/krill-fisheries

3 Scoping novel technical ideas to improve selectivity

In this section we identify two novel concepts for technical innovation that might be developed to improve the selectivity of fishing operations. These concepts have resulted from a thought exercise that responded to the intentionally open question: "*How can the catch of unwanted fish be reduced in Scottish fisheries?*" Selectivity was considered in its broadest sense, i.e. not limited to gear modification or devices, and potentially relevant innovation was sought from beyond the fisheries sector.

Ideas are presented here as general concepts rather than detailed design blueprints. For each idea we have provided a rationale and description of the general concept, explored relevant innovation and technologies that may be useful to the development of ideas into workable prototypes, and where possible identified relevant centres of research excellence or expertise by providing links and references. We have also provided a sense of the feasibility of developing the concepts further by identifying similar ideas and innovations that are already in use.

3.1 Concept 1: Automated post-haul selectivity system

3.1.1 Concept rationale

In most fishing operations it is standard practice to sort or grade catch at or shortly after the point of it being hauled on board. Typically this sorting is not considered within the scope of 'selective fishing' as unwanted fish are usually dead or moribund before they are discarded. The poor condition of the fish at this stage is most commonly due to damage incurred in the gear during the haul, transfer onto the boat and/or handling on the deck. However, if fish can be maintained in pristine or near-pristine condition throughout the hauling process, it may be possible for the sorting and release of unwanted fish to contribute towards improving fisheries selectivity. Unwanted fish would have to be released in a state in which survival in the long term is highly likely for this concept to be truly considered to improve fishery selectivity. For most Scottish fisheries, especially those using trawl and purse seine gears, this would require a substantial change in the processes and mechanisms by which fish are transported and handled on and around the vessel.

3.1.2 Concept description

A post-haul selectivity system would allow for fish to selected based on specific characteristics (e.g. species, size), with unwanted fish released directly into the sea. The system would eliminate or substantially reduce the damage caused to fish during the hauling and handling process, ensuring that released fish have a very high probability of survival in the long term.

An effective post-haul selectivity system would likely require the following elements:

- A low impact transport system that removes fish from the gear, passes them through a 'selection process', and finally transports them either back to the sea or into storage containers on board the vessel; and
- An automated selection process that rapidly identifies unwanted fish and separates them from the retained catch.

The technical mechanisms for both of these elements have been partly or fully developed previously in the fisheries sector, although not in the context of selectivity at the post-haul stage. In the case of low impact transport systems, these have been developed independently in at least two fisheries (Antarctic krill and Norwegian cod) for the purpose of achieving high product quality.[19] The process of identifying wanted/unwanted fish, specifically for the purposes of improving selectivity, has been automated and several 'fish selector' products that utilise cameras and identification software are available commercially. However, it is not clear to what extent these existing technologies would be directly transferrable into a post-haul selectivity system. See the following Section 3.1.3 for a further discussion.

A post-haul selectivity system would likely be feasible only for certain species, fisheries or hauls where fish are not seriously or fatally injured during the capture and haul process. Considerations regarding the feasibility of a post-haul selectivity system include the following:

- The gear type and the extent of mechanical damage it causes fish;
- The species and its susceptibility to damage during the fishing operation;
- The depth of the fishing operation and the duration of the trawl; and
- The composition of species in the catch.

For instance, deep water species would probably not be suitable as they are often killed during the haul due to rapid decompression. Similarly, certain species are more susceptible than others to receiving physical injuries through abrasion with the netting mesh, crushing in the cod end or interaction with (or predation by) other species, and consequently have lower probability of survival in either the short or the long term.

There is some question as to whether a post-haul selectivity system such as this would be applicable in the context of the EU landing obligation or any future UK version of this policy. The landing obligation, as set out in Article 15 of the CFP Basic Regulation, states that catches cannot be returned to the sea, but is ambiguous in precisely how catches are defined. This definition is likely to be fundamental in how a post-haul selectivity systems is designed, for instance where and in what manner captured fish are transported, sorted and released. The landing obligation also includes an exemption for species with a high probability of survival post-release. This may also provide an opportunity for the existence of a post-haul selectivity system, assuming high post-release survival of unwanted fish can be demonstrated. However, it is not clear at what level this exemption can be applied, for instance whether exemptions can be applied at a species-fishery-gear level.

3.1.3 Sources of innovation

The main technological components required in the conceptual post-haul selectivity system already exist, namely pump transport systems and in-gear 'fish selectors', and some designs have previously been trialled in the fisheries sector (see below). It is noted, however, that these systems are not necessarily suitable for the intended task in their existing form. Below we have identified and discussed low impact transport systems and automated fish selection that may provide useful starting points for developing fit-for-purpose post-haul selectivity system designs for use in Scottish fisheries.

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[19] We note that various pump-based transportation systems exist for moving (primarily dead) fish through processing systems; these are not considered at low impact systems, e.g. http://www.afak.nl/products/fish-processing-trawlers/afak-fish-vacuum-pump-systems.

Low impact transport systems

Fish pumps used in fisheries, aquaculture and fish passage

The use of fish pumps and elevators to transport live fish without causing damage is well established in the aquaculture sector and in small pelagic capture fisheries. Fish pumps typically use pressure vacuums (larger fish) or centrifuges (smaller fish) to move fish through pipes between ponds/tanks (aquaculture) or from nets onto the vessel (small pelagic fisheries), while fish elevators are usually based on an Archimedean screw design and are used to move fish between different heights. Fish pump technology is most developed in the aquaculture industry, where numerous commercial pump designs have been developed that vary in their capacity, power and mobility. Commercial suppliers in the UK include:

- IRAS (http://www.iras.dk)
- CFLOW (http://www.cflow.no/index_e.php)
- ETI Transvac (http://www.transvac.com)
- AFAK (http://www.afak.nl/products/fish-processing-trawlers/afak-fish-vacuum-pump-systems)

A slight variation on the theme of moving fish is the use of pumps to provide passage to fish around obstacles or remove them from vulnerable locations, such as drying rivers. The technology involved is very similar to fish pumps used in aquaculture. A commercial example of this type of system has been developed by Seattle-based Whooshh Innovations[20], which has developed a line of mobile, trailer-based pump systems that work on the principle of pressure differentials. This system, which has mostly been used to transport salmon species, is claimed to move up to 60 fish per minute with a relatively short transport distance (i.e. 20 m), with this rate reducing as the transport distance increases.

The use of low impact fish pumps to transport living fish from net to vessel has been trialled in at least one demersal fishery. Research is ongoing in Norway to develop a vacuum system that pumps cod from the trawl net to the vessel before it is hauled on board.[21] This is aimed primarily at ensuring quality of captured fish, although could in theory be adapted to sort unwanted fish and release them with high chance of survival. The research is part of the Centre for Research-based Innovation in Sustainable fish capture and Pre-processing technology (CRISP) project, which is focused on research-based innovation in sustainable fish capture, quality and economics. The project is financed by the Research Council of Norway.

Automated fish selection

Fish identification for selectivity purposes or fisheries research

Underwater video systems are widely used for counting and measuring fish in aquaculture, fisheries, and conservation management. To determine population counts, spatial or temporal frequencies, and age or weight distributions, length measurements are performed in video sequences, most commonly using a point and click process by a human operator. Current research aims to automate the identification, measurement, and counting of fish in order to

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[20] http://www.whooshh.com/passage-rescue.html

[21] https://nofima.no/en/nyhet/2014/08/trawl-caught-cod-survive-with-vacuum-pumping/

improve the efficiency of these systems. A fully automated process requires the detection and isolation of candidates for measurement, followed by the length measurement itself and species classification. There may also be need for the counting and tracking of individual fish.

There are a number of prototype systems in development or available commercially for identifying the species and/or size of fish automatically using images or video. Once such system under development is Deep Vision[22], developed by Scantrol Deep Vision AS, which takes constant stereo images of all objects passing through a trawl. These images can be used to identify and measure fish inside the gear, transmitting this information to a computer on the bridge. The stated objectives of this system are to improve fisheries surveys by employing new, non-lethal techniques or providing evaluation of the trawling methods presently used. Currently Deep Vision is not used with the aim of improving the selectivity of fishing, although the developers note that this is a possible application of the system.

3.1.4 Considerations for future research and development

Here we have identified a basic concept for an automated post-haul selectivity system that we consider is a viable approach for improving selectivity in certain Scottish trawl fisheries. This concept provides the visionary basis for a future programme of research and development that aims to develop a working prototype. If FIS should choose to take this concept further the following considerations should serve as a guideline for defining a suitable research and development project.

Considerations	Details
Goals and objectives	A project should aim to develop a prototype post-haul selectivity system. This project should involve a number of key stages: full feasibility study to determine candidate fisheries for trials; research and development phase where technologies are designed/adapted; and testing and refinement phase.
Size of project (duration / total cost)	Given the technology currently available, it is considered that this research and development project might run between 24 and 48 months with an approximate budget > £150,000. Note that the anticipated size of the project is illustrative only. The duration and cost of projects will vary depending on the contractor and their access to/experience with existing similar technologies.
Technical expertise required	The components of the conceptual system require expertise in fish/low impact transportation, fish/product identification systems, engineering and automation. Note that the project would likely require collaboration with the fishing sector, e.g. undertaking at-sea trials. This activity cost may depend whether the fisherman wants compensation if catches are reduced during the trial.

3.2 Concept 2: Automated pre-capture avoidance system

3.2.1 Concept rationale

Avoiding fish before they enter the net is arguably the ideal stage of the fishing operation for selection to occur as it eliminates all interaction between fish and fishing gear. A number of devices and practices are already available to facilitate the avoidance of unwanted species

[22] Further information and promotional video at: http://www.deepvision.no/deep-vision/deep-vision

pre-capture, which rely on provoking or exploiting a specific behavioural response from unwanted fish. For example, acoustic pingers are used to deter cetaceans from entering nets, and some specialised gears, such as the coverless trawl, are shaped in such a way as to allow certain unwanted species to escape over the top of the net. These devices and net designs have been shown to be successful in many cases, although they remain a passive measure and cannot easily be controlled or adapted by fishers to suit different situations.

Fishers may also use certain tactics to avoid or allow the escape of unwanted fish before they enter the net. For example, the position of some mid-water trawls in the water column can be changed by controlling the pitch of specially designed doors[23] in order to target only a certain part of a shoal, or demersal trawl fishers can temporarily slow the speed of tow to allow unwanted fish to escape from the path of the net. In both of these examples, fishers rely on real-time information on the underwater environment to be able to enact these tactics, which may, for example, come from cameras fitted to trawl headlines or echo sounder devices. However, the quality of this information is limited by the technology available (e.g. cameras that require minimum light levels) and requires fishers to quickly process and act upon a potentially large amount of information.

Given the limitations of existing technologies and tactics, there is therefore scope to develop a pre-capture avoidance system that is both more advanced in its ability to capture information on fish before they enter the net and to assist fishers in manipulating the fishing operation to ensure that unwanted fish are avoided.

3.2.2 Concept description

An automated pre-capture avoidance system for fish would be able to identify and track fish in the path of the net and subsequently manipulate the gear shape, position or characteristics such that unwanted targets are avoided. (This system could also potentially be utilised to increase the capture of desired fish).

This vision of an automated pre-capture avoidance system would likely consist of:

- A real-time sensory system that is capable of collecting and interpreting information on fish (e.g. species, size) in the immediate path of the net; and
- A gear design or configuration that can be controlled (autonomously or manually) to change shape and/or position to allow for the avoidance of unwanted species (and potentially to maximise the capture of desired species) in response to sensor-derived information.

This concept would likely be a feasible solution for all mid-water and demersal trawl fisheries, although it would probably be most suitable for demersal whitefish fisheries. This is both due to the need for the system (e.g. the critical issue of avoiding unwanted non-quota species in mixed fisheries) and the way in which demersal whitefish interact with trawl gear (i.e. fish will typically flee the net by swimming in front of it, allowing opportunity for evasive manoeuvres).

3.2.3 Sources of innovation

Some technical elements of this conceptual pre-capture avoidance system exist (partially or wholly) and are already used to some extent in the fisheries catching sector. For instance, fish

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[23] See for example http://www.notus.ca/trawlmaster-for-single-trawls/.

identification systems exist that are able to distinguish between different species and sizes when fish pass into the net, examples of which are described in Section 3.1. However, these systems operate only within very specific practical limitations, for example requiring fish to pass through a chamber to be photographed. There have been some promising advances in non-image based sensors, such as acoustic broadband echosounders,[24] although this research has been focused mainly at discriminating between pelagic rather than demersal fish species.

In term of gear manipulation, several commercial systems are already available that allow for control of fishing gear when it is in the water, some of which utilise sensors to feedback information to the fisher on the behaviour of the gear in real-time.[25] To our knowledge, however, none of these system are capable of making autonomous adjustments based on pre-determined rules or real-time information on the surrounding environment.

Noting existing technical innovations relevant to this concept that are already being explored in the fisheries sector, much of which is taking place in Scottish fisheries,[26] we have identified driver-less car technology as a research area that may be useful in future development of a pre-capture avoidance system. This technology is described briefly below.

Driver-less car technology

Autonomous vehicles use a 'sense-plan-act' design, which underpins many robotic systems.[27]. They utilise a suite of sensors (including lidar, radar, ultrasonic and infra-red sensors) which are placed around the vehicle to gather raw data about the outside world and the vehicles relation to the environment. Software algorithms then interpret these data and use it to decide the vehicles action, for example whether to accelerate or change direction. These plans are then converted to actionable commands to the vehicles control system. To determine the location of the vehicle on the road, GPS is utilised often in combination with inertial navigation systems. Telematics are also used to transfer data to and from moving vehicles.

The technological ability of vehicles has been arranged in a continuum, ranging from no automation (driver in complete control) to full self-driving automation (however in reality this will be difficult to fully achieve). Computer algorithms can rapidly evaluate, compare and select and then execute the best option from several potential manoeuvres taking into account speed, position and behaviour of other vehicles, obstacle trajectory, and the utility of various outcomes, potentially avoiding mistakes made by human drivers. Sense-plan-act loops can run in parallel, some at extremely high frequencies to allow for rapid emergency response and others much slower to plan and execute much more complex behaviours.

Camera-based systems can be used to see very long distances and provide rich information. They are relatively inexpensive technology however they are associated with limitations, such

[24] See for example: https://www.wur.nl/en/project/Fish-species-identification-from-acoustic-broadband-data.htm

[25] See for example: http://www.notus.ca/trawlmaster-for-single-trawls/.

[26] For instance, FIS project FIS04 'Slippage mitigation and acoustic characterisation (SMAC)' completed in 2015.

[27] http://www.rand.org/pubs/research_reports/RR443-2.html

as inability or reduced effectiveness to see in non-ambient or changing conditions and they are also not as sophisticated as humans at interpreting visual data.

UK-based researchers have been involved in the development of autonomous vehicles, and eight projects in the UK have recently been awarded £20 million in funding to research and develop enhanced communication between vehicles and roadside infrastructure.[28] This money has come from the UK Intelligent Mobility Fund. Google also has a Driverless Car Initiative which has developed and tested a fleet of cars.[29]

3.2.4 Considerations for future research and development

Here we have identified a basic concept for an automated pre-capture selectivity system that we consider may be a feasible approach for improving selectivity in Scottish trawl fisheries. This concept provides the visionary basis for a future programme of research and development that aims to develop a working prototype. If FIS should choose to take this concept further the following considerations should serve as a guideline for defining a suitable research and development project.

Considerations	Details
Goals and objectives	It is unrealistic for a single, short-term research project to develop a working prototype of the conceptual pre-capture selectivity system. Instead it is recommended that the main components of the system are developed in separate modules or work packages of a long term research programme (5+ years). At least three work packages (WPs) should be established to achieve the ultimate goal of a pre-capture selectivity system. Initially, two work packages should be created with the goal of developing and trialling the component features of the concept – fish identification/tracking (WP1) and gear control/manipulation (WP2) – and a final work package should combine these components into a complete working prototype (WP3). These separate WPs should be centrally managed as part of a research framework to ensure coherence between them (e.g. objectives, timeframes).
Size of project (duration / total cost)	WP1: 24-48 months; > £500,000 WP2: 18-36 months; > £300,000 WP3: 12-18 months; > £100,000 Note that the anticipated sizes of the work packages provided above are illustrative only. The duration and cost of projects will vary depending on the contractor and their access to/experience with existing similar technologies.
Technical expertise required	WP1: Sensory systems; information technology WP2: Engineering; automation; fishing gear design WP3: Gear trials Note that all WPs would likely require collaboration with the fishing sector, e.g. undertaking at-sea trials.

[28] https://www.gov.uk/government/news/driverless-cars-technology-receives-20-million-boost
[29] https://www.google.com/selfdrivingcar/how/

4 Identifying challenges to improving selectivity

4.1 Pathway to developing selective gears and practices

There has been considerable effort from within the Scottish and wider UK fisheries sector to develop more selective gears and fishing practices. The development of these selective measures can be broken down into four successive phases: drivers of change, development of solutions, uptake of solutions and solutions in place (Figure 1). Analysing these phases and the role of each in achieving the ultimate goal of more selective fishing is useful in identifying where innovation might be needed.

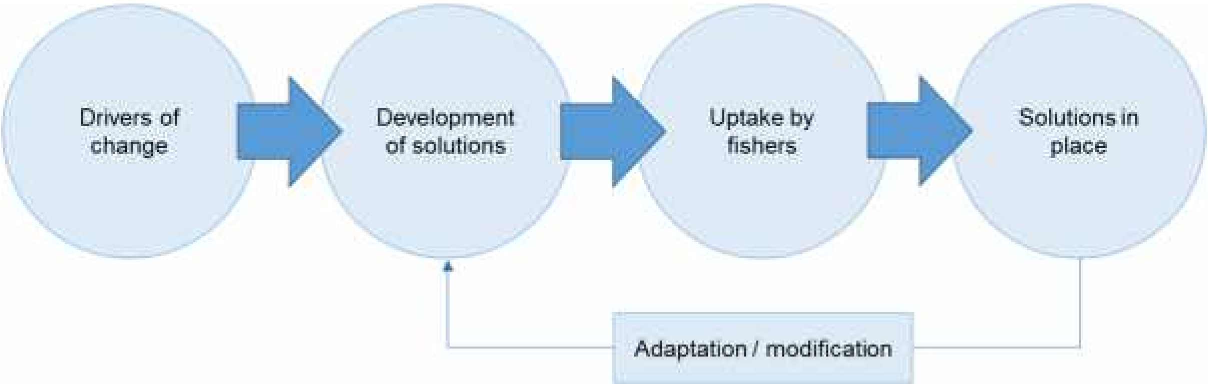

Figure 1 Conceptual view of the pathway to developing and using selectivity solutions.

In general, the pathway to improving selectivity proceeds as follows:

1. One or more **drivers of change** act on key actors to encourage or force a change to happen. In the Scottish context, these key actors are those with a business or management stake in the fisheries catching sector, which includes skippers and crew, vessel owners, producer organisations, fishers' associations and management authorities. Currently the most critical driver for improving selectivity is the EU landing obligation, although regulator and economic influences such quota allocations and operational costs are also important.
2. Solutions for more selective gears and practices are taken from concept to finished product within the **development stage**. In the case of selective gears and devices, ideas may begin with fishers or research scientists and be developed into prototypes with input from technical experts (e.g. net makers). Prototypes are often but not always subjected to trials in flume tanks and/or at sea, usually in collaboration with research scientists, before designs become finished commercial products. In the case of selective practices and techniques, fishers may experiment with and adapt these with limited external input, except perhaps undergoing scientific trials to assess the performance of the technique.
3. New selectivity solutions are made available to fishers in the **uptake stage** with the hope they will be widely adopted and used. This may involve the marketing of gears and devices for sale, or the dissemination of information about a technique for improving selectivity. In some cases uptake will be actively promoted, such as by a producer organisation, whereas in others there will be limited intent or effort made to ensure wide uptake, for instance where a fisher hopes to achieve a competitive advantage using a bespoke gear modification. The promotion of uptake may involve

considerable effort by a number of organisations to demonstrate the benefits of the solution and to allay concerns fishers may have in using it.

4. Assuming uptake is successful, the end of the pathway is reached when the **solutions are in place.**. There may, however, be some attempt made to improve the design or technique through adaptation and modification, which loops back to the development stage.

In this project we have focused on the development and uptake phases of the selectivity pathway. These phases consist of a number of separate stages (in the development phase) or considerations (in the uptake phase) that are important in achieving their outcomes, i.e. the development of a selective gear or practice and its uptake by fishers. The main stages/considerations to consider within each phase are listed below. Note that this list mainly relates to the development of technologies rather than behavioural techniques to improve selectivity.

4.1.1 Stages of the development phase

The following stages can be considered to follow on from each other in an approximately chronological order, although certain stages may not feature in the development of all solutions (e.g. some gears will not undergo scientific trials).

- **Ideas and design concepts for a solution.** Ideas may be for novel designs or devices or, more commonly, inspired from designs used in fisheries elsewhere. Ideas can arise from anywhere but generally come from fishers, researchers or gear experts. They usually address a very specific need to fish more selectively and therefore often relevant to a particular gear fleet or gear type.
- **Expertise and material resources to develop concepts further.** Developing an idea or design concept typically requires technical expertise in gear design, engineering, manufacturing and/or materials. Fishers and researchers will commonly work with net makers to develop prototype selective gears and devices or draw on relevant expertise within research institutes.
- **Funding to cover financial costs of design, manufacturing and expenses.** The costs of developing prototypes can vary considerably depending on the nature of the design, e.g. materials used or complexity of design. These costs may be met by net makers or more commonly through funding streams, such as the European Maritime and Fisheries Fund (EMFF). The Gear Innovation and Technology Advisory Group (GITAG) plays an important role in providing development projects in Scotland with financial support.
- **Financial or opportunity costs incurred in trialling design.** Selective gears and devices usually undergo sea trials that bear direct financial or opportunity costs on fishers (e.g. vessel charter, fuel, forgone catch or effort). Scottish government is often able to partially or fully compensate forgone catches by awarding fishers with additional catch quota or days at sea. Direct financial costs can often be met through funding (see previous point on design and manufacturing costs).
- **Permission to undertake trials.** Trialling new or modified gears very often requires fishers to seek permission from Marine Scotland to use an unregulated gear or component. Permission is generally given in the form of a derogation from gear regulations, although this process is potentially cumbersome.

- **Practical and technical capacity for undertaking scientific trials**. Not all solutions undergo scientific trials. Those that do generally require collaboration with research institutions with the technical expertise to develop a robust experimental design and collect and analyse data.

4.1.2 Considerations in the uptake stage

The following considerations are considered to be mutually exclusive of one another but are not listed in any particular order. The bearing of each of these considerations on the uptake of a given selective gear or practice is likely to vary considerably depending on its design, the fishing method it is aimed at and the incentive fishers have to improve selectivity.

- **Awareness amongst fishers that a solution is available.** Selectivity solutions are usually developed within a relatively closed group. For uptake to occur beyond that group, fishers in the wider world must be made aware that a potential solution is available.
- **Costs of purchase and installation of selective gears and devices.** The expense of adopting a gear modification or device is a critical consideration to all fishers. Ultimately uptake of a solution will be low if the costs associated with adopting it are not economically viable.
- **Scale and extent of negative impact on target catch rates.** Separate to purchase and installation costs, the losses in catch associated with operating a selectivity solution may be unacceptable to fishers and therefore limit uptake. These losses may or may not be offset by credits or incentives awarded for using a more selective gear.
- **Willingness to try a solution**. Most fishers are expected to change their behaviour when the incentives are right to do so. Some fishers, however, may show a reluctance to adopt a gear modification, device or technique regardless of the potential benefits. This might be due to an unwillingness to break habits or traditions, or might stem from a mistrust of the information presented to them.
- **Understanding how device or modification affects gear behaviour in the water**. Fishers may have doubts regarding how a new or modified gear will behave in the water, compared to their current gear, and how this will impact catches or their safety.

The components of the development and uptake stages listed above broadly represent the status quo in improving selectivity through changes in gear and fishing practices. There is potential for each of these components to hinder or even block the development and uptake of selective gears, devices and techniques. These potential roadblocks, and possibly solutions to limit or remove them, are examined in the following section.

4.2 Challenges to overcome

The section above describes the pathway for the development and widespread use of selective gears and practices. Two phases of this pathway – the development and uptake stages – can be broken down into separate components. Progress can be slowed or blocked at each of these points due to a wide range of issues, including inefficiencies, failings, a lack of resources and human behaviour. In this section we identify these issues, which we term ‘challenges’, and begin explore possible ways to avoid or overcome them. Note that we focus on challenges where innovation has the potential to achieve progress and do not consider solutions to financial and regulatory roadblocks in the development phase.

The key challenges and risks to the development and uptake phases of the selectivity pathway, and some potential solutions (at the broadest level) to overcoming these challenges are summarised in Table 2 and discussed further below.

Table 2 Challenges, risk and potential solution for the development and uptake of selective gears and practices.

Phase / stage	Challenges	Potential solutions
Development stage		
Ideas and design concepts for a solution	No knowledge that a potential solution (technical or behavioural) already exists elsewhere, i.e. inspiration Fishers do not feel they have the prerogative or support to develop their own ideas 'Home grown' selectivity ideas are being protected (due to confidentiality/competition reasons) or are not being captured and developed further	Share knowledge of selective gears and practices used in other fisheries and/or parts of the world with fishers and scientists Stimulate and incentivise fishers to think up new ideas that might work in their personal context Create incentives for fishers to share ideas and designs for selective gears and practices
Expertise and material resources to develop ideas further	Designers[†] have limited experience in gear design or engineering Designers have limited knowledge of or access to appropriate materials for developing prototypes (e.g. lightweight, durable plastics) Designers have no or limited access to manufacturers of design components (e.g. plastics or metalworkers)	Improve access to technical experts, e.g. net makers, product designers, industry developers Promote collaborations between different expert groups (e.g. fishers with practical fishing knowledge, net makers with technical gear knowledge and product designers with expertise in materials and design principles)
Uptake stage		
Awareness amongst fishers that a solution is available	No knowledge that a solution has been developed and is available Partial or incorrect information about the availability of a solution (e.g. fishers know about a device but wrongly believe it is not applicable to their situation)	Improved communication and promotion of specific solutions Awareness campaigns about selective gears and practices
Understanding of how device or modification affects gear behaviour	Fishers cannot observe or visualise how a selectivity solution will affect gear behaviour or fishing dynamics	Means to observe gear dynamics underwater, e.g. cameras, sensors

[†] Designers are primarily fishers, net makers and researchers but could include almost any individual or group e.g. product designers.

4.2.1 Challenges to development

In the development phase, two stages in particular face potential challenges that can limit or slow the design and building of selective gears and devices: ideas and design concepts for a solution, and expertise and material resources to develop ideas further. Through our investigation of selectivity work in Scotland and the UK more widely we found that limited availability of information about selective gears and practices was considered to be hindering the development of new and effective design ideas. The premise is that exposure to ‘success stories’ and examples of selectivity measures from elsewhere stimulates fishers to develop their own ideas. This is not to say that relevant information is not available – on the contrary, there exists a considerable amount of scientific research reporting on trials of selectivity measures, and there is also some useful literature aimed specifically at fishers. Rather, this information is not always being communicated effectively to fishers and other players in the catching sector, which is considered to be limiting the development of ideas and concepts by fishers for more selective fishing methods.

Limited access to appropriate expertise and material resources was also identified as a barrier to developing selectivity ideas further, although to a much lesser extent than information. In this situation expertise might include gear technologists, product designers, materials experts and others with expert knowledge of gear manufacture and engineering. It should be noted that in Scotland there is extensive collaboration between fishers and net makers and/or researchers (e.g. via GITAG) in developing selective gears. However, there may still be need to improve on how these collaborations are formed, or enrich them further with introduction of expertise from beyond the fisheries sector (e.g. TrawlLight; a collaboration between Youngs Seafood, Cefas and SafetyNet Technologies). With respect to material resources, we found that, in general, the materials currently available to designers of selective gear are considered to be sufficient. This includes the materials used in netting (e.g. polyurethane, nylon) and for selective devices such as panels and grids (e.g. metal or plastics).

4.2.2 Challenges to uptake

In the uptake phase, challenges in two of the considerations in particular may limit the adoption of solutions by fishers: awareness that a solution is available and understanding how device or modification affects gear behaviour in the water.

Through discussion with those involved in promoting selective gears and practices we found that there is only a moderate (albeit varying) level of awareness amongst fishers about the existence of certain selectivity solutions or measures. This is most likely to be true of newer designs, such as certain separator grids or panels, as awareness of more established measures - and certainly measures that are required through regulation (e.g. square mesh panel) - is generally high. Given that awareness is a fundamental first step in the uptake of selective gears or practices, careful consideration of how to build fishers’ awareness of new and emerging selectivity solutions is warranted.

Fishers’ understanding of a new selective gear or device is very important in their decision on whether to adopt it or not. From our discussions with gear technologists and Marine Scotland Science researchers it was clear that fishers’ are keen to understand how a particular gear modification or device will change how the gear behaves in the water. This is understandable, as even small changes may alter fishing efficiency or affect their safety at sea, and fishers must learn how to master the new gear. Interestingly, this challenge to uptake has been identified by observing how fishers have responded positively to viewing video footage of gear trials, rather than from fishers explicitly reporting that this is a major consideration to them in adopting a selective gear.

5 Strategic work plan for improving selectivity

This section identifies keys areas or themes where innovation and fresh ideas would be beneficial to foster more selective fishing in Scottish fisheries. This is presented as a strategic work plan that outlines a number of work themes that address the challenges to developing and rolling out selective gears and practices, as identified in the previous sections. For each of these themes we provide a short summary of relevant existing initiatives currently running in Scotland or the UK more widely, and also provide a number of novel ideas and approaches to illustrate the types of projects that might be appropriate. These are drawn from within or outside the fisheries sector. We also outline the main goals and objectives, approximate timelines, costs, and partnership opportunities.

The work themes of the strategic plan, all of which are aimed at improving development and/or uptake of selective gears and practices, are:

Theme area	Work theme name
Cross cutting initiatives for improving development and uptake	Theme 1: Communication and exchange of knowledge
	Theme 2: Raising awareness and incentivising fishers
	Theme 3: Facilitating interdisciplinary collaboration
Specific initiatives to increase uptake	Theme 4: Visualising gear behaviour & fishing operations

5.1 Theme 1: Communication and knowledge exchange

In the context of selectivity, a critical aspect of communication and knowledge exchange is learning of existing selectivity solutions used in fisheries elsewhere and using that knowledge to develop locally-relevant designs, adaptations or offshoot ideas. It is also important in increasing awareness of the need to fish more selectively and can influence fishers' willingness to try different gears, devices and techniques.

5.1.1 Existing initiatives within the fisheries sector

Those with a role to play in communicating and receiving information are skippers and crew, fishing companies, producer organisations, and government departments and agencies. Knowledge sharing within and between these groups has been practised traditionally, and will continue to be a vital part of the purpose of professional associations and collaboration in research. There are already many established ways that information and knowledge is shared, e.g. word of mouth, message boards, newspapers, magazines and social media.

Four examples of existing communication and knowledge exchange initiatives in the UK and Scottish fisheries sector aimed at fishers and industry groups are:

- **Gear Innovation and Technology Advisory Group (GITAG).** Part of GITAG's mandate is to "*establish knowledge dissemination routes and suitable vehicles, ensuring fullest possible industry* coverage". To date this has been done mainly through publishing news and articles on the Scottish Fishermen's Federation's website, and also through attending meetings and conferences.

- **Marine Scotland via the project DiscardLess.** The MariFish-funded DiscardLess project intend to publish a Selectivity Manual and gear factsheets before the end of November 2016. Following from this publication, Marine Scotland Science have committed to ensure industry and NGOs are made aware of these knowledge products.
- **Seafish magazine *Quay Issues*.** This is a magazine for the fishing industry and tells some of the stories uncovered during the Seafish annual Fleet Survey. *Quay Issues* looks at some of the challenges facing the industry and the creative and innovative approaches fishing vessel owners around the country are taking to overcome them. Issue 2 included content on developing selective gear, which has also been filmed as a YouTube segment.[30]
- **Seafish gear technology courses.** Seafish Gear Technologists run training courses for fishermen, often funded through the EU, in trawl gear technology and selectivity. These courses have been held mainly at the Sintef Flume Tank in Hirtshals, Denmark. Recent courses have been structured around a standard gear syllabus that is relevant to all trawling and covers the principles of trawl gear and selective modifications and devices.

Each of these existing initiatives have strengths and weaknesses, and some have been implemented more successfully than others. We have not attempted to evaluate their performance within the scope of this study.

5.1.2 Initiatives outside the fisheries sector

A number of potential communication and knowledge sharing initiatives not widely used in the fisheries sector, but potentially of value, are described below. We are not advocating these initiatives in particular, but rather including them as an illustration of the types of projects that might be considered by FIS as part of the strategic plan.

- **Knowledge exchange roadshows.** Roadshows are intended to encourage knowledge exchange by facilitating interaction between different stakeholder groups. An interesting case study is ‘Meet the Scientist’, a component activity of LifeLab. [31] This is an educational intervention being piloted in Southampton that is aiming to improve young people’s health and inspire an interest in science. A Meet the Scientist session provides secondary-level students with opportunities to talk with research scientists on an informal basis, and in so doing to explore or challenge their views of science and scientists.
- In applying this approach to fisheries, roadshow events could be organised at fishing ports throughout Scotland, inviting fishers to learn about ongoing selectivity research

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[30] Available at: https://www.youtube.com/watch?v=GqQbozSe9Gc&index=2&list=PLjmL1YNydu1HaT61DkNOT8XEIXpxe3jqm. Accessed 22nd September 2016.

[31] Details are available at: http://www.southampton.ac.uk/per/stories/case_studies/meet_the_scientist.page?. Accessed 19th October 2016.

and its potential applications to fishing activities. This would promote awareness of available solutions and enable liaison between researchers and fishers.

- **Sharing positive experiences with social media.** This is an approach designed to share positive experiences at a peer-to-peer level by utilising society's participation in online social networks. An example of this approach is 'PhotoVoice', an image-based method developed by researchers at Edinburgh University as a way of capturing and understanding people's lived experience in relation to recovering from alcohol-related harm.[32] Whilst the subject matter is very different to the selectivity context, the general aim – to share experiences between peers – is relevant, as is the mechanism by which to achieve this.
- In the context of Scottish fisheries, this approach might be used to encourage fishers to promote a certain selective gear or practice by sharing the results using photographs (e.g. composition of a haul taken with a phone camera) and social media.

5.1.3 Considerations for future initiatives

If FIS should choose to take this communications and knowledge work theme further the following considerations should serve as a guideline for defining a suitable project.

Considerations	Details
Goals and objectives	To develop and implement a pilot scheme that promotes communication and knowledge exchange with respect to selectivity measures within Scottish fisheries. The specific objectives should be sharing knowledge of existing selectivity solutions used in fisheries elsewhere and providing fishers and researchers with that knowledge and encouraging them to develop locally-relevant designs, adaptations or offshoot ideas. The project must consider a mechanism for tracking and measuring the success of the scheme.
Size of project (duration / total cost)	9-12 month pilot scheme, with opportunity for one year extension depending on success. Suggested budget of between £40,000 and £60,000 for the pilot scheme. This range covers mainly remote stakeholder engagement at the lower end and at the cost of top of the higher end would be determined by the level of physical stakeholder engagement.
Expertise required	Communication; knowledge exchange initiatives; stakeholder engagement; innovation support and business development support

5.2 Theme 2: Raising awareness and incentivising fishers

Many of the measures outlined in the previous section on communication and knowledge exchange play an important role in raising awareness and incentivising fishers to develop their own ideas for improving selectivity. In addition to the potential innovation ideas described in that section, here we highlight some existing and novel ideas that may be useful for raising awareness and incentivising Scottish fishers.

[32] Details are available at: http:/www.ed.ac.uk/arts-humanities-soc-sci/research-ke/support-for-staff/knowledge-exchange-resources/ke-projects/utilising-photovoice. Accessed 19th October 2016.

5.2.1 Existing initiatives within the fisheries sector

Two existing initiatives that aim to raise awareness of selectivity issues and incentivising fishers to develop solutions are:

- **Gear Innovation and Technology Advisory Group.** The first phase of this initiative aimed at encouraging individuals or groups of skippers to come forward with innovative proposals and conduct initial gear trials. Phase two will involve the industry and gear technologists coming together to develop and assess further trials with the purpose of assisting skippers maximise the potential of their ideas and meeting their responsibilities under the discard ban. It is understood that this phase will also look to work with all sectors to develop gears that will offer a choice of options and solutions over the coming years. A second application for funding is being submitted to the Scottish Government and European Maritime & Fisheries Fund for financial support running to 31 December 2019.
- **Marine Scotland via the project DiscardLess.** DiscardLess will provide the knowledge, tools, and methods required for the successful reduction of discards in European fisheries. To achieve this, DiscardLess will work through collaborations between scientists, stakeholders and policy makers to support and promote practical, achievable, acceptable and cost-effective discards mitigation strategies, and to make the EU landing obligation functional, credible and legitimate.

5.2.2 Initiatives outside the fisheries sector

- **Champions of change.** This approach seeks one or a small group of individuals who have experienced success with an idea or tool and go on to actively champion the idea amongst their peers. Nominations can be invited from stakeholders within a sector, allowing champions to be selected by their own peers. The achievements of the selected champions can then be publicised beyond their sector, and the champions can act as agents of further change in their professional and social networks.
- In the USA the Obama Administration operates a ‘Champion of Change for Sustainable Seafood’ Programme, which requests nominations in order to identify champions who are contributing to the recovery of the fishing industry and associated communities in America. A diverse range of fisheries stakeholders are eligible for nomination, including fishers, seafood sellers and processors, chefs, business owners, aquaculture professionals and community leaders. Previously selected champions are displayed and celebrated on the White House website, providing publicity for progress in seafood sustainability through highly visible media. The White House also runs other champion programmes addressing a range of issues including college education access, climate change, gender equality and innovation in manufacturing.
- Another similar ‘Champion of Change’ programme is operated by the Rotary Club of Great Britain and Ireland, which invites nominations for club members in order to recognise exceptional achievements in international social and humanitarian work.

With regard to Scottish fisheries, a scheme similar to the above examples could be operated through the national government, allowing stakeholders from throughout the fisheries sector to be identified as national fisheries champions by their peers. The chosen individuals could be mandated as ‘champions of change’ and encouraged to deliver outreach and communication activities which will increase engagement with selectivity and innovation among their peer groups.

5.2.3 Considerations for future initiatives

If FIS should choose to take this awareness raising and incentivising work theme further the following considerations should serve as a guideline for defining a suitable project.

Considerations	Details
Goals and objectives	To develop and implement and pilot scheme that aims to raise awareness of available technical selectivity measures and incentive Scottish fishers to adopt these. This initiative should be primarily focuses on existing solutions, but may also sever to promote new solutions that are currently undergoing development. The project must consider a mechanism for tracking and measuring the success of the scheme.
Size of project (duration / total cost)	12 month initiative, with opportunity for two year extension depending on achievements. Suggested budget of between £20,000 and £40,000 for the initial one-year initiative.
Expertise required	Communication; knowledge exchange and awareness initiatives; stakeholder engagement; business development support (cf. decision making advice)

5.3 Theme 3: Facilitating interdisciplinary collaboration

In any design situation, collaboration between groups with different expertise can result in novel and exciting ideas, and interdisciplinary collaboration is likely to be important, or even necessary, in the design and production of cutting edge technology to improve selectivity.

5.3.1 Existing initiatives within the fisheries sector

In Scotland and the UK more widely there has extensive collaboration in developing selective gears. One such promising example of collaboration extending outside of the fisheries sector is the SafetyNet project:

- SafetyNet Technology is a London-based start-up with a goal to design and build devices to increase the selectivity of commercial fishing practices. SafetyNet has been building LED systems to enable experimentation into how light can segregate between ages and species of fish, and is applying that knowledge to create simple sets of lights to help fishermen catch the right fish. The company is made up of a team of engineers and communicators and has been collaborating with fishery scientists and seafood companies to turn their theories into testable devices.

Furthermore, many of the examples provided in the sub-sections above also promote collaboration between experts in different research disciplines (e.g. phase two of GITAG's programme).

5.3.2 Initiatives outside the fisheries sector

- **Open door workshops or competitions**. This approach is based around inviting innovators from other sectors to confront key challenges in developing more selective gears and practices. These might follow the format of the successful computer coding and technology event 'Fishackathon' which was launched at the 2014 Our Oceans conference with the aim of 'developing usable solutions to address the problem of worldwide overfishing' through bringing a global community of coders and scientists together to build new digital tools.[33]

- **'Dragon's den'.** This concept is derived from the television series in which inventors and entrepreneurs pitch innovate ideas or products to a panel of potential investors, who then decide whether to provide funds in support.
- This setup could be applied within a Scottish fisheries context, using a central prize funding pot, with a panel of 'dragons' selected from across the sector in order to represent research, industry, fishers and other stakeholders. Applications could then be invited for any interested parties, both within and beyond the fisheries community, to put forward innovative ideas to the panel which aim to increase the uptake and impact of selectivity measures. Sectors of particular relevance to fisheries selectivity and technology could be targeted by advertising for the event, such as engineering, computer science and manufacturing.
- **Financial incentives and support.** Funding for selectivity and innovation work in Scottish fisheries is currently available under the EMFF programme. However, a dedicated national funding incentive in support of selectivity uptake could be beneficial. The availability of small loans which are specifically designed to mitigate the initial financial burdens associated with implementing a new gear configuration. The payback scheme for these loans could be conditional on certain outcomes from the selective gear, for example on condition that certain pre-agreed indicators for improvement in catch quality/reduction of bycatch are met.

5.3.3 Considerations for future initiatives

If FIS should choose to take this work theme for facilitating interdisciplinary collaboration further the following considerations should serve as a guideline for defining a suitable project.

Considerations	Details
Goals and objectives	To facilitate collaboration between groups with different expertise with the ultimate aim to promote the design and development of cutting edge technology to improve selectivity in Scottish fisheries. This initiative should focus on developing new and novel technical solutions, similar to the exercise undertaken in Section 3 of this study.
Size of project (duration / total cost)	12 month initiative, with collaborations expected to develop independently beyond this initial facilitation initiative. Suggested budget of between £10,000 and £20,000.
Expertise required	Communication; stakeholder engagement; partnership development. Contractor should have excellent links within Scottish, UK and wider fisheries catching and research sectors.

5.4 Theme 4: Visualising gear behaviour & fishing operations

Multiple factors may hinder selectivity uptake by fishing fleets, but an important issue to highlight is a lack of understanding or confidence in how a new gear configuration will behave

[33] Further details available at: http://www.fishackathon.co/. Accessed 20th October 2016.

in at-sea conditions or affect the conducting of a fishing operation. Key aspects of underwater gear behaviour and fishing operations that might be influenced by a selectivity measure (e.g. escape panels, grids, bigger mesh size) include; the shape and positioning of the gear in the water column or on the seabed; the movement of fish through the net and catch composition; the ease of setting and hauling the gear (particularly in rough conditions), and the effect of the gear on vessel fuel consumption and efficiency. Insufficient knowledge on any of these variables may create reluctance to engage with new selectivity measures due to concerns about negative impacts on catch level/quality, economic performance, fisherman workload and safety.

In response to the situation in which fishers are reluctant to engage with new selectivity measures, a variety of experimental initiatives have been trialled which employ video monitoring technology to increase selectivity and also provide evidence on the impact of selectivity measures on fishing activities.

5.4.1 Visualising gear underwater

With regard to visualising gear behaviour whilst fishing at sea, the deployment of underwater video cameras represents a potential tool to address knowledge gaps, building on the possibility for gear to be demonstrated in flume tanks prior to use by a fishing vessel. The positioning of cameras at key areas such as a modified net mouth or a new selection grid can provide footage of gear behaviour. This enables problems to be identified in near real-time, as well as providing footage of fishing which can be used as an outreach and uptake promotion tool in order to allay fisher concerns about gear behaviour. Furthermore, with the widespread availability of cheap, robust and portable video cameras with underwater housing (for example, GoPros), underwater net monitoring technology is accessible through consumer avenues. This may provide a lower cost opportunity for at sea video recording in situations where larger or bespoke net monitoring cameras are not viable. In addition the increasing availability of affordable drone technology might be combined with cameras in order to monitor deployed fishing gear, either from the air or underwater.

Thus cameras and other recent advances in commercially available technology represent potentially powerful tools for assessing gear behaviour and other aspects of fishing operations. The use of these techniques as part of gear selectivity measures provides both a source of real-time information at sea and a means to generate evidence which can drive uptake among commercial fishers.

For example, the experimental SmartCatch project[34] has designed camera rigs (known as Digital Catch Monitoring Systems or DigiCatch) which can be attached inside the body of a trawl net and record during a fishing operation. Thus catch composition can be assessed during a fishing operation for volume, bycatch and other variables, enabling captains to make selectivity-related decisions based on real time underwater footage. The project also aims to combine this camera technology with 'SmartNet', a pre-catch release system which would enable fishers to respond to underwater camera footage and alter their gear configuration if needed, for example by opening a release panel if unwanted species were contained in the net. This project is also a good example of collaboration between stakeholders from both

[34] For further information see: http://www.smart-catch.com/. Accessed 20th October 2016.

within and beyond the fisheries sector, including experts from engineering, software development, product design, gear technology and marine science sectors.

5.4.2 Considerations for future research and development

If FIS should choose to take this gear visualisation work theme further the following considerations should serve as a guideline for defining a suitable project.

Considerations	Details
Goals and objectives	A project should aim to develop a system for help fishers to visualise the behaviour of their gear in the water. This system may be intended for short term use (i.e. during trial period of new gear) or use in the long term, depending on the value of the information to fishers' operations. This project should involve a number of key stages: a feasibility study to determine candidate fisheries for the system; research and development phase where technologies are designed/adapted; and testing and refinement phase.
Size of project (duration / total cost)	Given the technology currently available, it is considered that this research and development project might run between 24 and 48 months with an approximate budget > £120,000. Note that the anticipated size of the project is illustrative only. The duration and cost of projects will vary depending on the contractor and their access to/experience with existing similar technologies.
Expertise required	This project would primarily require expertise in visualisation technologies (sensors/cameras). It would also likely require collaboration with the catching sector, e.g. undertaking at-sea trials.

6 Additional funding sources

The table below possible sources of funding that can be used to support innovation and more generally bring about improvements in the sustainability of fisheries. At the time of writing all of these grants and funding sources are open projects focusing on improving selectivity in fisheries.

Table 3 Additional funding sources for projects that deliver or support innovation in fisheries selectivity. The geographic eligibility of the funding is shown at the Scottish, UK or European level.

Name	Funding Amount	Scotland	UK	Europe	Comments	Website link
Fishing Industry Science Alliance	150,000 GBP annually	✓	-	-	The stated aim of this funding programme is 'to conduct research to enhance knowledge on current topics of interest to the Scottish fishing industry'.	http://www.gov.scot/Topics/marine/science/FISA
Horizon 2020-Excellent Science-Future and Emerging Technologies	2.4 billion EUR Ranging from 300,000 – 4 million EUR per project	✓	✓	✓	This part of the Horizon programme has a stated focus is on collaborative research projects which can open up new and promising fields of research, technology and innovation.	https://www.mygov.scot/horizon-2020-excellent-science-future-and-emerging-technologies-fet/
Horizon 2020-Industrial Leadership-Dedicated SME Instrument	616 million EUR 2016-2017	✓	✓	✓	This portion of Horizon funding focuses on SMEs across all industries-focusing on 'high risk high-potential innovation'.	https://www.mygov.scot/horizon-2020-industrial-leadership-dedicated-sme-instrument/
Horizon 2020-Societal Challenges-Food Security, Agriculture, Marine and Bioeconomy	3.8 billion EUR total 770 million EUR 2016-2017	✓	✓	✓	In this section of Horizon 2020 piloting is stated as a possible project type, and a specific marine focus identified. This indicates the potential for new selectivity measures to be trialled with support from Horizon funds.	https://www.mygov.scot/horizon-2020-societal-challenges-food-security-agriculture-marine-and-bioeconomy/
Fisheries Innovation Fund	9.3 million USD awarded to date	?	?	-	The stated priorities of this research fund include bycatch reduction and sustainable practices in fisheries. Whilst the funding pot is US-based, there may be potential for Scottish/UK/EU based researchers to collaborate with American partners who are eligible for the fund.	http://www.nfwf.org/fisheriesfund/Pages/home.aspx
Innovate UK-Robotics and Autonomous Systems Applications Funding Competitions	5 million GBP total Individual grants 50 - 500,000 GBP	✓	✓	-	Focus on innovative applications of robotics and autonomous systems.	https://www.mygov.scot/robotics-and-autonomous-systems-applications-funding-competition/

Name	Funding Amount	Scotland	UK	Europe	Comments	Website link
Innovation Voucher Scheme Scotland	1,000 - 5,000 GBP per project	✓	-	-	This small grant has the stated focus of building relationships between SMEs (small to medium-sized enterprises) and HEIs (Higher Education Institutes) in Scotland by supporting collaborative projects. This indicates potential for links to be built between research institutions and fishermen in order to facilitate selectivity experiments.	
International Society for Fish Biology Research Grants	5,000 - 6,000 GBP per project	✓	✓	-	Small grants with a focus on fish biology and ecology, with potential for the biological impacts of selectivity measures to be explored.	http://www.fsbi.org.uk/grants/research-grants/
LIFE Programme	3.4 billion EUR 2014-2020	✓	✓	✓	This conservation and environment-focused programme covers various potential routes under its funding themes, including innovation in industry, which may be appropriate to selectivity studies.	http://ec.europa.eu/environment/life/index.htm
Marine Biological Association Research Awards and Grants	Variable fellowships and bursaries	✓	✓	-	Diverse range of research foci depending on the specific grant, bursary or fellowship which is being applied for.	https://www.mba.ac.uk/awards-grants/
National Environmental Research Council (NERC) Innovation funding: Environmental Science Impact Programme	2-5 million GBP in total available over 5 years	✓	✓	-	The Environmental Science Impact Programme (ESIP) is dedicated to bringing research organisations together with businesses, policy bodies and other actors contributing to economic development specific to their location to deliver significant regional impact from NERC environmental science. Project sub categories include	http://www.nerc.ac.uk/funding/available/schemes/
Scotland Grants	150-300,000 GBP (range awarded in the examples provided)	✓	-	-	General Scottish business grants which have been applied to the fishing industry previously (see linked article).	http://www.ukbusinessgrants.org/blog/news-and-events/scotland-grants-earmarked-for-the-fishing-industry/
SEAFISH Strategic Investment Fund	Previous scheme 4 million GBP 2005-2012	✓	✓	-	Each call for proposals specifies particular areas of interest within UK fisheries.	www.seafish.org/industry-support/funding-and-awards/funding/strategic-investment-fund

Name	Funding Amount	Scotland	UK	Europe	Comments	Website link
Society for Conservation Biology Marine Section Conservation Research Small Grants Program	Variable small grants	✓	✓	✓	Biodiversity conservation focused grant programme which has previously included projects related to issues such as bycatch.	https://conbio.org/groups/sections/marine/small-grants/

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Annex 1 Literature used to develop the typology of selective gears and practices

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