Collaborating with Scotland’s creel fishers to reduce entanglement of minke whales, basking sharks and other megafauna through gear modifications

Susannah Calderan, Bianca Cisternino, Russell Leaper, Ellie MacLennan, Bally Philp, March 2024

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Executive Summary

Entanglement in static fishing gear (pots, or creels as they are known in Scottish fisheries) is a welfare and conservation concern for minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae*), basking sharks (*Cetorhinus maximus*) and other megafauna in Scottish waters. The Scottish Entanglement Alliance (SEA) estimated that an average of 6 humpback whales, 30 minke whales, and 29 basking sharks become entangled annually. Where entanglement type was known, 83% of minke and 50% of humpback whales, and 76% of basking sharks were caught in groundlines between creels. This occurs because floating polypropylene rope, the most widely-used rope in the creel sector, forms arches in the water between creel pots, often several metres high. The SEA project provided suggestions from Scottish creel fishers about entanglement mitigation options, such as replacing floating groundline with sinking groundline. A Whale and Dolphin Conservation project, supported by the Scottish Government's Nature Restoration Fund managed by NatureScot, collaborated with fishers on Scotland's west coast to trial negatively buoyant (sinking) groundline to assess its practicality. 15 *Nephrops* (langoustine) and crab fishers re-roped 61 sets of creel gear and fished the gear for up to 15 months, reporting on each haul as to the ease of handling of the rope, any snagging, signs of abrasion or other issues. Over 1500 gear hauls were reported throughout the trial, with the fishers encountering very few problems with the re-roped fleets, in some cases preferring them to gear made up with floating line. The project also deployed depth sensors/accelerometers and carried out Remotely Operated Vehicle (ROV) filming on a range of creel gear (*Nephrops*, crab, gear set deep/shallow, hand-shot/self-shot gear, floating/sinking rope) to gather qualitative and quantitative data on the performance of gear underwater, including whether sinking rope might cause any impacts to the seabed. No likely impacts were observed, with sinking rope lying lightly on the seabed with minimal movement. Floating rope was found to form arches, with no significant difference in the mean maximum height over the deployment of the loops for self-shot or hand-shot gear (both 3.7m). This project is highly encouraging, both because of its results – that there may be a simple, low-cost option to greatly reduce entanglement risk – and because of the very successful, bottom-up, partnership approach with Scottish creel fishers. Its implications are key to supporting the Scottish Government's commitment to reduce incidental bycatch in fisheries.

Glossary of Terms

Buoyant rope
Rope which floats in the water column

Crab
The main species caught in Scottish inshore creeling are *Cancer pagurus* (brown crab) and *Necora puber* (velvet crab)

Creel
A pot or trap that sits on the seabed for catching *Nephrops*, crab, lobster or other target species such as shrimp and wrasse

Creeping
Dragging a weighted device (grapple) across the sea bed to retrieve a fleet which has lost both ends and so cannot be hauled

Endline
The ropes at either end of the fleet which run from the seabed to a surface marker buoy, also known as the **riser** or simply **ends**

Fastener
When a rope snags on the seabed (becomes fast)

Fleet
A number of creels spaced along a line with surface markers at each end

Frap
A tangle in the rope

Groundline
The rope that runs along the length of the fleet to which the creels are attached by stoppers; also known as **backrope** or **backline**

Hand-shooting
A means of deploying a fleet of creels: the fleet is on deck and the crewman picks up each creel individually and throws it into the water at similar intervals as the boat moves forward

Hauler
Machinery used to pull the fleet of creels out of the water

Hauler plates
The pair of plates on the hauler which grip the rope when hauling, also known as sheaves

Hauling
Retrieving a fleet of creels onboard the vessel

Knife

The part of the hauler that ejects the rope from the hauler plates or sheaves, also known as a splitter

Lay
The construction of the rope – can be hard or soft, which refers to how difficult or easy it is to separate the individual strands

Lobster
Homarus gammarus

Making up
Putting together the components of a fleet of creels

Negatively buoyant rope
Rope which is slightly denser than seawater so lies on the seabed. Also known as **sinking** or **leaded** rope

Paying out (of rope)
Letting rope out over the side of the vessel

Prawn
(in the context of this project) *Nephrops norvegicus*, langoustine

RIFG (Regional Inshore Fisheries Group)
Forum where commercial fishers can discuss local fisheries management initiatives

Self-shooting
A means of deploying a fleet of creels: the creels are lined up on the deck of the vessel, and as it moves forward, the creels pull each other into the water when the line comes tight

Shooting
Deploying a fleet of creels from the vessel

Shooting over
Deploying one fleet over the top of another, either by accident or design (sometimes used to recover a lost fleet)

Splicing
Joining one rope to another by interweaving the strands of rope

Stoppers
The short ropes which attach each creel to the groundline, also known as droppers, tails, gangions, leg ropes

1. Introduction and background

Entanglement in static fishing gear (pots, or creels as they are known in Scottish fisheries) is a welfare and conservation concern for minke whales (*Balaenoptera acutorostrata*), humpback whales (*Megaptera novaeangliae*), and other endangered megafauna in Scottish waters, including basking sharks (*Cetorhinus maximus*) and leatherback turtles (*Dermochelys coriacea*). The Scottish Entanglement Alliance (SEA)[1], a partnership between 6 marine research, industry, conservation and welfare bodies, formed in 2018 to better understand the scale and impact of marine animal entanglements in Scottish waters. Based on reported entanglements over a 10-year period (2009-2019) extrapolated to all active vessels, it was estimated that an average of 6.4 (95% CI 3.7 – 13.4) humpback whales and 30.2 (95% CI 22.7 – 46.9) minke whales become entangled annually; where entanglement type was known, 83% of minke and 50% of humpback whales were caught in groundlines between creels (MacLennan et al. 2021; Leaper et al. 2022). Using the same dataset and analysis methods as Leaper et al. (2022), it was also estimated that an average of 29 (95% CI 24.8 – 34.2) basking sharks become entangled each year, 76% of which are in the groundline. This is because the buoyant polypropylene rope generally used in Scottish creel fishing forms arches or loops in the water between creel pots which can be several metres high (Figure 1.1(b)). These loops can entangle sharks and whales, generally by the mouth, tail, or flipper (Johnson et al. 2005). The SEA project provided suggestions from Scottish creel fishers about entanglement mitigation options, such as replacing floating groundline with negatively buoyant (sinking) groundline, which lies on the seabed rather than floating.

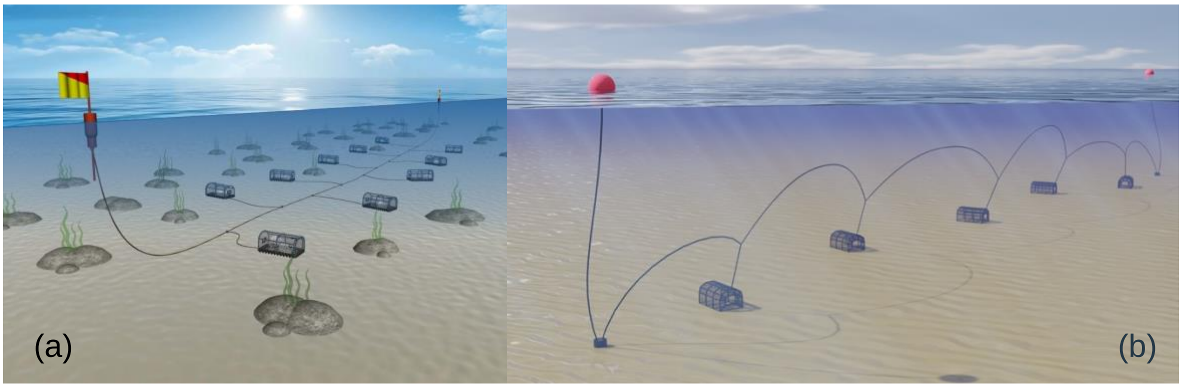

Figure 1.1. (a) shows how creel fleet ropes are sometimes assumed to sit on the seabed (from Seafish[2]) and (b) shows how the majority of rope used, which is buoyant, floats in loops (from Leaper et al. 2022)

Marine megafauna entanglement in static pot gear is a global issue (Hamilton and Baker 2019), often without straightforward mitigation options. The information from the SEA project on the location within the gear where entanglements occur (from 40 reports of entangled minke whales, 41 reports of entangled basking sharks, 8 reports

[1] https://scottishentanglement.org/
[2] https://www.seafish.org/responsible-sourcing/fishing-gear-database/gear/pots-and-traps-general/

of entangled humpback whales, and 10 reports of entangled leatherback turtles), which was obtained by interviewing fishers (MacLennan et al. 2021; Leaper et al. 2022), was of great value in its potential to suggest mitigation possibilities. There was a clear steer from the data and the fishers that work should be concentrated on reducing entanglements in the groundline in order to most effectively address entanglement risk.

Sinking groundline has been implemented in other areas of the world to address whale entanglement. However, the SEA dataset is one of the largest of its kind globally, with information on the location within the gear where whale and other marine megafauna entanglements have occurred. An equivalent dataset exists for minke whale entanglements in pot gear in Republic of Korea where 65 out of 67 entanglements (97%) were in the groundline (Song et al. 2010). Globally, the reduction in entanglement risk through a transition to sinking groundline has varied according to a number of factors, including the area and ground/seabed in which it was introduced, the level of collaboration with local fishers, the species involved, and prior knowledge of the nature of the entanglement issues.

Perhaps the world's best-known situation of whale entanglement in static pot gear is on the US/Canadian east coast, where it is a major cause of mortality for North Atlantic (NA) right whales (*Eubalaena glacialis*) (Knowlton et al. 2012). The history of entanglement mitigation efforts in the area, particularly with reference to groundline, is described in detail by Laist (2017), and summarised by Calderan (2022). Sinking groundline has been one of the components of ongoing mitigation measures since the 1990s. As for many of the other mitigations implemented, sinking groundline had a mixed reception and uncertain efficacy. Fishers from Maine, where the coastline can be rocky, with strong tides and currents, objected on the grounds of unacceptable probability of gear loss through abrasion and snagging. Due to their objections, a government rule mandating the use of sinking groundline in 2007 included a large exemption area in Maine (70% of the waters within 3 miles of the coastline), excluding approximately 1 to 2 million traps – almost 50% of those set along the east coast (Ludwig et al. 2016; Laist 2017). The process of implementing sinking groundline in NA right whale habitat was fraught, with numerous problems reported by the Maine lobster fishers such as chafing, poor handling, snagging, and noise in the hauler. In response to these complaints, several studies were carried out with a view to improving the performance and operational life of sinking groundline (Ludwig et al 2016). However, there was no clear evidence that the implementation of sinking groundlines in the US east coast trap fisheries reduced serious injuries and mortality of right whales to sustainable levels (Brillant & Trippel 2010, Knowlton et al. 2012, Van der Hoop et al. 2012, Werner & McLellan-Press 2016, Moore 2019). Part of the problem with assessing how effective the measure has been is that, whilst groundlines were known to entangle some NA right whales (Johnson et al. 2005), in the majority of cases it was not clear in which part of the gear the entanglement occurred, and so the extent to which groundlines were the cause of entanglement both before and after the implementation was not well understood, and the risk reduction has thus far not been quantified (Werner & McLellan-Press 2016, Laist 2017). Further, there is uncertainty as to how right whales behave in relation to the seabed, and the mechanism of any entanglements which occur in groundline (Brillant & Trippel 2010, Baumgartner et al. 2017, Laist 2017, Hamilton & Kraus 2019).

However, an example of a successful implementation of sinking groundline is the commercial octopus (*Octopus vulgaris*) fishery in South Africa. This fishery commenced in 2012, and between 2014 and 2021, of 7 Bryde's whale (*Balaenoptera edeni brydei*) entanglements where the position in the gear was known, 4 were in groundline (Segre et al. 2021). The implementation of sinking groundline (amongst other measures) went well and we are not aware of any further entanglements. In addition, Daniel (2021) noted that concerns that sinking line might become buried in the substrate and affect grappling and retrieval were unfounded. The Segre et al. (2021) study was particularly interesting in that it identified a feeding behaviour of Bryde's whales in the area – chasing prey at high speed close to the seabed – which makes them especially vulnerable to floating groundlines associated with static pot gear. In 2022, the Scientific Committee of the International Whaling Commission noted the apparent success of the South African initiative to switch to sinking groundlines in the octopus fishery, and recommended trials using sinking groundline in Scottish creel fisheries to address the entanglement issues there (IWC, 2022).

Together with suggested options from the fishers interviewed in the SEA project for investigating the use of sinking rope, this indicated an obvious next step for work to reduce entanglement risk. In 2022, Whale and Dolphin Conservation (WDC) applied for and received funding from the Scottish Government Nature Restoration Fund (managed by NatureScot) to investigate the viability of using sinking groundline in Scottish creel fisheries. The objective was to take a collaborative, bottom-up approach, working closely with fishers and the Scottish Creel Fishermen's Federation ((SCFF), which is also a member of SEA) to assess whether sinking groundline would be practical to fish with in Scottish inshore waters. This was an essential first step, drawing on the expertise of fishers, and ensuring that they were engaged and consulted from the beginning. However, we were not trying to assess any reduction in entanglement rate during the rope trial. This was in part due to the small temporal and spatial scale of the trial, and the number of fleets involved. It was also because, as the interview data indicated that loops of groundline in the water column entangle megafauna, it is reasonable to assume that removing those loops would reduce entanglement risk.

Although the efficacy of sinking groundline implementation in US east coast fisheries in reducing risks to NA right whales remains uncertain, we anticipated a future greater risk reduction and fewer implementation problems with a trial in Scottish waters for the following reasons:

- Whilst the part of the gear in which NA right whales become entangled on the US east coast is often unknown, this information is available for many entanglement cases in Scotland, due to the interview data from creel fishers collected as part of the SEA project. The evidence is particularly strong for minke whales and basking sharks, as they are generally not strong enough to escape from or swim off with gear and instead die *in-situ*, making the mechanism of entanglement clear.

- We expected the design and manufacture of sinking line to have improved since it was first implemented in the US.

- Much of the seabed environment in inshore Scottish waters (particularly on *Nephrops* ground) is soft mud substrate and therefore more benign than that of Maine (in Massachusetts, where the seabed is less rocky, sinking groundline was much less controversial).

- Engagement with fishers in the US was often problematic, whereas this project was planned from the start to take a bottom-up, highly collaborative approach.

On the west coast of Scotland, a large proportion of creel vessels target *Nephrops norvegicus* (known variously as Norway lobster, Dublin Bay prawn, langoustine or scampi, but referred to here as *Nephrops* or prawns). Details of this fishery are summarised by Calderan (2022) and Leaper et al. (2022). In 2022, 1,415 tonnes of creeled *Nephrops* were landed by Scottish vessels with a value of £16 million. 18,000 tonnes of trawled *Nephrops* were landed worth £67 million. Creeled *Nephrops* represent a smaller tonnage of landings, but attract an average price per tonne 4 times that of trawled *Nephrops*[3]. The *Nephrops* creel fishery accounts for a large proportion of entanglements (53% of minke whales and 45% of humpback whales reported during the SEA project) (MacLennan et al. 2021). It was decided therefore that this trial would start with vessels targeting *Nephrops*. Furthermore, *Nephrops* inhabit seabeds with soft substrates, which was expected to be a less problematic starting point for the trial. Crab fleets fished on harder ground would follow later on in the project once the rope had been trialled on prawn ground. In the following chapter, the selection of trial participants and choice of area in which to run the trial are discussed.

[3] https://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2023/09/scottish-sea-fisheries-statistics-2022/documents/scottish-sea-fisheries-statistics-2022/scottish-sea-fisheries-statistics-2022/govscot%3Adocument/scottish-sea-fisheries-statistics-2022.pdf

2. Sinking rope trials (methods)

The initial project objectives were to select the area(s) where sinking rope would be trialled, and by whom.

2.1. Selection of study area

For the study area, a key decision was whether to cover a range of areas around the Scottish coastline, or restrict the trial to a smaller area. In any event, a sufficient number of fleets deployed in a variety of conditions was required. The decision was made to conduct the trial in a relatively small area, the Inner Sound area to the east of Skye (Figure 2.1) which had a variety of bottom and sediment types, depths, exposure, tidal conditions and target species. This range of environments allowed for effective trials, with fishers operating year-round, with relatively few days restricted due to bad weather. There were straightforward opportunities for participating fishers to collaborate with each other, and for the project manager to meet regularly with all participants. The trial area was in the centre of the west coast of Scotland which has higher rates of entanglement than the east coast or Northern Isles (Leaper et al. 2022).

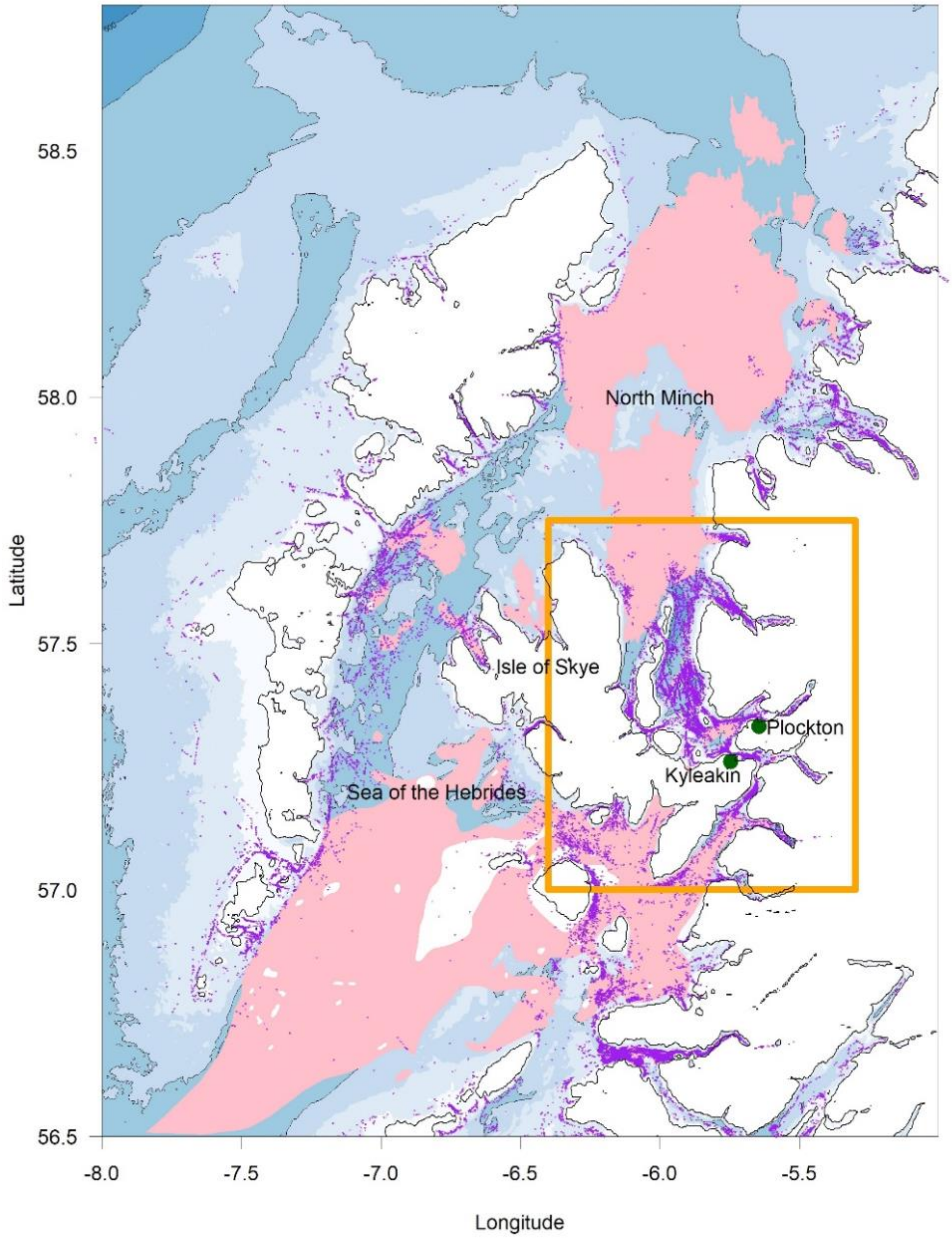

Figure 2.1. Area selected for trials (orange rectangle). Purple triangles indicate observed distribution of creels (from HWDT data presented in Leaper et al. 2022), pink area shows areas of *Nephrops* habitat from Marine Scotland data[4]

The *Nephrops* fishery accounts for a large proportion of entanglements (53% of minke whales and 45% of humpback whales reported during the SEA project) (MacLennan et al. 2021). For initial trials of sinking rope we therefore prioritised vessels targeting *Nephrops*. Furthermore, *Nephrops* inhabit seabeds with soft substrates where implementation of sinking groundline was expected to be least

[4] http://marine.gov.scot/maps/334

problematic due to less risk of abrasion or snagging than on crab ground. However, there was also a need to trial the line on other bottom types with other target species to obtain the most widely applicable results, and it was planned to phase this in later in the project. The selected area included the harbour areas (Broadford and Kyle) with the greatest *Nephrops* landings from 10m and under vessels (Table 2.1) and the harbour area (Portree) with the third highest landings for over 10m vessels (Table 2.2).

Table 2.1. *Nephrops* catches in 2020 for vessels ≤ 10m using pots and traps. Reported *Nephrops* landings are given in the UK Sea Fisheries Statistics[5], The most recent statistics at the time of the start of the project were from 2020, and data for harbours with greater than 5 tonnes total live weight

Harbour	Total Sum of Live Weight (tonnes)	Total Sum of Value (£)
Broadford	89.4	964,872
Kyle	40.4	398,583
Stornoway	38.2	324,373
Tarbert	36.2	396,767
Portree	36.2	350,411
Ullapool	35.1	358,714
Tayvallich	34.5	306,482
Oban	32.8	332,140
Kilchoan	26.0	254,917
Sleat	25.2	197,953
Shieldaig	24.9	337,109
Stockinish	23.5	193,143
Gairloch	23.4	263,334
Kylesku	22.2	264,362
Crinan	20.8	196,326
Ulva Ferry	19.2	190,150
Achiltibuie	19.1	227,751
Dunoon	18.7	171,164
Port Appin	18.5	209,922
Lochinver	15.7	172,971
Lochmaddy	15.0	128,648
Dunvegan	13.6	152,058
Leverburgh	12.4	97,531
Scalpay	12.2	112,249
Greenock	8.1	81,888
W.Loch Tarbert	8.0	51,770
Campbeltown	7.9	68,309
Erribol	7.8	68,936
Mallaig	7.2	69,201
Fort William	6.9	71,277
Strathaird	6.6	64,411

[5] https://www.gov.uk/government/collections/uk-sea-fisheries-annual-statistics

Uig	6.6	63,304
Glenuig	6.4	71,393
Cuan	6.3	68,001
Balvicar	5.4	49,092
Portaskaig	5.0	59,376

Table 2.2. *Nephrops* catches in 2020 for vessels >10m using pots and traps. Reported *Nephrops* landings are given in the UK Sea Fisheries Statistics[6], The most recent statistics at the time of the start of the project were from 2020, and data for harbours with greater than 5 tonnes total live weight

Harbour	Total Sum of Live Weight (tonnes)	Total Sum of Value (£)
Tarbert	48.7	533,787
Stockinish	36.6	312,559
Portree	34.3	390,329
Oban	30.0	328,024
Kallin	29.9	200,780
Tayvallich	28.3	277,729
Balvicar	25.0	271,584
Kylesku	22.3	235,948
Gruinard/Aultbea	20.4	190,142
Scalpay	16.4	157,437
Campbeltown	15.5	142,824
Stornoway	15.2	83,979
Leverburgh	11.9	117,626
Luing	11.9	123,359
Shieldaig	11.0	129,258
Tobermory	10.3	120,169
Achiltibuie	10.0	115,793
Dunvegan	9.9	103,306
Lochinver	7.6	84,495
Uig	7.4	59,981
Ullapool	7.4	109,160
Fort William	7.1	80,797
Gairloch	6.0	65,305
Kilchoan	5.8	56,195
Bunessan	5.2	61,487
Broadford	5.1	58,505

2.2. Selection of participating fishers

For the selection of participating fishers, they obviously needed to want to collaborate in the project, but it was also important to include fishers who were

[6] https://www.gov.uk/government/collections/uk-sea-fisheries-annual-statistics

initially sceptical of how practicable the rope would be. It also needed to be decided whether it was preferable to involve a larger group of fishers trialling a smaller number of fleets each to achieve a sufficient sample, or a smaller group with more fleets each. The decision was taken to use a larger group. Partly this was again to ensure a wider variety of fishing areas, methods (e.g. whether the creels were deployed by hand (see video) or 'self-shot' where each creel is pulled off the deck by the line in the water (see video) and target species. However it was also important not to put disproportionate pressure on just a few individuals who would have been required to give more time to the project and incur more risk, and therefore be perhaps disinclined to take part in the trial. The choice of area and trial participants was also made because of the collaboration with the Scottish Creel Fishermen's Federation (SCFF), who have been instrumental in facilitating, supporting and inputting into the project at every stage. 15 skippers from the inshore fleet in the Inner Sound/Skye area of the west of Scotland were recruited. Their vessels ranged between 6.5m to 12m in length, were a mix of hand and self-shooting, had a variety of hauler types, and fished in a range of environments. The majority of the fishers were exclusively targeting *Nephrops*, although some fished both crabs and *Nephrops*, and one just crab and lobster.

2.3. Rope trial aims and objectives

The central aim of the project was to assess whether sinking rope was practical for fishers to use, based on collecting direct feedback from experienced fishers. Once fishers had re-roped the agreed number of fleets with sinking rope (see Chapter 3), we asked for summary information on each haul of the sinking line fleets, comprising the date, position, depth, bottom type of the fleet being hauled, and whether there had been any issues or other comments on the rope. The Project Manager aimed to make the feedback process with fishers as convenient for them as possible, so the priority was to be flexible, with a variety of communication means available. These included:

- WhatsApp message for each haul, with a photograph of the vessel's plotter showing the position
- Photograph or scan of logbooks at the end of each month
- Transcription of relevant fleet information into a separate document, submitted regularly
- Summary of situation submitted on more ad-hoc basis.

These data were all entered into a database by the Project Manager to compile a temporal and spatial record of all the sinking line fleets hauled in the trial, with details of any observations from the fishers.

The terms of the trial were that that sinking rope would be provided to the fishers free of charge. They were also given a small payment per fleet re-rigged with sinking line, 60% of which was paid at the start of the trial to cover time spend re-roping fleets and reporting on hauls, and 40% of which was paid at the end of the trial once all the data had been submitted.

In addition to the haul information, the Project Manager was in regular contact with the fishers in the trial, going to sea with several of them, having conversations in the harbour or pub, and communicating by phone, email and WhatsApp messaging. The trial was a collaboration throughout, with the fishers providing industry expertise, and the Project Manager planning and facilitating the work, and collecting and analysing the data.

The metrics of success for whether the rope would be assessed to be practical to use were broadly whether it was indistinguishable from, or better, to work with than floating rope – or at least if any differences did not cause any inconvenience, difficulty or safety issues. These criteria included:

- Ease of splicing
- Ease of handling
- Performance in hauler, including noise
- Weight
- Frequency of coming fast on the seabed
- Accumulation of mud/sediment on the rope
- Rate and characteristics of abrasion (as a result of hauling and while deployed)
- Rate of tangling
- Any general safety issues.

Many of these metrics were inevitably qualitative or anecdotal. There was also no means of establishing the different rate of some factors such as abrasion or fasteners compared to floating rope, and this was reliant on the judgement and experience of the fishers involved. We were also not trying to assess whether the trial resulted in a reduction of the entanglement rate (see Chapter 1).

3. Sinking rope procurement

3.1. Rope choice and purchase

Creel fisheries in Scotland and elsewhere have generally used floating polypropylene (or combined polypropylene and polyethylene) rope for their groundlines, endlines and stoppers. There is thought to be less risk of it chafing or snagging on rocky bottoms than with sinking line, and if the endlines on a fleet are lost, floating line can be easier to retrieve using a grapple or by shooting over the fleet with another one. However, the main reason it is used is because it is cheaper than sinking line, and so has become the creel fishery standard. It is generally about half the price of similar sinking line with a lead core (dependent on the global price of lead). Other alternative line materials that are negatively buoyant are nylon and polyester, but these are expensive and not used extensively in creel fisheries.

As sinking line is less common in inshore fisheries than buoyant rope, there was a fairly narrow choice of sinking rope types and suppliers available to this project. Preliminary research suggested that much of the leaded rope on offer is very hard lay and oversized, likely more suitable for offshore fishing in challenging environments by larger vessels with more substantial haulers than the inshore creel fleet, and so not appropriate for this trial. We decided to use leaded Polysteel rope, which is a blend of polypropylene and polyethylene, stronger and more abrasion-resistant than polypropylene on its own. This rope looks the same as the floating rope in general use, and is available in the usual diameters. However, it has a thin thread of beaded lead which runs through the weave to make it slightly negatively buoyant (Figure 3.1).

Figure 3.1. A sample of Seasteel sinking rope with the strands separated to show the thread of beaded lead

Densities of rope in the trial varied between 1.21 and 1.57g.cm^{-3} (see Table 3.1) compared to 1.025 g.cm^{-3} for seawater and between 0.90 and 0.96 for different polymers of polypropylene and polyethylene. Standard leaded rope was available from a small number of suppliers, and was purchased from both Gael Force Marine and Karl Thomsen Marine Riggers for this trial. These are both Scottish-based suppliers, and commonly used by Scotland's inshore creel fishers. Polysteel is a medium lay rope, which is relatively cheap and general purpose. Polysteel variants (which were proprietary to Gael Force Marine) were also used and were:

Seasteel: Medium-to-firm lay, one thread of beaded lead. Greater abrasion resistance than Polysteel, easy to splice.

Seaking XL: Firm lay, two threads of beaded lead, greater abrasion resistance, stronger, heavier, and thicker than standard Polysteel.

Rope densities were measured for the types and quoted diameters (Table 3.1). Some rope types, particularly Sea King XL are 'oversized' and the actual diameter is greater than the quoted size. All samples sank in sea water, mostly straight away except for 12mm Sea King XL which took some time to sink, presumably due to trapped air in the lay of the rope.

Table 3.1. Measured densities for Gael Force sinking line

Rope Type	**Density g/cm^3**
10mm Seasteel	1.53
10mm Polysteel	1.57
10mm Sea King XL	1.30
12mm Seasteel	1.47
12mm Polysteel	1.43
12mm Sea King XL	1.21

In order to further inform our rope choice prior to the purchase of large quantities for the trial, a test fleet made up with combinations of these 3 different types of sinking line, and also with floating line was shot and surveyed using a remotely operated vehicle (ROV) to enable decisions to be made about what ropes to use in the main trial. All the sinking ropes appeared to lie well; the test fleet also indicated that it would not be sufficient to simply replace floating stoppers with sinking stoppers and allow the floating groundline to remain (which had been a possible initial option), as the floating groundline pulled the sinking stoppers off the seabed and the rope still floated. During the rigging of this test fleet, the SeaKing XL was found to be prohibitively tough to splice (a splice is needed to join the stopper of each creel to the groundline), and was largely excluded from the trial, even though it would have been a good option for strength and abrasion resistance.

3.2. Rope distribution

At the outset of the trial, participating fishers were asked to complete a form with details of their vessel, hauler, fishing area, target species and fleet set-up (number of creels, diameter of rope) to enable the trial to be planned and the rope purchased. Supply and lead-times on rope orders were often long and unpredictable throughout the project, with rope going out of stock and deliveries being delayed. It is not clear whether this was an issue particular to leaded rope, or a problem with general global freight. The first rope order was distributed to fishers at a project start-up meeting in December 2022. These early distributions were all for *Nephrops* fleets (see Chapter 2), with crab fleets being added into the trial subsequently once we had assessed the performance of the rope. Further rope was ordered and distributed throughout the trial according to demand and budget, with fishers able to choose how many fleets they wanted to trial. By the end of the project, the 15 fishers in the trial were fishing between 2 and 12 sinking line fleets each.

Each fisher in the trial was provided with both standard leaded Polysteel rope from the two different providers (Gael Force and Karl Thomsen), and Seasteel rope (from Gael Force), so that all the fishers had experience with both types of rope to enable a comparison and inform recommendations. Two crab fleets were re-roped with Seaking XL (also proprietary to Gael Force).

For the 15 fishers involved in the trial, their fleets varied in rope diameter, number of creels per fleet, and spacing of creels. However they all used either 10mm or 12mm diameter rope for their groundline, and 8mm, 10mm or 12mm for their stoppers. Some examples of typical fleet configurations are given in Table 3.2. Stoppers are generally between 1m and 2m in length, depending on how they are attached to the creel (average 1.3m). A coil of rope is between 200m and 220m. The number of coils given in Table 3.2 easily cover the requirements for one fleet, so if multiple fleets were being re-roped, the coils could be used more efficiently to re-rope more fleets.

Table 3.2. Examples of typical fleet configurations of trial participants

Fleet type	**Number of creels**	**Groundline rope diameter (mm)**	**Average groundline length (m)**	**Number of groundline coils**	**Stopper rope diameter (mm)**	**Number of stopper coils**
Nephrops large	60	12	750	4	10	1
Nephrops small	50	10	620	4	8	1
Crab	20	12	250	2	12	1

4. Sinking rope trials (results)

All 15 fishers in the trial contributed and participated actively to the project throughout its whole duration, trialling between 2 and 12 fleets each. No fishers withdrew from the trial, and they took the opportunity to re-rope additional fleets of sinking rope when this was offered at other times later on in the trial. All of the trial fleets were still being actively fished at the end of the project (March 2024).

4.1. Rope trials at sea

A total of 61 fleets of creels were re-rigged with sinking line and deployed from 16 vessels (one of the 15 fishers changed vessel partway through the project period). This resulted in over 18,000 fishing days for the fleets in total, and 1545 hauls where comprehensive data were reported. The number of days the sinking line fleets were in the water for the purposes of the trial varied between 105 and 426 days (mean 294 days) depending on what stage in the trial the fleet had been re-rigged.

Of the 16 vessels in the trial, 15 (94%) were 10m or under and one was 10-12m. This is similar to the overall proportion within the Scottish creel fleet of which 90% of vessels are 10m or under[7].

4.2. Haul data

Of the 61 fleets, 46 were targeting *Nephrops* (80% of fishing days) and 15 fleets were targeting crab (20% of fishing days). The relatively lower proportion of fishing days for fleets targeting crab was due to these trials starting later in the project, and the main focus being *Nephrops* fleets. Fleets targeting *Nephrops* comprised 40, 50 or 60 creels (mean = 55). The fishing areas are shown in Figure 4.1. The fishing depth ranged from 30 to 200m (mean = 89m). Fleets targeting crabs comprised either 20 or 30 creels with fishing depths ranging from 6 to 46m (mean = 20m). The distribution of fishing depths for all fleets in the project is shown in Figure 4.2. This shows a clear distinction between *Nephrops* and crab fleets. The depths of gear targeting *Nephrops* were broadly representative of Scotland as a whole although with a slightly higher proportion of shallower gear. The mean depth of 20m for fleets targeting crabs was rather shallower than in other areas (mean for Scotland of 53m) (Leaper et al 2022).

There were several different descriptions for the type of ground. Where ground could be classified as either soft or hard (rather than a combination of the two), 35% of these hauls were on hard (firm sand, rock, boulders) and 65% on soft (mud).

[7] ttps://www.gov.scot/binaries/content/documents/govscot/publications/statistics/2023/09/scottish-sea-fisheries-statistics-2022/documents/scottish-sea-fisheries-statistics-2022/scottish-sea-fisheries-statistics-2022/govscot%3Adocument/scottish-sea-fisheries-statistics-2022.pdf

Of the crab fleets, 97% were on ground described as hard or sand with gravel or rock. Of the prawn fleets 83% were on ground that was described as soft or mud.

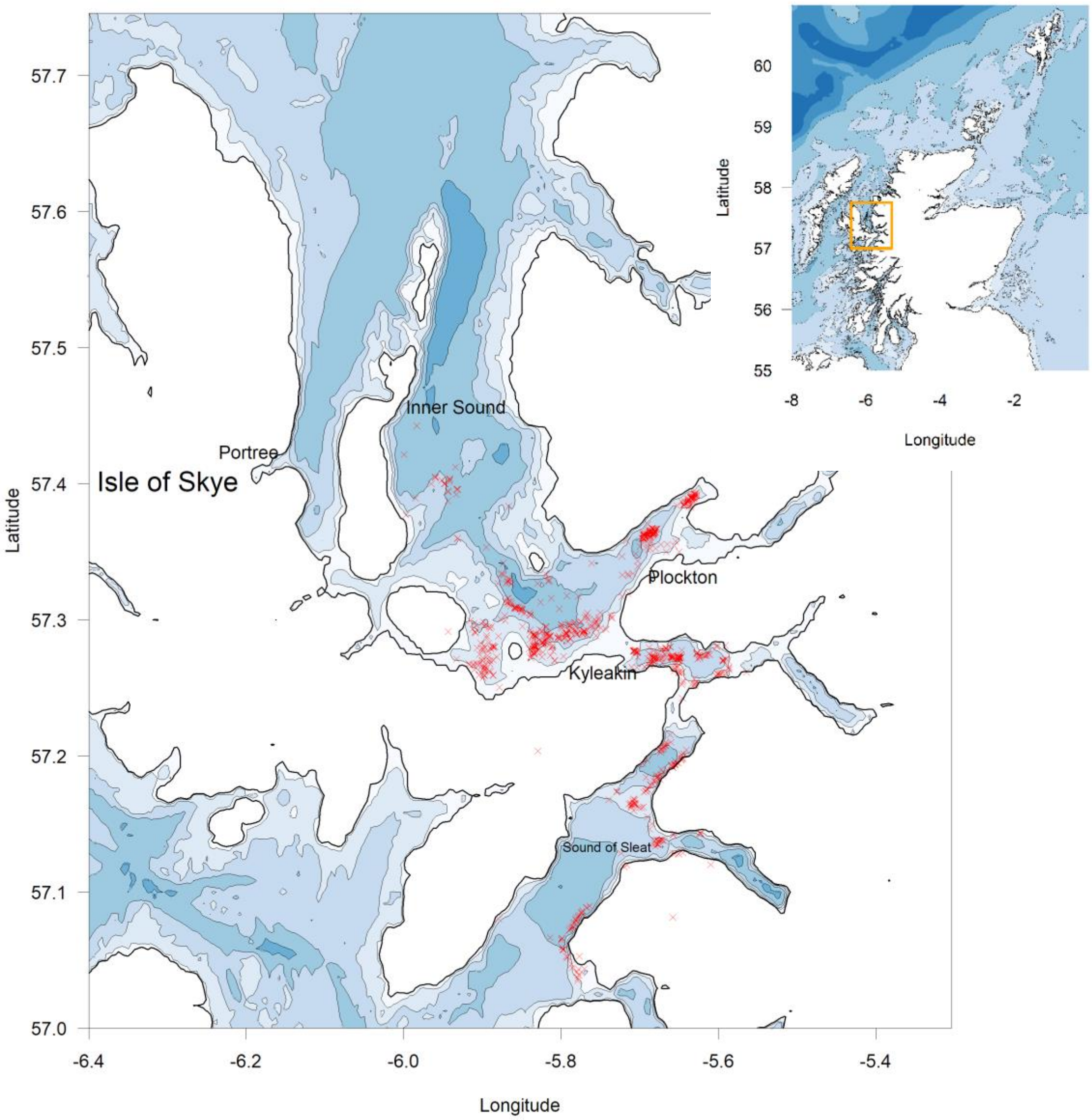

Figure 4.1. Locations of 1545 hauls of fleets rigged with sinking line in the Inner Sound and Sound of Sleat (red crosses). Most of the fishers in the trial kept their fleets in approximately the same locations. Inset shows the area of the large-scale map as an orange rectangle

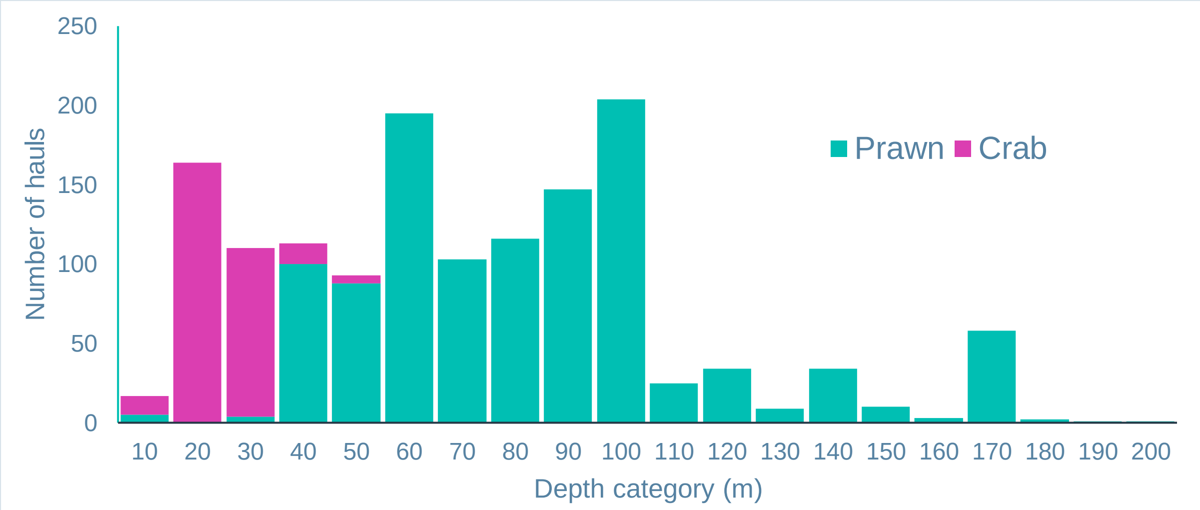

Figure 4.2. Distribution of all hauls by depth

There were 8 vessels which reported every haul in a systematic way, comprising a subset of 1141 hauls (11,191 fishing days). For these vessels, median haul interval was 7 days (mean 9.8). There were some longer intervals of over two weeks (14% of hauls) due to bad weather or other factors (Figure 4.3). If gear that is hauled at least every two weeks is considered actively fished (and conversely gear that is hauled with a longer than two-week interval is not actively fished) then actively fished gear represented 56% of the total days. Apart from when it is being hauled, the gear remains in the water all the time, so the frequency of haul data does not describe any increase or decrease of entanglement risk in itself. However, if a fleet is hauled less regularly, it represents a higher risk in relation to yield.

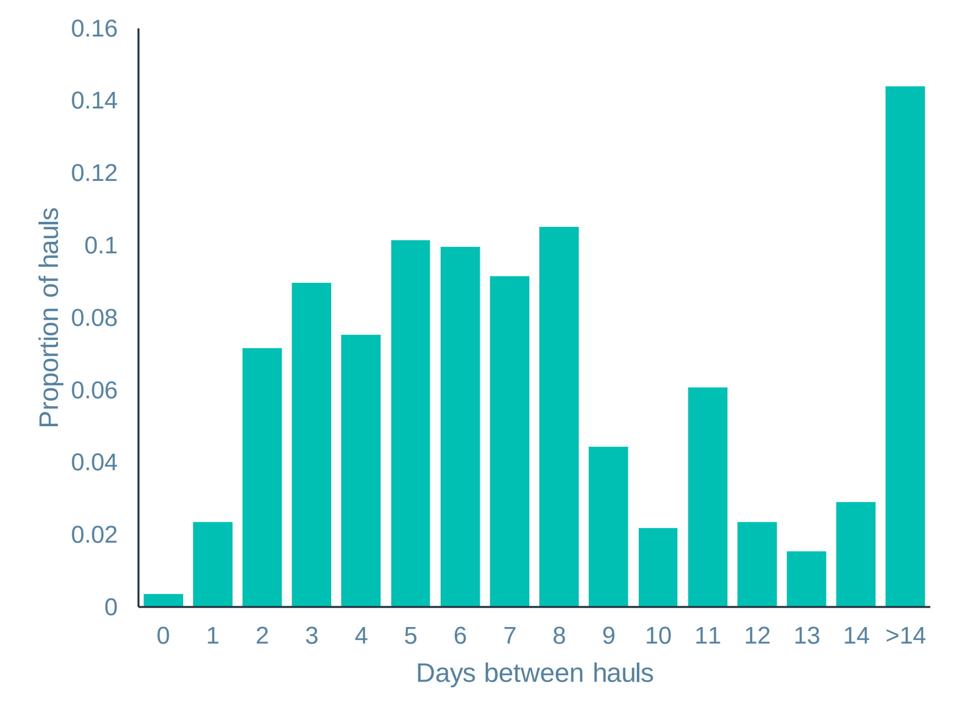

Figure 4.3. Distribution of haul intervals for 8 vessels which reported every haul

4.3. Feedback from fishers on sinking line

There were few reported problems with sinking rope, with most fishers reporting that it hauled and handled well, lay well on deck and was very similar to standard floating rope. Out of 1545 haul reports, there were 23 reports of an issue, 18 in *Nephrops* fleets, 4 in crab fleets and one in a lobster fleet (one of the crab fleets was shot for lobster at one point in the trial in shallow bouldery ground, where it came fast). Of these issues, 11 were fasteners, 7 were light snags, 3 were cases of abrasion, 1 of the rope breaking and 1 case of the rope coming out the hauler when hauling in poor weather and then paying out quickly. Out of these issues, 5 resulted in some damage to the fleet (rope or creels). The 23 cases out of 1545 where issues were reported related to a range of different circumstances, all of which also occur at times with floating line. This small number precluded any systematic analysis of the factors that might cause these issues to arise.

In addition to the haul data provided, a large number of qualitative comments were received from the participating fishers. The main points made by fishers are summarised here:

Ease of handling

- No difficulties were reported with working and splicing the sinking rope during re-rigging, apart from the two fleets of SeaKing XL, which were considered to be very tough to work due to the hard lay.
- The sinking rope was considered to lie better on deck than floating rope when new, and not add excessive weight to the boat, although one fisher reported that his crew disliked it as it was slippery when he stood on it.
- There was no reported difference in the ease of handling the sinking rope between self-shooting and hand shooting vessels.
- Those in the trial who had tried sinking rope before (for example, 20 years ago) were initially more sceptical about this trial. However, they were all more satisfied with the rope used in this trial – it was considered to be lighter, with fewer problems snagging on the ground or getting muddy (see below).

Differences between sinking rope types

- There were no differences reported between the handling or wear of the Polysteel vs the Seasteel. However, the Seaking XL was considered to be too wirey – not coiling well on deck, and jumping out the hauler (probably due to it being oversized). This did not improve as the rope wore in through the course of the trial.

Performance in hauler

- Generally the rope gripped well in the hauler and was quiet. However, when parts of the hauler (plates/knife) became worn, it appeared to become an issue sooner with the sinking rope than with floating rope, although there was no indication that the wear was being caused by the leaded rope itself. There was no reported difference in handling between the types of hauler used.

Frequency of coming fast on seabed

- Although the sinking rope did sometimes snag on the seabed, the rate of snagging was not considered to be unusual compared with floating rope.

Accumulation of mud/sediment on the sinking rope

- There were some reports of sinking rope on the *Nephrops* ground coming up slightly muddier than floating rope, but this was mentioned only rarely, and generally it was reported that the rope came up clean.

Abrasion

- There were a small number of reports of abrasion to the rope, especially around the end creels where they interacted with the endline/riser, but not considered to be either frequent or serious on either crab or *Nephrops* ground.

Tangling

- Fleets rigged with sinking rope had less tendency to tangle than floating line, especially during big tides and swell.

Loss of endlines

- There are issues in the study area with other vessels such as military or aquaculture vessels accidentally cutting one or both endlines. If both ends are lost, a common practice with a fleet roped with floating line is to catch the lost fleet by shooting another over the top of it and hauling them together. Another way is to grapple for the fleet. Both these methods are more difficult with sinking rope, although the one fleet in the trial where both ends were lost was successfully grappled and retrieved.

General safety issues

- In general, none were reported, apart from that in poor conditions, with strong wind, the sinking rope can pay out quickly if it comes out of the hauler due to the motion of the vessel.

Effect on fishing and seabed

- There were some reports of creel fleets rigged with sinking rope fishing better, which was thought to be because they move around less on the seabed. This was especially the case with newer-design creels which are lighter-weight and are thought to move around a lot on when on the seabed. No data were available to validate these reports.
- It is likely that creels rigged with sinking line cause less damage to the seabed, also due to less movement. This observation is particularly interesting, given a concern that sinking line might negatively impact the seabed/sensitive seabed features by lying on it. In fact the reverse might be the case.

4.4. Rope wear tests

A concern of many fishers prior to the trial had been that sinking line would abrade more quickly due to contact with the seabed, and also collect mud from the seabed on soft ground. There was little evidence of the line coming up muddy by the time it reached the hauler, although this did happen occasionally. The ROV images of the line on the seabed show it resting very lightly on the seabed (due to only being slightly negatively buoyant), which would explain why it rarely picked up mud (see Chapter 5).

Although the trial was not long enough to test the life expectancy of the sinking rope (which may last around 10 years of normal use), a number of tests were conducted on samples of line in order to measure the load that they would take before breaking. Two-metre sample lengths of sinking line were sent to Plant and Safety Ltd, Staffordshire, who placed each sample into a tensile test machine and increased the load until the breaking load had been achieved. All samples were of 12mm sinking rope (Seasteel or Polysteel) supplied by Gael Force Marine. The samples that had been used had been on actively fished fleets for over one year. We were not able to test a new sample of Polysteel, and the manufacturer does not provide a breaking load for sinking rope, but for the equivalent floating rope the breaking load given by the supplier for Seasteel and Polysteel are the same. Hence, we assumed this was also the case for sinking rope in calculating the proportional loss of strength (Table 4.1.).

Table 4.1. Breaking load tests of sinking line samples

Rope Type (all from Gael Force Marine)	**Description**	**Total load achieved (kg)**	**Proportion of new strength**
12mm leaded Seasteel	New	1525	1
12mm leaded Seasteel	Used for whole trial, minor abrasion	1400	0.92
12mm leaded Seasteel	Used for whole trial, minor abrasion	1411	0.93
12mm leaded Polysteel	Used for whole trial, heavy abrasion	1340	0.88
12mm leaded Polysteel	Used for whole trial, medium abrasion	1390	0.91

Figure 4.4. Seasteel rope used in trial showing typical levels of minor abrasion after over one year of use. Breaking load 93% of new equivalent

Figure 4.5. Polysteel rope used for the trial showing heavy abrasion after over one year of use. Breaking load 88% of new equivalent

The rope that appeared to have moderate wear based on the time that it had been in the water had maintained over 90% of its original strength. The sample that appeared heavily abraded still had 88% of its original strength.

4.5. Implications of sinking rope trials

This trial of sinking line in Scottish inshore creel fisheries, although at a quite a small spatial and temporal scale, represents an impressive body of work from the fishers involved, and offers valuable insights into the fishery and working practices. Comments from fishers on the trial and other aspects of fishing, although often qualitative, provide useful indications of the priorities and challenges of small-scale coastal fishing. The key standout results of the trial are the low rate of problems with using sinking line in the west coast *Nephrops* and crab fisheries, and the value of working collaboratively with fishers at all stages of the project.

5. Interaction of creel fleets with seabed and water column

5.1. Background

There has been a lack of qualitative and quantitative information about the behaviour of creel gear when it is being shot, hauled, and when it is on the seabed. Therefore in addition to fishers trialling the practicality of sinking rope by regularly shooting and hauling gear, we also deployed instruments to describe and quantify the relationship of both floating and sinking rope with the underwater environment, water column, and seabed. This was to assess and measure metrics such as:

- the loops which floating rope form in the water column
- whether the floating rope in self-shot fleets results in tighter groundline and therefore no/reduced loops
- how much movement occurs in ropes and creels
- whether sinking rope might impact on the seabed.

We used a Remotely Operated Vehicle (ROV) to obtain video of fleets, and sensors attached to creels and rope to obtain measurements of depth and movement.

5.2. Sensors to measure depth and movement of gear in the water

The instruments used to measure depth and movement were Star Oddi DST tilt sensors[8]. These are small, self-contained units (15mm x 46mm, 12g weight in water) which provide measurements of water depth and temperature, together with pitch and roll from accelerometers. The manufacturer's quoted depth accuracy is +/-0.6% of the selected range. With the depth range of 270m for the sensors used in this project, the expected accuracy would be +/- 1.6m. Given that measurements were being taken of the difference in depth between sensors, additional calibration experiments were conducted to assess and further improve the accuracy of the relative measurements between sensors.

5.2.1. Calibration tests of depth sensors

The calibration tests were conducted in Loch Linnhe (west coast of Scotland) by deploying all the sensors together to the same depths. Measurements were taken across a range of depths between 30 and 70m, two months apart. The aim of the second test was to check whether any observed differences between sensors were consistent over time. For each test, linear regression of the difference between the reading from that sensor and the mean from all the sensors over the range of depths > 30m was used to derive a calibration correction for each sensor.

At a depth of 50m the correction values for individual sensors ranged from 0.0 to 3.1m. For all sensors the correction related to the offset of the regression was greater than the correction related to the slope. There was good correspondence between the correction values for each sensor between the two tests (Figure 5.1).

[8] https://www.star-oddi.com/media/1/dst-tilt.pdf

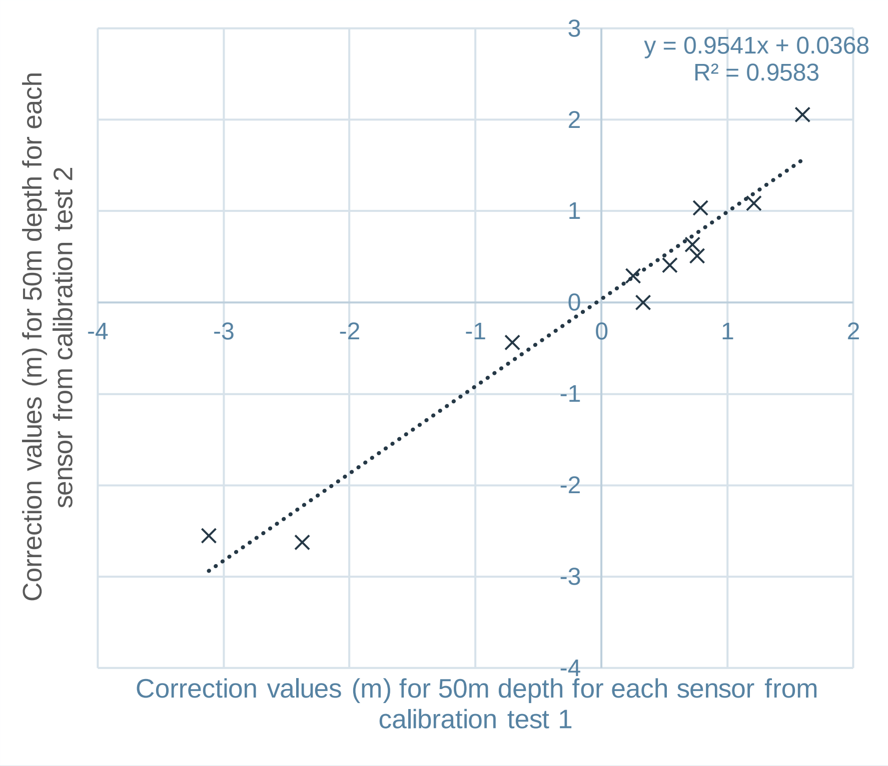

Figure 5.1. Comparison of correction values from two sets of calibration tests

These results suggest little change over time in the sensor calibrations. The calibration tests also showed good correspondence between the sensor reading in air and the correction for depth. This provided a correction factor (offset only) for one sensor which failed during a deployment, but prior to the calibration tests.

5.2.2. Measurement of depths of lines relative to the seabed

5.2.2.1. Attachment and deployment of sensors

In order to measure the depths of rope relative to the seabed, sensors were attached both to the midpoint of the groundline between each creel, and inside the adjacent creels such that the difference in depth could be measured. To attach the sensors to the groundline, a deployment device was made up, containing short lengths of buoyant line so that the whole attachment was neutrally buoyant and did not affect the height of the groundline (Figure 5.2 (a – c)). The sensors placed inside creels were attached using a specialist housing to protect them (Figure 5.2(d)).

Figure 5.2. (a-c) Attachment of DST tilt sensors to groundline. The sensors are the small white cylinders in between two sections of rope within the orange netting. The whole attachment was neutrally buoyant; (d) the sensor is in the white housing attached to the inside of the creel

Measurements were carried out in different depths of water for both hand-shot and self-shot fleets and in different tidal conditions. In each case, sensors were placed inside creels 3 and 5 and on the groundline between creels 2-3, 3-4, 4-5 and 5-6 (see Figure 5.3).

Whilst sensors were being attached and prior to shooting the instrumented fleet, the length of groundline between each creel was measured (length between the stoppers and the length of the stoppers themselves). A floating loop would be expected to follow a catenary curve from the joint with each stopper (Figure 5.3). Taking the maximum height of the loop less the height of the stoppers (h - s in Figure 5.3) gives an approximate equation for the catenary which can be used to derive the actual spacing between the creels on the seabed (c), based on the measured length of ground line between the creels (L).

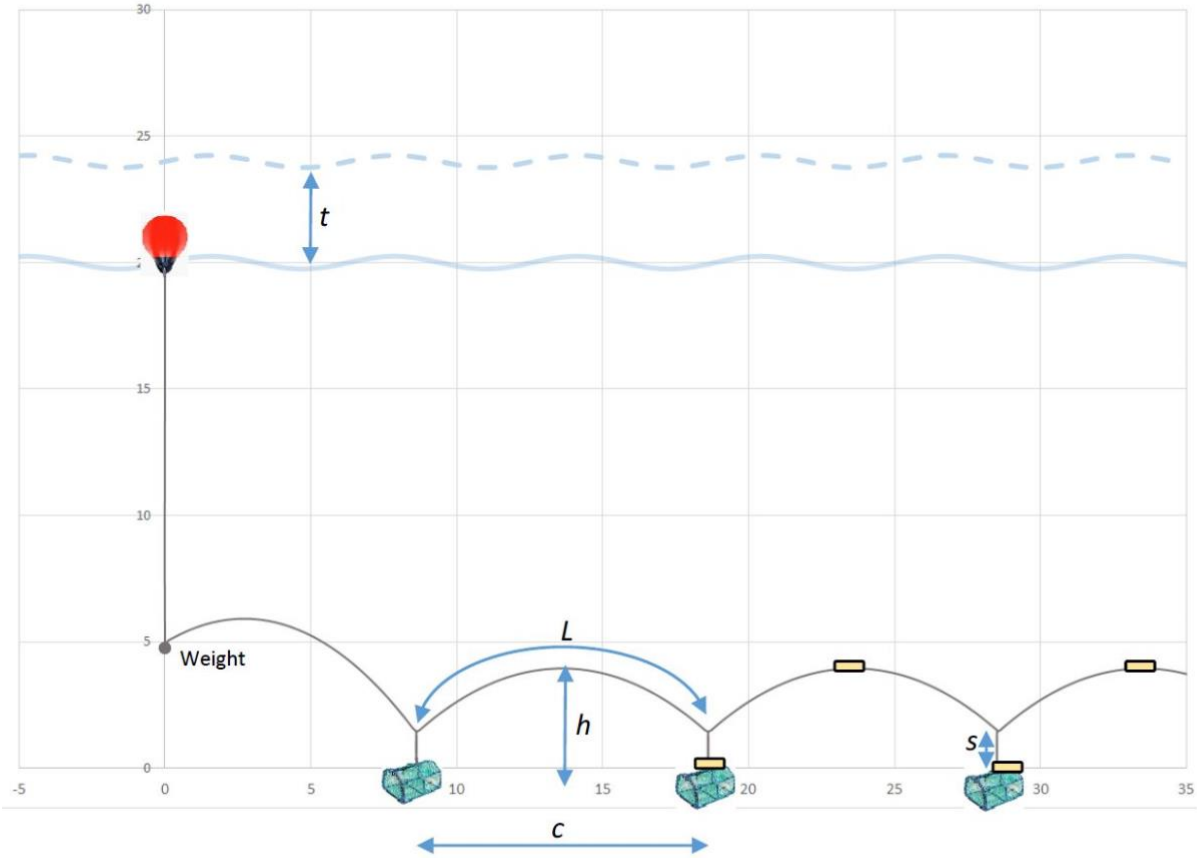

Figure 5.3. Measurements of typical creel set up in 20m water (low tide), x and y axes in m. *h* = height of loop above sea bed, *L* = length of groundline between stoppers, *c* = distance between creels on the sea bed, *s* = stopper length, *t* = tidal height. Yellow lozenges = sensors on groundline and inside creels

5.2.2.2. Measurements of loop heights

Six experiments were carried out to measure the heights of the arches of floating rope in both crab and *Nephrops* fleets, both hand-shot and self-shot. The measurements obtained are given in Table 5.1. In tidal conditions the height of the loops was often quite variable. To allow for this, both the mean and maximum heights are reported. The mean and maximum heights are similar when not affected by tidal currents.

Table 5.1. Measurements of loop heights of fleets with floating line

Area description	Average stopper length (m)	Average creel to creel ground line (m)	Mean depth of creels (m)	Maximum heights of loops (m) over deployment. Mean values over time in parentheses. Loop1 (creel 2-3)	Loop2 (creel 3-4)	Loop3 (creel 4-5)	Loop4 (creel 5-6)
1. Hand-shot *Nephrops* fleet, W of Kyle, opposite Balmacara. Strong tidal stream.	1.43	12.7	110	7.2 (5.7)	6.9 (6.0)	4.2 (3.3)	2.1 (0.8)
2. Hand-shot *Nephrops* fleet, Loch na Beiste no tide	1.45	11.9	16	4.8 (4.7)	4.3 (4.2)	4.7 (4.5)	4.1 (3.9)
3. Self-shot *Nephrops* fleet Loch Kishorn, moderate tide	0.83	13.4	20	2.6 (2.1)	2.9 (2.3)	3.6 (3.0)	3.6 (2.9)
4. Self-shot crab fleet Kyleakin, strong tide	1.64	14.4	13	2.1 (1.1)	3.2 (2.7)	3.5 (1.5)	2.6 (1.6)
5. Self-shot *Nephrops*, fleet, Crowlins, no tide	1.18	11.4	196	3.7 (3.2)	5.6 (5.1)	4.8 (4.3)	4.8 (4.2)
6. Hand-shot *Nephrops* fleet, Crowlin Sound, no tide	1.11	10.9	117	0.5 (0.2)	0.6 (0.4)	2.9 (2.8)	2.9 (2.7)

There was no significant difference in the mean maximum height over the deployment of the loops for self-shot or hand-shot gear (3.7m), or the ratio of creel separation to groundline length between self-shot (0.91) and hand-shot (0.89) fleets, although the maximum height of any loop was lower for self-shot (5.6m) than hand-shot (7.2m). The first two loops on the gear in the Crowlin Sound (Experiment 6) were surprisingly low given that there was very little current in that location. It is possible that the rope got caught on the seabed and so did not form loops.

These results show that fishers generally achieve a spacing between the creels which is about 90% of the available length of line regardless of the method of shooting. With self-shooting the line is very taut when it leaves the vessel, but that tension on the lines is not maintained by the time the creels reach the seabed.

In other static pot fisheries where the heights of loops have been measured, these have been found to be similar to those obtained here. In South Africa, Daniel (2021) measured a mean loop height of 5.5m (range 2.0 to 8.8m) for traps in the octopus fishery that were spaced 20m apart along the groundline. Brillant and Trippel (2010) measured the height of floating ground lines in the Bay of Fundy lobster fishery traps. They describe traps attached to the groundline at intervals of 22–37 m by gangions (equivalent to stoppers in the Scottish creel fishery) connected to the bridles on the ends of the traps. Gangions are typically 1.2– 1.5 m long. The average maximum height of loops was 3.8m and for most deployments the ratio of trap separation to ground line length was between 0.92 and 1 with a minimum of 0.72 and a median of 0.94.

5.2.3. Movement of sinking line on seabed

Sensors were deployed to assess whether and how much sinking line might move around on the seabed and therefore whether it could potentially cause scouring. To obtain visual images of any impact, an ROV survey was carried out (see Section 5.3). For the sensor experiment, movement of the sinking line on the seabed was monitored in an area of fast-running tides close to Kyleakin on gear targeting crabs on rocky bottom in around 15m of water. This was the most dynamic environment available, and where most movement was expected if it were occurring. The sensors on the groundline were attached as shown in Figure 5.4 on discs that rotated around the rope, so that any movement of the rope would alter the orientation of the tilt sensor.

Figure 5.4. Set up of sensor to measure line movement on the seabed. The clear disc is 60mm diameter and can rotate around the line

Four sensors were deployed on the groundline between creels and two in creels, as per previous experiments (although one of sensors in the creels failed during the experiment). The sensors were set to record at either 1s or 10s intervals. The number of measurements was limited by the storage capacity of the sensors. The sensors recording at 1s intervals were set to start closer to spring tides when the movement was expected to be greatest. The gear was set in an area with complex tidal patterns close to rocks, which may have caused substantial eddies.

The height of the tidal cycle is shown in Figure 5.5 from the measurements on the creel. Pink crosses indicate periods when the creel was moving. Initially there was no movement detected on the creel but as tidal range increased the frequency of movement also increased. There was generally most movement about two hours after high water.

On average the ropes showed evidence of movement for 3% of the time (range between 0.1% and 5.4%). The maximum movement in any one direction was 45mm based on the change in angle of the tilt sensor and the diameters of the disc (this could be underestimated if the disc dragged rather than rolled, but this is unlikely to have happened for all the discs, and any more substantial movement would likely have moved the disc more). During the same deployment, the creel also moved through an angle of around 90 degrees and showed evidence of movement 3.3% of the time.

The overall conclusion from this experiment was that the movement of the sinking lines on the seabed was similar to that of the creel. Given the size and weight of the creel, any impact of the lines on the seabed will be minimal compared to that of the creel.

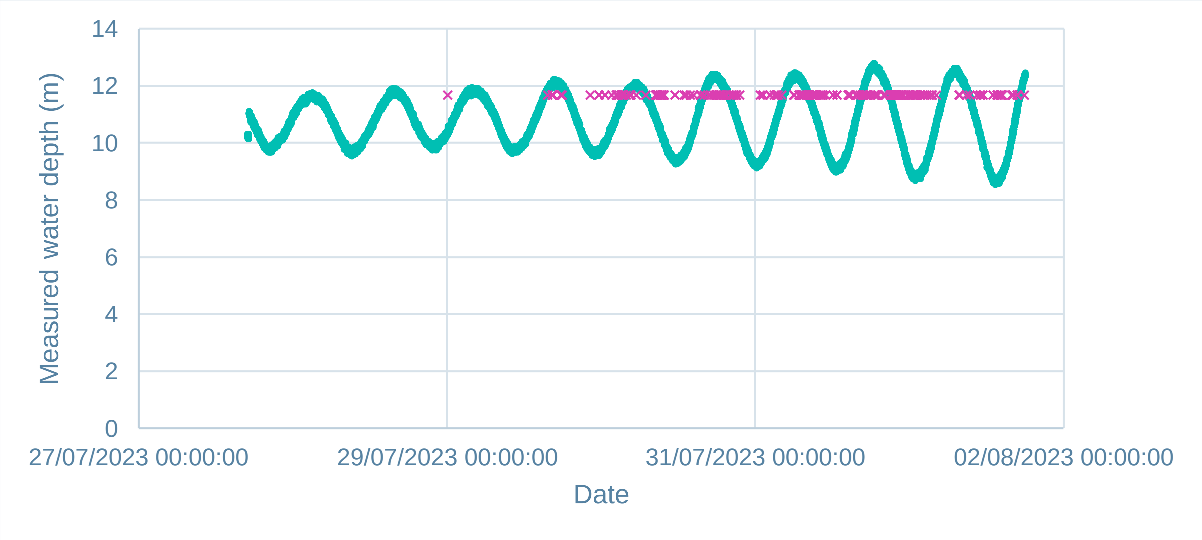

Figure 5.5. Depth measurements from sensor mounted on creel (turquoise dots) over a five-day period as tidal range increased towards spring tides. Pink crosses indicate periods when the creel moved

5.2.4. Monitoring movement of creels caused by tension on endlines

The SEA project showed that endlines were also an important component of the entanglement risk posed by creel fishing gear, with 50% of humpback whale entanglements, 20% of minke whale and basking shark entanglements, and 90% of leatherback turtles reported by fishers occurring in this part of the gear (MacLennan et al. 2021). Although the focus of this project was groundline risk mitigation, an exploratory endline experiment using the sensors was also carried out. In addition to movement caused by tidal currents, creels may be moved by the pull of the surface marker buoy on the endline. Sensors were placed on the creels at each end of a fleet and on the centre creel. This was done for two fleets shot close to each other in deep water on gear targeting *Nephrops* in an area where tidal currents would be expected to be minimal to monitor any movement of the creels over a ten-day period of mixed wind speeds. One fleet was rigged with all floating line, a second fleet was rigged with all sinking line (endlines, stoppers and groundline).

Both fleets showed more movement of the end creel at the north (more exposed) end of the fleet than the south end. The fleet with floating line showed more movement of the end creels than the fleet with sinking line, with the north end moving for 8.5% of minutes of the deployment and the south end for 2.8%. The end creel of the fleet with sinking line moved for 0.3% of minutes at the north end and showed no movement at the south end. Neither sensor in the creel in the middle of the fleet (with either sinking or floating groundline) showed evidence of movement.

The time data provided by the sensors showed that when the fleets were hauled, tension came on the fleet with floating groundline such that it moved at 13:42 and was lifted off the seabed at 13:51 (tension came on the first creel at 13:40). With the sinking groundline, tension came on at 14:38 and it was lifted off the bottom at 14:42 (tension came on first creel at 14:27 and last creel at 14:53). Hence with floating groundline the centre creel was moving for 9 minutes before being lifted off the bottom whereas with sinking line the centre creel was only moving for 4 minutes. These are only data from one experiment, but suggest that fleets with sinking groundline may cause less impact to the seabed rather than more as creels move less, and drag less when hauled.

5.3. Use of an ROV to observe fleets on the seabed

Video images from an ROV (Fifish V6) were used to provide qualitative data on how fleets of creels looked on the seabed with sinking and floating line, and in different tidal conditions. These observations were also be used to assess if sinking line might impact on the seabed.

Six ROV surveys were carried out over the course of the project:

1. At the beginning of the project, a hand-shot trial fleet made up with different combinations of sinking and floating rope as groundline and stoppers was surveyed. This was to assess how different rope types performed and enable an informed choice as to which rope to purchase for the trial.
2. A hand-shot fleet was surveyed as it was hauled to assess how it interacted with the seabed.
3. A hand-shot fleet with sinking endline and groundline deployed on a soft seabed was surveyed to assess its interaction with the seabed.
4. A hand-shot fleet with floating groundline was surveyed to acquire video evidence of rope arches in the water column (sensors were also attached to the fleet to take measurements – see 5.2.2.2).
5. A self-shot fleet with floating groundline was surveyed to acquire video evidence of rope arches in the water column (sensors were also attached to the fleet to take measurements – see 5.2.2.2).
6. A hand-shot fleet with sinking groundline which had been deployed in a soft substrate tidal area for 10 days was surveyed to look for evidence that sinking

rope might cause seabed scouring. We considered that a tidal area with soft substrate would be the most likely to show visible signs of rope movement.

The survey at the beginning of the project showed combinations of floating groundline and stoppers forming loops in the water column, and combinations of different types of sinking groundline lying lightly on the seabed. Of particular interest was that a sinking line stopper was not sufficiently heavy to pull floating groundline to the seabed, demonstrating that both sinking groundline and stoppers are necessary to prevent loops of rope in the water column (see Fig. 5.6 and also video ROV1).

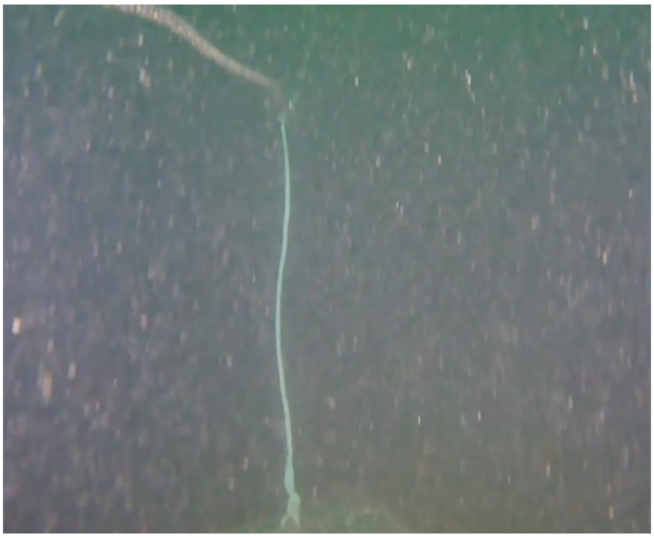

Figure 5.6. A still from ROV footage showing floating groundline (at the top of the image) pulling a stopper made from sinking line straight up from the creel (the top of which is visible at the bottom of the image).

The ROV video also shows how a combination of floating groundline and stoppers look in the water column, both with hand shot gear (see Fig. 5.7 and also video ROV2) and self-shot gear (video ROV3). The video is consistent with the measurements obtained from the accelerometers in showing that rope floats in loops with both hand-shot and self-shot gear (see Table 5.1).

Figure 5.7. A still from ROV footage showing floating groundline and stopper. The groundline is rising away from the stopper to form loops

The video of the sinking rope on the seabed shows that it has enough weight to prevent it from floating, but sits quite lightly on the seabed (see Fig. 5.8 and also video ROV4).

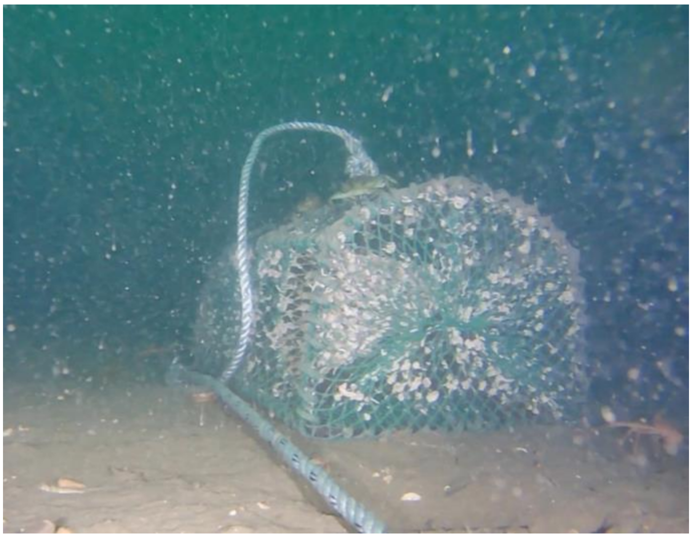

Figure 5.8. A still from ROV footage showing sinking stopper and groundline lying on seabed

ROV video of a fleet in a tidal area with a soft seabed which had been left for 10 days before being surveyed, shows no evidence of the rope having moved, sunk into the substrate, or any scouring marks on the seabed. There are no signs of impact on the area's benthos, which can also be seen in the video (Fig. 5.9 and also video ROV5). This is consistent with accelerometer data from a very tidal area which demonstrated that the rope only moved as much as the creels did (Section 5.2.3).

Figure 5.9. A still from ROV footage showing sinking groundline which has been lying on seabed for 10 days

The only seabed impact that was visible in ROV surveys appeared to be from creels being dragged during hauling, which initial accelerometer data suggest might be reduced by the use of sinking rope (video ROV6).

5.4. Implications of sensor and ROV experiments

5.4.1. Performance of floating vs sinking rope

Both the sensors and ROV provided valuable and much-needed information on creel fleet and rope behaviour under a range of conditions, which provide answers to several areas of uncertainty. There is now both quantitative and video evidence of the presence of floating line loops in both hand-shot and self-shot gear, with the mean maximum height of the loops for both self-shot and hand-shot gear of 3.7m (maximum loop height of 5.6m for self-shot gear and 7.2m for hand-shot gear). The sinking line lay only lightly on the seabed, and there was no evidence of it moving.

5.4.2. Interaction of fleets with seabed

There has been little prior work on the interaction between creel fleets and the seabed. Other studies have shown that the footprint of creels and lines is small, and the potential for greater impacts on benthic habitats occurs during shooting and hauling, when creels can be dragged across the seabed (Stevens 2020). Eno et al. (2001) and Schweitzer et al. (2018) found a low likelihood that creels would actually land on benthic organisms, but a higher risk of damage when they were dragged. Whilst these studies did not use sinking rope, the greater footprint and weight of creels compared to rope means that the majority of impact on the seabed will come from the creel themselves when they move during a deployment and when hauled. In addition, if the current, rather ad-hoc system of weights on endlines were to make contact with the seabed then this could potentially scour a large area. As previously discussed, there are some indications that creels move less when rigged with sinking line. This would be expected in stronger tidal currents where the loops of floating line have substantial drag (estimates for a typical loop across the current are 22N for 1knot rising to 350N in 4 knots), but this would need to be tested with carefully paired experiments, with enough sensors on creels to obtain a reasonable sample size.

Fishers in the trial reported that they suspected less movement of the creels with sinking groundline and this appears to be supported by the measurements of the creels. In addition, after periods of bad weather gear can often become tangled, indicating substantial movement of the creels. Some of this may be avoided using sinking line.

6. Conclusions and recommendations

6.1. Conclusions

This project, funded by the Scottish Government's Nature Restoration Fund (managed by NatureScot), has demonstrated a viable route to substantially reducing megafauna entanglement in static pot gear in Scottish waters – through the implementation of sinking groundline. It has done so through positive collaboration between the project partners, and provides a rare cause for optimism in tackling bycatch and entanglement, an issue of national and global importance to whale and other megafauna conservation and welfare. The key outcomes from this trial are that there is an available means of substantially reducing bycatch in static pot gear, and that this should be implemented through bottom-up, collaborative working, with fishers involved at all stages.

The potential offered by sinking groundline as an entanglement mitigation in Scottish fisheries should not be underestimated. Although entanglement risk would not be eliminated, sinking ground line would be expected to remove the risk from the groundlines which account for 83% of minke whale, 50% of humpback and 76% of basking shark entanglements. Unlike in some fisheries, such as those using gillnets, a transition to sinking groundline would not require any modifications to the parts of the gear that are involved in catching the target species. And unlike other modifications to static creel gear such as ropeless (on-demand) gear (see 6.2.3.2.), it is relatively inexpensive, reliable, and does not require changes in fisheries management or to fishers' working practices.

The reporting from the 15 fishers involved in the project, both from quantitative haul data and qualitative feedback, was that using sinking rope was not very different to using to floating rope, and indeed was sometimes preferable. They reported that fleets rigged with sinking rope often did not move around so much on the seabed (possibly resulting in higher catches, and less impact on the seabed). Fishers also reported fewer tangles, especially during periods when tidal ranges were large, or weather was rough. With respect to sinking rope's potential seabed impact, the ROV surveys showed that, whilst floating rope formed arches in the water several metres high, sinking rope lay lightly on the seabed and did not cause scouring or damage. This is consistent with the low level of snagging and abrasion to the sinking rope seen during the trial, in both the *Nephrops* and crab fleets, and contrasts with the substantial seabed impacts of bottom trawl fisheries (Sala et al. 2021). Whilst there may be some very rough seabed areas where sinking rope is inadvisable, from our study of 15 fishermen and over 1500 hauls, it was remarkable how few problems there were, in particular when targeting crabs on hard ground which had been expected to be more challenging.

The project gathered data from 61 creel fleets rigged with sinking line that were monitored for a total of around 18,000 days in the water. Detailed data were reported for 1545 hauls. The results from the trial are promising for fishing that targets crabs as well as *Nephrops*. The amount of data reflects the work put into the project by the fishers involved and represents a substantial data set that demonstrates a pathway to substantially reducing entanglement risks.

The measurements of the heights of the loops of floating line off the seabed are consistent with those from other fisheries and confirm the entanglement risk from floating line to whales and basking sharks. There were no significant differences in loop height between hand-shot and self-shot gear. The average creel spacing on the seabed was 90% of the length of the groundline, and it seems unlikely that this proportion could be easily increased in order to reduce the loop heights from floating line. Neither the ROV data nor the accelerometer data supported a common assumption that self-shooting creels and shooting with the tide results in tight groundline which does not form loops in the water column (MacLennan et al 2021). For the average length of stopper (1.3m), and groundline spacing of 12.5m, the average maximum loop height for creels spaced at 90% of the ground line spacing would be 3.7m. Even if creel spacing could be increased to 95% by maintaining tension on the line as creels sink to the sea bed, the loop height would still be 3.0m.

6.2. Policy implications, recommendations and further work

Engaging with entanglement in Scottish creel fisheries must be a high priority for Scottish Government and regulatory agencies. The estimates from the SEA project of an average of 6 humpback whales, 30 minke whales and 29 basking sharks becoming entangled each year are of substantial welfare and conservation concern. Addressing this bycatch issue will support a number of policy objectives, and assist the Government in fulfilling its legal obligations. Scotland's Future Fisheries Management Strategy (2020 to 2030) commits to monitoring and reducing incidental bycatch (including cetaceans); the UK Fisheries Act (2020) also establishes an Ecosystem Objective, that 'incidental catches of sensitive species are minimised and, where possible, eliminated'. This project has demonstrated a relatively low-cost, straightforward mitigation measure with the potential to substantially reduce bycatch risk in Scottish creel fisheries. This contrasts with the majority of bycatch situations globally, where it has been very challenging to develop effective mitigation strategies. In addition to sinking groundline, the project identified ways that the entanglement risks from endlines could also be reduced. The proposed measures have a good chance, if approached correctly, of support from individual fishers and the industry as a whole, which is key to success. There is an opportunity for Scotland to provide a global example of best practice on entanglement mitigation, which should be addressed urgently to meet policy commitments.

6.2.1. National stakeholder familiarisation and implementation

In order to progress implementation, some areas require further work due to the limited temporal and spatial scale of this project. The trial area was fairly restricted (although topographically varied and including harbours with the highest *Nephrops* landings), and the timescale of this project was inevitably quite short (fleets with sinking line were fished for a maximum of 15 months). Work on implementing sinking groundline now needs to take place at a national level within Scotland to reach a wide geographical range. There should be a programme of familiarising fishers with the results of this trial, and working with them collaboratively to develop a fisher-led strategy for broadscale implementation, continuing the bottom-up approach, but facilitated and supported by Government. This should take place through local stakeholder workshops involving fisheries associations, Regional Inshore Fisheries Groups and other fishing associations from the key areas around Scotland's coasts. These workshops should be used as both information dissemination and information gathering opportunities to investigate the pathways and barriers to national implementation. Groups in other regions should also be given opportunities to use the sinking line combinations trialled in this project to build confidence and collaboration through examples of modified gear in action.

6.2.2. Socio-economic analysis

The main issues raised by the fishers involved in the trial related to the lifespan of sinking rope, its additional expense compared to floating line, and how any transition to sinking line would be managed. These issues need to be assessed through a socio-economic analysis. In terms of the lifespan of sinking rope, it is only possible to assess this over an extended time period, so any uncertainty over its longevity should not be considered a barrier to a wider implementation of sinking rope, given the urgency of addressing entanglement, and the efficacy of the mitigation. The cost of sinking rope is currently around double that of floating rope, varying according to the global price of lead. The price of the rope and how any transition to sinking rope might be managed should be part of the socio-economic analysis, developed in consultation with stakeholders. This would consider the economic implications of different options for transitioning to sinking rope, including the purchase cost of the rope, economic implications of the time spent re-rigging fleets and any costs (financial and environmental) associated with disposal of end-of-life rope. Schemes might include subsidies or incentives, and would require information on the quantity of rope currently in use in a specified area, the proportion of rope that is currently sinking, the life expectancy of rope that is currently in use, how frequently creel fleets are re-roped, and the work involved (fishers' time) in re-rigging creel fleets. A socio-economic study could consider scenarios such as all fleets being re-rigged with sinking line by a certain date, a proportion of fleets (that pose the highest entanglement risk) being re-rigged with sinking line by a certain date, all fleets being re-rigged with sinking line, but only when the existing line is end of life, or a proportion of fleets (that pose the highest entanglement risk) being re-rigged with sinking line, but only when the existing line is end of life.

Any recommendations for an implementation strategy would need to place a transition to sinking rope within the context of any wider changes within the inshore fisheries sector in Scotland. Paragraph 25 of the Fisheries Act (2020) requires Scottish Ministers to use criteria that relate to the impact of fishing on the environment when distributing catch quotas and effort quotas for use by fishing boats, and to seek to incentivise the use of fishing techniques that have a reduced impact on the environment. Incentives to transition to sinking line could include preferential access to fishing opportunities, market-based accreditation schemes or financial support for the transition.

6.2.3. Changes to how gear is made up/set

Although sinking groundline should be the primary focus for entanglement risk reduction in Scottish creel fisheries, other changes could also be made to reduce risk. Fishers interviewed as part of the SEA project had several suggestions for reducing entanglement risk in addition to sinking groundline. These broadly divided into how gear was made up and set (such as shorter/tighter ends, shooting with the tide, self-shooting gear) and how the fishery was managed (such as caps on creel numbers, better regulation, seasonal/area closures).

6.2.3.1. Endlines

Data from the ROV and accelerometer surveys conducted as part of this project suggested that self-shooting and shooting with the tide do not prevent loops of rope between creels. However, there is further work required that could reduce the risk from endlines. The SEA project showed that endlines were also an important component of the entanglement risk posed by commercial creel fishing gear, with 50% of humpback whale entanglements, 100% of small cetaceans, 90% of leatherback turtles and 20% of minke whale and basking shark entanglements reported by fishers occurring in this part of the gear (MacLennan et al. 2021). Excess rope in the water is also a hazard to maritime traffic.

Preliminary work was carried out during this project as to how fishers might reduce the length of their endlines. Low drag surface marker buoys were purchased and distributed amongst the trial participants in order that they could experiment with shortening their ends. These buoys were very popular amongst the participants – one of the fishers in the trial already exclusively uses them to reduce tangles. Some fishers in the trial also already use sinking rope for their ends. Some experience abrasion to the rope where it meets the seabed, but this could be mitigated by using a small section of floating line at the bottom of the end, which would also minimise impact on the seabed. Other fishers use weights on the endlines, and the measurements of the loop heights from this study will help fishers locate weights as deep as possible (to minimise length of line close to the surface), but not so deep that there is a risk of the weight becoming entangled in the loop between the first and second creels.

During this project, there was also experiment into creel fleet movement using accelerometers. However, providing advice on optimal endline lengths is a larger piece of work than could be covered within the scope of the groundline project. This will be continued in a forthcoming complementary project. The research will trial different lengths and configurations of endlines to assess how short these can be in proportion to the water depth being fished, and develop best practice guidance for fishers to minimise excess vertical rope in the water column. Creel fleets will be deployed in pairs from three commercial vessels to ensure comparable sea and weather conditions, with one used as a reference fleet and the other adjusted to assess the effect of different endline configurations and lengths on the movement of the gear. This movement will be measured over a number of days using accelerometers attached to the first, middle and last creels of each fleet.

6.2.3.2. Ropeless/'On-demand' systems

Another future possibility in the creel fishery to reduce entanglement risk is the development of ropeless/'on-demand' technology, which removes endlines from the water column. There are several systems being developed and trialled, especially in the US (Gahm et al. 2023). However, they are not yet at a stage of cost or reliability where they are ready for roll-out in the Scottish creel fleet (e.g. in recent trials, the rate of successful on-demand gear hauls was still only 90% (Gahm et al. 2023)), and concentrating on sinking groundling is still the cheapest, simplest, most accessible option for maximising risk reduction. In addition to the technical challenges of the 'on-demand' systems, there are considerable challenges with changes to the way fishers interact with each other if the location of static gear is not visible from surface marker buoys.

6.2.4. Modifications to working practices

There are some other changes that fishers could make to their working practices which have been suggested by this project, which could provide both financial and environmental benefits. In terms of extending the longevity of rope, it was noted by some fishers in the trial that when parts of their haulers, such as the knife, were worn, they noticed it first when hauling sinking rope. Studies in the US suggested that some small modifications to hauler plates decreased the wear on sinking rope, as did keeping the knife in good condition (Allen, 2012; Ludwig et al. 2016). Transitioning to sinking rope might also therefore include guidelines for how fishers could inspect and maintain haulers in order to increase the longevity of sinking rope, but this might require specific experimental trials similar to those carried out in the US.

In terms of general environmental improvements, whilst sinking rope was not shown to be impacting on the seabed, dragging creels during hauling could affect the seabed, and efforts should be made avoid this. The haul data also indicated that there were often periods of time when fishers were not hauling their gear regularly. This represents a higher risk in relation to fisheries yield than gear which is hauled more often, and is a form of wet storage. This was not an aspect of the inshore creel fishery's working practices covered by the project, but it is an issue which should be considered in the context of best practice for entanglement risk reduction.

6.2.5. Changes to fisheries management

A reduction in the amount of rope in the water will reduce entanglement risk. This can be achieved by using sinking rather than floating rope, but also by restricting the amount of gear set, and limiting fishing effort. There were several suggestions from fisher interviews in the SEA project regarding gear caps and better regulation of the fishery. However this would need to be pursued as part of a wider marine spatial planning process taking into account stock assessments and the role of other fisheries in affected areas. In addition to bottom-up processes, these changes would have to take place at a policy level.

The Scottish creel fishing fleet comprised around 900 active vessels in 2022[9], and as a major employer, is a key part of the economic and community structure of Scottish rural coastal communities. The fishery largely has a low environmental and seabed impact. The entanglement rate of marine megafauna is, however, an issue which the fishery can and should address as part of wider inshore fisheries reforms. Through the SEA project and this trial, it has been clear that Scottish inshore creel fishers have both the expertise and willingness to be part of the solution, and to make their fishery more environmentally sustainable. There is now a need at a national level to engage with megafauna entanglement and with the mitigation options available, in particular sinking groundline. This will address the pressing welfare and conservation challenge to megafauna in Scottish waters, enable the Scottish creel fishery to develop in an environmentally sustainable way, and contribute towards the Scottish Government fulfilling its legal obligations to reduce sensitive species bycatch.

In particular, the Scottish Government has committed to supporting and delivering the bycatch objective of the Fisheries Act (2020). As part of this the UK-wide marine wildlife bycatch mitigation initiative (BMI) has been developed. This strategy outlines the UK Government's ambition to address sensitive species bycatch through five main elements:

1. Improve our understanding of bycatch and entanglement of sensitive marine species through monitoring and scientific research.
2. Identify 'hotspot' or high-risk areas, gear types and/or fisheries for bycatch and entanglement in the UK in which to focus monitoring and mitigation.
3. Develop, adopt and implement effective measures to minimise and, where possible, eliminate bycatch and entanglement of sensitive marine species.
4. Identify and adopt effective incentives for fisheries to implement bycatch and entanglement mitigation measures.
5. Work with the international community to share best practice and lessons learned to contribute to the understanding, reduction and elimination of bycatch and entanglement globally.

The SEA project addressed items 1 and 2 with respect to entanglement, while the current project has progressed through stage 3. Further work is now needed on

[9] https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2022/pages/5/

stage 4. The UK strategy identifies what successful outcomes for stage 4 might look like from a fisheries perspective:

- Fishing industries and communities are central to the decision-making process around the implementation of bycatch mitigation measures.
- The fishing industry and fishing communities have not experienced disproportionate costs resulting from the implementation of bycatch mitigation measures.
- Financial and behavioural incentives have been used effectively to remove barriers and encourage increased uptake of bycatch mitigation measures.

All of these successful outcomes are now realistically achievable alongside a substantial reduction in entanglements of protected and endangered species in Scottish waters.

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