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Review of king scallop dredge designs and impacts, legislation and potential conflicts with offshore wind farms

Report to Moray Offshore Renewables Limited

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Executive Summary

Worldwide energy demands are forecasted to increase three-fold by 2050 and with an estimated 40 year supply of gas and oil reserves left, it is becoming increasingly important to develop alternative and renewable energy options. Globally, offshore wind power represents just 2 % of global wind power (the majority supplied by land-based wind farms). However, Europe has 90 % of installed global offshore wind power with >50 % (3650 MW capacity) of this in UK waters (GWEC, 2013). UK energy suppliers are obligated to provide a proportion of their power from renewable sources such as offshore wind or tidal energy; meaning the industry is rapidly expanding. There are over 6,000 active fishing vessels registered in the UK, which has the second largest fleet capacity in Europe (exceeded only by Spain). Total landings from the UK fleet into the UK and abroad were £770 million in 2012 (MMO, 2012). Inevitably, the development of offshore wind farms coincides with fishing grounds and conflicts can arise between the two activities. In order to protect the economic interests of both industries it is essential to ensure that the two activities can co-exist where possible. The safety of fishermen is paramount, as is ensuring the security of energy supplies for future generations.

Wind farms pose logistical and safety challenges to fishermen, while one of the major concerns of wind farm development companies is the risk of underwater cables being snagged by anchors or bottom towed fishing gear such as scallop dredges. Subsequent to consent for the Telford, Stevenson and MacColl offshore wind farms in the outer Moray Firth, Scotland, this report was commissioned by Moray Offshore Renewables Ltd (MORL) to review: documented interactions between scallop dredgers and underwater cables; current dredge designs that could potentially mitigate the risk of cable snagging and provide environmental benefits; and changes required to use an alternative dredge design under UK fisheries legislation. The report also includes in the appendices an experimental design suitable for testing of alternative dredge gear designs, in relation to catch efficiency, fuel efficiency, sediment resuspension and retained bycatch.

Four alternative scallop dredge designs have been developed in the UK recent years and tested to varying degrees. Two of these designs show potential to maintain or improve catches of scallops while reducing impacts on the seabed and associated fauna, by reducing the impact of the steel belly bag. Another design has been proven to achieve good commercial catch rates and reduced damage to organisms through use of individually sprung tines that replace the fixed dredge teeth. No data is available on snagging risk for any of the designs. Empirical trials for all but one of the designs are limited and therefore further trials are necessary prior to evaluation of their commercial viability. A design that reduces the impact of both the tooth bar and the belly bag is likely to demonstrate the greatest environmental benefits, while reducing snag risk would benefit both fishers and wind farm companies. Due to financial limitations, no such design has yet been developed or tested, however investment in this area could result in significant economic and environmental advantages. Gear design alone will not fully mitigate all the conflicts and risks associated with fishing within a wind farm therefore safety guidelines are recommended.

The report is based on a review of existing information and consultation with various stakeholders associated with the UK scallop sector. Gear trials should be conducted with the full support of, and input from, the fishing industry with trials conducted on board commercial scallop vessels. Finally, consideration must be given to the legislative processes that may be required to amend current legislation in each devolved UK administration in order to put an alternative design into use.

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List of Abbreviations

CFP	Common Fisheries Policy
Defra	Department for Environment, Food and Rural Affairs
ETP	Endangered Threatened or Protected (species)
HVDC	High Voltage Direct Current
ICES	International Council for the Exploration of the Sea
IFCA	Inshore Fisheries Conservation Authority
IFG	Inshore Fisheries Group
LOA	Length overall
MFIFG	Moray Firth Inshore Fisheries Group
MLS	Minimum Landing Size
MMO	Marine Management Organisation
MORL	Moray Offshore Renewables Ltd
MSC	Marine Stewardship Council
nmiles	Nautical Miles
SSMO	Shetland Shellfish Management Organisation
VMS	Vessel Monitoring System

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1. Introduction

This report was commissioned by Moray Offshore Renewables Ltd (MORL) in response to concern over conflict that may arise between a consented offshore wind farm development zone and a dredge scallop fishery on Smith Bank in the outer Moray Firth, Scotland. The development zone lies 12 nautical miles (approximately 13.5 statute miles or 22 km) from the Scottish coast and consent has been granted for three wind farms within the boundaries of the zone: Telford (93 km^2), Stevenson (77 km^2) and MacColl (125 km^2) (Figure 1).

The report has been subject to consultation with the scallop industry and Marine Scotland Science and The Crown Estate. The experimental protocol was subject to comments from industry and Marine Scotland Science and these comments have been integrated and duly considered. It is considered that the protocol will continue to develop with further consultation with industry.

1.1. The scallop fishery in Scotland and the Moray Firth

The king scallop, *Pecten maximus* occurs around the coast of the UK with substantial fisheries off the south coast of England; areas of Cardigan Bay and north Wales; around the Isle of Man (Irish Sea), Jersey and around the east and west coasts of Scotland. King scallops live in a range of habitats from shallow, sandy sheltered inshore grounds to areas of sandy gravel interspersed with cobble (Ansell *et al.,* 1991), although the commercial dredge fishery is generally associated with dynamic sandy-gravel seabed habitats from 3 nmiles to >12 nmiles of UK coastal waters. Typically, king scallops recess into the seabed. This burial behaviour involves ejection of water jets from the mantle to redistribute surrounding sediment and allow the top, flat half of the scallop shell to lie flush with the seabed. *P. maximus* can jump or swim for limited distances but normally this only occurs when disturbed, as an escape response (Jenkins & Brand, 2001).

With a first landings value of £68 m p.a. in 2012, the scallop fishery is the 3rd most valuable in the UK and the 2nd most valuable in Scotland, with Scottish landings totalling £31.3 m in 2012 and accounting for 20 % of the value of shellfish landings for Scottish vessels (Dobby *et al*., 2012). The number of active vessels has remained relatively stable over recent years. There are approximately 90 currently active scallop vessels in Scotland ranging from <10 to >40 m length overall (LOA), comprising around 30 <15 m vessels and 60 >15 m vessels. Smaller vessels of <15 m LOA generally fish inshore grounds (within 0 – 12 nautical miles of the coast). Larger vessels (>15 m LOA) tend to be nomadic, fishing grounds all around the UK with the specific location depending on seasonal variations in scallop condition and fishing effort restrictions (see section 1.4). Scallop fishing effort increased in Scottish waters in 2012 and 2013 due to Western Waters restrictions (Council Regulation (EC) No. 1415/2004) which displaced the >15 m UK scallop fleet from preferred fishing grounds in ICES Area VII (which encompasses the English Channel and Irish Sea) for over 200 days a year. This issue first arose in 2010 when the fleet exceeded the total allowable effort limits in Area VII for the first time due to fleet capacity expansion.

The fishery in the north east of Scotland developed in the 1980s and scallops are exploited in the inner and outer Moray Firth by vessels >15 m LOA. Marine Scotland conducts an annual survey of eight defined assessment areas to evaluate stock status. Although the health of Scottish scallop stocks varies with region, recruitment and spawning stock biomass have been relatively stable in recent years

(Dobby *et al*., 2012). Scallops represent 75 % of the total fisheries landings value in ICES sub rectangle 45E7, in which the three consented offshore wind farms are located.

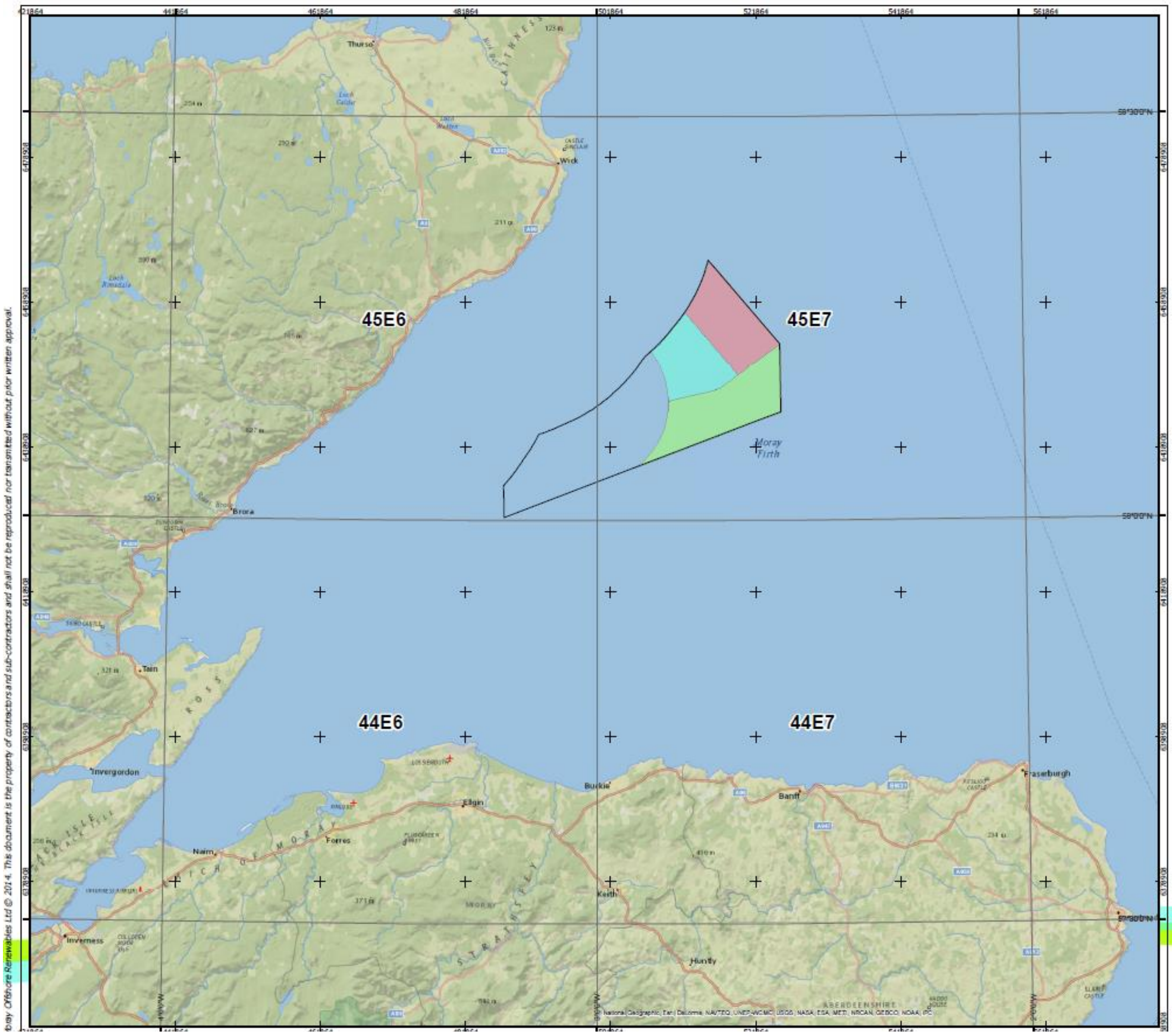

Figure 1: Location of the consented MORL development zone boundary (black line) and wind farms: MacColl (green); Stevenson (blue); Telford (pink) within ICES sub-rectangle 45E7 on Smith Bank in the outer Moray Firth, Scotland.

1.2. Conflict with offshore wind farms

Worldwide, energy demands are increasing and requirements are estimated to be 3 x greater by 2050 (WEC, 2014). Due to pro-active policies, the UK is the most attractive location for development of offshore wind farm arrays and is the world leader, responsible for over 50 % of the world's total offshore wind power capacity. The 62 operational offshore wind turbines in Scotland represent 5 % of current UK offshore wind power. The UK must obtain 15 % of its energy consumption from renewable sources by 2020 under the 2009 Renewable Energy Directive; however the Scottish Government has increased this target to 100 % (REN21, 2014). Currently offshore wind represents just under 3 % of Scotland's renewable energy resource. This equates to a total of 190 MW, with a further 4523 MW capacity either in planning or construction phases (www.scottishrenewables.com). Competing interests for marine space occur between wind farm developments and fishing or conservation objectives. Co-location of activities may be possible however there are many logistical requirements that need to be considered.

High voltage Alternating Current (HVAC) export cables transport electricity generated by wind turbines to the mainland. The target burial depth of these cables in coastal areas is 0.6 -1.0 m (OSPAR, 2012), however this may vary with seabed conditions and if burial is not possible the cables can be covered with rocks or concrete mattresses. At the three consented wind farms there will be up to four export cables, separated by 4 x water depth, in addition to single inter array cables. Scallop dredge gear is made of steel and is required to be heavy in order for it to maintain contact with the seabed while fishing. Dredge gear can potentially interact with subsea cables by landing on top, dragging over, or snagging them. The latter causes the greatest danger to fishermen as snagging can cause a vessel to tip over or capsize. Fishing gear that snags may have to be cut free and discarded, resulting in financial loss. Landing on, or dragging of the dredge and collector bag over the cables can damage the cables, and the damage occurring would be related to the total weight of the gear and the fullness of the collector bags. Damage may result in expensive repairs, interrupted supply and lost revenue for a wind farm company. Similar damage can also be caused by anchors being dropped on or dragged over cables.

Scallop dredges typically affect the top 2-5 cm of sediment (Grieve *et al*., 2014). Although cables are buried to depths of 0.6-1.0 m, shifting sediments and tidal scour in dynamic habitats may leave cables exposed and vulnerable. Scallop dredging can flatten sand ripples from an initial amplitude of 1.5-2 cm to <1 cm (O'Neill *et al.*, 2013; Figure 2). The gear creates a turbulent wake as it travels over the seabed, which can entrain fine sediment particles and small infaunal organisms. The Newhaven dredge entrains a maximum of a 1 mm layer per swept width of suspended sediment, from a depth of 10 mm (O'Neill *et al*., 2013). The finer the sand particles, the greater their proportion in the sediment plume. This issue will not occur on gravel/cobble seabed, and the degree of sediment mobilisation and resuspension will depend on local sediment composition and hydrodynamic conditions (O'Neill *et al*., 2013). It may be possible that repetitive dredging over the same area will gradually reduce the cable burial depth, although this has not been empirically tested and the impacts will vary with sediment type and composition. The seabed in the Moray Firth comprises a high proportion of medium sands, intermixed with gravel. This type of sediment is susceptible to movement through natural disturbances such as wind or storms.

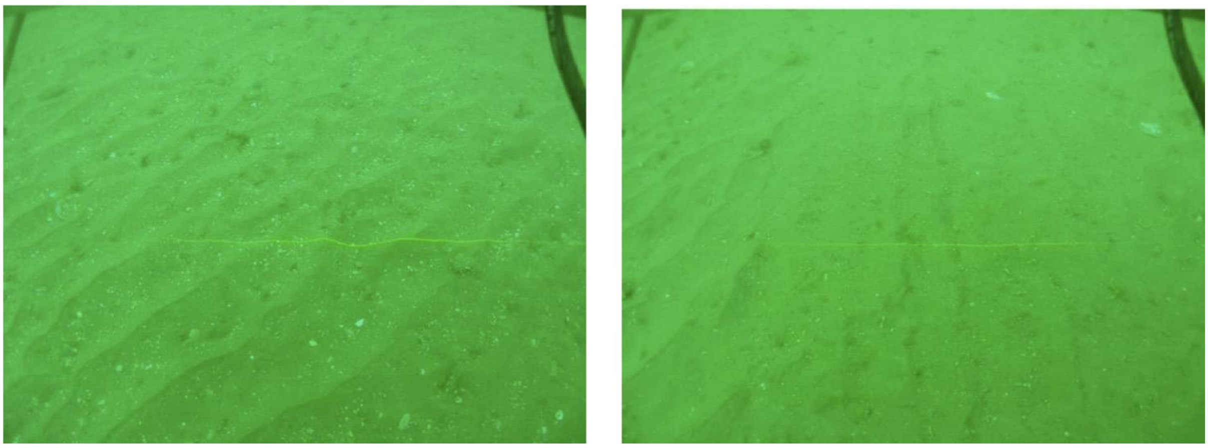

Figure 2: Sand ripples before (left), and flattened ripples with visible dredge marks (right) after scallop dredging. From O'Neill *et al*., 2013.

1.3. Scallop fishing gear

Traditional Newhaven (also known as Bedford) scallop dredges used by the majority of the UK scallop fishing fleet comprise heavy steel tow bars with spring-loaded, toothed dredges attached to a steel ring collector bag that is dragged along the seabed behind the teeth. As the dredge bag fills the weight increases, as does the impact on benthic (seabed dwelling) fauna it comes into contact with (discussed in section 3.2). The teeth rake the seabed to a depth of 5 cm (Grieve *et al*., 2014). Due to the shallow penetration depth, cables that are buried and remain buried are unlikely to become snagged by gear. However, exposure of cables following natural or anthropogenic disturbances (such as tidal scour or repeated fishing) increases the risk of snagging.

The Newhaven dredge has been reported as the most environmentally damaging type of fishing gear to benthic habitats including gravel, sand and mud (Collie *et al*., 2000; Kaiser *et al*., 2006), however some types of seabed are more 'sensitive' to damage from the dredge than others. For example Sciberras *et al*. (2013) reported no discernible effect of scallop dredging on a naturally dynamic, sandy seabed in Cardigan Bay, Wales, but in slow-growing biogenic reef habitats (that are not targeted by commercial scallop vessels), experimental dredging showed severe and long lasting (>4 years) effects (Hall-Spencer & Moore, 2000). The ecosystem impacts of bottom-trawling and dredging are linked to habitat type, which is highly correlated with depth (Kaiser *et al*., 2006). Some authors cite the steel teeth of the dredge as being the most harmful component of the dredge to benthic organisms (Shephard *et al*., 2009) but it is likely that the weight of the belly bag dragging along the seabed is responsible for a large amount of damage, in particular to soft, erect or fragile organisms (Hinz, 2012). Alternative dredge designs have addressed both of these issues, although not simultaneously.

In France, the 'French dredge' is used to fish for scallops on clean sandy ground. This consists of a 2 m wide dredge with rigid fixed teeth (spaced 9 cm apart) and is used with or without a diving plate, which causes the dredge to dig further into the sediment. Some French fishermen use the N-Virodredge (see section 2.3). Elsewhere in Europe, in the Gulf of Venice the Italian rake is used. This is a 3 m wide dredge weighing 170 kg and uses a reinforced rubber matting and mesh net to retain the catch. There are 4 skids of 12 cm in width on the underside of the dredge to aid passage over the substrate. The teeth are fixed 8 cm apart and this dredge is used to catch *Pecten jacobaes*, a close relation of *P. maximus*.

Belly ring size, and to a lesser degree, teeth spacing determines the selectivity of the gear towards scallops over minimum landing size (MLS), as well as bycatch organisms (Lart *et al*., 1997). Wider tooth spacing leads to reduced catch rates of MLS scallops, but a larger belly ring size does not. Dredge efficiency can vary greatly depending on the experience of the skipper, wind and tidal conditions, seabed type and dredge design.

Improving the current dredge design to reduce environmental impacts could improve public perception of the scallop dredge fishery which has in recent years been targeted by negative press reporting. Benefits to fishers of an improved design could include the possibility of averting area closures (due to decreased environmental impact), greater catch efficiency and improved profitability through reductions in fuel consumption. However, reducing fuel costs can act as a subsidy and in turn prolong the use of unsustainable fishing practices. If an improved dredge design was able to reduce the risk of snagging underwater cables this would be beneficial to both wind farm developers and fishers.

Scallop dredge gear is costly and can account for around 20 % of the operating costs (Humphrey, 2009). The skipper of a 10-a side scallop vessel reported spending £126,000 replacing worn gear in one year. The tooth bars wear down through abrasion with the substrate (this occurs faster in predominantly sandy habitats) and the belly bags are also subject to wear as they are dragged along the seabed. For example, on the east coast of Scotland tooth bars require replacement every two to three days and the belly bags every six months. Any modifications must balance cost and ease of use with greater, if not comparable catch rates to current designs.

A dredge design that is considered more environmentally friendly may lead to Marine Stewardship Council (MSC) certification of the fishery; UK supermarkets are becoming increasingly concerned with environmental perception and sustainable sourcing. The MSC is a globally recognised certification body and many UK retailers are now focussing on sourcing and promoting MSC certified (or other sustainably certified) seafood, therefore achievement of this for the UK scallop fishery would ensure sales security. The Shetland king scallop fishery is currently the only *P. maximus* fishery certified by the MSC and is able to meet the environmental criterion through the use of a closed area rotational management strategy which controls the environmental footprint of the fishery.

1.4. Current legislation

Management of UK scallop fisheries are based largely on political regimes under EU law with little consideration to the biological requirements of the stocks. Each devolved UK Administration has the power to implement additional management within the coastal zone (<6 nmiles from the shoreline) and management in this zone varies between regions. Gear design is regulated throughout UK waters, with the French dredge banned in all areas. Specifications include belly ring size, tow bar length and diameter, number of teeth per dredge, total number of dredges, total weight of the dredge and a ban on attachments.

Marine Scotland has jurisdiction over Scottish waters up to the 200 nmile limit, under the Marine (Scotland) Act 2010. Scottish legislation includes a cap on licences (although there are currently around 50 latent licences in the fishery, which if utilised would significantly increase effort), limits on the total number of dredges per vessel (8 within 6 nmiles; 10 between 6 and 12 nmiles; 14 outside 12 nmiles) and a minimum landing size (100 mm). Additional inshore measures can be implemented by Inshore Fisheries Groups (IFG), formulated for six defined regions in 2009, with a remit to develop inshore fisheries policies and initiatives. These include the Moray Firth and North Coast IFG. An area fisheries management plan was produced by the group in 2011 (Moray Firth IFG Executive Committee, 2011).

In England there are 10 Inshore Fisheries Conservation Authorities (IFCAs) which have the power to implement additional fisheries management or conservation measures, by way of byelaws, within the 6 nmile limit. From 6-12 nmiles there is a limit of 8 dredges per side. The same dredge specifications apply both within and outside 12 nmiles and the only other management outside 12 nmiles is the Western waters effort regime (Council Regulation (EC) No 1415/2004) which restricts the number of days for the fleet of > 15 m vessels in ICES Area VII (English Channel and Irish Sea).

Welsh waters are managed by the Welsh Government and scientific research is undertaken by Bangor University. Management in the Isle of Man and Shetland (the latter operated by the Shetland Shellfish Management Organisation via a 'Regulated Fishery Order') both demonstrate good affinity with biological data on scallop stocks. Measures such as TACs, MLS, permanent or seasonal closed areas and curfews are based on annual stock assessment and other available scientific evidence, allowing reactive management and the implementation of emergency measures.

There would be a requirement to amend legislation for a new dredge design that did not meet current rules. It will be desirable for nomadic vessels (generally > 15 m LOA) to use gear approved by all UK devolved Administrations, as the nomadic nature of such vessels mean they frequently travel around UK waters and carrying two different sets of gear on board would be undesirable and potentially unfeasible.

1.5. Aims and objectives

Traditional 'Newhaven' dredges may conflict with and/or damage subsea cables, resulting in loss or damage to both cables and fishing gear. Therefore it is desirable to explore solutions that will allow wind farms and scallop fishing to coexist. This could be achieved by the use of an improved dredge design that will mitigate these impacts. Therefore, the aims of this study are to:

1. review available scallop dredge gear designs;
2. review available information on the risk of fishing gear snagging offshore wind farm cables;
3. evaluate the suitability of available dredge designs to mitigate conflict with offshore wind farms and also meet economic and environmental objectives;
4. review current legislation regarding dredge design with a view to potential changes required to undertake commercial gear trials and subsequent use; and
5. recommend potential mitigation measures to enable the co-location of fishing and wind farms

An experimental protocol for the testing of different dredge designs is included in Appendix 7.8.

2. Conflict with offshore wind farms

UK law protects public rights to fish and rights to navigation in UK waters. An amendment to the Electricity Act 1999 allows safety zones that prevent fishing within a 50 m radius around a wind turbine in operation, but not in the waters between turbines. A 500 m safety zone excluding fishing activities can be enforced during the installation of cables, turbines and other infrastructure associated with an offshore wind farm (a summary of exclusion zones that can potentially be implemented can be found in FLOWW, 2014). Depending on the distance between turbines, fishing within a wind farm is potentially feasible, however may be undesirable to fishermen due to the limited ground on which they can actually fish and safety issues; from risk of collision with turbines in poor visibility or high winds and the risk of dragging up a cable and potential loss of fishing gear. If a vessel has to avoid an area covered by a wind farm negative impacts may include: loss of valuable fishing grounds, increase in steaming time and costs associated with having to fish elsewhere and potential conflict with other fisheries at alternative fishing grounds.

The impact of wind farms on the fishing industry can be mitigated against during planning, development and operational phases through timely consultation and interaction between both industries. Such measures can include a Fisheries Liaison plan (FLOWW, 2014), however the aim of developers should be to allow the safe continuation of fishing activities where possible. Fishing activity may need to be temporarily suspended during survey or construction phases, however this is generally only for short time periods. There may be an opportunity for fishing vessels to generate additional income as 'guard' or survey vessels during the construction or operational phases (FLOWW, 2014).

2.1. Cable burial

More than two thirds of all subsea cable faults are caused by fishing gear or anchors, the latter achieving much deeper penetration of the seabed (Drew & Hopper, 2009), with insufficient burial or seabed movement also playing a part. Risks to fishermen associated with offshore wind farms can be surface or subsurface. Spacing between turbines at the Telford, Stevenson and MacColl wind farms will be up to 1200 m crosswind; therefore in good weather conditions risk of collision is minimal, however with storms or fog this may increase. Cables pose a much greater risk to fishing vessels. Direct impacts of cable snagging on fishermen include loss or damage to fishing gear, loss of fishing time and in the worst cases, capsize. If a vessel owner can prove the sacrifice of an anchor or fishing gear when trying to avoid damage to an underwater cable the Submarine Telegraph Act 1885 states that the cable owners are obliged to provide compensation, however there will be no automatic assumption of liability by the industry if a cable is snagged and fisherman can also be held liable for repair costs to damaged cables.

British Telecom conducted trials of burial depth on a beach by dragging a beam trawl over cables laid in trenches 300 mm deep. It was concluded that a deeper trench (600 mm), combined with burial under a layer of sediment would significantly increase protection of the cable (BERR, 2008). For cables buried to 0.6 m depth, the likelihood of interaction with fishing gear is once or twice in a 10-15 year period, however cables buried to 1.0 m are more likely to experience no incidents (BERR, 2008). The recommended burial depth for cables to mitigate against interactions with scallop dredges ranges from <0.4 m on hard substrate to >0.5 m on seabed consisting of soft mud or clay (BERR, 2008). Most cables in coastal areas are buried in to the seabed to a target depth of 0.6-1.2 m (Drew & Hopper,

2009) and are assessed by post-lay inspection thereby reducing the potential risk of contact. However, cables can become uncovered over time due to erosion of sediment from tides and currents, or be moved by anchors or fishing gear, potentially up to several hundred metres from the original track (Kogan *et al*., 2006). Specialist equipment can bury cables to depths of up to 5 m where necessary (BERR, 2008). Erosion is particularly prevalent in the North Sea due to strong currents (Drew & Hopper, 2009). Some cables are surface laid where the seabed is too hard, rough, steeply sloping or uneven, and are either protected by concrete mattresses or left exposed. Buried cables which become exposed are normally reburied; however there is a time delay prior to this occurring where risks to fishing vessels increase and the original burial depth may not be achieved. Depending on the substrate type and prevailing hydrodynamic conditions at the seabed, subsea cables may self-bury or become looped, suspended above the seabed or incised into rock outcrops (Kogan *et al*., 2006).

Information and charts are available to fishermen regarding the location of cables but there are still instances when fishing gear becomes snagged on subsea cables. The most effective way of avoiding conflict is for fishermen to avoid all areas where there are known to be cables. However, the use of wind energy is increasing and developing ways to enable colocation of both activities is necessary.Therefore methods to reduce snagging risk are essential to ensure safety and also reduce the costs associated with repairing or replacing damaged cables and fishing gear.

2.2. Snagging incidents

Although snagging incidents are not common, they do occur and it is likely that not all snagging incidents are reported. In the UK there have been a number of incidents reported in recent years (reported at: http://www.kis-orca.eu/):

In July 2009 three lives were lost when a scallop vessel overturned and capsized almost immediately after its gear became snagged on an underwater cable near the island of Muck, Scotland. In March 2013 it was reported that a fishing vessel had gear entangled in a cable off the north-west coast of Cornwall. The fishing gear was cut away and abandoned in order to release the vessel. Between April and July 2013 the SHEFA-2 cable running between Manse bay, Orkney and Banff, Scotland suffered from two breaks attributed to fishing activity. It has since been acknowledged that this cable was poorly buried in places (Peter Moore, MORL Ltd, pers. comm.). There are further sections of the SHEFA-2 cable that have been surface laid or are unburied representing a hazard to fishing. Again in June 2013, beam trawl and scallop gear were both abandoned north of Ireland after becoming entangled in a cable. The beam trawl dragged the cable from its original positioning resulting in 80 m of exposed cable and the abandoned scallop gear attached to the cable further increased the risk of future incidents.

2.3. Safety considerations

Scallop fishermen are capable of fishing very precise corridors of seabed (c. 300 m wide), demonstrated through experimental fishing trials (unpublished data, Bangor University). Although scallop fishing within a wind farm is not banned, scallop fishermen in Scotland have indicated their reluctance to fish between turbines that are <2 km apart (Andrew Hamilton, MORL Ltd, pers. comm.). Scallop dredges are normally fished from a cable with a warp (length) of approximately 3-4 times the depth of seabed. For example a 90-120 m warp may be used when fishing a depth of 30 m. The deeper the seabed, the wider the corridor between turbines required to avoid conflict. Depth within the consented development zone ranges from 37 m to 57 m, however construction is planned to a maximum depth of 47 m and turbines will be 1200 m apart (MORL, 2012). Scallop fishermen tend to fish in an elongated figure of eight pattern and will repeatedly dredge over the same track until the density of scallops is reduced to a level at which catch rates are no longer economically viable. It is technically possible for fishing vessels to operate within a turbine array; however there are a number of safety aspects that require consideration.

Apart from an increase in risk of snagging underwater cables when fishing between turbines, difficulty in obtaining assistance should a snag or any other incident occur, and being blown into a turbine if weather conditions deteriorate, are cause for concern. To mitigate risks it is recommended that a code of practice is put in place for all fishing vessels operating within a wind farm array. The proposed measures below are not tested, merely common sense suggestions that may help to increase safety when operating within a wind farm, however they will not necessarily prevent snagging or collisions occurring.Proposed safety measures:

- Alert local coastguard whenever fishing is due to commence within a turbine array and state planned duration.
- Vessels should fish in pairs, so if one vessel encounters difficulties there is another close by to provide, or call for assistance.
- Permitted dredging lanes between turbines should include a safety buffer that incorporates a sufficient margin of error.
- VMS (vessel monitoring system) polling rate should be increased (currently every 2 hours) to aid in management, enforcement and vessel tracking for safety purposes.

Another issue that arises from repeated dredging over the same area of seabed is that the natural topography is flattened. If dredging occurs too frequently within the turbine corridors this may severely impact on habitat complexity and associated species richness. Wind farms have the potential to alter natural tidal regimes, current speeds and direction as well as wave height, period and direction; however such effects within the consented development zone were assessed in the Environmental Statement and were found to be non-significant at the proposed sites. The following information is from the Environmental Statement prepared by MORL Ltd (MORL, 2012):

The sediment on Smith Bank consists of sand and gravel of thickness varying between 1 and 5 metres. Combined wave and storm currents are likely to mobilise sea bed sands on a regular basis. Prevailing winds are from the west (20 %) and from the south and south-east (35%). Depth-averaged peak spring tidal current speeds are around 0.45 to 0.5 m/s and residual tidal currents flow into the Moray Firth (south-south west). Waves generated by swell and wind can reach 6-7 m in height and are sufficient in strength to impact on the sea bed. The development of the wind farm will cause no significant change to the speed, direction or asymmetry of tidal currents which is controlled predominantly by natural wave and tidal regimes. It is also expected that the development will have no significant effect on wave and tidal regimes in the area.

3. Scallop dredge designs

3.1. Newhaven dredge

Traditional Newhaven scallop dredges used by the UK scallop fishing fleet comprise a triangular frame with a row of 8 or 9 teeth on a spring-loaded bar, in front of a steel ring collector (or 'belly') bag that is dragged along the seabed behind the teeth (Figure 3). Vessels that fish for scallops can range in size from < 10 m LOA (towing 3-12 dredges on one or two towing bars) to > 40 m LOA (towing up to 22 dredges on each side of the vessel on two separate tow bars). The dredge teeth can be either a sword (with flattened edges and pointed tip) or peg (cylindrical with a flat end) design. Scallops are rotated out of the seabed by the downward force of the teeth and collected inside the steel belly bag. Not all scallops in the path of the dredge are retained by the dredges and efficiency of the Newhaven dredge can vary between <10 % on soft ground to 51 % on hard ground (Dare *et al*. 1993; Jenkins *et al*., 2001; Bell & Palmer, 2001). Dredge efficiency is affected by ground type (e.g. soft sand, gravel or cobble), towing speed, warp length, tide strength and direction and the experience of the skipper.

The dredge teeth are between 5 to 6.5 inches in length when new and wear down during use. The actual penetration depth of seabed sediments that occurs is 2-6 cm (Currie & Parry, 1996; Løkkeborg, 2005). Although the springs and hinges attached to the tooth bar allow it to bend back and spring clear of objects, the high tension of the springs mean that the gear can become snagged on obstructions on the seabed (such as large rocks, subsea cables and wreckage or debris).

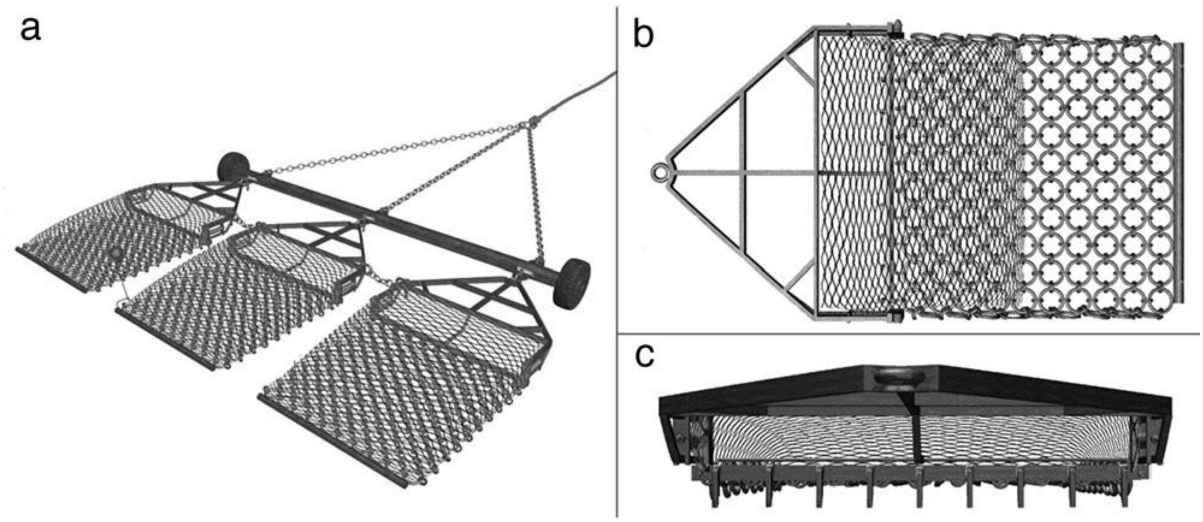

Figure 3: Newhaven king scallop dredge design: (a) aerial view of a gang of 3 dredges attached to the tow bar; (b) top elevation of the steel rings of the belly bag; (c) forward elevation of the tooth bar. From Boulcott & Howell, 2011.

3.2. Dredge impacts and habitat vulnerability

The natural environmental context of a location shapes the seabed and determines the organisms that can exist in that habitat. The intensity, frequency and extent of natural disturbance determine the degree to which a habitat and its associated species are likely to be affected by additional disturbance from fishing activities. The effects of towed mobile fishing gear on seabed communities are well understood as a result of 25 years of research. Our ability to understand the effects of these fishing gears relies heavily upon a good understanding of the distribution, frequency and intensity and identity of these fishing activities, coupled with a detailed understanding of habitat distribution and overlying environmental parameters. In some circumstances fishing disturbance may have minimal effect compared to natural disturbance. Sciberras *et al*. (2013) reported no discernible effect of scallop dredging on a naturally dynamic seabed in Cardigan Bay, Wales. In other circumstances fishing may cause long-lasting or irreversible changes (Hall-Spencer and Moore, 2000), however scallop fishing is not generally associated with sheltered soft sediments (such as mud and muddy sand) or biogenic reef habitats that have lower natural resilience to disturbance. Understanding the distribution of habitats and their extent, and the overlying physical processes, provides the basis to evaluate the potential effects of fishing disturbance. Such an understanding enables the formulation of effective management policies. The sediment on Smith Bank consists of sand and gravel of thickness varying between 1 and 5 m. Prevailing winds are from the west, south and south-east and residual tidal currents flow into the Moray Firth (south-south west). Waves can reach 6-7 m in height during extreme events and combined wave and storm currents are likely to mobilise sea bed sands on a regular basis (MORL, 2012). This results in a moderately dynamic system, typical of that in which scallops live.

Fishing affects the seabed in a number of different ways. Firstly, fishing gear can change the physical structure of the seabed either by creating furrows or smoothing topographic features. Second, biota may be removed, disturbed, damaged or killed as a direct result of physical contact with fishing gear. This can result in the modification of species composition or population size-structure within populations of target and non-target species. It is possible to rank towed mobile bottom fishing gear based on their initial impacts which would indicate that scallop dredges and hydraulic dredges have the most negative instantaneous effects, while other gears such as beam or otter trawls are less damaging (Kaiser *et al*., 2006).

Scallop dredge belly bags are made from inter-connecting metal rings. The rigid rings have the advantage that they do not collapse when the gear is towed and permit bycatch organisms to escape, thus scallop dredge catches can be very clean. Physical damage can be caused by scallop dredges to non-target organisms; on contact with the heavy steel tow bar, dredge teeth (Figure 4) or collector bag, or from being towed inside the dredge along with the catch, rocks and stones (if present in the substratum). Desiccation and stress may occur due to handling on deck or a delay in returning unwanted or undersized catch to the sea. Rough weather conditions will increase the rate at which the dredges rise and fall on the seabed which is also likely to increase the level of damage to organisms.

By-catch assemblage varies depending on the substrate. The degree of damage is related to the morphological (Eleftheriou & Robertson, 1992) and behavioural (Bergman *et al*., 1990) characteristics of the organism. Commercially valuable species caught in the UK scallop fishery include: flatfish, skates, rays, monkfish, edible crabs, octopus and cuttlefish (Hill *et al*., 1996, Enever *et al*., 2007). Other benthic species that are retained but not considered to be of commercial importance include: sea urchins, brittle stars, starfish, small crustaceans, bivalves and small fish species. Erect, habitat forming fauna such as soft corals, hydroids and bryozoans are also susceptible to dredge impacts. Catch efficiency for bycatch organisms can vary between 2-25 %, depending on the species (Jenkins *et al*., 2001). Reducing the volume of and damage to bycatch species is a key requirement of MSC assessment.

Figure 4: Damage to *P. maximus* caused by a scallop dredge tooth. Source: Beukers-Stewart & Beukers-Stewart, 2009.

The volume of stones in the dredge and the total catch volume are correlated with damage levels (Veale *et al*., 2001). Selective mortality occurs between taxa, with implications for short-term (Kaiser *et al*., 1996) and long-term community changes (Veale *et al*., 2001). Damage can be equal, or greater, in large, benthic invertebrates (e.g. *Cancer pagurus*) when not captured than when occurring in the bycatch (Jenkins *et al*., 2001). As dredge capture efficiency of such organisms is on average <25 % this implies most damage to by-catch occurs to individuals that remain on the seabed. Other organisms including the common starfish (*Asterias rubens)* and the whelk *(Neptunea antiqua),* obtain greater damage inside the dredge than on the seabed. Increasing the selectivity of the gear would benefit organisms such as these.

Fatal damage to *P. maximus* can occur during dredging (Figure 4) and varies between 2 and 20 %, largely due to spatial variation in shell thickness (Beukers-Stewart & Beukers-Stewart, 2009). Intermediate damage may not be immediately fatal but could lead to an increased likelihood of predation (Caddy, 1973; Jenkins & Brand, 2001). Damage to the mantle, similar to that caused during dredging increases the likelihood of death within 30 days post-dredging (Gruffyd, 1972). The majority of damage that occurs is in the form of small chips on the perimeter of the shell that, although unlikely to cause immediate problems, can result in the redirection of energy from reproduction to repair leading to lower reproductive output (Kaiser *et al*., 2007). Mortality following dredging is greater in younger scallops as their smaller size means they are more likely to be caught up in the mesh of the steel belly and they may be more susceptible to the effects of stress (Gruffyd, 1972; Maguire *et al*., 2002).

In other fisheries, gear modifications have led to an increase in catch efficiency (Hinz *et al*., 2009) and selectivity (Graham *et al*., 2007). Hinz *et al*. (2012) compared the impact and bycatch associated with an otter trawl, scallop dredges and modified dredges with a rubber lip replacing the tooth bar. The direct effects of the dredges were more negative than the effects of the otter trawl which also had lower bycatches of benthos. This study highlighted that the tooth bar fitted to the scallop dredges is not necessarily the greatest source of physical impact on seabed biota, but the abrasion associated with the steel ringed bags can be largely responsible for effects on the seabed community.

3.3. Alternative dredge designs

Depending on the environmental context, seabed habitats and their associated fauna can take from 100 days to >12 years to recover. Knowledge on specific causes of damage as well as bycatch vulnerability can inform the development of gear modifications (for more efficient and selective dredges) to reduce the environmental impacts of the fishery. Coupled with incentives to adopt gear technology, such modifications can provide economic and conservation benefits. The minimisation of the contact of towed bottom fishing gear with the seabed has been the focus of a number of fishing industry/science partnerships over the last decade and industry led innovations are to be encouraged.

To date, a number of alternatives to the Newhaven scallop dredge design have been developed with the aim of: reducing environmental impacts; reducing unwanted bycatch (organisms and inert material such as rocks and stones); and increasing fuel efficiency while maintaining or increasing catches of the target organism, the king scallop. There have been national and EU funded projects (Ecodredge FAIR CT98-4465; Lart *et al*., 2003) to encourage development of new scallop dredge designs, which are discussed below. Due to legislation, current modifications to the Newhaven dredge design have the same basic dimensions and fittings to attach to the tow bar. This also makes changing designs more economically viable to fishermen, as it means only the dredges need be replaced. Trials of alternative gear have generally been confined to small scale experiments rather than larger scale comparative experiments at the scale of the fishery.

3.4. N-Virodredge™

The N-Virodredge™ is a modified Newhaven dredge designed by Deeside Marine Ltd (Kirkcudbright) that replaces the fixed metal teeth with individually sprung tines and has rollers underneath the metal collector bag. Each tooth is a metal rod of 8 mm in diameter and approximately 17 cm in length. This rod comes in the extension of a spring to 7 coils, and the spacing between teeth matches that of a Newhaven dredge, to meet current legislation. Skids on either side of the tine bar support the weight of the bar, the total dredge weight being similar to a Newhaven dredge (Figure 5).

Figure 5: The N-Virodredge design (left) separate from the steel belly bag, with individually sprung tines and side skids; compared to the Newhaven dredge (right) with a fixed tooth bar. Source: Filippi, 2013.

The tines aim to reduce seabed penetration and drag; to avoid larger cobbles or boulders becoming trapped by the teeth and being dragged along the seabed. It is expected that the tines may also reduce damage to organisms due the individual movement of the tines allowing greater escape gaps and significantly lower tension compared to the tooth bar of a Newhaven dredge, although this has not yet been empirically tested. Trials in the Bay de Seine showed that less stones are retained and dragged over the seabed which reduces the weight of the belly (and therefore impact on benthic fauna) as well as reducing damage to the catch (Filippi, 2013). A further benefit is a reduction in fuel use due to the reduction in weight of the collector bag and reduced seabed penetration and drag. The tines can be vertically adjusted to alter penetration depth depending on the substrate. The N-Virodredge designers claim that the tines also improve the lift of the scallops in to the collector bag, thereby increasing efficiency.

During trials it was established that N-Virodredges could be fished efficiently at lower speeds resulting in a reduction fuel requirement of 12-35 % (Filippi, 2013). However, there are many considerations that must be taken into account when evaluating fuel use, such as engine size, fishing strategy, gear configuration, warp length, weather and tidal strength, which all impact fuel consumption. Catch efficiency was equivalent or greater than Newhaven dredges and varied between sandy and stony ground. It is expected that optimum catches could be maintained by adjusting the settings of the gear and tines when switching between ground types, however the dredges were not trialled on sea bed with a high concentration of stones and further testing is necessary. Bycatch of commercially important fish species (such as plaice, sole and dab) were similar to that of a Newhaven dredge. The trials indicated Newhaven dredges were more likely to catch under-sized scallops, although the difference in the mean size of scallop retained by the two gears was not significant. There was almost no damage recorded for scallops caught using the N-Virodredge, however the study did not investigate damage to organisms that remained on the seabed, which can be greater than that which occurs when retained by the dredge (Jenkins *et al*., 2001). Fewer stones were also retained by the N-Virodredges, reducing the workload involved in sorting the catch on deck, as well as reducing damage to organisms inside the dredge.

Fishermen reported that it took around one month to establish optimal configuration of the gear for different ground types, in order to maximise catches. Important adjustments include bar height, the angle of the dredge, teeth length, speed of tow and warp angle. Configuration of Newhaven dredges also varies depending on ground type and weather conditions, and alterations are made based on skipper knowledge and experience. Negative aspects reported were a higher purchase cost (although this is somewhat offset by fuel savings) and short durability of the tines; however since the study occurred the material used for the times has been improved and the durability doubled (Richard Gidney, Deeside Marine, pers. comm.). Wear of the tines is also dependant on the tightening of the springs and substrate. Provided the teeth last a minimum of two days and incorporating the fuel savings, the N-Virodredge is estimated at around 10 % cheaper to maintain (Filippi, 2013). Since the trials, a number of French fishermen have been using N-Virodredges. Around 40 UK vessels also use N-Virodredges, although these are all smaller vessels with a maximum of 6 dredges per side. Larger vessels that fish up to 40 dredges may be reluctant to make the initial investment required to switch gears. Fishermen using the dredges report increased profitability due to fuel savings and more efficient working, as the catches contain no stones.

Although the tines are likely to reduce damage to organisms, the steel belly bag remains, and as this fills the drag over the seabed increases. The designers intend to replace the belly bag with a cage mounted on rollers to reduce this area of impact, although significant financial investment in order to develop this design is required.

3.5. Oban dredge

Oban Scallop Gear Ltd (Oban, Scotland) have developed a dredge that replaces the steel belly rings on the underside of the collector bag with a rubber or polypropylene mat, with a cut out square mesh (Figure 6). This reduces the weight of the dredge by just over two thirds compared to a traditional dredge. Benefits include reduced drag on the seabed, reduced fuel use (although this has not been empirically tested) and the potential to reduce impacts on organisms. The reduction in weight possibly also reduces the extent to which the collector bag digs into the seabed, which may result in a reduction in stones retained (Ian Fletcher, FV *Rhos Mairi*, pers. comm.). The matting is less flexible than the steel belly rings, so on certain seabed types such as gravelly/shelly ground the dredges occasionally fill up with this material and become less efficient.

During preliminary sea trials the dredge performed well, retaining equivalent catches of king scallops (similar in biomass and size composition) to Newhaven dredges and significantly less cobble/stones. There was no significant difference in damage to bycatch organisms or bycatch biomass and composition compared to a Newhaven dredge. Fuel efficiency was not directly measured during the trials however, warp tension (used as a proxy for fuel efficiency) was similar between the Oban and Newhaven dredges (unpublished data, Seafish). The skipper that trialled the gear said he would use it in preference to the Newhaven dredge if the design was made economically viable.

Figure 6: Sea trials of the Oban dredge (centre two dredges) against standard Newhaven dredges (outer two dredges). Source: Bill Lart, Seafish.

The main economic issue with the design is that materials for the matting tested to date are more expensive than the steel belly and have proved unsustainable due to poor durability. The rubber matting lasts approximately 30-40 days on harder ground and up to 100 days on sandy/muddy seabed. Efforts are being made to source or develop a suitable product that will make the design cost-effective (Stewart Adams, Oban Scallop Gear Ltd, pers. comm.). Due to the reduction in weight of the belly bag this design has potential to reduce environmental impact and damage to organisms on the seabed, although abrasion will still occur from the weight and area of the belly bag in contact with the seabed. The design offers potential for reduced fuel use and it is likely that viable catches of scallops will be maintained. The Oban design is currently being developed and trialled in collaboration with a local scallop vessel (John McAllister, pers. comm.). The design does however still present a snagging risk due to the tooth bar.

3.6. Hydrodredge

The Hydrodredge uses cups to deflect water downwards and the resultant turbulence helps to 'lift' scallops off the seabed and into the mouth of the dredge bag (Figure 7). It was originally designed by the Massachusetts Institute of Technology to be used in the New England giant scallop (*Placopecten magellanicus*) fishery. *P. magellanicus* is morphologically different to *P. maximus*, is more active and lives on, rather than recessed into the seabed. During trials in the *P. magellanicus* fishery the Hydrodredge was found to be 50 % less efficient than the standard toothed dredges.

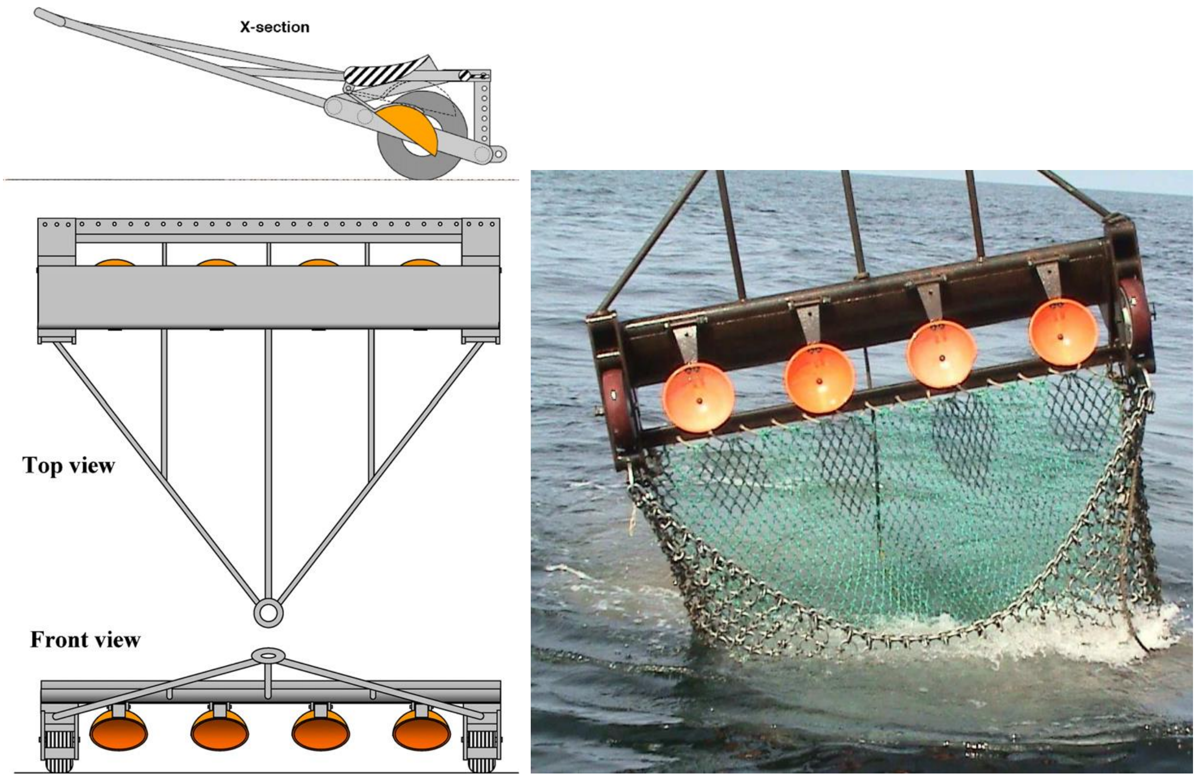

Figure 7: Diagram and image of the Hydrodredge, showing the four rubber cups that replace the tooth bar. Source: Shephard *et al*., 2009.

During trials in the Isle of Man in 2007, the Hydrodredge was found to be 60-90 % less efficient at catching *P. maximus* than the Newhaven dredge. Results were similar between smooth, medium and hard ground types. No difference in non-fatal damage to organisms was found between gears; however there was significantly higher numbers of dead scallops in the Newhaven than the Hydrodredge (Shephard *et al.,* 2009). These findings indicate that the majority of non-fatal damage is caused by other parts of the gear, such as the metal chain collector bag, rather than the dredge mouth design and that the metal teeth on the tooth-bar are responsible for severe or fatal damage to organisms. When the dredge was fished without the cups, there was no difference in the catch of scallops indicating the ineffectiveness of the turbulent flow generated by the flow to lift *P. maximus* from its recessed position. The Hydrodredge is 2.1 m wide, more than twice the width allowed under current UK legislation.

This dredge design aims to reduce impact on the seabed by removing the metal teeth that rake into the sediment during operation. However, the issue of the belly bag dragging over the seabed is not addressed by this design; therefore the overall environmental benefits are questionable. Also, due to the poor catching efficiency for king scallops it is unlikely to be commercially viable for the king scallop fishery. No data regarding fuel efficiency is available for this design.

3.7. Skid dredge

Skid dredges are identical in design and operation to Newhaven dredges; however there are two pairs of supporting skids (3 inches wide) attached by D-shackles on either side of the steel belly bag, at the middle and the rear of the bag (Figure 8). These lift the bag off the seabed, significantly reducing the surface area of the dredge in contact with the seabed and in turn limiting contact with organisms that remain on the seabed. The impact of the teeth and skids remains but, due to the gaps, is much reduced and many organisms can pass through and remain intact. There is potential for fuel savings if the skids are proven to reduce friction between the gear and the seabed.

Trials of this gear revealed that the weight of the skids can be offset by using thinner steel rings for the belly bags; therefore a dredge with skids attached weighs the same as a standard dredge without skids (104.5 kg). Another benefit to fishermen is reduced wear on the belly bags, meaning replacement is required much less frequently, resulting in cost savings. Trials with thinner skids, further reducing the area in contact with the seabed, are also a possibility.

Figure 8: Image of dredges with (from right to left) two and three skids attached, during sea trials. Designed by Ewout Costerus (Cyclone Marine Ltd) and John Coppack (Gannet Marine Ltd). Image: Ewout Costerus.

King scallop dredges with skids attached were trialled by Bangor University and initial results showed that the dredges could pass over eggs and shells causing greatly reduced levels of damage (Figure 9). During preliminary trials at sea, scallop catches were similar to standard gear. It is expected that the raising of the belly bag improves ‘riddling’ (removal of unwanted catch through the belly rings) and during trials lower catches of bycatch, debris, queen scallops and immature king scallops were obtained. Unfortunately poor weather restricted the scope of the trials, therefore data is limited and it is not possible to confirm these trends statistically.

Although not yet empirically tested, this design presents potential to significantly reduce the environmental impacts of the dredge due to the reduction in surface area in contact with the seabed. Further work should also address durability and wear in order to produce a prototype suitable for extensive testing in the commercial scallop fishery. Like the Oban dredge, this design incorporates the Newhaven dredge tooth bar; therefore snagging risks are likely to be similar.

Figure 9: Beach experiment demonstrating the much reduced impact on eggs and shells of a dredge with skids (left) than without skids (right). Images: H. Hinz.

3.8. Evaluation of different gear designs

Fishermen may perceive the following potential benefits from a new dredge design: increased catch efficiency, increased fuel efficiency, reduced bycatch and environmental impacts and improved public perception. The possibility of achieving MSC accreditation and the new EU Common Fisheries Policy (CFP) requirement for zero discards provide motivation for the industry to endorse improved gear designs that reduce environmental impacts and bycatch.

Trawls and dredges demand much higher energy consumption to pull through the water than nets. Changes in fishing behaviour, and gear innovations that reduce drag on the seabed and through the water column, will reduce fuel consumption (e.g. Sala *et al.,* 2011). Such innovations should be encouraged to reduce carbon emissions. However, it should be noted that reducing fuel costs acts as a subsidy that prolongs the use of unsustainable fishing practices; during a peak in fuel prices in the late 2000s some fishers changed from trawling to less fuel intensive techniques such as seine netting.

Increasing dredge selectivity not only increases catch efficiency but reduces stress on under-sized scallops and avoids them being repeatedly dredged and returned to the seabed prior to reaching the minimum landing size (MLS) for the fishery. Cumulative disturbance events redirect energy towards repair and reduce the reproductive output of individuals (Kaiser *et al*., 2007). Increased selectivity will reduce unnecessary fuel use and reduce the impact of the fishery on non-target organisms. The Hydrodredge trials indicate the significance of the dredge teeth in causing fatal damage and highlight the potential benefit of removing or reducing such impacts.

None of the gear trials discussed included assessment of snagging risk. Table 1 summarises the performance of the alternative dredge designs discussed in comparison to the Newhaven dredge.

These results reflect data currently available. The only design that has been subject to significant testing is the N-Virodredge. For all other designs trials have been limited and therefore the data available do not necessarily reflect the true comparison between the designs. Further empirical trials of these designs (in a variety of habitats and conditions) are recommended before conclusions regarding their performance are made.

Table 1: Performance of alternative dredge designs compared to the standard Newhaven scallop dredge, based on current literature and research: (✔) – performs better; (✘) – performs worse; (~) equivalent performance; (NA) - no data available; (?) - partial evidence / inconclusive, or requires further investigation.

Gear	Impact on seabed	Scallops retained	Bycatch retained	Damage to bycatch	Fuel efficiency	Fewer stones	Snagging risk	Compliance with legislation
N-Virodredge	NA	~	~	✔	✔	✔	NA	~
Oban dredge	NA	~	~	~	~	✔	NA	?
Hydrodredge	NA	✘	NA	✔	NA	NA	NA	✘
Skid dredge	✔ ?	~	✔ ?	✔	NA	NA	NA	?

The N-Virodredge is currently in use by some fishermen in the UK therefore no changes to current legislation are required. The Oban dredge meets current legislation, however it would have to be confirmed that a rubber mat could replace the steel belly rings, as current legislation specifies the following: ["row of belly rings" means a line of single interconnecting rings]. The Hydrodredge and skid dredge designs both fall outside of current technical specifications (see section 4).

The Hydrodredge is unsuitable for catching king scallops therefore further trials are not recommended. Both the Oban and skid dredges show potential for reduced environmental impact and improved fuel efficiency, however it is likely that snagging risk remains equal to that of the Newhaven dredge. Further modifications to these two designs could reduce this risk. The N-Virodredge tines may be less prone to snagging, although this has not been tested. The impact of the dredge teeth on organisms may be reduced; however the environmental credentials of this design could be greatly improved by reducing the impact of the steel belly bag.

4. Legislation

Although legislation on scallop dredge design is similar across all the devolved UK administrations, each has its own written legislation with variations on technical specifications. Collectively these result in two dredge designs being used in UK waters (the Newhaven and the N-Virodredge). Many scallop vessels (even those <10 m LOA) fish in the waters of more than one devolved administration and therefore gear must meet regulations in all areas in order to allow transition from one area to another without the expense of investing in different gear. Some fishermen choose to use slightly heavier or lighter gear, depending on preference and the type of substrate they typically fish on; however each dredge must be within the 150 kg total weight limitation in English and Welsh waters.

4.1. Scotland

The Prohibition of Fishing for Scallops (Scotland) Order 2003 specifies the maximum dredge number allowed: eight dredges per side out to six nautical miles; 10 per side out to 12 nautical miles; and 14 per side out to 200 nautical miles (Appendix 7.1). "French" dredges, and any attachment which obstructs in whole or in part the rings or netting of the dredge, are not permitted. Unlike the other devolved administrations, Scotland has no specific legislation on dredge design, although the legislations will be reviewed in 2015. A number of areas around Scotland are subject to seasonal (e.g. Luce Bay) or other temporal closures (there is a weekend ban in the Clyde).

The Sea Fisheries (Shellfish) Act 1967 allows UK fisheries Administrations to implement further management measures within the 6 nmile coastal zone using Shellfish Regulating Orders. For example in Shetland a Regulatory Fishing Order permits a maximum of 5 dredges per side. Fishing may only occur between the hours of 0600 and 2100 and recordings of landings and effort are required. The Shetland Shellfish Management Organisation (SSMO) is currently the only management organisation of its kind in Scotland.

Marine Scotland issued a consultation on the 'Proposed introduction of new statutory scallop fishing management measures' in January 2012. This included a proposal to remove the prohibition of attachments to dredges (e.g. attachments that assist in tipping the dredges onto the deck to improve safety, or improve the speed at which dredges can be operated), for which there was near universal support. Concerns were voiced that any attachments used should not reduce the selectivity of the dredge.

To trial a new dredge design, dispensation can be applied for through Marine Scotland. To amend the current legislation, an application of secondary legislation would be required, which would be scrutinised by the Scottish Parliament Rural Affairs and Subordinate Legislation Committees. The design would also have to be assessed under the Technical Standards Directive (Malcolm MacLeod, Marine Scotland, pers. comm.).

Table 2: Legislation regarding scallop dredge gear design for devolved UK Administrations, Isle of Man and the Channel Islands.

	Tow bar	Maximum dredge width	Teeth	Minimum tooth spacing	Minimum net mesh size	Belly rings	Other
Scotland							Attachments that obstruct in whole or in part the rings or netting, and French dredges are banned.
England		85 cm. If the dredge width is less than 80 cm, it must not have more than 6 rows of belly rings hanging from the belly bar; or more than 6 teeth on the tooth bar.	Max 9 teeth if each tooth is ≤ 12 mm*. Max 8 teeth if any tooth is > 12 mm*. Max width 22mm if dredge is ≥ 80 cm. Max width 12mm if dredge is < 80 cm.			Maximum of 1 row of belly rings hanging from either side of the dredge perpendicular to the rings which hang from the belly bar. Max 8 rows of rings.	Must have a spring-loaded tooth bar. No attachments or diving plates. Maximum weight 150 kg.
Wales	Max diameter of 185 mm	85 cm	Maximum of 8. Max diameter 22 mm, max length 110 mm.			Maximum of 7 in a row	Must have a spring-loaded tooth bar. No attachments or diving plates. Max weight 150 kg
Northern Ireland		Width of a dredge or gang of dredges ≤ 1219 cm	Maximum of 9 per dredge. Minimum spacing 75 mm.	75 mm	100 mm	Minimum internal diameter 75 mm	
Isle of Man	Max diameter of 185 mm	762 cm within 3 nmiles, 1067 cm outside 6 nmiles	Maximum of 9	75 mm	100 mm	Minimum internal diameter 75 mm	
Channel Islands	≤4 m (3-6 nmiles), ≤5.8 m (6-12 nmiles) (Guernsey)	Total width of dredges ≤12.8 m (Jersey). Max of 4 dredges in total inside 3 nmiles (Guernsey)				Minimum internal diameter 85 mm	Ban on any attachments or obstructions to the rings

*max 8 teeth in ICES division VIIa north of the line 52° 30′N but outside the Scottish zone, and all of ICES division VIId; max 9 teeth elsewhere.

4.2. Other UK devolved administrations

In **England** the 'Scallop fishing Order 2012' applies. This specifies technical measures to regulate the fishery including:

- Type and specification of dredge allowed
- Maximum number of 8 dredges per side within the 6 nmile limit (this is reduced in some areas through local byelaws)
- Ban on dredge attachments
- Ban on carriage of scallops <110 mm in size from ICES area VIId to VIIe

The order specifies a ban on any attachments to the rear, top or inside of the dredge, which could potentially be used to:

- Limit the size of the belly rings
- Reduce selectivity (increasing catches of species subject to management or protection, and undersized scallops)
- Increase the weight of the dredge (resulting in more damage to the seabed)

Any proposed change to the legislation (amendment to the current statutory instrument) would need to supported by i) robust evidence/clear rationale/mandate for the change and ii) would be subject to full impact assessment and public consultation. Finally, any proposed change is also subject to Ministerial approval (Shaun McClennan, Defra, pers. comm.). In order to trial new dredge designs dispensation is required. Dispensation applications submitted to the MMO are handled within a four week time period.

Full details on English dredge specification can be found in Appendix 7.2.

In **Northern Ireland** fisheries are governed by the Fisheries & Environment division of DARD (Department of Agriculture and Rural Development) under the "Conservation of Scallops Regulations (Northern Ireland) 2008". DARD also deals with applications for dispensations for scientific research purposes.

Full details on Northern Ireland dredge design specification can be found in Appendix 7.3.

Wales has some of the strictest regulation of fishing in its waters enforced through the Scallop Fishing (Wales) Order 2010 with a ban on all dredging within 1 nmiles of the coast and restrictions on the number of dredges per side within 3 and 6 nmiles. Further measures include restriction on vessel length, engine size, permanent closure of large areas and a total closure of the fishery in winter. Shellfish Regulating Orders are also used, for example the Menai Strait Fishery Order Management Association has implemented measures for the mussel fishery that has led to MSC certification. A 12 week notice period is required for scientific dispensations. Amendments to current legislation would be through a process of internal consultation within Welsh Government, a draft set of proposals, public consultation, and assessment of the response of the consultation including economic impact assessments, followed by draft legislation.

Details on Welsh dredge design specification can be found in Appendix 7.4.

4.3. Isle of Man

The Isle of Man is a self-governing British Crown dependency and not a member of the EU, therefore has sole jurisdiction for fisheries within 3 nautical miles of the island. Previously, the Isle of Man required concurrence from the UK jurisdictions to amend local legislation between 3 and 12 nmiles. However, since revision of the Fisheries Management agreement in 2012, the Isle of Man Government is no longer required to obtain concurrence, but must only consult on fisheries legislation between 3 and 12 nmiles.

Scallop fishing is regulated by the Sea Fisheries (Scallop Fishing) Bye-Laws 2010. Curfews and seasonal or permanent closed areas are in place as well as dredge specifications: maximum aggregated dredge width, number of teeth per dredge, net mesh size and tow bar diameter; and minimum spacing between teeth and belly ring size.

Modification to primary legislation can be made by way of regulations and orders, rules or Byelaws (known as secondary legislation).

Details on Manx dredge design legislation can be found in Appendix 7.5.

4.4. Channel Islands

Scallop dredging is not permitted in the waters of Sark. A special licence is not required to dredge for scallops in Jersey waters as long as the UK licence held by the vessel includes scallop entitlement. In Guernsey, all vessels must have a valid Bailiwick of Guernsey fishing vessel licence to fish within the 12 nmile limit. The States of Guernsey Commerce and Employment Department are responsible for the administration and enforcement of a fishing vessel licensing scheme as well as fisheries management and enforcement for British fishing vessels. Guernsey vessels will normally be granted an equivalent UK licence by Defra and reciprocal arrangements for UK vessels wanting to fish within the Guernsey 12 nmile limit are in place.

Details on Channel Islands dredge design legislation can be found in Appendix 7.6 (Jersey) and 7.7 (Guernsey).

5. Discussion

Scallops are the 3rd most valuable species in UK fisheries and populations occur around the UK, from the east and west of Scotland, through the English Channel and up into the Irish Sea. Landings totalled £68 million in 2012 and have increased year on year for the last decade. Scotland has committed to achieving 100 % of its energy from renewable sources by 2020 and the UK renewables industry is expanding rapidly due to the suitability of the seabed and climate and an urgent need to become less reliant on dwindling global fossil fuel reserves. This report highlights issues that occur when the two industries require use of the same area of seabed. The main issues identified are:

- Risk of fishing gear snagging on underwater cables resulting in damage to the cables and potential loss of fishing gear or human life
- Loss of fishing grounds and displacement of fishing activity
- Risk of vessel collision with wind turbines if fishing within a wind farm
- Restricted access for assistance or emergency services that may be required by a fishing vessel when navigating between wind turbines

It is in the interest of both industries to investigate and develop ways to mitigate such risks and it was proposed by MORL Ltd to commission a study into alternative dredge gear designs that could reduce conflict between fishing gear and wind farms. If such a design could also improve dredge efficiency and catch rates fishermen are more likely to consider investing in the new gear, and if the environmental impact of the dredge can be reduced this will improve the green credentials and sustainability of the fishery.

The current Newhaven dredge design incorporates a row of fixed steel teeth that dig into the seabed and lift scallops into a collector bag formed of rows of steel rings, which is dragged along the sea bed behind the dredge. The impacts are two-fold: from the weight and action of the tooth bar digging into the sediment causing damage to organisms with which the teeth make contact; and the increasing weight of the steel collector bag on the sea bed and organisms over which it is dragged, as the bag fills. The Hydrodredge was designed to mitigate the impacts of the steel dredge teeth, however has been shown to be ineffective in catching the target species, *Pecten maximus*. The N-Virodredge also aims to reduce the impact of the teeth, as these are replaced by individually sprung tines. The action of the tines reduces the penetration depth of the dredge and also allows larger organisms to pass between rather than be crushed by the teeth or retained as bycatch in the dredge. It is this action that may reduce the risk of snagging of the gear on underwater cables, although this has not been tested. Significant testing of the N-Virodredge has occurred and the dredge used by UK and French fishermen. The N-Virodredge design offers no solution to the impacts of the steel collector bag and it is proposed that further modifications to the bag could reduce such impacts. It is the aspiration of the dredge designer to make such modifications in the future, however significant financial investment is required. The Oban dredge and the skid dredge both retain the traditional steel tooth bar, therefore are unlikely to reduce the risk of snagging with underwater cables, however both demonstrate potential for reduction of the environmental impacts of the dredge. The Oban dredge reduces the weight of the collector bag by replacing it with rubber matting and is reported to retain fewer stones with the catch, further reducing the weight of the full dredge. The skid dredge lifts the collector bag off the seabed so the area of impact is reduced to two, 3 inch wide skids, which allow non-target organisms to pass under the dredge unscathed and may also reduce damage to emergent epifauna.

Due to the limited testing of the latter two designs, the authors are unable to conclude with certainty whether these designs would result in significant environmental benefits. Unless modification to the teeth is made, they are unlikely to reduce the risk of snagging on underwater cables.

Based on the information outlined in this report it is therefore recommended that the N-Virodredge, Skid and Oban dredges are subject to further testing for catch efficiency and environmental impact compared with the Newhaven dredge. Trials should be conducted on board commercial scallop vessels and an appropriate survey design is outlined in section 7.8.

The N-Virodredge is already in use around the UK and therefore meets current legislative requirements for dredge design. Scottish legislation for dredge design is limited and therefore it is unlikely that any changes would be required for the implementation of the other designs. However, legislation for England, Wales, Ireland, Northern Ireland, the Isle of Man and the Channel Islands contain specific requirements relating to dredge design. The most pertinent of these is a ban on attachments in England, Wales and the Channel Islands that could impede the use of the skid dredge. Legislation relating to the use of the rubber matting of the Oban dredge is less clear. For all administrations except Scotland legislation contains specifications relating to the 'belly rings'. English legislation species further that this "means a line of single interconnecting rings".

Finally, this report recommends safety considerations for the co-existence of scallop dredging and turbine arrays. Such considerations are additional to the risks posed by the snagging of gear but are highly relevant to fishermen. Even with a dredge design that can provide economically viable catches, environmental benefits and reduced snagging risk, there are other factors which could deter fishermen from fishing within a wind farm, therefore rendering investigation into alternative dredge designs redundant. The authors have attempted to address such concerns by proposing a code of conduct when fishing between turbines; however it is stressed that such measures should be developed in close consultation with the fishing industry and the Maritime and Coastguard Agency in order to be effective and approved.

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7. Appendices

7.1. The Prohibition of Fishing for Scallops (Scotland) Order 2003

Prohibition of fishing for king scallops by means of dredge to which obstruction attached

3. Fishing for king scallops by a Scottish fishing boat or by any relevant British fishing boat by means of a–

a) French dredge; or
b) scallop dredge,

to which anything has been attached which obstructs in whole or in part the rings or netting on any part of the dredge is prohibited in the Scottish zone.

Prohibition of fishing for king scallops – French dredges

4. Fishing for king scallops by a Scottish fishing boat or by any relevant British fishing boat by means of a French dredge is prohibited–

a) in Scottish inshore waters; and
b) in any other part of the Scottish zone, where more than 6 French dredges are towed from each side of the fishing boat.

7.2. The Scallop Fishing (England) Order 2012

Specification of scallop dredges:

(1) No British fishing boat may carry or tow a scallop dredge within British fishery limits unless the dredge conforms to the following specifications.

(2) It must—

a) include a functioning, operational and moveable spring-loaded tooth bar and belly bar;
b) not have any part of its frame that exceeds 85 centimetres in width;
c) not contain any attachments;
d) not contain a diving plate or any other similar device;
e) not exceed 150 kilograms in weight including all fittings;
f) not contain more than 1 row of belly rings hanging from either side of the dredge perpendicular to the rings which hang from the belly bar.

(3) If the dredge measures 80 centimetres or more in width, it must not have—

a) more than 8 rows of belly rings hanging from the belly bar;
b) more than—
    i. 9 teeth on the tooth bar, if—

the fishing boat in question is outside the relevant area; or each tooth measures 12 millimetres or less; or

i. 8 teeth on the tooth bar, if—

the fishing boat in question is inside the relevant area; and any tooth measures more than 12 millimetres.

(4) If the dredge measures less than 80 centimetres in width, it must not have—

a) more than 6 rows of belly rings hanging from the belly bar; or
b) more than 6 teeth on the tooth bar.

(5) Each tooth on the tooth bar must measure no more than—

a) 22 millimetres if the dredge measures 80 centimetres or more in width; or
b) 12 millimetres if the dredge measures less than 80 centimetres in width.

(6) For the purposes of this article—

a) the size of the tooth on a tooth bar is its maximum width measured in the direction of the line of the tooth bar; and
b) belly rings and the fastenings that attach the belly rings to each other and to the frame are not attachments.

(7) In this article—

"attachment" means anything that is fitted to the scallop dredge (other than something that is used solely to aid the lifting and emptying of the dredge and which in no way obstructs the belly rings or any netting);

"belly bar" means the bar attached to the frame of a scallop dredge which runs parallel to the tooth bar and from which most of the belly rings ultimately hang;

"row of belly rings" means a line of single interconnecting rings, where the ring at one end of the line hangs either from the belly bar or from the main structure of the dredge perpendicular to the belly bar;

"the relevant area" means that part of ICES division VIIa which is north of the line 52° 30´N but outside the Scottish zone, and all of ICES division VIId;

"tooth bar" means the bar to which are attached teeth, the ends of which point downwards and are dragged along the sea bed when the dredge is towed.

7.3. Conservation of Scallops Regulations (Northern Ireland) 2008

(2) A person shall not use or carry on board any fishing vessel in waters within British fishery limits which are adjacent to Northern Ireland—

a. a scallop dredge or system of scallop dredges with a width, or in the case of a system of scallop dredges, an aggregate width, of more than 1219 cm (40 feet);
b. a scallop dredge with more than 9 teeth per dredge or tooth bar;
c. a scallop dredge with a tooth spacing between the internal edges of less than 75 mm on the dredge or tooth bar;
d. a scallop dredge with belly rings having a clear opening of less than 75 mm internal diameter;
e. a scallop dredge with a minimum mesh size of 100 mm in the netting cover; and
f. a French dredge.

7.4. The Scallop Fishing (Wales) Order 2010

(1) Subject to the provisions of this article, no British fishing boat is permitted to tow any scallop dredge within Welsh waters unless in relation to such a dredge—

a) no part of its frame is greater than 85 centimetres wide;
b) it includes a functioning, operational and moveable spring loaded tooth bar;
c) it does not contain any attachments to the rear, top or inside of the dredge;
d) it does not contain a diving plate or any other similar device;
e) the total weight of the dredge including all fittings does not exceed 150 kilograms;
f) the number of belly rings in each row suspended from the belly bar does not exceed 7;
g) the number of teeth on the tooth bar does not exceed 8; and
h) each tooth on the tooth bar measures no more than 22 millimetres in diameter and 110 millimetres in length.

(2) No British fishing boat is permitted at any time, in any part of Welsh waters to use any tow bar in connection with fishing for, taking or killing scallops, which exceeds 185 millimetres in external diameter.

7.5. The Sea-Fisheries (Scallop Fishing) Bye-Laws 2010 (Isle of Man)

(3) No person shall fish for, take or kill scallops by means of a scallop dredge, or system of scallop dredges if the width of the scallop dredges or, in the case of a system of scallop dredges, the aggregate of the widths of scallop dredges exceeds –

a) in the three mile area, 762 cm (25 feet); or
b) in the Territorial Sea other than the three mile area, 1067 cm (35 feet).

(4) No person shall fish for, take or kill scallops in the Territorial Sea by means of –

a) a scallop dredge with more than 9 teeth per dredge or tooth bar;

b) a scallop dredge with a tooth spacing between the internal edges of less than 75 mm internal diameter;
c) a scallop dredge with a mesh size of less than 100 mm in the netting cover;
d) a French dredge;
e) A scallop dredge with belly rings having a clear opening of less than 75 mm internal diameter;
f) A tow bar that exceeds 185 mm in diameter.

7.6. Sea Fisheries (Trawling, Netting and Dredging) (Jersey) Regulations 2001

26B Scallop dredges regulated

(1) It is prohibited to carry on board or use a scallop dredge if, where the belly of, or any side of, the bag that comprises part of the dredge consists of interlocking rings, the smallest part of the internal diameter of the rings measure less than 85 millimetres across.

(2) It is prohibited to carry on board or use a scallop dredge if, where the belly of, or any side of, the bag that comprises part of the dredge consists of interlocking rings –

a) a device or material is attached to the device, in the vicinity of the rings; and
b) the device or material may have the effect of obstructing the movement of any object through the diameter of the rings.

(3) It is prohibited for a fishing boat to use more than 16 scallop dredges at any one time.

(4) It is prohibited to use a number of scallop dredges at any one time with aggregate mouth sizes that exceed 12.8 metres.

(5) It is prohibited to carry on board a fishing boat a number of scallop dredges with aggregate mouth sizes that exceed 12.8 metres unless the dredges that would cause that size to be exceeded are stowed in a way in which they may not readily be used.

7.7. States of Guernsey Fishing Vessel Licence: Schedule & Conditions - 01 /2014

(Over 10 Metre and Under 10 Metre Sector and Non - sector Vessels) (3 – 12 nmiles limit only)

Scallop Dredging

24. A licenced vessel shall only fish using up to a maximum of four dredges in total within the 3 nautical mile territorial waters of Guernsey. (Scallop dredging is not permitted within the territorial waters of Sark).

25. Within the 3 – 6 nmiles limit (or median) of Bailiwick waters, a licenced vessel shall only fish using up to a maximum of 8 dredges in total, and the total length of any tow bar shall not exceed four metres. The tow bar must not be constructed or rigged in a way which enables more than 4 scallop dredges to be attached to it at the same time. The towing bar shall not be extendable beyond the prescribed maximum length and shall be measured between its extremities including all attachments thereto.

26. Within the 6 – 12 nmiles limit (or median) of Bailiwick waters, a licenced vessel shall only fish using up to a maximum of 12 dredges in total, and the total length of any tow bar shall not exceed 5.8 metres. The tow bar must not be constructed or rigged in a way which enables more than 6 scallop dredges to be attached to it at the same time. The towing bar shall not be extendable beyond the prescribed maximum length and shall be measured between its extremities including all attachments thereto.

27. Within the territorial waters of Sark, a licenced vessel shall ensure that any dredges carried on board are disconnected from the towing bar and are securely lashed and stowed and may not be readily used.

28. When, during any fishing trip, dredges are used or carried on board, it is prohibited for the quantities of marine organisms (as defined in article 3(a) of Council Regulation (EC) No. 850/98) retained on board, landed or trans-shipped, with the exception of bivalve molluscs, to exceed 5% of the total weight of marine organisms on board.

For the purposes of this paragraph a 'dredge' shall be constructed in accordance with Council Regulation (EC) 850/9. The vessel to which this licence is applied may carry a dredge within Bailiwick waters not complying with Council Regulation (EC) 850/9 provided such dredge is disconnected from the towing bar and is securely lashed and stowed and may not readily be used.

7.8. Scallop dredge gear trial experimental design

This document is designed to provide a protocol to be used to evaluate the catch rate and bycatch composition in scallop gear trials to compare the performance of different scallop dredge designs. This is version 2 of the protocol which takes into account comments made at a meeting with the scallop industry. It is anticipated that the design will be subject to a number of additional iterations. Comments from Marine Scotland Science and The Crown Estate were received in relation to version 1, these and our responses are included in a table at the end of the document.

In order to make valid comparisons between one fishing gear type and another, as many confounding variables as possible need to be eliminated. These confounding variables include the seabed (ground) type, seabed community type, scallop density, sea state, tidal state, vessel size and engine power. For these reasons the following recommendations are made:

1. The fuel efficiency of vessels will be monitored throughout the experimental tows using fuel flow meters.
2. O'Neill *et al*., (2013) deployed a sledge behind the tow bar of the scallop dredge. The sledge was fitted with plankton netting to catch displaced organisms, to quantify the amount of animals displaced in the turbulence generated sediment cloud. In addition, a LISST particle sizer was also fitted to the sledge to record the size distribution of particles resuspended by the scallop dredge. It is recommended to take measurements of the sediment cloud behind the dredge using the LISST particle sizer as this would enable an evaluation of the amount of sediment entrained by each dredge design. This may or may not be feasible given financial constraints and requires further consideration and discussion due to additional costs.
3. Undertake a preliminary survey (or use existing environmental data) to ascertain the variability in the variables above across the chosen study site. Eliminate areas from the survey area that show considerable differences (e.g. in depth, seabed type). Seabed type and depth will influence the resilience of the seabed communities that live in that environment and hence the extent to which they are influenced by scallop fishing. In the case of the proposed study EDPR have provided geophysical data for the area relevant to the wind farm development. This provides the basis to account for some (but not all) of the environmental variability at the site.
4. Choose a vessel or vessels of similar capability (e.g. engine size, tonnage, towing and sea-keeping ability). Discussions with industry indicate that fishing different designs of fishing gear from port and starboard beams will create unbalanced drag which may affect the performance of one gear c.f. the other. Thus it is better to use two or more vessels of similar specification and exchange the different gears among these vessels to account for the 'vessel' effect. Similarly towing different designs of dredges off the same towing bar will produce inconsistent results due to the differences in catchability that occur from the end to the middle of the towing bar. For this reason it is recommended to use only one type of gear on a vessel during a specific tow.
5. Decide how many different habitat types are relevant to the fishery (e.g. if the gear is normally fished over sand, gravel and cobble habitats, then three different trials may be required, one in each habitat type). Variation in performance between habitats will need to be quantified. Caution is required to standardise for depth and sea state as well as tidal condition for each of the trials to the extent possible. Adding additional habitats will greatly increase the cost of trials, therefore the immediate need to add in the 'habitat

effect' should be considered carefully. It makes sense to choose as a priority the most common type of seabed encountered by the industry e.g. coarse sand and gravels.

6. For each trial in each habitat a recommended minimum of 10 replicates (10 repeated tows of standard duration or distance over the ground e.g. each tow is 15 minutes long) should be undertaken. This should provide adequate statistical power to be able to detect differences in catches and bycatch in two different gear types. Nevertheless, it is recommended that during the trial, a power analysis is undertaken as results begin to emerge at the end of each day to enable the number or replicate tows required to be evaluated properly. There should be a preliminary discussion about the acceptable level of statistical power that is required (normally this would be expressed as for example: an 80% to detect a 20% difference between gear type A and gear type B).
7. Tows of excessive duration may mask beneficial effects associated with the new gear design. The reason for this is that as the dredge bag fills up the rings on the belly bag will become less selective and will clog. Thus shorter tows (15 - 20 minutes duration) are preferred. Standardising tows to the distance fished across the ground is a better approach than using timed tows as the distance covered in a fixed period of time will vary according to tide and sea state. Using a standard tow length of 1 nautical mile or 2 km would be appropriate. If catch rates are very high, a lower tow duration or distance may be appropriate. However this needs to be set at the outset and applied consistently throughout all trials. If catches are low then variability among replicates will be high which will make statistical analysis of the data less powerful. Thus preliminary test tows are recommended to help select the appropriate tow length to maximise the statistical power of the trials.
8. The number of dredges to be fished should be the normal number for the vessel used (4 per side, 8 per side, 16 per side etc), but should be standardised among different vessels when using two or more vessels. It is suggested that vessels capable of towing a maximum of 8 dredges per side are used as a baseline comparator as this fits with much of the legislation around the UK within the 12 nm territorial limit.
9. In the case of the current experiment, there are two elements of the fishing gear that have the potential to be modified, the tooth bar and the bellies in the dredge bag. The effects of these different gear components need to be assessed separately to understand the effect of each on the resulting bycatch.
10. Thus to compare the performance of a new tooth bar or tooth design, a comparative study needs to be undertaken using standard gear fitted either with standard tooth bars or the new design of tooth bar. In this case the only alteration to the gear is the tooth bar and any differences will be associated with this modification. Further trials to ascertain the effect of modifications to the belly of the dredge bag would need to be undertaken using both the traditional tooth bar and the new design of tooth bar. It is not possible to eliminate the possibility that the combination of one tooth bar design and a dredge belly design may outperform all others, hence it would be risky to discard one tooth bar design at this stage. However discarding one tooth bar design is a possibility if the results of stage 1 (the tooth bar comparison) are considered to be compelling enough.
11. Each vessel will require two scientists aboard to record the necessary data. The parameters to quantify from each catch are as follows:

From all dredges:

Total number of scallops from the entire catch from each beam.

Number of scallops over MLS and number under MLS from both beams.

Identify and measure all fish from all dredges.

This element could be done by the crew of the vessel after a short period of training with QA from the on-board scientists.

From one dredge from each side of the vessel:
Number of rocks and their volume (this could be measured in consistent volumes using a standard bin with volumes marked off on it).
Bycatch of benthic invertebrates should be quantified from one dredge selected at random from each side per tow. If bycatches are low, the number of dredges from which bycatch is sampled should be increased making a note of the number of dredges sampled. For this reason, it is essential that any vessel tendering for the trial will have access for the scientific team to the contents of an individual dredge as the catch is hauled aboard. This can be problematic in automated scallop dredgers with conveyor belts. Tendering vessels should describe how this can be facilitated. If a vessel does not describe how access can be given to the catch from a single dredge then it should be disqualified from the tender process.

From the bycatch, crabs, starfish, urchins, brittlestars are all biota that can be identified (to species level) consistently, and counted reliably with relative ease. If it is not possible to do this at sea, the benthic bycatch could be retained in plastic bags for quantification ashore at the end of the day (to avoid degradation in the quality of the bycatch which would make identification difficult). The latter approach may give better quality results depending on the quantity of material deposited aboard the vessels. This will require a shore based team to be available to undertake this analysis (this requirement has not been taken into account in the budget). There will need to be suitable facilities to allow this to happen, e.g. a well illuminated shed with tables and access to running water.

Outline of experimental plan:

The outline of the experimental plan with approximate costings is given in an accompanying table.

The following assumptions and allowances have been made.

It has been assumed that the trial will be conducted in the summer hence only one day of down time (contingency) has been budgeted in the cost calculations. This is an unquantifiable variable and vessels may incur additional downtime days, hence an 'in port' rate may need to be included in the tender. Similarly the science team may need to bid for a 'standby' rate in the event that there are periods of inactivity forced by weather.

One day has been given over to testing the catch efficiency of each vessel by using the standard Newhaven gear on all vessels that participate in the trial on the same day. This eliminates the effects of weather, tide, sea state etc and will differentiate between the different vessels used in the trial. This will enable us to identify any 'vessel' effect on catch rate.

Prior to this 'vessel' effect trial day, one day will be given over to working out the best length of tow for the subsequent days. This will involve deployment of the Newhaven standard gear increasing the duration of tow length in subsequent tows. The following increments will be used: 15 min, 20 min and 30 min. Each vessel will undertake three tows of each tow duration.

A mid-trial break is planned to enable refuelling, revitalling, unloading of scallops and a crew break.

The costings assume that the tender will specify the following:

1) A mid-trial break and that no fees will incurred for this day.

2) That mobilisation costs will be built into any bid received.
3) Catches can be landed and sold to offset costs.
4) Vessels will work a 12 h day returning to port each day which is stipulated in the protocol.
5) Port fees are included in the tender price
6) Crew costs account for a mid-trial break for fuelling, unloading of scallops etc.
7) There is no more than one day of down time associated with weather.
8) That one day is sufficient for each vessel to change from one gear type to another, do test the new gear at sea and tune it to perform adequately within its capability.

It is assumed that the science team will comprise 6 sea-going scientists plus one senior scientist who will undertake shore-side support, coordination and live statistical analyses. It is assumed that the sea-going scientists will be accommodated ashore overnight each day but that the chartered vessels will provide food aboard for the science team.

It is assumed that as each vessel changes over from one gear to another, half a day in port will be needed to achieve this together with an afternoon period to trial the unfamiliar gear and set it up correctly. Thus an area of seabed will need to be identified for ‘gear set up’ that is outside the experiment.

It is expected that the science team will review the sample processing, emerging data and on-board protocols with the vessel skippers at the end of each day in a joint session such that sample processing and practices can be improved and adapted as the experiment proceeds. This will be critical at the end of the first day of trials.

Although feedback from the scallop industry suggested that tidal state would have a strong potential effect on catches, splitting the study into two separate time slots to coincide with neap tides would make the experiment prohibitively expensive. For this reason the use of each gear type by each vessel has been randomised across the period of the experiment and each gear will be utilised across a 12 h period in each day thus smearing any daily effect of tide on catch rate.