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NatureScot Research Report 1268 - Scottish Entanglement Alliance (SEA) - understanding the scale and impacts of marine animal entanglement in the Scottish creel fishery

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Year of publication: 2021
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Cite as: MacLennan, E., Hartny-Mills, L., Read, F.L., Dolman, S.J., Philp, A., Dearing, K.E., Jarvis, D. and Brownlow, A.C. Scottish Entanglement Alliance (SEA) - understanding the scale and impacts of marine animal entanglement in the Scottish creel fishery. NatureScot Research Report 1268.

Contents

Keywords

whale; basking shark; dolphin; porpoise; turtle; entanglement; bycatch; fishing; creel; static gear; welfare; economic impact; conservation; Scotland

Background

Marine animal entanglements are a growing and severe problem globally, considered by the International Whaling Commission (IWC) to be the single most significant marine mammal welfare issue of our time (IWC, 2017). Around Scotland, a diverse array of marine animals including whales, dolphins, porpoises (collectively known as cetaceans) and basking sharks inhabit the inshore waters, which also provide valuable fishing grounds for static and mobile fishers. The Scottish fishing industry makes a significant contribution to the national economy and forms the social and cultural backbone of many small fragile coastal communities. However, with thousands of miles of rope and netting associated with these fisheries in the water at any given time, the incidence of entanglement is increasing. We define entanglement as 'wraps of line, netting or other materials around body areas (which may include cases in which animals are towing gear or anchored by gear) from which the animal cannot escape and which subsequently causes harm'. This process can impair an animal's ability to breathe, feed, swim and reproduce, and cause serious injury including deep tissue lacerations, amputations, and infections, as well as death. Entanglement of marine animals in Scottish waters can be a significant welfare issue, especially to larger, stronger animals who appear able to survive, but not escape, entanglement for longer. Chronic entanglements are bioenergetically costly (Van der Hoop et al., 2016), can eventually be fatal, either through drowning or the animal succumbing to secondary injuries, infection or debilitation caused by the entanglement, or cause long term debilitation which can impact the animal's health, resilience and fecundity. These incidents can be distressing and potentially dangerous for those discovering them, particularly when the animal is still alive. Financial losses can also be incurred by individual fishers, for example through lost fishing time, and damage or loss of fishing gear and any associated catch.

The Scottish Entanglement Alliance (SEA) is a partnership between six organisations dedicated to promoting and protecting Scotland's wildlife, natural heritage and sustainable creel fishing. Initiated by the Scottish Creel Fishermen's Federation (SCFF) upon recognising a potential issue within their sector, SEA partners aimed to engage directly with the inshore creel fleet to determine 1) if marine animal entanglement is perceived to be an issue within the static sector, and 2) what the risks and consequences of entanglements are from a conservation, welfare, human safety and economic perspective.

Key points

- Interviews with 159 creel fishers (representing approximately 11% of the commercial fleet) revealed that almost half had experienced at least one entanglement between 2008 – 2018, with a total of 146 entanglements reported involving at least 12 species of cetacean, shark and turtle. Factors which appeared to be influential in entanglement risk were fishing depth, gear length, hauling frequency and target species
- The number of entanglement cases which get reported to the Scottish national strandings network (SMASS) remains low, however both the absolute and relative incidence has been steadily increasing over the past decade.
- Extrapolating from reports received by SMASS and fishers' interviews, there is significant underreporting of entanglement events in Scottish waters, with less than 5% of entanglements encountered by creel fishers reported to SMASS.
- Marine animal entanglements have been reported from all regions of Scotland, with some regional hotspots. Minke whales, grey seals and basking sharks were the most commonly reported species from 1992-present, and the majority were discovered entangled in groundlines.
- The likelihood of any individual fisher encountering an entanglement is rare (<1 per decade) but events become common when aggregated to the level of the industry. This has implications for the feasibility of certain monitoring strategies, for example placing observers on vessels.
- The gear type and chronicity of marine animal entanglements varies by species, likely due to a combination of reasons including anatomy, body size, foraging behaviour and distribution.
- Data from strandings, interviews and sightings all suggest minke whale and basking shark are most often reported entangled in the groundline, whereas the endline (risers) appears to be more of a hazard to other cetaceans and marine turtles. Mortalities involving trawl and monofilament netting have also been recorded.
- The most typically reported entanglement case, reported from 1992-current are minke whales, entangled acutely by rope around the tail. In most of these cases the entanglement is rapidly fatal due to drowning or anoxia. All but one fatal humpback entanglements in the strandings database showed evidence of chronic entanglement (n = 4). This all has a significant impact on animal welfare.
- Strandings reports show some seasonality, with humpback entanglements clustering around late spring, minke whales in summer and leatherback turtles in autumn.
- Over 80% of fishers suggested theoretical measures that they felt could prevent or reduce the risk of entanglement, almost 75% expressed willingness to test mitigation measures, and over 65% expressed interest in training to report entangled animals and/or disentangle them.
- 75% of fishermen interviewed disagreed with the suggestion that marine animal entanglements have a major economic impact on the Scottish creel fishing sector, either because they had never experienced one, they were very rare, or were not costly when they did occur.

- The use of creels is widespread throughout inshore waters off the west coast of Scotland and the data suggest an increase in the number of creel fleets encountered during surveys in recent years.
- The areas that showed the greatest co-occurrence of sightings of minke whales and creel fleets were to the east of the Outer Hebrides, west of North Uist and throughout the waters around Skye. It is within these areas that interactions between whales and creels are most likely, and therefore have the highest risk of an interaction occurring that may result in an entanglement.
- Photo-identification records of minke whales on the west coast of Scotland were assessed for evidence of entanglement. In total, 22.3% (n = 57) of the individuals assessed had entanglement related scars. This comprised of 4.7% of animals (n = 12) that had scarring which was highly consistent with a current or previous entanglement in fishing gear (i.e. extensive tissue damage or deformation) and 17.6% (n = 45) had marks that were likely caused by a previous entanglement in fishing gear (i.e. linear scars wrapping around the body).
- This project demonstrated a positive collaboration between the fishing industry, research and conservation organisations. In association with IWC Global Whale Entanglement Response Network, we were able to respond to the fishers need for knowledge of safe disentanglement practice by providing Europe's first disentanglement training workshop for fishermen.

Recommendations

- The extent and incidence of entanglement events in Scottish waters may be sufficient to impact at a local population level, and this is a concern for conservation and the population recovery trajectories of minke and humpback whales. The hazard posed to marine species from entanglements should be recognised, alongside other comparable areas of concern of human-induced mortality, e.g. common dolphin and harbour porpoise bycatch.
- Entanglement of marine animals is a severe welfare problem which merits the urgent development of workable mitigation solutions. This is likely best achieved through a continued interdisciplinary approach involving fishers, researchers and policymakers.
- Expanding the amount and quality of data collected from future entanglement cases is essential in order to better quantify the prevalence, incidence and range of marine animal entanglements and provide vital assessments of the impact on animal welfare and conservation. This could include developing a lesion impact scoring system to assess the physiological and welfare implications of future cases reported to strandings networks.
- From this study we have estimated more than 95% of entanglement cases currently go unreported. Improved awareness of, and engagement with, current systems for fishers to report, assess and respond to live and dead entanglements are required. This is necessary to both safeguard animal welfare and human safety and fill large data gaps in our understanding of the true incidence and nature of interactions between fishing gear and marine mammals. In order to collect robust entanglement data in future, monitoring and reporting should be a condition of fishing licences.
- The increase in fishing effort reported through this programme, in terms of both quantity of gear being deployed and soak time represents an increasing hazard to marine life from entanglements. Current understanding of the spatio-temporal distribution in fishing effort for the under 12m fishing fleet is insufficient and better information on this is urgently required. This should include a census on the amount of both active and derelict gear currently in the water and estimates of rates and amount of gear loss.
- Robust risk maps that account for the distribution, behaviour and movements of animals and fishing gear should be developed using existing data to provide a better understanding of the spatial and temporal distribution of entanglement risk to inform and assess the efficacy of any potential mitigation measures.
- There is an urgent need to develop and encourage adoption of best-practices to minimise the threat to marine animals from entanglement in fishing gear in order to ensure effective conservation and adherence with international obligations e.g. ASCOBANS, Habitats Directive.
- Studies and trials to assess the feasibility, costs and wider implications of mitigation are needed. Initiatives which aimed to reduce entanglement risk including a move toward negatively buoyant ropes, reduced creel fishing effort and ropeless fishing systems were supported by fishers interviewed in this study.
- Areas with a high co-occurrence of minke whales and creels were identified within the newly designated Sea of the Hebrides marine protected area (MPA). Entanglement has important implications for the conservation of marine animals in Scotland and effective management measures must be implemented, including of MPAs and the fishing industry. The introduction of fishing restrictions needs careful consideration to ensure fishing effort is not shifted into other areas with high densities of vulnerable animals, or around the MPA boundary.

- Reducing the amount of rope in the water column, both as active fished gear and marine litter/debris will reduce the incidence of entanglements. To achieve this aim there needs to be joined up thinking between Regional Spatial Planning (Marine Scotland Act 2010) and fisheries management (Fisheries Act 2020). Reducing the amount of gear in the water, through mechanisms such as creel limits, will reduce entanglement rate. There is industry recognition and backing for the need for creel limits in some situations, but acknowledgement that effective implementation requires legislative support. Trials to assess strategies for limiting fishing effort should therefore be implemented, in tandem with approaches to minimise gear conflict between different sectors of the industry.
- Addressing the issues highlighted in this report requires wider conversations to be had on fisheries management in Scotland, including industry regulation of both mobile and static sectors. Both 'top-down' legislative and policy change and 'bottom-up' engagement with fishers will be required to effectively and sustainably mitigate impact while also maintaining economic viability.

Acknowledgements

The project partners would like to acknowledge the support of the European Maritime and Fisheries Fund, Marine Scotland Fisheries team and NatureScot. We would also like to thank every fisher who gave up their time to contribute to the project, without which this work would not have been possible.

We are grateful for the help of Simon Northridge with the original proposal. We would also like to thank Alastair Sinclair (SCFF), Noel Hawkins (SCFF and BDMLR), and Stephen Marsh (BDMLR) for their help during the project. We would also like to thank the reviewers for their time and effort to help improve this report.

The Hebridean Whale and Dolphin Trust (HWDT) extend their thanks and appreciation to the volunteers, staff and crew, past and present, who have contributed to our long-term species monitoring and research programmes on Silurian and through Whale Track. We would also like to thank our members, donors and funders who have supported these long-term research programmes including: Heritage Lottery Fund, The Nàdair Trust, NatureScot, WWF-UK, Coastal Communities Fund, William Grant Foundation and Sea-Changers.

Foreword

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Entanglements have been observed in every ocean basin, and appear to be increasing in many regions, including in Scottish waters. For coastal species, particularly larger species such as humpback whales able to pick up and carry fishing gear, entanglements of live whales are very visible from the coast and draw public and media attention, but many more cases go unreported. Over half of minke whales that washed ashore dead and were examined by forensic necropsy showed signs of entanglement. Interviews with fishers show basking shark as one of the most frequently entangled species yet these animals almost never make landfall. Scottish creel fishers recognised that further investigation was required to prevent entanglements and this project was the result.

The report findings show us that action is required to prevent entanglements of whales, basking sharks and other protected species. Implementation of recent legislation and policy provide the tools to take the next steps. Scotland's Future Fisheries Management Strategy – 2020 to 2030 commits to monitor and reduce incidental bycatch, and the UK Fisheries Act (2020) establishes an Ecosystem Objective, including to 'minimise and where possible eliminate sensitive species bycatch'.

Severe suffering can result from becoming entangled in fishing gear, those resulting in either death or significant injury for an increasing number of non-lethal entangled whales. Whilst entanglements are rare to the individual fisher, collectively their impact is significant. Humpback whales may not be recovering from old whaling days due to entanglements. Entanglement prevention must now be the focus of our efforts and where the creel sector has led the way, other parts of the fishing industry should follow.

This project demonstrated the scale and impact of creel entanglements. Also, that concern for animal welfare is a more important consideration for fishers than financial costs as a result of entanglement and that fishers have shown a commitment and a willingness to implement entanglement solutions. Only by working together, with ongoing engagement and industry support, will we solve this problem.

Scotland can lead the way by putting into place the solutions that can then be exported to prevent entanglements in other parts of the world. Political motivation is central to this.

Executive summary

This EMFF funded, two-year duration project sought to assess the extent, scale and impact of marine animal entanglements in creel fishing gear from an animal welfare, conservation and industry perspective. The findings of this research have demonstrated that, throughout all Scottish waters, marine animal entanglement is more prevalent, and impacts a wider range of species, than previously thought. There is, however, a significant drive to address the issue from the creel fishing industry and therefore opportunity to develop practical and sustainable solutions to this problem.

Entanglement can have devastating impacts on the health and welfare of individual animals, and the number of individuals potentially being killed or injured also is potentially high enough to raise conservation concerns due to impacts at a population level. At the level of the individual, entanglement poses a significant welfare issue, especially to larger, stronger animals who appear able to survive, but not escape, entanglement for longer. Chronic entanglements can be eventually fatal either through drowning or the animal succumbing to secondary injuries, infection or debilitation caused by the wounds inflicted by the material. Based on available data the incidence of entanglement appears to be increasing, plausibly linked to the increase in the creel fishing effort over recent years. There is, however, a significant underreporting of cases, with estimates, based on fishers' interviews within this study, of fewer than 5% of historic entanglements being recorded prior to this study. Some species, especially basking shark and marine turtles, are hardly ever reported to the national strandings networks, despite being cited by fishers as common victims of entanglements, and those animals which make landfall seldom do so in a state where detailed examination is possible.

The economic impact of entanglement on the fishing industry as a whole in terms of lost time or gear is seen as negligible, both in absolute terms and relative to much higher reported losses due to weather or gear conflict. Many fishers reported entanglement events as stressful experiences, with the primary concern being for the animal. This, alongside awareness that entanglements are a fundamental shortcoming of an otherwise selective and comparatively benign form of fishing, appear to be driving a significant, industry led interest in finding workable solutions to reduce entanglement. This highlights the importance of engaging with fishers in ways which utilise their experiences and expertise to identify those mitigation options which are technically, logistically and economically workable at reducing the risk of entanglement.

It was emphasised that both 'top-down' legislative and policy change and 'bottom-up' engagement with fishers were both vital to develop effective, sustainable solutions able to mitigate impact on important marine species while also maintaining the economic sustainability of the creel fishery.

While this research has the potential to influence future policy and practice with respect to management of the creel sector and protection of our charismatic marine species, there is considerable value in continuing and expanding this work to better understand the detail of how, why and where animals become entangled, and how best to support industry to sustainably mitigate risks through sound scientific evidence and engagement with fishers. This will help safeguard the future of our marine ecosystems whilst ensuring traditional fisheries have a viable future.

Data

In this report we demonstrate the scale and extent of entanglement in Scottish waters. All available data from long-term monitoring programmes run by the Scottish Marine Animal Stranding Scheme (SMASS – chapter 3 – Understanding the distribution, trends and welfare impacts of marine animal entanglements from strandings data) and the Hebridean Whale and Dolphin Trust (HWDT – chapter 6 – Assessing the spatial distribution of entanglement risk to minke whales off the West Coast of Scotland and chapter 7 – Entanglement survivors – assessing the extent of non-lethal entanglement) were analysed alongside questionnaire data collected from 159 commercial creel fishers from 67 harbours across Scotland (chapter 4 – Capturing fishermen's knowledge – fishing activity and experience of entanglement and chapter 5 – Costs and socio-economic impacts of marine animal entanglement to the Scottish creel fishery). Measures to prevent entanglements should be a priority. Future assessments should build on the data and analysis presented here to further our understanding of entanglement in Scottish waters to inform suitable mitigation strategies. There is a clear need for better data on both fishing effort and entanglement incidents, at high enough resolution to characterise, species dependant, seasonal heterogeneity in incidence rate. Subsequently applying these indices to estimates of population distribution and abundance will allow for some estimates of impact to be extrapolated to the population level. This requires more robust population estimates and therefore it is a further recommendation that abundance and distribution estimates are generated for large baleen whales in Scottish waters.

Chapter 3 – Welfare

Entanglement presents a severe welfare risk to cetaceans, particularly in the larger species who can survive acute entanglement but remain attached to the material for weeks to months. This can lead to death, through drowning, tissue injury, infection or negative energy balance, and sub-lethal entanglements carry a fitness cost which may impact resilience, reproductive fitness and population recovery rates. These processes were all evidenced in the cases necropsied as part of this study. Expanding and developing the range and detail in the data collected from future entanglement cases is an essential next step in order to better quantify the prevalence, incidence and range of marine animal entanglements and provide vital assessments of the impact on animal welfare.

Chapter 4 and 5 – Interviews and economics

It is clear from the limited data available via strandings and information collected through interviews that entanglement is a concern in Scottish waters, and this cannot be ignored. It is also clear that while fishers are actively and positively engaged in addressing this issue, they are not reporting entanglement incidents. Discussions with fishers suggest that this is due to a combination of reasons including a lack of understanding of the relevant legislation surrounding marine animal bycatch and entanglement, fear of potential negative repercussions for them or their fishery, or because they do not know how and where to report entanglements, or why this information is valuable. As a result of this underreporting, large data gaps in our understanding of the true incidence and nature of interactions between fishing gear and large marine animals remain. Without accurate information it will not be possible to ensure that any potential future mitigation measures are appropriate, proportional, and acceptable to fishers. Therefore, fishers must be encouraged to report both live and dead entanglement incidents, and safe accessible channels to facilitate this must be made available with assurances that any information shared will be treated sensitively, positively and confidentially.

Future regulations should address the number of boats that can operate (commercial and recreational), the number of creels each boat can deploy, how often gear must be hauled, and the possibility of separating the mobile and static sectors. The project should be extended to include other fishing sectors such as trawls, purse-seines and static nets, which would allow us to further investigate marine animal entanglement in Scottish waters.

Any future prevention and mitigation methods will only be successful with stakeholder engagement and support from industry.

New legislation and associated government policy such as the Joint Fisheries Statement (JFS) provide an opportunity to put in place requirements to address marine animal entanglements whilst setting out the mechanisms to achieve the policy outcomes and targets for tackling entanglements, based on best-available evidence and precaution.

Fishing characteristics potentially influencing entanglements have not been well investigated to date. Further, the collection of more detailed data on the individual vessels, e.g. days at sea, landings, etc., would enable the determination of effort and the number of days that the gear is active, to help to identify part-time fishers and ensure the data collected reflects the make-up of the fishing fleet.

A census on creel fishing effort, including the amount of both active and derelict gear currently in the water and estimates of rates and amount of gear loss is a necessary next step.

It would be useful in future studies to quantify the cost of other causes of gear loss and damage as a comparison to those losses resulting from entanglement.

Chapter 6 – Spatial distribution of entanglement risk

The use of creels is widespread throughout inshore waters off the west coast of Scotland and in some areas overlaps with the distribution of minke whales. Areas where there is the greatest co-occurrence of whales and creels have been identified as they represent the highest risk of a whale and creel interaction occurring that may result in an entanglement. Measures to prevent entanglements should be a priority and future assessments should be used to inform suitable mitigation strategies. Existing data should be analysed more thoroughly to investigate the distribution, behaviour and movements of both animals and fishing gear to provide a better understanding of the spatial and temporal distribution of entanglement risk, and the likely efficacy of potential mitigation measures. This should include looking in more detail at the trends and changes over time, and using future climate change predictions to determine how this may affect the distribution of fish stocks and prey species for larger animals and where commercial stocks are fished. The analysis should also be extended to provide a year-round assessment. To achieve this, year-round monitoring should continue to build a better baseline for winter months and provide more reliable data on creel and minke whale distributions during the winter months. With the number of entanglements and the number of species affected increasing, the types of analysis outlined here should also be performed for other protected species that are commonly entangled e.g. basking sharks.

Chapter 7 – Entanglement survivors

Twenty-two percent of minke whales seen off the west coast of Scotland show evidence that they may have previously been entangled, which provides a conservative assessment of non-lethal entanglement for this species. Future assessments must continue to include information about the number of live animals that show evidence of entanglement to better understand the implications these types of interactions have on individual animals. Using these data alongside data on mortalities will provide better estimates of the effects of entanglement on minke whale mortality rates.

Effort should continue to catalogue individual animals and effort should be made to increase the photographic coverage of individual animals to allow an assessment of entanglement related scars to be made for a higher proportion of animals. Future studies should consider using drones to capture aerial photographs of minke whales to provide a more accurate assessment of scarring and hence prevalence of entanglement.

Chapter 8 – Fisher's perspective

Having reviewed the findings of this project, including the experiences and insights of fishers detailed in earlier chapters, SCFF support further study into several proposed entanglement mitigation strategies. These include research to understand the behaviour of floating groundline near the seabed, and the feasibility, costs and other implications associated with a move toward negatively buoyant ropes. Encouraging fishers, potentially through subsidised exchanges and disposal schemes, to transition to negatively buoyant rope when replacing worn lines where safe and practical is also supported by SCFF and other project partners.

As ropeless technologies develop toward commercial availability, SEA partners recommend trials of ropeless fishing gears be formalised in Scottish waters, and Scottish fishers be encouraged to participate in refining these systems to suit their own needs to determine if these systems could realistically be deployed.

SCFF recognise that the risk of entanglement needs to be considered in setting creel limits. The Scottish Governments new Fleet Modernisation Program (Scottish Government 2020), which will require all inshore Scottish vessels to use tracking systems, will potentially lend itself well to developing trials of some suggested mitigation measures by mapping fishing effort.

We recommend a second SEA phase be launched, to start trialling these mitigation measures and assess which, if any could be feasible in Scotland. A key component of any trials will be to maintain input and guidance from the fishing industry, and ensure fishers continue to be encouraged to report entanglement incidents in order to improve knowledge and data required to initiate effective change. SCFF recommend the above consortium partners form part of a SEA phase two programme of research.

Glossary of terms

Becoming fast – when fishing gear becomes caught or snagged on the seabed and cannot be lifted.

Bycatch – the accidental capture of non-target species in fishing gear.

Cetacean – group name for whale, dolphin and porpoise.

Creel fishing – a traditional form of static or passive coastal fishing using baited creels (also referred to as traps or pots) which are typically constructed of round steel bars coated in plastic and covered in net. These are strung together in fleets and dropped to the seabed to fish for shellfish including prawn, lobster and crab.

Creel limits – reducing the amount of creels deployed, in terms of absolute numbers, density, soak time or spatial extent

Dorsal fin – the top fin most often seen as animal surfaces.

Endline – also referred to as a leader, riser or tailing. The endline is the vertical rope at either end of a fleet of creels. The endline extends from the seabed to the surface where a marker buoy is attached, which signals the location of the fleet, and is used to haul creels.

Entanglement – the unintentional capture or restraint of marine animals in materials of anthropogenic origin, typically rope, line or netting which become wrapped around the head, body and/or fins. This includes cases where animals are anchored by the entangling gear or are towing this.

Groundline – also referred to as backline or backrope. The groundline is the horizontal rope that extends between the endlines and to which creels are attached.

Monofilament netting – is fishing line made from a single fibre of plastic, rather than being braided together.

Pectoral fin – the flippers or forelimbs of cetaceans

Peracute – very severe entanglements and of short duration, generally proving quickly fatal (<2 hours)

Ropeless fishing – a fishing system that reduces the need for vertical endlines to mark the position of creels or pots on the sea floor. Also referred to as 'on-call' systems.

Rostrum – the jaws of a baleen whale elongated forward to enlarge the mouth cavity.

Self-shooting – creels are automatically deployed, eliminating the need for anyone to manually handle creels or be on deck during the shooting process.

Ship strike – collisions between marine animal and vessels.

Trawl – method of fishing that involves pulling a fishing net through the water behind a vessel.

Weighted rope – ropes that are negatively buoyant in the water column. Also referred to as leaded or sinking rope.

Introduction

Bycatch and entanglement in fishing gear is recognised as the most prevalent anthropogenic threat to cetacean welfare and conservation globally, resulting in hundreds of thousands of deaths each year (IWC, 2017; Read, 2008). Every species of large whale is known to have been affected by entanglement (IWC, 2010), which can have devastating, long-term conservation impacts. For example, entanglement is a major causal factor in the endangered and critically endangered status of the humpback whale (*Megaptera novaeangliae*) in the Arabian Sea (Minton, 2008*)* and the North Atlantic right whale (*Eubalaena glacialis*) (Knowlton et al., 2012), respectively. While over 1700 entanglement incidents involving every known large whale species have been documented worldwide since 1979 (IWC, 2010) it is estimated that the true number of cases is much higher. For example, Robbins et al., (2009) suggested that fewer than 10% of cetacean entanglements are actually reported*.* Ramp et al*.,* (2021) compared entanglement rates of fin (*Balaenoptera physalus*) and blue whales (*Balaenoptera musculus*) using vessel-based photo-identification versus drone photography. They found a higher occurrence of entanglement from aerial-based photography. Impacts of entanglement to basking sharks (*Cetorhinus maximus*) and other elasmobranch species are also underreported (Parton et al., 2019).

Entanglements in Scotland

In Scotland a diverse array of large marine animals inhabit inshore waters, which also provide valuable fishing grounds for mobile and static fishers. There is a long history of mixed fishing in Scottish waters, and the economic, social and cultural significance of the industry is particularly valued in small fragile coastal communities (Fulton, 1998). As the industry continues to grow and both humpback whale and basking shark populations are thought to have begun to recover post-whaling and hunting, so has the potential for interactions between large marine wildlife and both active and derelict fishing gear (Ryan et al., 2016). There is no fundamental distinction between the terms bycatch and entanglement, which are often used synonymously. While both describe the unintentional capture of marine animals, for this report entanglement is defined as '*wraps of line, netting or other materials around body areas*' and '*may include cases in which animals are towing gear or anchored by gear*' (IWC, 2010). Based on animals reported from Scottish waters and examined by SMASS 1992-2019, entanglement is now the largest identified cause of anthropogenic mortality in baleen whales and the only known anthropogenic cause of mortality in basking sharks and turtles (SMASS, 2019). Based on lesion morphology, the most frequent type of entanglement involves long lengths of 10-15mm diameter polypropylene ropes, such as those used in creel fishing. The most common cetacean species reported entangled in Scottish waters since 1992 are minke whales (*Balaenoptera acutorostrata*) and humpback whales, however entanglements involving basking sharks, leatherback turtles (*Dermochelys coriacea*), harbour seals (*Phoca vitulina*), grey seals (*Halichoerus grypus*), and killer whales (*Orcinus orca*) have also been recorded (details in Section 3 below and SMASS, 2019).

Creel fishing in Scotland

Creel fishing dominates the Scottish fishing fleet with a total of 1,457 registered commercial vessels in 2018. Over 92 per cent of these are vessels under 10 metre which equates to 65 per cent of the Scottish fishing fleet, and 88 per cent of the under 10 metre fleet. Between 2009-2018 the number of shellfish vessels over 10 metres has fallen 12 per cent, while the number of creeling or nephrops trawling vessels under 10 metre has risen three per cent.

Creel fishing is a static form of fishing that takes place around Scotland's coast. Gear comprises steel-frame creels or pots covered in netting which are baited to entice the given target species (Figure 1). Creels are strung together with rope and fished in fleets which are baited, set, and retrieved typically one or two days later. The main species targeted in Scotland are prawns *(Nephrops norvegicus*), lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*) depending on area, seabed type (e.g. mud, rocky bottom) and depth. Creel fishing is considered to be a very selective and environmentally sustainable form of fishing. Target species are brought to the surface alive and undamaged, with very little bycatch. The carbon footprint (in particular fuel consumption) is minimal as the majority of boats are small and fish relatively close to shore. Creeling is often a main source of employment in fragile rural communities, contributing to the economic and social survival of these areas (Fulton, 1998).

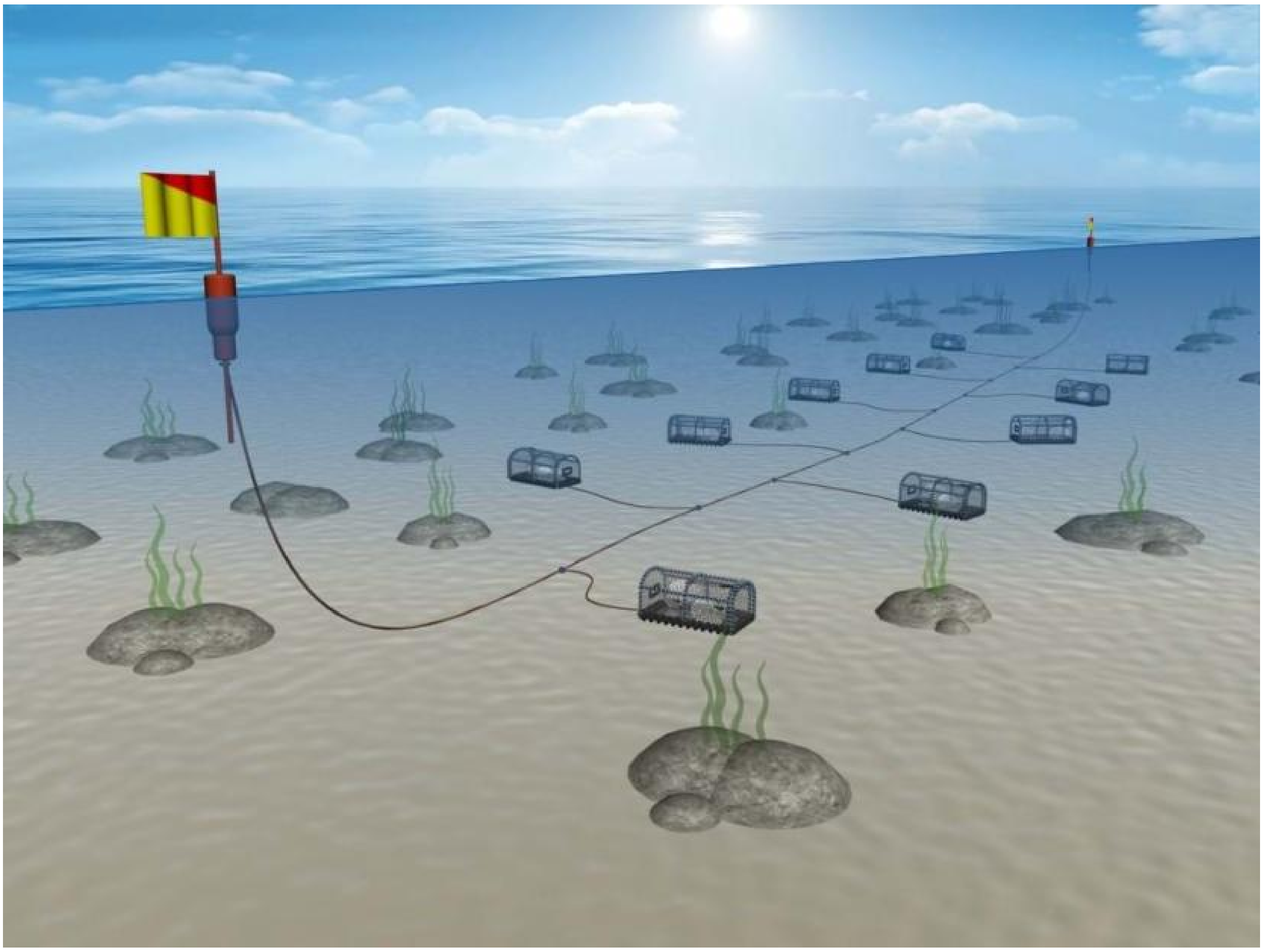

Figure 1. A typical creel fleet set-up. © Seafish, 2020.

Entanglement legislation, regional conventions and policy

All cetacean species found in Scottish territorial waters are classed as European Protected Species (EPS), and are given protection inshore under the Habitats Conservation (Natural Habitats, & c.) Regulations 1994 (as amended in Scotland), which includes protection from deliberate or reckless capture, injury, killing, harassment, or disturbance (NatureScot, 2019a). Cetaceans in waters more than 12 nautical miles from land are protected under the Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2017. There is a requirement to report bycatch of non-target species under the EU Common Fisheries Policy Data Collection Framework Regulation (2017/1004) and a requirement for mitigation measures in some circumstances under the Regulation on the conservation of fisheries resources and the protection of marine ecosystems through technical measures (Technical Conservation Regulation). The UK is also a member of the regional conservation convention ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas), which aims to reduce bycatch and entanglement levels towards zero. The Fisheries Act 2020 makes provision in relation to fisheries and marine conservation. The Bill contains an "Ecosystem Objective" that includes a requirement for "incidental catches of sensitive species to be minimised and, where possible, eliminated". The UK has set up a stakeholder group called Clean Catch, chaired by Defra, to inform and implement a bycatch strategy to meet the legal requirement. In addition there is a requirement to monitor the incidental capture and killing of whales and dolphins in fishing gear, to ensure that significant negative impacts do not occur to the population concerned. To monitor these requirements Scotland has two long-term programmes to understand levels of bycatch and entanglements in the Scottish and UK fleet. There is an on-board bycatch observer programme led by St Andrews University which monitors bycatch of marine mammals, elasmobranchs, turtles and seabirds in trawl and static net fisheries, and a strandings analysis programme is led by the Scottish Marine Animal Stranding Scheme (SMASS), which investigates the causes of cetacean, seal, shark and turtle strandings around the Scottish coast. The data collected within these government-funded programmes are essential to understand a range of threats facing marine species, including entanglement, via SMASS reports. Of four newly designated nature conservation Marine Protected Areas (NC MPAs), three (Southern Trench, Sea of the Hebrides and North-east Lewis) identify minke whales, basking sharks and/or Risso's dolphins (*Grampus griseus*) as protected biodiversity features for which the sites have been designated.

Knowledge gaps on the impact of entanglements

Despite the aforementioned protections, a thorough scientific understanding of the impact of entanglement on large marine animal populations is still lacking. This is due to low coverage of observer programmes (less than 5% of UK fishing operations and none within the creel sector), a largely unregulated static sector, poor levels of reporting of incidents by fishers, the low likelihood of retrieving whale and basking shark carcasses, and subsequent limitations of post-mortem examinations (Cassoff et al., 2011; Northridge et al., 2010; Cole et al., 2006). Despite these shortfalls, although the reported prevalence of entanglement cases in Scotland has remained low over the past 20 years (<10/year), the incidence and range of reported species does show an increase over time (SMASS, 2019). Using 12 documented cases, Ryan et al., (2016) reported potential population level concern regarding the number of humpback whale deaths due to entanglement, stating that the creel entanglement alone is an order of magnitude higher than sustainable levels. Nearly half of baleen whale deaths investigated by SMASS since 1992 have been attributed to entanglement. Of these, 71% were acute i.e. the entanglement was short-lived with death due to the animal acutely drowning (within minutes to hours). The remaining 29% of cases were chronic, whereby the animal was entangled for a period of weeks or months, resulting in debilitating injuries and representing a significant welfare concern. The incidence of chronic entanglement was significantly higher in humpback whales than other species. Further details can be found in chapter 3 - Understanding the distribution, trends and welfare impacts of marine animal entanglements. As few as 10% of whale entanglements are believed to be reported in other areas around the world (e.g. Robbins and Mattila, 2004) and with no reason for reporting rates to be any different in Scotland, it has not been possible to assess the full scale of the potential issue here previously. The SMASS database also includes 14 cases of basking shark strandings reported since January 2015. Whilst entanglement of basking sharks is not uncommon in fishers reports (chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement) confirming entanglement as a cause of death in shark carcases is difficult, as animals seldom make landfall in sufficiently fresh enough condition to enable meaningful diagnosis.

SEA aims and objectives

The Scottish Entanglement Alliance (SEA) is funded through the European Maritime and Fisheries Fund (EMFF) and led by NatureScot (formerly Scottish Natural Heritage). It is a partnership between NatureScot and five other organisations dedicated to promoting and protecting Scotland's wildlife and sustainable creel fishing. These are detailed in Table 1.

Table 1. SEA partner organisations

Partner organisation	Role
NatureScot (formerly Scottish Natural Heritage, SNH)	NatureScot is the lead public body responsible for advising Scottish Ministers on all matters relating to the natural heritage. It advises local authorities and works with the Scottish Parliament and public, private and voluntary organisations.
Scottish Creel Fishermen's Federation (SCFF)	SCFF is a national trade association for the creel fishing industry, a traditional and sustainable form of coastal fishing for shellfish that supports more jobs around the coastline of Scotland than any other type of fishery.

Partner organisation	Role
Whale and Dolphin Conservation (WDC)	WDC is the leading international charity dedicated to the protection of whales and dolphins. Their vision is a world where every whale and dolphin is safe and free. WDC has considerable international expertise in whale entanglement and is a member of both international and regional agreements to progress cetacean welfare and conservation initiatives.
Scottish Marine Animal Stranding Scheme (SMASS)	SMASS aims to provide a systematic and coordinated approach to the surveillance of Scotland's marine species by collating, analysing and reporting data of all cetaceans, seals, marine turtles and basking sharks that strand on the Scottish coastline.
Hebridean Whale and Dolphin Trust (HWDT)	HWDT has been leading the way for the conservation of whales, dolphins and porpoises in the waters of western Scotland for over two decades. HWDT's research has advanced the understanding of species that visit seasonally or are resident in the Hebrides, and provides data to the Scottish Government to inform protection measures for minke whales, Risso's dolphins, harbour porpoises, and basking sharks across Hebridean seas.
British Divers Marine Life Rescue (BDMLR)	BDMLR is a UK charity dedicated to the rescue and rehabilitation of injured and distressed marine wildlife and co-ordinates Europe's only large whale disentanglement team.

The Alliance aims to improve our understanding of the extent and magnitude of large animal entanglements in Scottish waters, and was formed following an industry-led request for help with, and willingness to engage in, work to address large marine animal entanglements. The research presented in this report builds on that of Northridge et al., (2010), who assessed the entanglement issue in Scotland, specifically of minke whales in creel fishing gear. This work reviewed data available at the time on strandings where entanglement was a contributing factor, the extent of the implicated fisheries in Scotland, and the likelihood of co-occurrence between minke whales and fisheries to identify potential 'high risk' areas for entanglement. It also builds on more recent work by Ryan et al., (2016) who estimated abundance and entanglement probability of humpback whales and concluded that Scottish waters currently act as a mortality sink due to the entanglement threat.

This project aimed to engage with the Scottish inshore creel fishing industry to provide a co-ordinated, comprehensive monitoring and engagement programme to better understand the scale and impact of marine animal entanglements in our waters, as well as provide the first estimates of the financial cost of entanglement(s) to the Scottish creel fleet. To achieve this, the goals set out by the project partners were to:

- Raise awareness of marine animal entanglements amongst fishers and other marine users;
- Improve reporting rates of marine animal entanglements;
- Provide a platform for fishers to suggest solutions to this problem;
- Provide opportunities for fishers to become involved in entanglement research and disentanglement efforts through workshops and training courses;
- Assess the risk and impact of entanglements to marine animals at an individual and population level; and,
- Better understand the socio-economic impact of marine animal entanglements on the Scottish fishing fleet.

Entanglement prevention is the ultimate goal, however achieving these aforementioned targets would provide the evidence required to enable the development of workable and proportionate mitigation strategies and provide support for a second phase of work to trial and implement these.

Table 2. Data sources, description and time period for each chapter of this report

Data Source	Description	Time period	Chapter	Data owned by	Reference

Data Source	Description	Time period	Chapter	Data owned by	Reference
SMASS dataset	Stranded marine animals reported to the Scottish marine Animal Stranding Scheme	1992-current	**3**	Scottish Government/ Public access	Marine Scotland Maps NMPi Search strandings
Interview data	Responses from face-to-face interviews with fishers	2008-2018	**4 & 5**	SEA Project	-
Sighting data	Sightings of minke whales and creel fleets recorded on the west coast of Scotland	2003-2019	**6**	Hebridean Whale and Dolphin Trust	Hebridean Whale and Dolphin Trust (2020). Minke whale and creel sightings with associated effort for the west coast of Scotland. Silurian Dataset 2003 – 2019. Accessible via Hebridean Whale and Dolphin Trust (HWDT), Tobermory, United Kingdom.
Photo-ID data	Photographic records of minke whales on the west coast of Scotland.	1990-2017	**7**	Hebridean Whale and Dolphin Trust	Hebridean Whale and Dolphin Trust (2020). Minke whale photo-identification data and associated sighting data for the west coast of Scotland. Whale Track and Silurian Datasets 1990 – 2017. Accessible via Hebridean Whale and Dolphin Trust (HWDT), Tobermory, United Kingdom.

Understanding the distribution, trends and welfare impacts of marine animal entanglements from strandings data

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Summary

This chapter explores the number of cases reported to Scotland's national strandings monitoring programme and outlines a method for assessing the welfare implications of large animal entanglements based on pathological examination of stranded carcases. The data is based on the SMASS strandings dataset (n = 12,500 strandings reports, 1992-current). Although the number of entanglement cases reported to the Scottish national strandings network remains low (n=97) there is significant underreporting of cases compared to the results of the questionnaires (Table 6). The reported incidence has been steadily increasing over the past 5 years, with entanglements reported from all regions of Scotland. Although there are some regional clusters, it is notable that there are no regions of the Scottish coastline free from reports of entanglements demonstrating this is indeed a national problem. Strandings reports show some seasonality, with humpback (*Megaptera novaeangliae*) entanglements clustering around late spring, minke whales (*Balaenoptera acutorostrata*) in summer and leatherback turtles (*Dermochelys coriacea*) in autumn. The gear type and chronicity of marine animal entanglements varies by species, likely due to a combination of reasons including anatomy, foraging behaviour and distribution.

The most typically reported entanglement case reported to SMASS are minke whales (n = 37), entangled acutely by rope around the tail (table 3). Grey seals (*Halichoerus grypus*) are the second most frequently entangled at 23% (n = 17). In most of these cases the entanglement is rapidly fatal due to drowning or anoxia. The number of humpback entanglements assessed for welfare impacts was low (n = 4) three of them showed evidence of chronic entanglement and all scored in the worst two categories for animal welfare, demonstrating prolonged suffering. Entanglement of marine animals in Scottish waters is irrefutably a significant welfare issue, and especially to larger, stronger animals

who appear able to survive, but not escape, entanglement for a longer period of time. Chronic entanglements are bioenergetically costly, and can be eventually fatal, either through drowning or the animal succumbing to secondary injuries, infection or debilitation caused by the entanglement, or cause long term debilitation which can impact the animal's health resilience and fecundity (van der Hoop et al., 2016).

Welfare data presented in this study is limited by sample size (n = 39, table 2) but this initial work highlights what can be derived from pathological assessments of photographs and/or recovered carcases. Expanding and developing the range and detail in the data collected from future entanglement cases is an essential next step in order to better quantify the prevalence, incidence and range of marine animal entanglements and provide vital assessments of the impact on animal welfare.

Introduction

Assessing the impact of entanglements and by-catch on cetaceans is challenging. The effect on the individual animal ranges in duration from a few moments to a lifetime impact, and in severity from negligible to fatal. Entanglement events can profoundly influence the welfare and survivorship of an individual and, if sufficiently iterated within a population, have detrimental impacts on conservation. There is a clear need to better quantify the impact of marine animal entanglements at an individual and population level. There is also a clear policy need, driven by requirements of national legislation and international treaties, to contextualise impacts in terms of other sources of mortality and morbidity of anthropogenic origin, such as bycatch, ship strike, marine debris and underwater noise. Frameworks for integrating multiple impacts, for example population consequences of disturbance models (PCOD) require profiling and parametrisation of the impact from individual threats, however, as can be seen from chapter 5 - Coast and socio-economic impacts of marine animal entanglement to the Scottish creel fishery, these data are difficult to acquire from free ranging marine mammals. Examination of stranded or at-sea carcases offers a unique insight into the health of and threats to these individuals, and the UK, along with many other countries, has well established and long standing strandings investigation programmes. Here, data from the Scottish strandings network, the Scottish Marine Animal Stranding Scheme (SMASS) was interrogated to describe the nature, range and distribution of fatal entanglements on stranded marine animals. This can be used to inform stakeholders on the severity and impact of injuries sustained as a result of peracute underwater entrapment and chronic entanglement.

Descriptive statistics

Incidence of entanglement reports

Entanglement cases reported to SMASS from 2005-2019 inclusive are given in Figure 2. As can be seen from the bar plot, reported cases were low with fewer than five per year until 2014. After this point there was a general year on year increase to 18 cases in 2018 and 15 in 2019. As evidenced in chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement, the true incidence is plausibly one or two orders of magnitude higher, due to significant underreporting of cases.

The most frequently reported entangled marine animal are minke whales, comprising 46% (n = 34) of cases, with grey seals the second most frequently entangled at 23% (n = 17) of case reports during this period.

The type of entanglement varies by species, with seals largely presenting with encircling neck lesion in a range of materials, including packing straps, throwing discs and thin twine, likely from marine debris rather than active fishing gear. In contrast, cetaceans and marine turtles are mostly found with evidence of entanglement marks consistent with ropes used in creel fishing, however cases involving trawl and monofilament netting have also been recorded.

It should be noted that less than a third of animals are found with material still attached and where it is not, a diagnosis of entanglement is made by lesion pattern and, where possible, pathological evidence derived from post-mortem examination.

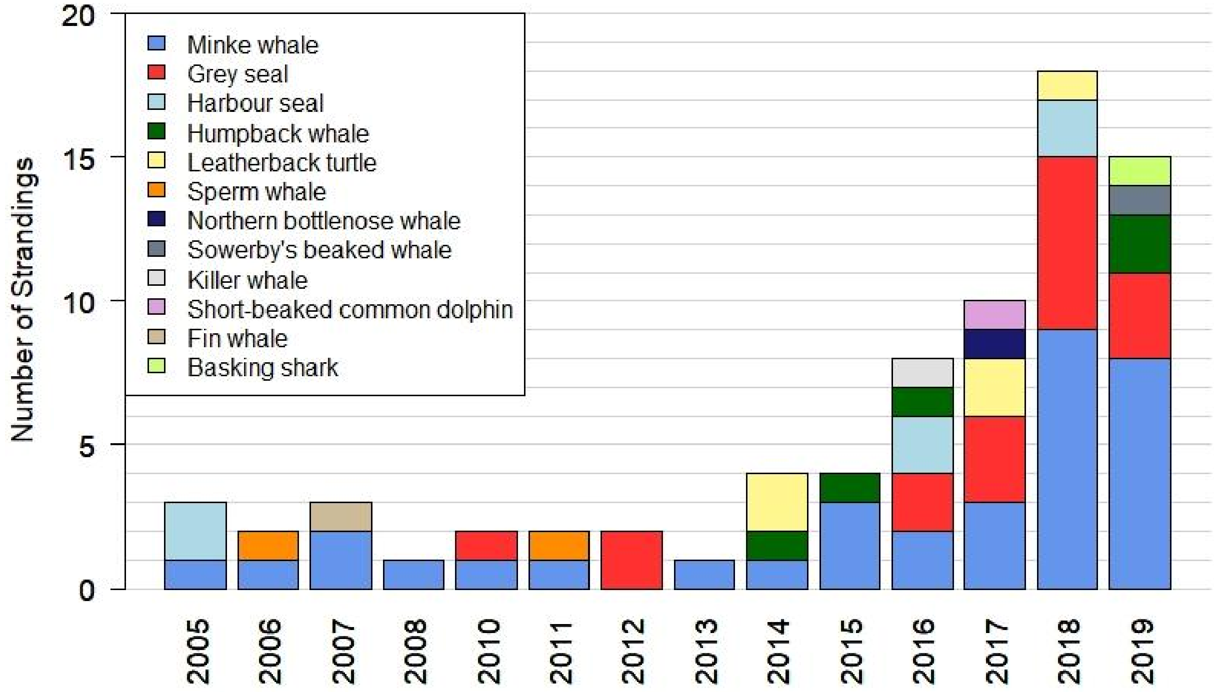

Figure 2. Incidence of entanglement cases reported to SMASS 2005-2019. (Click for a full description)
Entanglement cases reported to SMASS from 2005-2019 inclusive are given in Figure 2. As can be seen from the bar plot, reported cases were low with fewer than five per year until 2014. After this point there was a general year on year increase to 18 cases in 2018 and 15 in 2019. As evidenced in Chapter 4 – Capturing fishermen's knowledge: Fishing activity and experience of entanglement, the true incidence is plausibly one or two orders of magnitude higher, due to significant underreporting of cases.

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Spatial maps – where do entanglements occur?

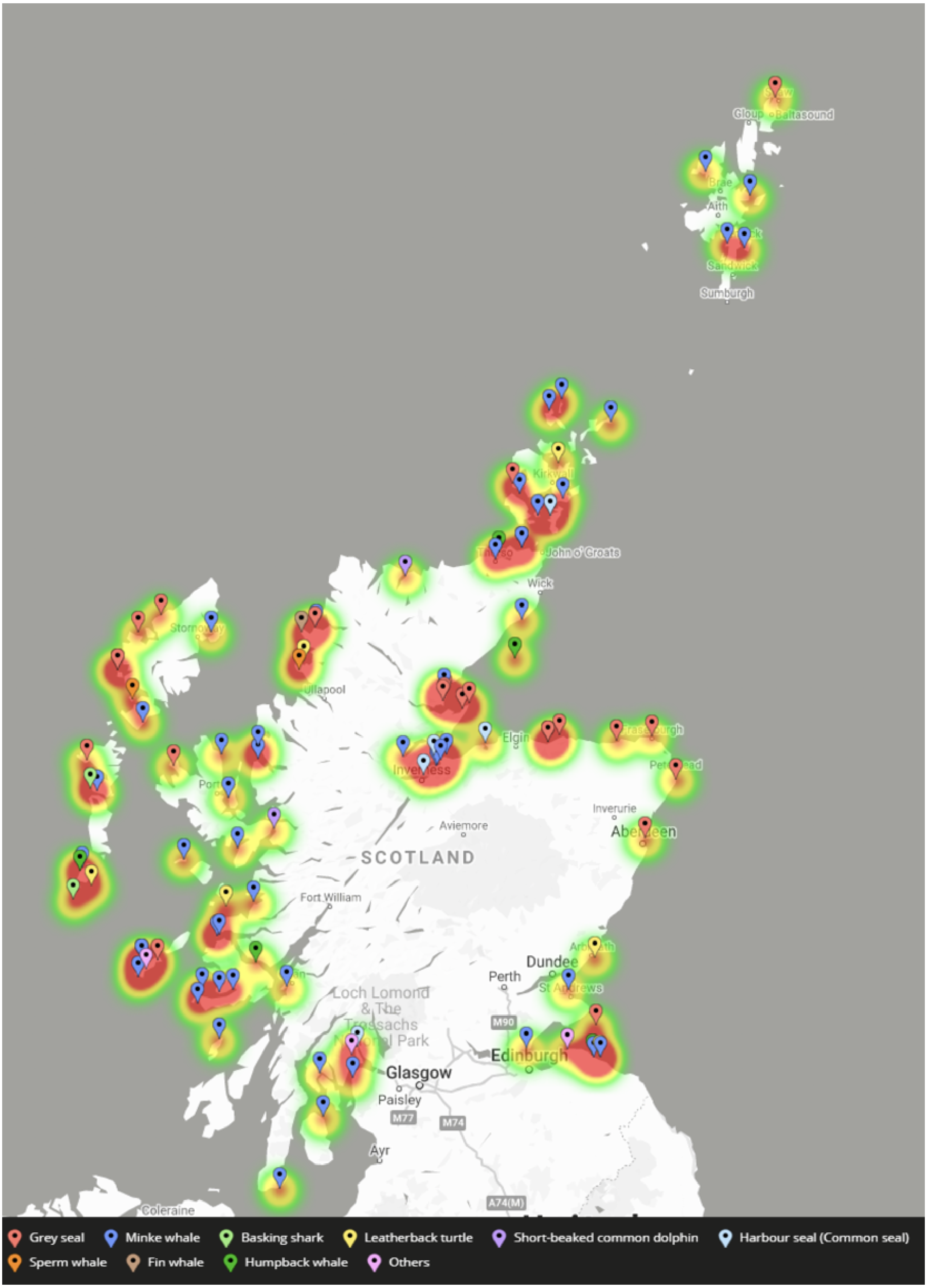

Figure 3. The distribution and relative density (red = high) of entanglement cases reported to SMASS 2005-2019 (Click for a full description)

Heat spots showing species and density distributions are spread around all coastal regions of Scotland. There are apparent hotspots but these could be linked to combination of both fishing density and reporting effect. The data confirms that there is no regions of Scotland which has avoided entanglement cases, confirming this is an issue for the whole of Scotland.

These same data can be viewed in an interactive map.

There is no clear spatial segregation by species, with cases reported from all regions of Scotland. There are apparent hotspots in each region, for example Tiree, Pentland Firth, Western Isles and the Forth, Dornoch and Inner Moray Firths. This is likely due to a combination of fishing density and reporting effort, however more data are necessary before any more definitive spatiotemporal patterns can be described. These data do confirm, however, that there is no region of Scotland which has avoided entanglement cases, confirming this is an issue around the whole coast.

Summer is a peak season for all species, likely due to an increase in both true incidence and observer effort (Figure 4 and Figure 5). All humpback entanglements occurred in spring, between March and June. The reason for this pattern is not clear, but would be consistent with either an increase of fishing effort, and hence material in the water, or an increase in humpback whale abundance from seasonal migration into Scottish waters, for example as animals travel between high-latitude summer feeding grounds and low-latitude winter breeding grounds. In contrast, marine turtle entanglements are distributed in autumn and early winter, again likely corresponding to changing prey foraging patterns for this species.

With this low sample size it is not possible to conclude a definitive seasonal risk pattern, but this analysis does highlight the need for finer scale collection of data on entanglements, given there appears to be strong indications of species dependant, seasonal heterogeneity in incidence rate (Figure 4 and Figure 5 below).

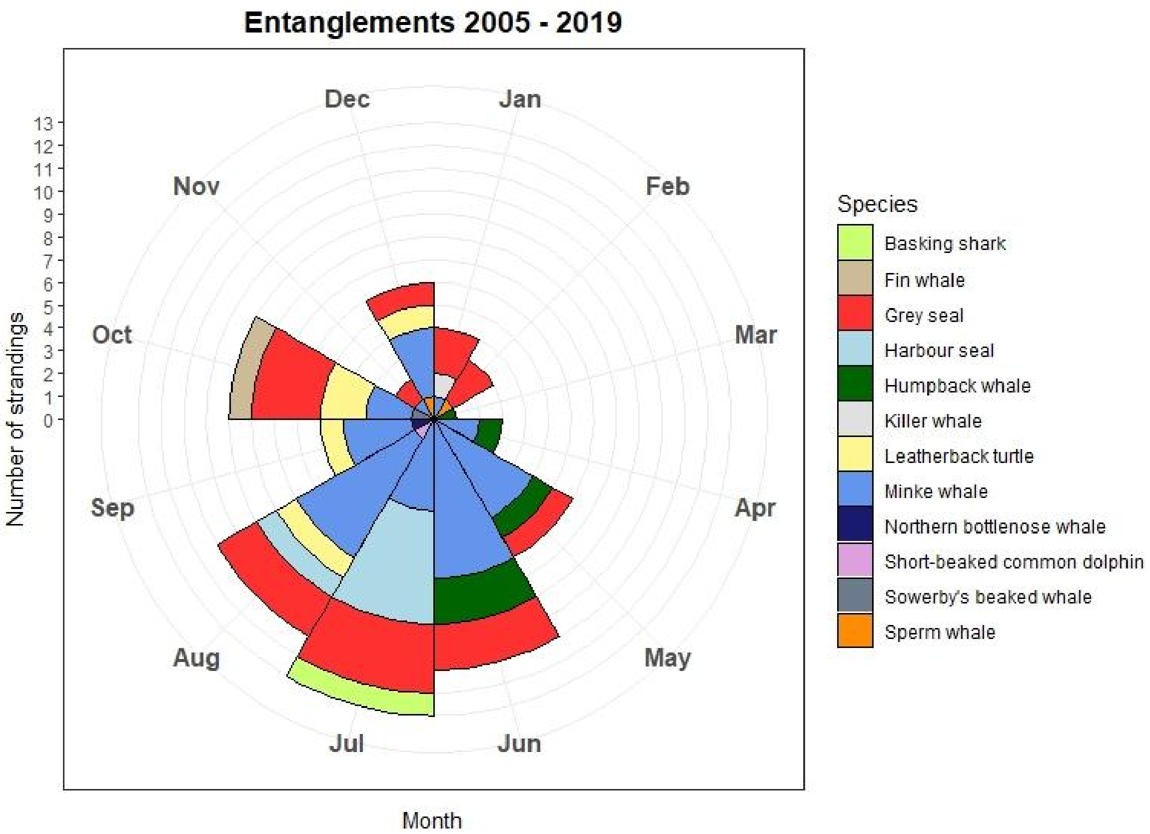

Figure 4. All entanglements reported by month, 2005-2019. (Click for a full description)
Summer is peak season for all species, this is likely due to an increase in both true incidence and observer effort. All humpback entanglement occurs in spring, between March and June. This pattern is not clear but likely due to increases in fishing activity and increase in abundance of humpback whales from seasonal migration into Scottish waters. Marine turtle entanglements are distributed in autumn and early winter, likely corresponding to changing prey foraging patterns.

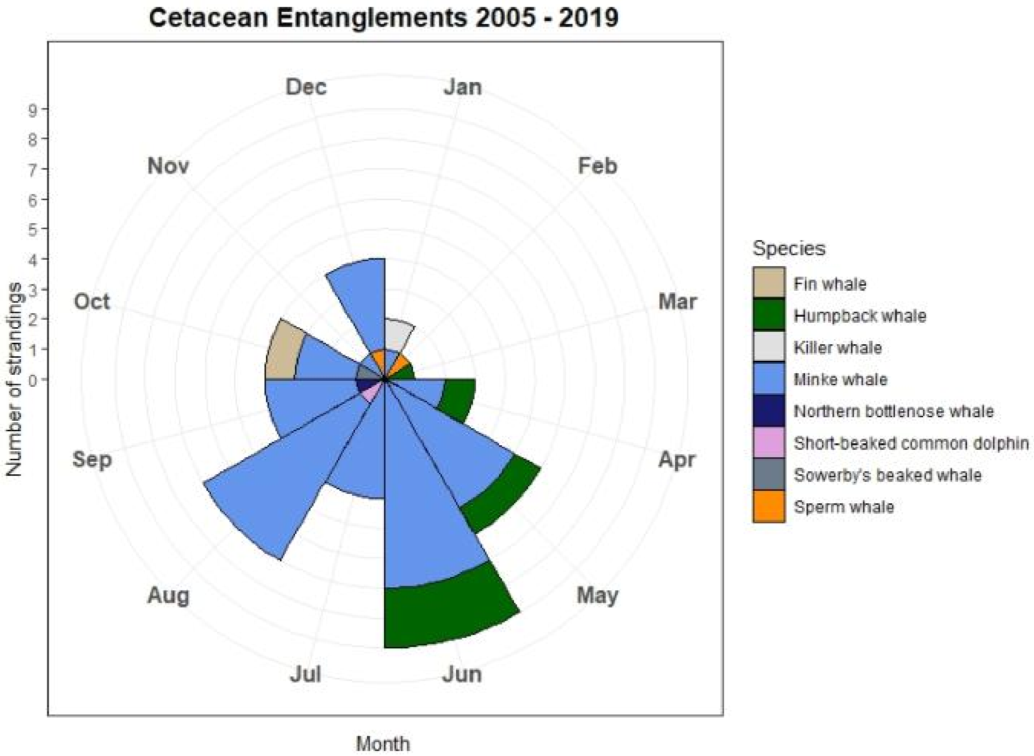

Figure 5. Entanglement reported by month, 2005-2019, excluding seals. (Click for a full description)

Summer is peak season for all species, this is likely due to an increase in both true incidence and observer effort. All humpback entanglement occurs in spring, between March and June. This pattern is not clear but likely due to increases in fishing activity and increase in abundance of humpback whales from seasonal migration into Scottish waters. Marine turtle entanglements are distributed in autumn and early winter, likely corresponding to changing prey foraging patterns.

Welfare analysis – methodology

Due to the lack of consistently detailed photographic evidence for some cases prior to 2015, only cetacean and marine turtle cases examined 2015 onwards were assessed for entangling gear type, entanglement location on the animal and welfare impact. Seals were excluded from this analysis due to difficulties in getting cases recovered for necropsy or sufficient quality of images. These data are summarised in Table 3.

Entanglement gear type

Where the animal was found with no material attached, the gear type was derived based on the lesion pattern. Entanglement was attributed to creel gear where the lesion pattern matched that from known creel rope entanglements made by 12-18mm ‘polysteel’ rope (e.g. Figure 6 and Figure 7). This was characterised by single or multiple abraded linear lesions with full or partial loss of skin and evidence of acute tissue bruising or tissue loss from abrasion. Note it was not possible to ascertain if the gear was being actively fished at the point of entanglement based on lesion pattern. A diagnosis of trawl netting entanglement could only be reliably made when the gear was attached to the animal.

Acute and/or chronic entanglement

Cases were assessed for the likely duration of entanglement, and lesions scored as either acute, chronic or both in cases which were a two-stage entanglement.

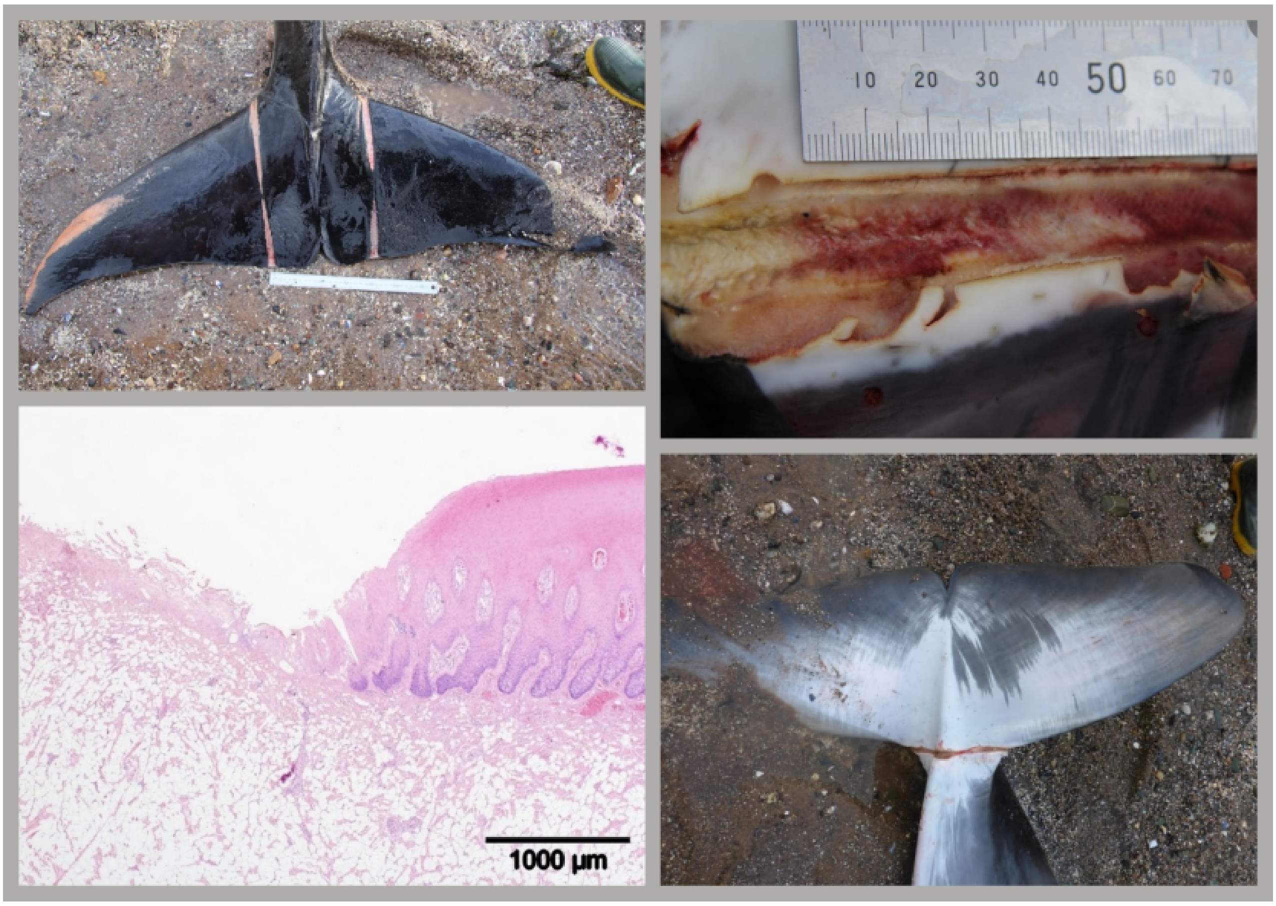

Figure 6. Example of a peracute entanglement case, fatal within a few hours of first becoming entangled. (Click for a full description)
Four photos in one figure. Top left is a tail fluke with two pink lines either side of tail stock. Top right shows close up tissue damage on dead whale. Bottom left is microscope slide of whale tissue. Bottom right is underside of the fluke with pink line at bottom of tail stock.

This is a typical tail entanglement in a minke whale (a) showing an encircling lesion around the tailstock (c) and twin linear abrasions (a, b) caused by taut rope dragging behind the animal causing acute skin loss. Imprint of rope but little tissue damage can be seen in b) and histology of same area d) shows haemorrhage but little tissue healing, confirming the acute nature of the injury.

Characteristics of acute entanglement cases:

- Entanglement duration likely a matter of hours, animal died relatively soon after first becoming entangled
- Clean edge to edge of wound
- No evidence of normal healing processes having started.
- Often associated with bruising to tissue and/or haemorrhage.

Figure 7. Close up of skin region around jaw of an entangled humpback whale showing acute entanglement. Note the imprint of the rope which has abraded the skin, but the absence of any tissue reaction.

Characteristic of chronic entanglement

- Entanglement likely occurred many days, weeks or even months before the animal died, significant tissue reaction
- Cuts or abrasions deep into the underlying tissue
- Often evidence of severe tissue reaction and secondary infection
- Material often embedded in tissue
- Animal is thin and debilitated, head entanglements restricting ability to feed
- Images of chronic entanglement seen in Figure 8, Figure 9 and Figure 10.

Figure 8. Chronic entanglement lesion from an adult female humpback whale. (Click for a full description)
8a) cross-section through skin and blubber layers showing ongoing trauma and healed skin, longstanding severe trauma where rope has dug into tissue (8b) with ongoing more superficial skin trauma (8c) and associated hyperkeratosis (8d). This would be a significant welfare issue for the animal.

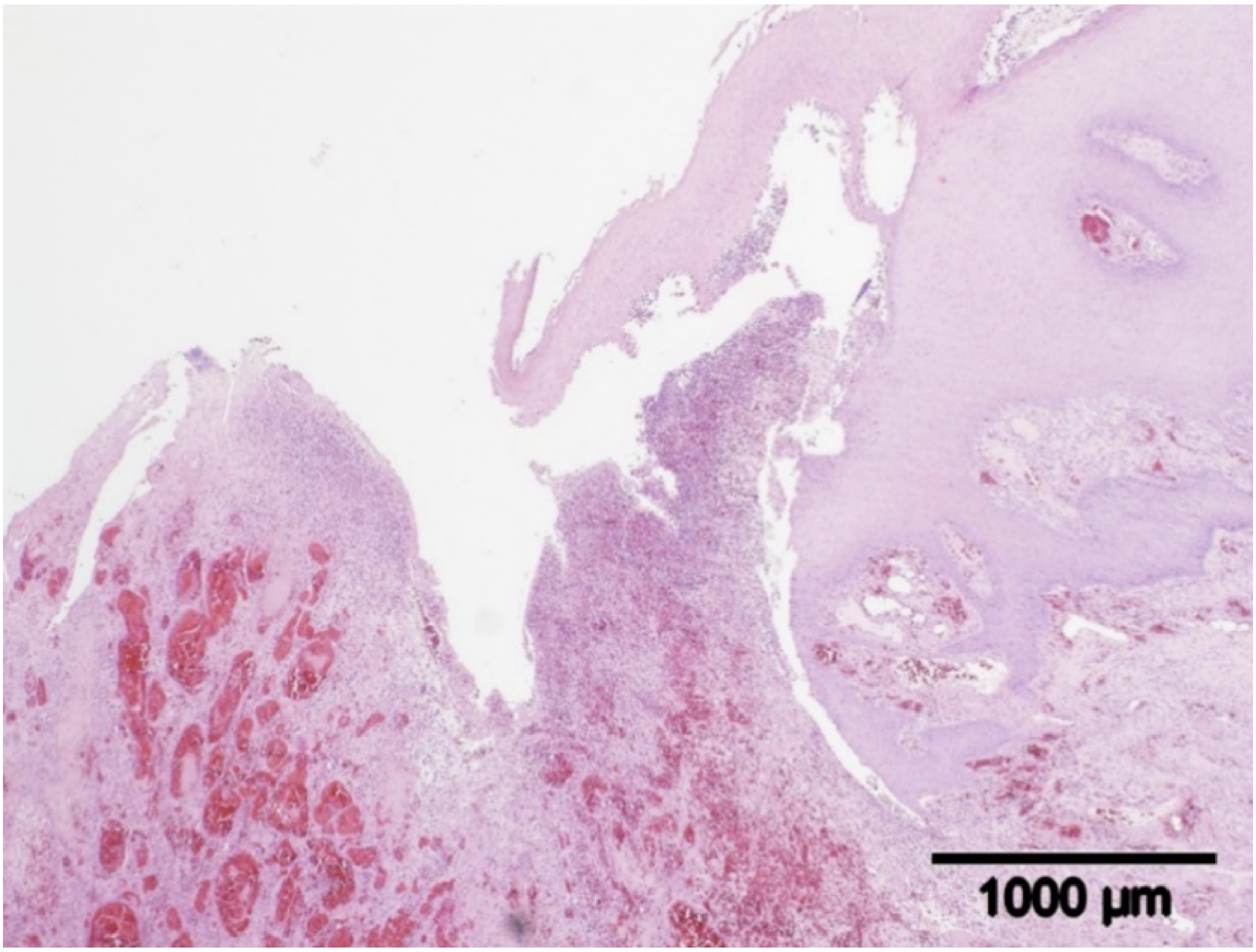

Figure 9. Example of a histological cross section through the chronic entanglement lesion shown in 8a above, showing tissue reaction, inflammatory cells and remodelling.

Figure 10. Chronic entanglement around mouth in a juvenile minke whale showing material still embedded in wound. This animal was emaciated as the rope was restricting ability to feed.

Welfare index

This index is a subjective, derived, three-point score which assessed the assumed welfare harm caused by the entanglement. It is based on a combination of lesion **severity**, **extent** and **duration**. Because it is impossible to assess the physiological or behavioural responses which are traditionally used to assess welfare in free-living animals, reliance must be placed on assumptions made on the photographic images and, where applicable, observed pathology as a correlate for welfare. Adjectival description of this scoring system is:

Score 1: Non-fatal - animal released alive.

Score 2: Lesions are peracute (estimate <1 hours), tissue trauma was moderately superficial and entanglement was likely fatal within minutes and due to asphyxia or drowning.

Score 3: Lesions are acute but there is tissue trauma indicative of a prolonged struggle, entanglement was likely fatal within one tide cycle (<12 hours) and due to asphyxia or drowning.

Score 4: Lesions are chronic, with evidence of extensive or severe tissue trauma, and secondary harm, such as infection or emaciation due to impaired feeding. Entanglement lesions were likely painful, constrained normal behaviour and only fatal after many days, weeks or months.

Table 3. Welfare assessment of cases examined by SMASS 2015-2019

SMASS ID	Species	Date	Region	Gear type	Acute	Chronic	Tail	Pect fins	Body	Mouth	Welfare score
M163/15	Humpback whale	04/06/15	Highland	Creel	**1**	**1**	**1**	**1**	**1**	**1**	**4**

SMASS ID	Species	Date	Region	Gear type	Acute	Chronic	Tail	Pect fins	Body	Mouth	Welfare score
M133/16	Humpback whale	01/03/16	Western Isles	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**3**
M245/19	Humpback whale	23/04/19	Lothian	Creel	**0**	**1**	**0**	**1**	**1**	**0**	**4**
M297/19	Humpback whale	29/05/19	Highland	Creel	**1**	**1**	**0**	**1**	**1**	**0**	**3**
M251/16	Minke whale	01/06/16	Fife	Creel	**1**	**0**	**1**	**0**	**1**	**0**	**2**
M585/16	Minke whale	05/12/16	Strathclyde	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**3**
M269/18	Minke whale	30/04/18	Strathclyde	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M798/18	Minke whale	08/12/18	Highland	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**3**
M271/19	Minke whale	05/05/19	At sea	Creel	**1**	**0**	**0**	**1**	**1**	**0**	**2**
M538/19	Minke whale	11/10/19	Western Isles	Creel	**1**	**0**	**1**	**0**	**1**	**0**	**2**
M180/15	Minke whale	16/06/15	Western Isles	Creel	**0**	**1**	**0**	**0**	**1**	**1**	**4**
M285/15	Minke whale	26/08/15	Highland	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M396/15	Minke whale	27/11/15	Strathclyde	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M227/17	Minke whale	28/05/17	Highland	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M275/17	Minke whale	07/07/17	Strathclyde	Creel	**1**	**1**	**1**	**0**	**1**	**1**	**3**
M372/17	Minke whale	28/08/17	Strathclyde	Creel	**1**	**0**	**0**	**0**	**0**	**0**	**2**
M287/18	Minke whale	16/05/18	Fife	Creel	**1**	**0**	**0**	**0**	**1**	**0**	**2**
M299/18	Minke whale	27/05/18	Lothian	Creel	**1**	**1**	**1**	**1**	**1**	**0**	**3**
M346/18	Minke whale	29/06/18	Strathclyde	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M521/18	Minke whale	31/08/18	Shetland	Creel	**1**	**0**	**0**	**1**	**1**	**0**	**2**
M622/18	Minke whale	08/10/18	Orkney	Creel	**1**	**0**	**0**	**1**	**1**	**0**	**2**
M288/19	Minke whale	19/05/19	Western Isles	Creel	**1**	**1**	**1**	**0**	**0**	**1**	**4**
M364/19	Minke whale	15/07/19	Highland	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**

SMASS ID	Species	Date	Region	Gear type	Acute	Chronic	Tail	Pect fins	Body	Mouth	Welfare score
M433/19	Minke whale	16/08/19	Highland	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M450/19	Minke whale	27/08/19	Shetland	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M502/19	Minke whale	24/09/19	Strathclyde	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M189/20	Minke whale	25/03/20	Western Isles	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M306/20	Minke whale	26/06/20	Highland	Trawl netting	**0**	**1**	**1**	**0**	**0**	**0**	**3**
M592/18	Minke whale	25/09/18	Highland	Trawl netting	**1**	**0**	**0**	**0**	**0**	**1**	**2**
M509/19	Minke whale	28/09/19	Orkney	Trawl netting	**1**	**0**	**0**	**0**	**1**	**1**	**2**
M239/20	Minke whale	11/05/20	Highland	Trawl netting	**1**	**0**	**0**	**0**	**0**	**1**	**3**
M340/18	Minke whale	25/06/18	Strathclyde	Unknown	**1**	**0**	**0**	**0**	**1**	**1**	**2**
M418/17	Northern bottlenose whale	22/09/17	Strathclyde	Creel	**1**	**0**	**1**	**0**	**0**	**0**	**2**
M4/16	Killer whale	01/01/16	Strathclyde	Creel	**0**	**1**	**1**	**0**	**0**	**0**	**3**
M380/17	Short-beaked common dolphin	31/08/17	Highland	Trawl netting - released alive	**1**	**0**	**1**	**0**	**1**	**0**	**1**
M539/19	Sowerby's beaked whale	12/10/19	Lothian	Thin green cord	**0**	**1**	**0**	**0**	**1**	**0**	**4**
M419/17	Leatherback turtle	20/09/17	Tayside	Creel	**1**	**0**	**0**	**1**	**1**	**0**	**2**
M597/17	Leatherback turtle	10/12/17	Orkney	Creel	**1**	**0**	**0**	**1**	**1**	**0**	**2**
M445/18	Leatherback turtle	13/08/18	Western Isles	Creel	**1**	**0**	**0**	**1**	**1**	**0**	**2**

Welfare analysis – results

The data in this section only refer to the 39 cases assessed and scored in Table 3. The following key points can be seen in these data.

What type of gear entangles marine animals?

Of the cases examined, 32 (83%) were identified to have been entangled in rope consistent with creel fishing. Five (12%) of animals were found entangled in sections of trawl netting, with the remaining two (5%) of cases entangled in material that was inconclusive or classified as marine debris.

What is the duration of entanglement?

Acute entanglement accounts for 29 (74%) of cases, chronic entanglement five (13%) and animals enduring a two-stage entanglement event also five (13%). This is species specific however, with 88% of minke whales examined showing acute entanglement, whereas three out of the four humpback whales examined showed evidence of chronic entanglement. This pattern influences the welfare assessment, with 24 (61%) of all cases and 71% of minke whale entanglements scoring 2 or less, characterised by fatality within 12 hours of becoming entangled with limited evidence of tissue trauma. In contrast all humpback whale entanglements show a score of 3 or 4, with all cases exhibiting severe long-term welfare issues.

In terms of other species, leatherback turtles are all found as acute entanglements, however this is likely a function of reporting as, due to the tendency for leatherback turtle carcases to sink, it is less likely chronic injury cases would be recovered for necropsy. Two other noteworthy cases are highlighted in this dataset - M4/16 a killer whale found stranded on Tiree and identified as 'Lulu' – an adult female from the small group of killer whales known as the West Coast Community. Entanglements in killer whales are rare, however the loss of this animal was significant as this small community of animals is now thought to number only eight individuals although only two adult males from the group have been seen in recent years (Hebridean Whale and Dolphin Trust, 2018). This animal also had a very high PCB contaminant burden, and the impact this was having on the health and behaviour of the animal could be significant. Case M539/19, a Sowerby's beaked whale found stranded in Lothian had a chronic entanglement of encircling green twine which had embedded through the blubber layer of the animal (Figure 11) and caused numerous other injuries. This case had led to significant emaciation and caused a severe welfare issue that lasted for weeks if not months. The origin of the material is unknown, and this highlights the hazard presented by both material involved in active fishing and marine debris and abandoned lost or discarded fishing gear (ALDFG).

Figure 11. M539-19 Sowerby's beaked whale with embedded material in tissue.

Where on the body do animals get entangled?

Assessing where on the body animals exhibited entanglement lesions is a useful first step in identifying risk behaviours and potential mitigation solutions. Table 3 shows where animals become entangled.

Most animals show entanglement lesions on the tail or the body, with 23 (59%) and 19 (49%) of cases respectively. As expected, however, there are clear species differences. Minke whales were mostly entangled by the tail, with 64% of cases presenting with encircling lesions around the tailstock, and in 46% of cases this was the only lesion found on the animal. In contrast only half of the humpback whales examined showed tail entanglements, but three quarters had entanglement around the pectoral fins or body. A quarter of both minke and humpback whales were entangled around the head or mouth, usually in trawl net fragments.

Table 4. Where do animals become entangled?

-	Tail	Pectoral fins	Body	Mouth
Humpback whale	2	3	3	1
Killer whale	1	0	0	0
Leatherback turtle	0	3	3	0
Minke whale	18	4	11	7
Northern bottlenose whale	1	0	0	0
Short-beaked common dolphin	1	0	1	0
Sowerby's beaked whale	0	0	1	0
Total	**23**	**10**	**19**	**8**
% of cases with this entanglement	59%	26%	49%	21%

From the lesion pattern of rope entanglements it was not possible to ascertain if the entanglement was in the groundlines or endlines of creel fleets, but it is likely that loops of rope in the water column, for example between creels, pose the highest hazard. Both anatomical and behavioural attributes are likely to be influential on entanglement risk, for example with the large pectoral fins and acrobatic feeding behaviours of humpback whales or the observed response of minke whales to spin rapidly along their long axis when entangled. Possibly evolved as a response to predator attack, such behaviour rapidly exacerbate any entanglement. An example of this is shown in Figure 12 of a minke whale entangled in a creel endline.

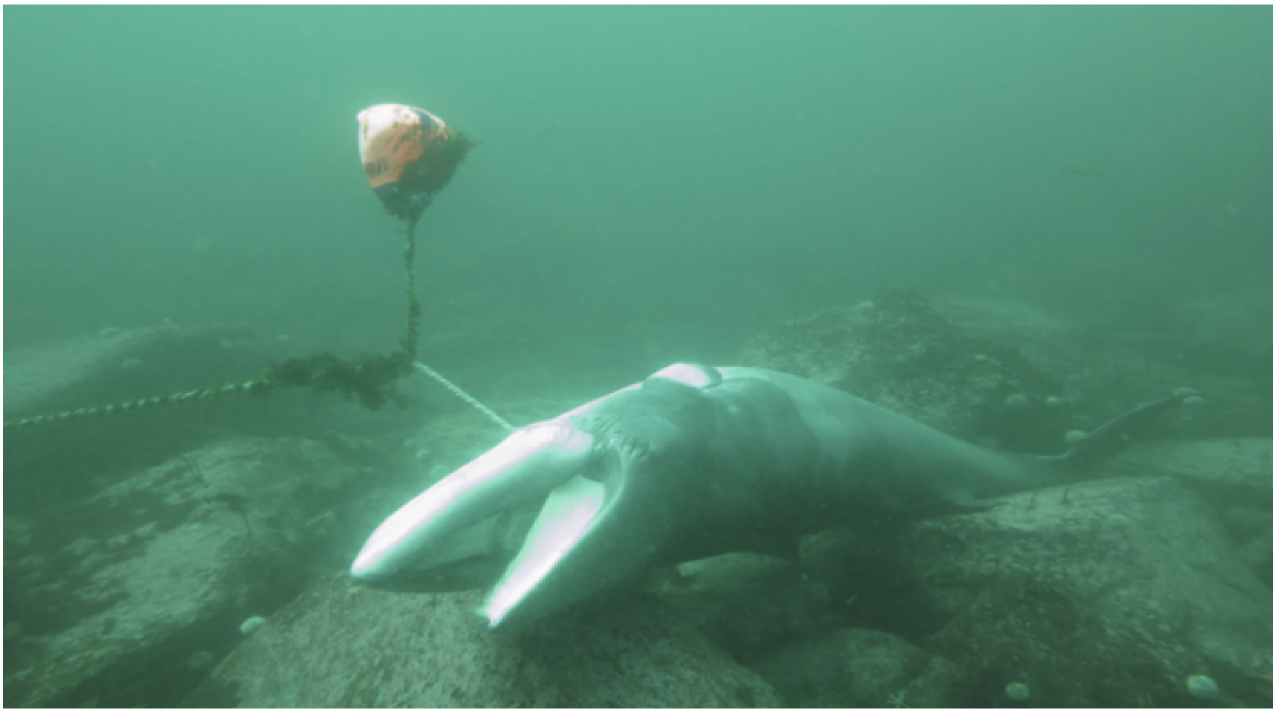

Figure 12. Example of how the behavioural response to entanglement by the animal spinning can fatally exacerbate the situation.

Next steps

Developing the welfare assessment in future cases would be a useful progression of this work, and this could be developed further in any subsequent follow-on programme. For example, a lesion impact scoring system could be developed allows a scoring system to be applied to lesions observed at necropsy in order to assess the chronicity and severity of wounds and therefore estimate the consequence of the entanglement in terms of individual welfare and fitness cost. This could be based on the welfare assessment tool modified from a widely accepted ‘Five Domains model’ (Mellor, 2017) adapted to wild cetaceans (Nicol et al., 2020; IWC, 2016). Subsequently applying these indices to estimates of population incidence and abundance will allow for some estimates of impact to be extrapolated to the population level. In order to do this however, more robust population estimates are required.

Data collected at necropsies of marine mammals with lesions consistent with entanglement in a) active fishing gear b) abandoned lost or discarded fishing gear (ALDFG) or c) marine debris, can all be used to develop a scoring system for impact, severity, duration and consequence of marine animal entanglements. Previously published information on the range of lesions observable with entanglement and bycatch will be compiled and the consequence of each ‘injury’ attributed to each lesion. The impact of these is related to one or more of the 5 domains in Table 3 and using quantifiable pathological attributes will ensure consistency in assessment and minimise subjectivity. This framework was devised to facilitate systematic, structured, and coherent assessment and grading of animal welfare compromise. It incorporates four physical/functional domains (“nutrition”, “environment”, “health”, and “behaviour”), assessed through sources of measurable sensory inputs from within and outside the body, that are likely to give rise to subjective experiences. These are then accumulated into a fifth domain, inferred mental or “affective state” (Nicol et al., 2020). These metrics can be further taken to estimate impact by combining welfare compromise and premature death components using the welfare-adjusted life years model (Teng et al., 2018).

Cetacean trauma cases can present with multiple interrelated pathologies and the scoring system will account for the separate injuries sustained and the sum thereof. A lesion scoring system based upon anatomic location and result of injury (i.e. consequence), severity and duration will be produced.

Chronicity of lesions is challenging to classify. One suggested system is fresh/recent lesion (acute 1-7 days), evidence of early healing (subacute 8-14 days) and change characterised by scar/callus formation (chronic greater than 14 days). This may require histopathology both to establish duration upon which gross assessment can then be based and/or histopathological assessment of lesions to assess duration.

It is also advised that a photographic atlas is collated, which can be used to compare lesions for the assessment of duration. This would go some way to standardising the recording of different observers, and can be used to assess lesions based on photographs for cases where the pathological examination of cases is not possible.

The following proposals suggest future research direction and aims based on analysis of strandings data, expert pathological interpretation, diagnostic testing and population modelling:

- A retrospective review and quantification of impact in terms of a) welfare b) morbidity and 3) mortality of marine animal entanglements in the UK, not just Scotland.
- Attribution, where possible of the plausible origin of entanglements, e.g. active fishing gear, ALDFG or marine debris.
- Extrapolation to incidence at a population level and quantification of impact at an industry level.
- Assessment of the relative risk for populations exposed to specific risk factors, and estimated reduction achievable through different mitigation strategies.
- Input of these metrics into assessments of differing mitigation strategies and communication of options to fishers and other stakeholders to support policy.

Capturing fishermen's knowledge – fishing activity and experience of entanglement

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Summary

A questionnaire was completed by 159 Scottish commercial creel fishers in 67 different harbours around Scotland, to find out about their experiences of marine animal entanglement over a 10-year period between 2008-2018. Almost half of fishers had experienced at least one entanglement in the last ten years. Entanglements are a rare event at an individual fisher level and for most this was a single event.

One hundred and forty six marine animal entanglements involving at least 12 different species were reported during the interviews. The main species reported were minke whale (*Balaenoptera acutorostrata*) and basking shark (*Cetorhinus maximus*). Over 70% of recorded entanglements were found dead in the gear. Six cetacean species reported, and the majority of leatherback turtles (*Dermochelys coriacea*), were found entangled in endlines. Minke whales and basking sharks were more often found entangled in groundlines and humpbacks (*Megaptera novaeangliae*) were found in both groundlines and endlines.

Reported entanglements occurred all around the coast, although more entanglements of all species were reported along the west coast and around the Northern Isles than on the east coast. Average fishing depth and gear hauling frequency were associated with experiencing a marine animal entanglement. Targeting brown crab (*Cancer pagurus*) and Scottish prawn *(Nephrops norvegicus*) and fishing in water over 50m was significantly associated with experiencing a basking shark entanglement. Longer total gear lengths and observing minke whales in the fishing area were significantly associated with experiencing a minke whale entanglement.

Only three of the entanglements had previously been reported to SMASS and BDMLR, highlighting the extent of underreporting these events in Scottish waters. Fishers must be encouraged to report entanglement incidents.

The majority of fishers provided measures that they felt could prevent or reduce the risk of entanglement including best practice, e.g. short endlines, use of negatively buoyant rope, as well as implementing caps on creel numbers, better regulation of the industry in general, and seasonal area closures. Many fishers are willing to test ideas that may help reduce the risk of entanglements, as long as they are practical and there are no financial implications.

The growing concern about the welfare and potential population level impacts of entanglements indicates the need for solutions. Successful prevention, and mitigation relies on continuous engagement and support from fishing communities. Setting out the policy mechanisms and targets for tackling entanglements, based on best-available evidence and precaution, is essential.

Future regulations should address the number of boats that can operate (commercial and recreational), the number of creels each boat can deploy, how often gear must be hauled, and the possibility of separating the mobile and static sectors. The project should be extended to include other fishing sectors such as trawls, purse-seines and static nets, which would allow us to further investigate marine animal entanglement in Scottish waters.

Introduction

Globally marine animal entanglements are believed to be under-reported; as few as 10% in some areas (Knowlton et al., 2016; Robbins and Mattila, 2004). Within the Scottish fishing fleet, data on the level of entanglements have not been readily available which poses a barrier to understanding the true scale and impacts of these events within the different sectors. Some data exist from various sources, including strandings data and sightings of entangled animals reported to the media or to groups such as BDMLR, SMASS and HM Coastguard. Reasons for not reporting can include fishers not knowing why this information is important to share or who to share this with, and/or because they are fearful of any potential legal or reputational repercussions against themselves or their industry.

The likelihood of encountering an entanglement during a fisheries observer scheme is low. Interviews are a time and cost-effective method to cover multiple sites and allow the possibility to obtain data on fisher's opinions (White et al., 2005). A questionnaire was designed to be given as a structured interview to Scottish creel fishers in order to find out about fisher's experiences of marine animal entanglement over a 10-year period from 2008-2018. The questionnaire also included questions about the associated economic impact to Scottish fisheries through lost or damaged gear as a result of an entanglement, the results of which are detailed in chapter 5 - Coast and socio-economic impacts of marine animal entanglement to the Scottish creel fishery.

Methods

Questionnaire

Interviews using a questionnaire composed of 22 questions were conducted face-to-face with fishers, mostly in fishing harbours, on-board vessels, in harbour offices or at fishers' homes. Interviews were conducted one-to-one or in small groups of two or three fishers. The interviews were undertaken by the same interviewer (E. MacLennan) to ensure consistency and exclude any 'interviewer effect' (e.g. influence of the interviewee by the interviewer). The use of the interview form meant that all fishers were interviewed following the same format and much of the data collected were quantitative. Prior to commencing each interview fishers were assured that all data would be confidential. If the fisher used other types of fishing gear aside from creels (e.g. mackerel jigs or trawls for part of the year) they were requested to only answer the questions based on their experience with creels. The minimum sample size recommended for interview surveys is 5% (Czaja and Blair, 2005). To get a representative sample of the industry we aimed to interview 10% of the Scottish creel fleet (i.e. 146 interviews).

The questionnaire was mostly structured with closed-ended questions including the option to decline to answer individual questions as recommended in White et al., (2005). Open-ended questions were included towards the end of the questionnaire to find out about the fisher's opinions, concerns and suggestions to reduce marine animal entanglements. Before being finalised, the questionnaire was submitted to Research Governance at the University of Aberdeen for a formal ethical review and was adapted based on the suggestions of the review. Once finalised, the questionnaire was trialled with two retired fishers to check that the questions were clear and the questionnaire flowed.

Interview process

Interviews were only conducted with commercially active creel fishers and all questionnaires were kept anonymous. Names and contact details of fishers who expressed an interest in participating in future training events were recorded on a separate sheet to the completed questionnaire, and stored apart from these to ensure anonymity. The main fishing harbours chosen to conduct the interviews were determined based on the distribution of creel fishers around the Scottish coastline, following discussions with the Scottish Creel Fishermen's Federation (SCFF) and Regional Inshore Fisheries Group (RIFG) representatives. Prior to visiting most harbours the interviewer made contact with the Harbour Master and/or local fisheries association representatives to request advice on the best time of day to visit, names of key fishers who might be willing to participate, and/or a tour of the harbour on arrival and an introduction to fishers. The interviews were mostly conducted opportunistically, although a few were prearranged. Fishers were generally approached in the harbours either before or after fishing operations and the aim was to get as many interviews per harbour as possible. 'Snowball' sampling was used whereby interview participants were asked if they could recommend other fishers who might also be willing to participate.

The questionnaire collected information about the interviewee's fishing career (years of creel fishing experience and function on board the boat), fishing activity (full-time or part-time, number of creels, total length of gear, distance travelled from the coast to fishing grounds, fishing depth, fishing area, and target species), marine animal sightings (observed species, sightings frequency, and animal proximity to active fishing gear), issues of gear loss or damage (partial or total, frequency of occurrence, and retrieval success) and any experience of marine animal entanglement (species, location within the gear, and whether the animal was alive or dead). Species reported entangled were verified by the interviewer either through photographs held by the interviewee of the incident/s, and/or by using identification keys and descriptors of the animals. Fishers were also asked their opinion on the main cause(s) of gear loss and damage, if marine animal entanglements have an economic impact on the creel sector, the factors that influence these events, what measures they felt might prevent/reduce the risk of entanglements occurring in the future, and if they knew of any existing initiatives to prevent entanglements around the world. The questionnaires were concluded by asking fishers if they would be willing to participate in training events for recording, sampling and/or disentangling entangled animals. When possible, additional qualitative information from fishers' comments was recorded to complement and validate the quantitative data.

Data analysis

The dataset was simplified by grouping several of the answers into categories (e.g. harbour areas, number of creels, etc.). The dataset was then coded using the 'value labels' function in SPSS (e.g. 0 = no, 1 = yes, 7777 = don't know, 8888 = no answer, 9999 = not applicable). Statistical analysis was performed using IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.

After initial data exploration, some categories had to be further broken down due to the sparsity of data (e.g. harbour areas had to be changed from 8 areas to 4 areas). Table 5 gives an overview of the categories the answers were grouped into. All lengths and distances were converted from fathoms or feet into metres and miles, respectively.

Table 5. List of variables used in the analysis with their description and categories.

Interviewee profile & fishery data

Variables	Description and categories
Harbour area	1) The Clyde to Dunvegan, 2) Broadford to Lochinver and Outer Hebrides, 3) Orkney and Shetland, 4) East Coast
Fisher work experience	0-10, 11-20, 21-30, ≥ 30 years
Function on board of vessel	skipper, crew member
Fishing frequency	full-time, part-time
Target species	brown crab, lobster prawn, velvet crab, whelks, wrasse
Number of creels	0-500, 501-1000, 1001-4000
Total gear length	0-10,000, 10,001-20,000, 20,001-30,000, >30,001 metres
Maximum distance to fishing grounds	0-6, 6-12, > 12 miles
Distance from shore	0-6, 6-12, > 12 miles
Average fishing depth	0-50, 51-100, >100 metres
Gear hauling frequency	0.5-1 day, 2-3, >3 days

Marine animal sightings

Variables	Description and categories
Marine animal sightings	basking shark, bottlenose dolphin, common dolphin, fin whale, harbour porpoise, humpback whale, killer whale, long-finned pilot whale, leatherback turtle, minke whale, Risso's dolphin, seal, Sei whale, sunfish, white-beaked dolphin, white-sided dolphin, unidentified dolphin, unidentified whale

Variables	Description and categories
Frequency of sightings	Daily, weekly, monthly, annually

Entanglements

Variables	Description and categories
Animals in close proximity to gear or boat during fishing operations	yes, no, don't know
Experienced an entanglement in the last 10 years	yes, no, don't know
Number of entanglements in the last 10 years, per species	number of animals entangled for each species

Suggested mitigation

Variables	Description and categories
Awareness of initiatives to prevent entanglements (location)	Scotland, Canada, USA, other
Initiatives to address/prevent entanglements	Disentanglement, closed areas, ropeless gear, weighted line or ends, other
Measures to reduce entanglements	Cap on creel numbers/ less gear in the water, seasonal/area closures, reinstatement of the 3 nm limit, lost gear recovery/better gear collection, best practice, shorter or tighter ends, negatively buoyant or weighted ropes, gear maintenance, subsidised gear exchanges, self-shooting lines, not shooting gear when animals around, better regulation of the industry, make gear more visible, other
Aware of Best Practice Guidelines and booklet	yes, no, don't know

Training

Variables	Description and categories
Test ideas that may help reduce the risk of entanglements	yes, no, don't know
Training to assist reporting of entangled marine animals	yes, no, don't know

Variables	Description and categories
Training to assist sampling of entangled marine animals	yes, no, don't know
Training to assist disentangling entangled marine animals	yes, no, don't know

When fishers mentioned two categories in their answer, e.g. for distance from coast, the first answer was taken as the main answer for further analysis. If a range of values were reported, e.g. fishing depth, the mid-point was used for further analysis.

Chi-square (X^2) test of association was performed to identify significant correlations or associations between two variables. The data was too sparse to allow further analysis, e.g. generalised linear models (GLM), to be performed to determine the factors most influential on the frequency of marine animal entanglements.

Basking shark and minke whale were the only species with a sufficient number of entanglements (49 and 51, respectively) for further analysis on factors potentially influencing entanglements of individual species. Questions relating to causes and financial implications of gear loss and damage are covered in chapter 5 - Coast and socio-economic impacts of marine animal entanglement to the Scottish creel fishery.

Results

Between June 2018 and September 2019, 159 commercial creel fishers from different vessels were interviewed in 67 harbours around Scotland, representing approximately 11% of the registered Scottish creel fleet. See Figure 13 for an overview of the harbour areas and number of interviews conducted, grouped roughly on areas of water fished. The harbours were broken-down into categories for data analysis after the interviews were conducted. The east coast was originally two smaller categories but the data was insufficient for further analysis so the two areas were grouped together to form one larger category. The number of interviews conducted per harbour/harbour area is not relative to the total number of creel boats in the area.

The majority of fishers interviewed were skippers (91%, n = 145) and fished full-time (80.5%, n = 128). All fishers interviewed were male with between 3 and 65 years fishing experience (mean = 23.8 years, SD = 13.7). No significant difference between fishers working part-time and full-time was found in the different harbours areas (X^2 = 4.653, DF = 3, p = 0.199).

The interviews were designed to take around 15-20 minutes to complete, however, several took much longer, for example where fishers had experienced multiple entanglements, and/or were happy to talk about other aspects of their fishing experience.

Fishing activity

Fishers reported using between 30 and 4000 creels (mean = 783, SD 644.4) and a total length of gear of between 1280 and 94,183 metres (mean = 19,318 metres, SD = 17,621). No significant association was found between harbour area and gear length (X^2 = 15.914, DF = 9, p = 0.069) although a highly significant association was found between harbour area and number of creels (X^2 = 31.911, DF = 6, p = < 0.001). 59.1% (n = 39) of fishers operating in Area 4 were fishing with 0-500 creels, with less than 5% of fishers in this area using more than 1000 creels. The majority of interviewees operating in Areas 1 and 3 were using between 501-1000 creels (58.8% n = 20 and 60%, n = 12, respectively). In Area 2, 28.9% (n = 11) of fishers interviewed were working 0-500 creels, 36.8% (n = 14) were working 501-1000 and 34.2% (n = 13) were working 1001-4000 creels. Only one fisher was unwilling to disclose information about his gear (creel numbers and gear length) or fishing activities (fishing area and depth).

Average fishing depth varied between 6 and 320 metres with a mean of 75.9 metres (SD = 57.3). A highly significant association was found between the average fishing depth (metres) and harbour area (X^2 = 73.833, DF = 6, p = < 0.001) with significantly more fishers fishing at depths >100 metres on the west coast than the east coast and Orkney and Shetland.

The maximum distance travelled in any direction from harbours to fishing grounds was 40 nm, with a mean distance of 13.6 nm (SD = 8.9 miles). 20.8% of interviewees (n = 33) travelled between 0 and 6 nm, 38.4% (n = 61) travelled between 6 and 12 nm and 40.9% (n = 65) of fishers travelled over 12 nm to reach their fishing grounds. A significant association was found between the maximum distance travelled from a harbour to fishing grounds, and harbour area (X^2 = 16.119, DF = 6, p = < 0.05) with more boats operating in Areas 1 and 3 steaming more than 12 nm.

The majority of fishers interviewed (67.3%, n = 107) fish within 6 nm of shore. 22.6% (n = 36) fish between 6 and 12 nm from shore and 10.1% (n = 16) fish beyond 12 nm. In Area 3, 50% (n = 9) were fishing between 0 and 6 nm and 45% (n = 9) were fishing between 6 and 12 nm from shore. Area 4 has the most fishing working over 12 nm from shore (62.5% of all interviewees).

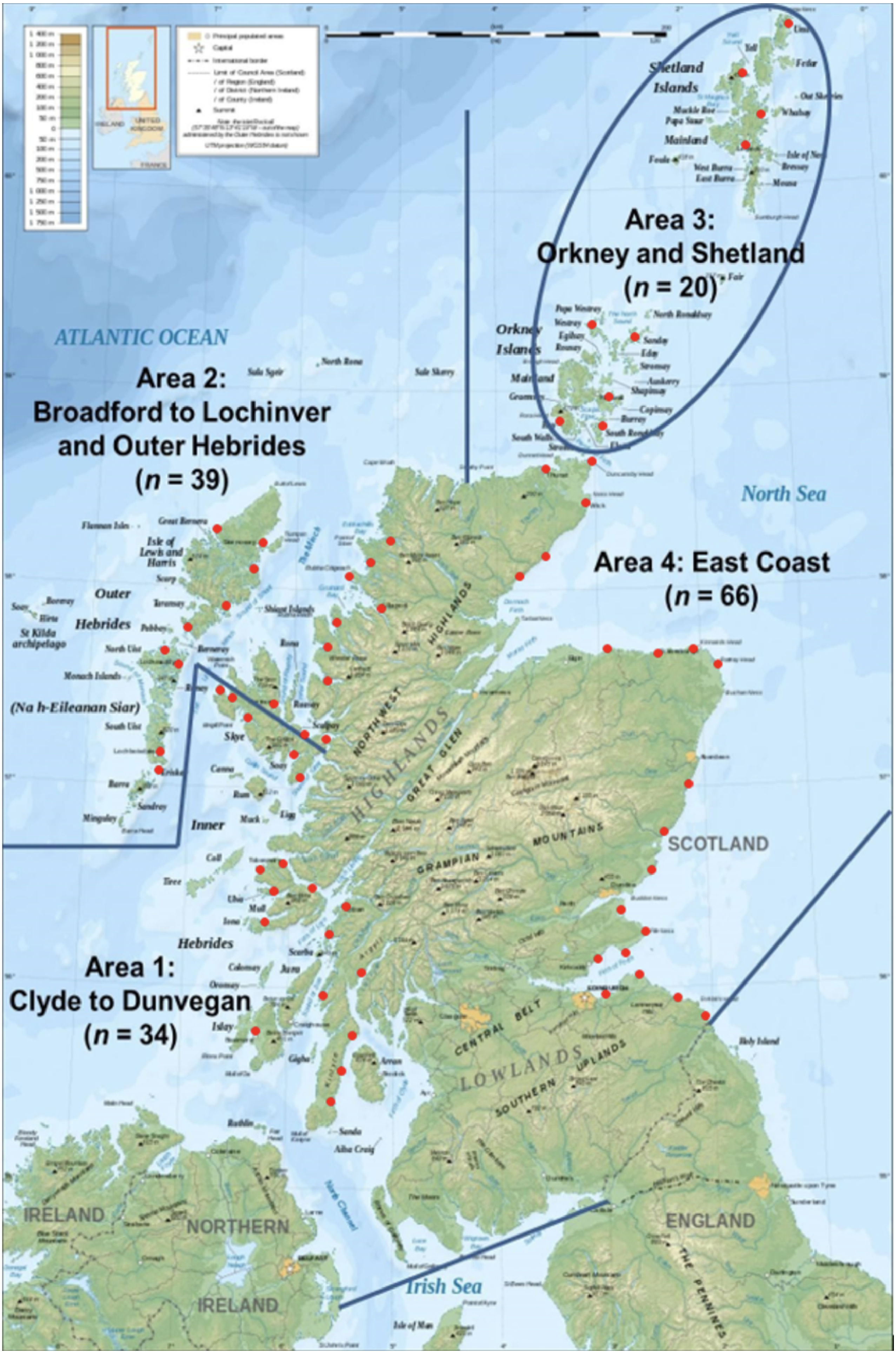

Figure 13. Map of harbour areas and number of interviews conducted in each.

In regards to gear hauling frequency, assuming fair weather conditions the majority of fishers (98.7%, n = 157) reported hauling their gear at least once every seven days. One fisher reported an average hauling frequency of 10 days, and another of 28 days. A significant association was found with harbour area and gear hauling frequency (X^2 = 15.867, DF = 6, p = < 0.05), with over 60% of all fishers from Areas 2-4 reportedly hauling their gear every 2-3 days. However, in Area 1 only 38% hauled their gear between 2-3 days, with 47% reportedly hauling at least once a day. This is largely due to the Clyde closures to trawlers at weekends, and creel fishers maximising this window to reset gear up to twice a day.

Interviewees reported targeting six key species depending on the area and depth they worked. Lobster (*Homarus gammarus*) and brown crab were targeted by 37.1% (n = 59) and 33.3% (n = 53) of fishers, respectively. Of the 46.5% (n = 74) of fishers who reported having one target species, over half (55.4%) were (n = 41) fishing for prawns, followed by brown crab and lobster (21.6% each). Only 1 fisher (1.4%) was targeting velvet crab (*Necora puber*) as their only target species. Around a quarter of fishers were targeting either two (26.4%, n = 42) or three species (25.8%, n = 41), typically brown crab and lobster, or brown crab, lobster and prawn. Wrasse (various sp.) and whelk (*Buccinum undatum*) were targeted by four fishers each (2.5% of all fishers) but never as a main species. A highly significant association (X^2 = range 16.015 and 109.907, DF = 3, p < 0.001) between harbour area and target species was found for all the main target species. All but one of the 61 fishers targeting prawns were fishing from the west coast. In contrast, the majority of fishers targeting brown crab and lobster were fishing from Areas 3 and 4.

Marine animal sightings

Nearly all fishers (96.9%, n = 154) reported observing marine animals in their fishing area. A total of 18 different species were reported including dolphin, whale and seal species. Unidentified dolphin, harbour porpoise (*Phocoena phocoena*), minke whale and basking shark were the main species sighted, with killer whale (*Orcinus orca*) and humpback whale observed less frequently. Figure 14 shows the species observed and sighting frequency reported by the fishers; note that seals are excluded from this figure due to likely under-reporting. All five of the fishers who reported no observations of marine animals in their fishing area were fishing on the east coast.

Over three-quarters of fishers (78%, n = 124) who reported observing marine animals reported these within close proximity to their gear and/or fishing boat. Half of all fishers that observed marine animals in close proximity reported only observing one species, 29.8% (n = 37) observed two species, 11.3% (n = 14) observed three species, 8.1% (n = 10) observed 4 species and only one fisher observed five species (0.8%). The main species observed close to vessels and/or gear were unidentified dolphins (reported by 68.5% of interviewees, n = 85), minke whale (23.4%, n = 29, Figure 15a), basking shark (17.7%, n = 22), harbour porpoise (16.1%, n = 20), killer whale (15.35%, n = 19, Figure 15b), common dolphin (*Delphinus delphis*) (7.3%, n = 9, Figure 15c) and humpback whale (5.6%, n = 7). Seals were reported by 16.9% (n = 21) of fishers. Seals are generally not considered a notable species so it is likely that they were observed more frequently but not mentioned during the interviews.

Entanglement experience

Almost half of fishers (49.1%, n = 78) said that they had experienced at least one entanglement in the last 10 years. Of these fishers 59% (n = 46) had experienced one entanglement, 20.5% (n = 16) had experienced two entanglements and 11.5% (n = 9) had experienced three entanglements. Four, five and six entanglements were reported by one, two and three fishers, respectively. The maximum number of entanglements experienced by one fisher within the specified 10 year time frame was nine. A total of 146 marine animal entanglements were reported during the interviews by 78 fishers. 70.5% (n = 103) of these animals were found dead entangled in the gear. All the entanglements were a single event with one animal entangled. Table 6 shows the number of animals reported entangled by species and if the animal was alive or dead.

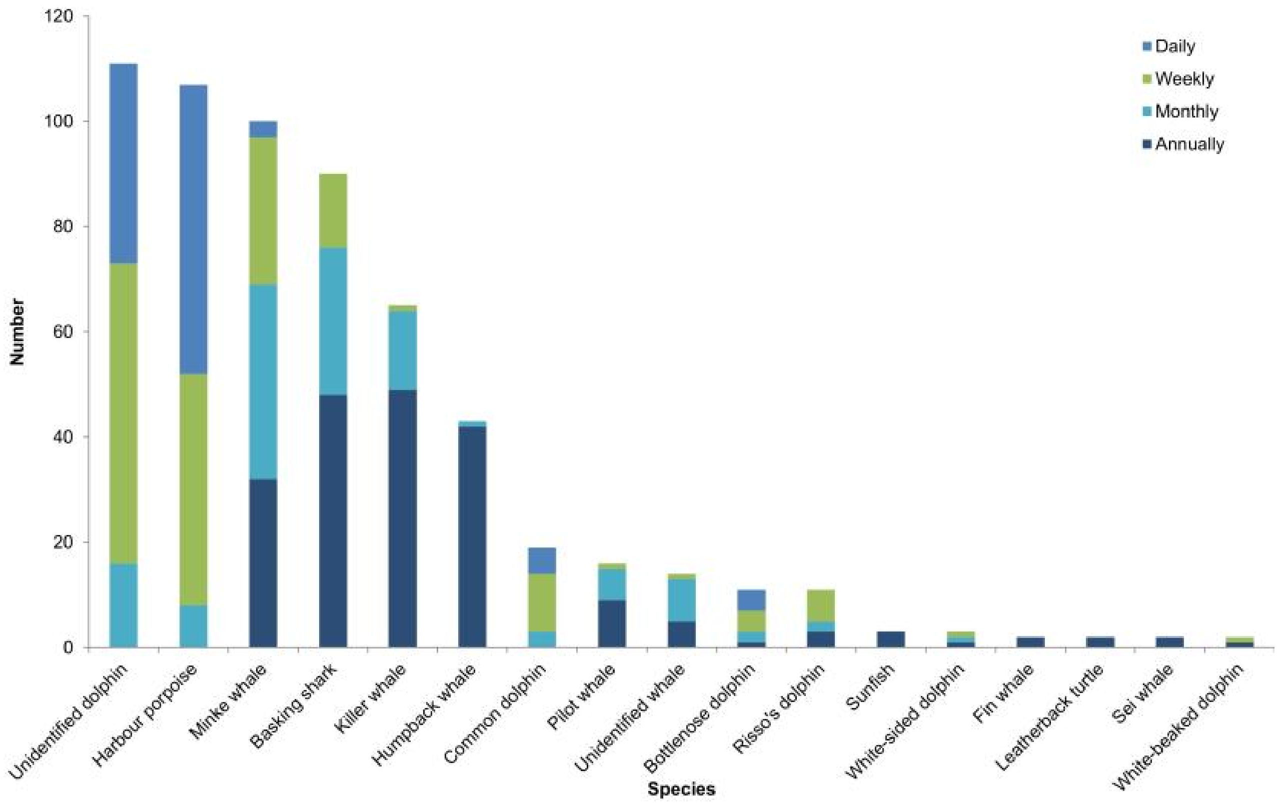

Figure 14. Species observed during fishing operations and the frequency of observations (seals excluded due to likely under-reporting).

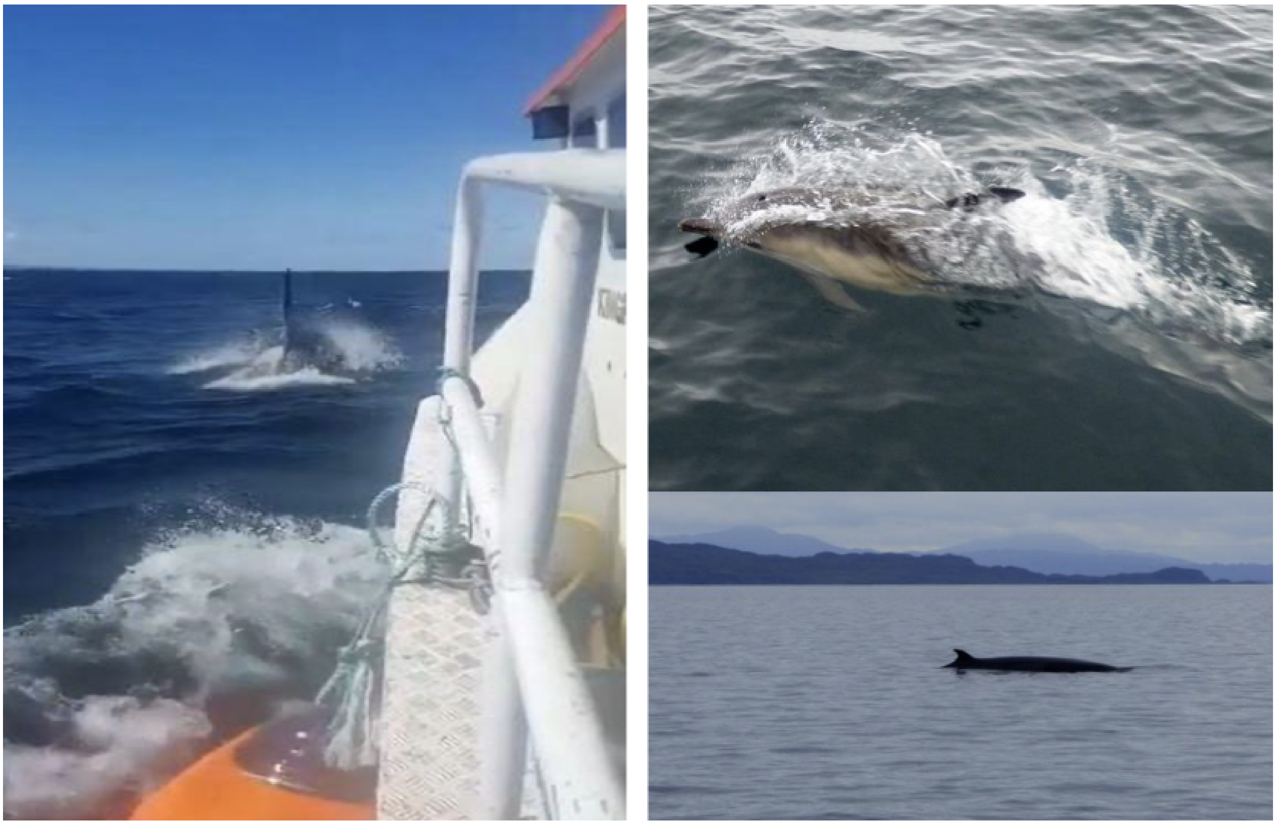

Figure 15. Cetacean sightings from fishing vessels: a) Killer whale bow riding. © Anon. b) Common dolphins in the Inner Sound. © J. Nicholson. c) Minke whale near the Isle of Rum. © E. MacLennan.

Table 6. Species and number of animals reported entangled, and whether they were discovered live or dead.

-	Alive	Dead	Total

-	Alive	Dead	Total
Minke whale	8	43	51
Basking shark	10	39	49
Humpback whale	8	3	11
Leatherback turtle	6	4	10
Harbour porpoise	0	6	6
Pilot whale	3	1	4
Unidentified dolphin	3	1	4
Porbeagle shark	0	3	3
Risso's dolphin	2	1	3
Killer whale	2	0	2
Fin whale	0	1	1
Sei whale	1	0	1
White-sided dolphin	0	1	1
-	-	-	**146**

At least 12 different species of large marine animals were reported entangled by fishers through the SEA questionnaires, and configurations varied from ropes being caught through the mouth, to around the body, fins and flukes. 73% (n = 8) of humpback whales reported entangled were released alive, whereas 80% (n = 39) of basking sharks and 84% (n = 43) of minke whales were discovered drowned. No entangled seals were reported during the interviews. The only species with sufficient data for further analysis on the factors potentially influencing entanglements were basking shark (n = 49) and minke whale (n = 51). Table 7 shows the results of the chi-squared tests for the different variables and fishers that had reported a marine animal entanglement, basking shark entanglement and minke whale entanglement in the last ten years.

Years of fishing experience was significantly related to experiencing an entanglement in the last ten years for all entangled species ($X2 = 7.896$, $DF = 3$, $p = < 0.05$). Fishers with 11-20 years fishing experience were more likely to have experienced an entanglement than the other experience categories and fishers with 0-10 years fishing experience experienced the least entanglements. No association was found between fishers working full-time or part-time and experiencing an entanglement in the last ten years ($X2 = 1.650$, $DF = 1$, $p = 0.199$).

A highly significant association was found between harbour area and fishers that had experienced an entanglement in the last ten years for all species ($X2 = 13.415$, $DF = 3$, $p = < 0.001$). Fishers working in Area 4 reported fewer entanglements than those working in Areas 1-3. There was also a significant association between harbour area and fishers that had experienced a basking shark entanglement ($X2 = 8.579$, $DF = 3$, $p = < 0.05$). Fishers on the west coast were more likely to have experienced a basking shark entanglement than fishers in Areas 3 and 4. No significant association was found between harbour area and minke whale ($X2 = 4.417$, $DF = 3$, $p = 0.220$), although more fishers from Area 1 reported minke whale entanglements than the other areas.

A significant negative association was found between fishers that had experienced a marine animal entanglement in the last ten years and those targeting lobster ($X2 = 9.530$, $DF = 1$, $p = < 0.05$) and velvet crab ($X2 = 7.536$, $DF = 1$, $p = < 0.05$). Over 60% of fishers targeting lobster, and over 70% of fishers targeting velvet crab had not experienced a marine animal entanglement. A significant association was found between fishers that had experienced a basking shark entanglement and target species for brown crab ($X2 = 4.929$, $DF = 1$, $p = < 0.05$) and prawn ($X2 = 4.510$, $DF = 1$, $p = < 0.05$). Over 70% of fishers targeting brown crab had not experienced a basking shark entanglement whilst just over 50% of fishers targeting prawn had experienced a basking shark entanglement.

No significant association was found between the maximum distance travelled by fishers from their home port to their fishing grounds and experiencing a marine animal entanglement ($X2 = 5.621$, $DF = 2$, $p = 0.06$), nor the distance from shore to fishing grounds and experiencing a marine animal entanglement ($X2 = 3.552$, $DF = 2$, $p = 0.169$). Average fishing depth ($X2 = 9.210$, $DF = 2$, $p = < 0.05$) and gear hauling frequency ($X2 = 6.028$, $DF = 2$, $p = < 0.05$) were significantly associated with experiencing a marine animal entanglement in the last ten years. 64.7% of fishers fishing at depths of 101 metres or more had experienced an entanglement, compared to 53.3% of those fishing between 51-100 metres, and only 37.7% fishing in depths shallower than 50m. Of all the fishers that had experienced an entanglement, 65.4% (n = 51) were hauling their gear every 2-3 days. Although no statistically significant association was found between the number of creels deployed and experience of an entanglement ($p = 0.210$), 60% of the fishers using 1001-4000 creels had experienced an entanglement in the last ten years compared to 41.3% and 52.9% using 0-500 and 501-1000 creels, respectively. Total gear length ($X2 = 10.571$, $DF = 3$, $p = < 0.05$) and observing minke whales in the fishing area ($X2 = 5.847$, $DF = 1$, $p = < 0.05$) were also both significantly associated with experiencing a minke whale entanglement, with 75.7% of fishers that had experienced a minke whale entanglement reporting that they had observed minke whales in the fishing area. Within the gear length categories, 40.6% of fishers that had experienced a minke whale entanglement were fishing with 10,001-20,000 metres of rope and 29.7% with >30,001 metres of gear compared to 10.8% fishing with <10,000 m and 8.9% fishing with 20,001-30,000 m.

Table 7. The results of the chi-squared tests for the different variables and fishers that had reported a marine animal entanglement, basking shark entanglement and minke whale entanglement in the last ten years.

Variables	Marine animal entanglement in last 10 years	Basking shark entanglement in the last 10 years	Minke whale entanglement in the last 10 years
Harbour area (4 areas)	$X^2 = 13.415$, $DF = 3$, $p = < 0.005$ (highly significant)	$X^2 = 8.579$, $DF = 3$, $p = < 0.05$ (significant)	$X^2 = 4.417$, $DF = 3$, $p = 0.220$
Fisher's work experience (years)	$X^2 = 7.896$, $DF = 3$, $p = < 0.05$ (significant)	$X^2 = 3.834$, $DF = 3$, $p = 0.280$	$X^2 = 3.536$, $DF = 3$, $p = 0.316$
Fishing full-time or part-time	$X^2 = 1.650$, $DF = 1$, $p = 0.199$	too few data	$X^2 = 0.189$, $DF = 1$, $p = 0.663$
Target species - Brown crab	$X^2 = 0.126$, $DF = 1$, $p = 0.723$	$X^2 = 4.929$, $DF = 1$, $p = < 0.05$ (significant)	$X^2 = 1.691$, $DF = 1$, $p = 0.194$
Target species – Lobster	$X^2 = 9.530$, $DF = 1$, $p = < 0.05$ (significant)	$X^2 = 0.001$, $DF = 1$, $p = 0.971$	$X^2 = 0.947$, $DF = 1$, $p = 0.330$
Target species – Prawn	$X^2 = 2.742$, $DF = 1$, $p = 0.098$	$X^2 = 4.510$, $DF = 1$, $p = < 0.05$ (significant)	$X^2 = 1.195$, $DF = 1$, $p = 0.274$

Variables	Marine animal entanglement in last 10 years	Basking shark entanglement in the last 10 years	Minke whale entanglement in the last 10 years
Target species - Velvet crab	$X^2 = 7.536$, DF = 1, p = < 0.05 (significant)	too few data	$X^2 = 1.399$, DF = 1, p = 0.237
Number of creels	$X^2 = 3.124$, DF = 2, p = 0.210	$X^2 = 0.600$, DF = 2, p = 0.741	$X^2 = 4.496$, DF = 2, p = 0.106
Total gear length (meters)	$X^2 = 7.189$, DF = 3, p = 0.066	$X^2 = 2.475$, DF = 3, p = 0.480	$X^2 = 10.571$, DF = 3, p = < 0.05 (significant)
Maximum distance from base to fishing ground (miles)	$X^2 = 5.621$, DF = 2, p = 0.060	$X^2 = 1.438$, DF = 2, p = 0.487	$X^2 = 3.360$, DF = 2, p = 0.186
Distance from shore (miles)	$X^2 = 3.552$, DF = 2, p = 0.169	$X^2 = 3.653$, DF = 2, p = 0.161	na
Average fishing depth (meters)	$X^2 = 9.210$, DF = 2, p = < 0.05 (significant)	$X^2 = 0.574$, DF = 2, p = 0.751	$X^2 = 3.354$, DF = 2, p = 0.187
Gear hauling frequency (days)	$X^2 = 6.028$, DF = 2, p = < 0.05 (significant)	$X^2 = 0.057$, DF = 2, p = 0.972	$X^2 = 0.363$, DF = 2, p = 0.834
Observe marine animals in the fishing area	too few data	na	na
Observe basking sharks in the fishing area	na	$X^2 = 0.936$, DF = 1, p = 0.333	na
Observe minke whales in the fishing area	na	na	$X^2 = 5.847$, DF = 1, p = < 0.05 (significant)
Observe marine animals in close proximity to gear/boat	$X^2 = 0.798$, DF = 1, p = 0.372	na	na
Observe basking sharks in close proximity to gear/boat	na	$X^2 = 0.019$, DF = 1, p = 0.889	na
Observe minke whales in close proximity to gear/boat	na	na	$X^2 = 0.763$, DF = 1, p = 0.382
Knowledge of initiatives to prevent entanglements	$X^2 = 0.459$, DF = 1, p = 0.498	$X^2 = 0.014$, DF = 1, p = 0.907	$X^2 = 0.630$, DF = 1, p = 0.427

Variables	Marine animal entanglement in last 10 years	Basking shark entanglement in the last 10 years	Minke whale entanglement in the last 10 years
Aware of Best Practice Guidelines and booklet	$X^2 = 0.004$, DF = 1, p = 0.952	$X^2 = 0.005$, DF = 1, p = 0.943	$X^2 = 3.184$, DF = 1, p = 0.074
Test ideas to help reduce the risk of entanglements	$X^2 = 0.968$, DF = 1, p = 0.325	$X^2 = 0.465$, DF = 1, p = 0.495	$X^2 = 0.439$, DF = 1, p = 0.508
Training to assist reporting of entangled animals	$X^2 = 0.161$, DF = 1, p = 0.689	$X^2 = 2.654$, DF = 1, p = 0.103	$X^2 = 1.373$, DF = 1, p = 0.241
Training to assist sampling of entangled animals	$X^2 = 0.203$, DF = 1, p = 0.653	$X^2 = 1.171$, DF = 1, p = 0.279	$X^2 = 1.164$, DF = 1, p = 0.281
Training to assist disentangling entangled animals	$X^2 = 0.396$, DF = 1, p = 0.529	$X^2 = 2.654$, DF = 1, p = 0.103	$X^2 = 1.373$, DF = 1, p = 0.241

Fisher's that had experienced an entanglement were asked if they could identify the location of the entanglement in the gear (Table 8). 11 species were discovered entangled in endlines, including all dolphin and porpoise species reported, and the majority of leatherback turtles. Minke whales (65%) and basking sharks (63%) were more often found entangled in groundlines and humpbacks were found in both groundlines and endlines. The majority of basking sharks (63%) and minke whales (65%) were found entangled in the groundline.

Table 8. Location of the animal's entanglement in the gear as reported by the fishers.

Species	Endline n	Endline %	Groundline n	Groundline %	Unspecified n	%
Basking shark	10	20.4	31	63.3	8	16.3
Fin whale	1	100	0	0	0	0
Humpback whale	4	36.4	4	36.4	3	27.3
Harbour porpoise	5	83.3	0	0	1	16.7
Killer whale	2	100	0	0	0	0
Leatherback turtle	9	90	1	10	0	0
Minke whale	7	13.7	33	64.7	11	21.6
Porbeagle shark	2	66.7	0	0	1	33.3
Pilot whale	4	100	0	0	0	0
Risso's dolphin	2	66.7	0	0	1	33.3
Sei whale	0	0	0	0	1	100

Species	Endline n	Endline %	Groundline n	Groundline %	Unspecified n	%
Unidentified dolphin	4	100	0	0	0	0
White-sided dolphin	1	100	0	0	0	0

Almost all (83%, n = 132) of the fishers interviewed provided measures that they felt could prevent or reduce the risk of entanglement. 10.1% (n = 16) said that they didn't know of any measures and only 6.9% (n = 11) said that they thought that there were no measures that could prevent entanglements. Of the 132 fishers that provided measures, 68.2% (n = 90) mentioned more than one measure that could prevent entanglements. The measures reported by fishers to prevent entanglements were: best practice in general (n = 67, 50.8%), shorter/tighter ends (n = 56, 42.4%), negatively buoyant or weighted ropes (n = 48, 36.4%), less gear in the water/cap on creel numbers (n = 41, 31.1%), better regulation of the industry (n = 22, 16.7%), seasonal area closures (n = 19, 14.4%), better recovery of lost gear (n = 13, 9.8%), gear exchanges from floating to negatively buoyant rope (n = 6, 4.5%), not shooting gear when animals are in close proximity (n = 6, 4.5%), self-shooting rather than hand-shooting fleets (n = 5, 3.8%), making gear more visible to animals (n = 3, 2.3%), shooting with the tide (n = 3, 2.3%) and reinstating the three-mile limit (n = 2, 1.5%). 'Other measures' reported by individual fishers (n = 21, 15.9 %) included shooting fleets with the tide, better knowledge of the animal's distribution and movements, and banning hobby and nomadic vessels.

When asked whether they were aware of any initiatives in Scotland and/or elsewhere aimed at tackling marine animal entanglements, 28.3% of fishers (n = 45) said that they were, including in; Scotland (n = 5, 10%), Canada (n = 9, 18%), and the USA (n = 34, 68%). These initiatives included ropeless technologies (n = 10, 22.2%), disentanglement teams (n = 4, 8.9%), closed areas (n = 3, 6.7%) and negatively buoyant rope (n = 1, 2.2%). No association was found between fishers that had experienced an entanglement in the last ten years and knowledge of initiatives to prevent such incidents (X2 = 0.459, DF = 1, p = 0.498). Other initiatives mentioned by the fishers, but not considered further in this project due to our focus on the creel industry, were measures to mitigate dolphin and porpoise bycatch in gillnets and trawls in Southwest England, France and Portugal (n = 5). The use of acoustic deterrent devices (e.g. pingers), global clean-up projects and devices to prevent entanglement in tuna longline fisheries were also mentioned.

Best Practice Guidance booklets produced by the SEA project partners have been handed out to creel fishers since 2017. 45.9% of fishers (n = 73) interviewed were aware of these booklets. One fisher in Shetland had a 'Cetacean Entanglement Prevention Guide' on board that the Shetland Shellfish Management Organisation (SSMO) produced. No association was found between fishers that had experienced an entanglement in the last ten years and awareness of the Best Practice Guidelines and booklets (X^2 = 0.004, DF = 1, p = 0.952) nor the harbour area that the fishers were based (X^2 = 4.128, DF = 3, p = 0.248). The latter indicates that the distribution of the guides to fishers was even around the Scottish coast.

74.8% of fishers (n = 119) said that they would be willing to test ideas that may help reduce the risk of entanglements. However, the majority reported that they would only be willing to test ideas as long as they are practical are not time consuming, do not compromise the gear or limit the amount they are able to fish, and there are no financial implications to the fishers. 14 of the 33 fishers who said they would not be willing to test ideas to help reduce entanglements had experienced at least one entanglement, including two fishers that had experienced four and five entanglements, respectively. The main reasons given for not being willing to test ideas include already doing their own best practise (e.g. short ends, well maintained gear), too hard to prove what method(s) might work because entanglements are so rare, entanglements do not occur or at least not frequently enough to be an issue, and the fishers were close to retirement age. Of the six fishers that reported 'not applicable' to testing ideas to reduce entanglements, five had reported no entanglements in the last ten years. No association was found between fishers that had experienced an entanglement in the last ten years and willingness to test ideas that may help reduce the risk of entanglements (X^2 = 0.968, DF = 1, p = 0.325).

Fishers were asked if they would be interested in taking part in free training sessions to assist in reporting, sampling and disentangling entangled marine animals. Of the 158 fishers that responded, 67.7% (n = 107) said that they would be interested in training to assist the reporting of entangled animals to SEA partners (species, alive or dead, entanglement configuration etc.) and 71.5% (n = 113) were interested in training to disentangle animals. There was a highly significant association between the two trainings (X^2 = 78.330, DF = 1, p = < 0.001) with 63.3% of fishers (n = 100) willing to do both.

No association was found between fishers that had experienced an entanglement in the last ten years and willingness to do training to assist reporting of entangled marine animals ($X^2 = 0.161$, DF = 1, $p = 0.689$), training to assist sampling entangled marine animals ($X^2 = 0.203$, DF = 1, $p = 0.653$) nor training to assist disentangling entangled marine animals ($X^2 = 0.396$, DF = 1, $p = 0.529$). This demonstrates that fishers who have not experienced a marine animal entanglement are equally as willing to attend training sessions as those who have.

In general, the majority of fishers said that they would be willing to do training for reporting and disentangling entangled animals providing it doesn't interrupt their fishing activities (e.g. conduct training events in the winter, outside of the fishing season). The main reasons given by the fishers that did not want to do the disentanglement training included: good community of fishers so we would help each other out if someone had an entanglement, dealt with previous one(s) without issue, retiring in the near future, and unsure how one can train for such an event.

Discussion

The fisher interviews covered over 10% of the Scottish commercial creel fleet, the majority of whom were fishing full-time. In general, it is hard to find statistics on the fishing industry although Northridge et al., (2010) estimated that 74% of the creel industry in Scotland is working part-time, therefore how representative our data are of the whole fleet is uncertain. In addition demand for crab from new markets in recent years has resulted in an increase in creel fishing effort, but with little to no regulation (Williams and Carpenter, 2016). It is notably harder to encounter part-time fishers in the harbour and the interviews were mostly conducted opportunistically. Knowledge on days-at-sea potentially allows one to determine if the fishers are part-time or full-time rather that the number of days that the gear is active for. A part-time fisher might check their gear less frequently but still have gear set throughout the majority of the season/year depending on their target species. It is not known if part-time fishers are using different gear throughout the year or have a different profession outside of fishing. A concern of some fishers interviewed was that hobby fishers were not setting their gear correctly and leaving their gear for long periods of time, and were therefore more likely to encounter an entanglement.

When the interview form was initially designed, it was decided to limit the questions on the logistics of the individual vessels due to concerns that fishers wouldn't collaborate. Of the 159 fishers interviewed, only one fisher did not want to disclose information on their fishing activities. In future questionnaires it would be helpful to collect more data on the individual vessels, e.g. days at sea, landings, etc., to determine effort and the number of days that the gear is active. Whilst this study shows that there were no significant associations between working full or part-time and the fishing harbour areas or experiencing an entanglement, including questions on days-at-sea, landings, etc. would help to identify the part-time fishers to ensure the data collected reflects the fishing fleet.

About half of fishers interviewed had experienced an entanglement in the last 10 years. A total of 146 marine animal entanglements were reported and most were found dead in the gear. A wider variety of species were entangled than had been documented previously, including turtles and porbeagle sharks (*Lamna nasus*). Entanglements were all single events although one fisher working on the west coast reported seven basking sharks in one season. This fisher thought that cleaning the gear better after an entanglement might have prevented subsequent entanglements, as the animals may have been attracted to the mucus left on the rope.

Only three of the entanglements (all humpback whales) reported during the interviews were previously known to the SEA, through the SMASS stranding scheme and BDMLR disentanglement team. This has highlighted the extent of under-reporting of these events in Scottish waters. No seals were reported to be entangled. Some fishers said that they observe seals playing with the marker buoy and considered seals smart enough to get into creels and take the bait without getting entangled (Vanhatalo et al., 2014). No entanglements were reported for bottlenose dolphins (*Tursiops truncatus*), white-beaked dolphins (*Lagenorhynchus albirostris*), common dolphins (*Delphinus delphis*) and sunfish (*Mola mola*) despite the species being sighted, although there were four entanglement reports from interviewees involving 'unidentified dolphin species'. In contrast, no porbeagle shark sightings were reported but three animals were reported entangled. The lack of observations is likely due to the animals not needing to breathe at the surface, like the marine mammals and turtles. This suggests that not only are some species more vulnerable to entanglement than others, but the likelihood of surviving these incidents also varies by species, and is likely dependent on individual behaviours, physiology, and seasonal abundance. Some fishers gave the impression that they thought the entangled animal(s) had drifted into their gear already dead. Whilst this cannot be ruled out due to the lack of reporting and therefore pathology on the specimens, (e.g. bruising, distinct lacerations and rope patterns indicating an attempted escape only show on animals alive prior to entanglement), therefore, it seems unlikely.

Fishers with 11-20 years fishing experience were more likely to have experienced an entanglement than the other experience categories while those with 10 years or less at sea experienced the least entanglements, demonstrating the rarity of entanglement occurrences at an individual fisher level. However, even a low incidence of entanglements for individual fishers may have an impact on the population of some species such as humpback and minke whales. MacLennan et al., (2020) estimated that around five humpbacks and 30 minke whales become entangled annually in the Scottish creel fleet which pose both a welfare and conservation issue, and may cause including localised depletion of the minke whales.

More entanglements of all species were experienced on the west coast and around Orkney and Shetland, than on the east coast. Most basking shark entanglements occurred on the west coast, where their distribution is focused (Doherty et al., 2019). There was no significant association found between harbour area and minke whale entanglements, although more fishers within Area 1 reported entanglements of this species than the other areas. The Scottish Government has recently approved a Nature Conservation Marine Protected Area (NC MPA) for basking sharks and minke whales in the Sea of the Hebrides, a large site that is encompassed within this area off the west coast. The Southern Trench MPA is also designated for minke whales on the east coast. As yet, there are no fisheries management measures associated with these sites, discussions around fisheries management will come over the next few years and this research will help inform the type of creel management that may be necessary to conserve the features of the site.

Identifying fishing characteristics of creel fishers is difficult due to the dynamics of the industry. Whilst individual fishers might have areas where they always set their gear, even during one fishing event they may be fishing in slightly different depths, on different substrates, or targeting more than one species. In Scotland, four main shellfish species are targeted by creel fishers. Targeting lobster and velvet crab was significantly negatively associated with experiencing a marine animal entanglement (of any species) in the last ten years. During the interviews, it was mentioned that lobster is fished in the shallowest waters on rocky ground and so the likelihood of an entanglement was expected to be lower. Targeting brown crab and prawn was significantly associated with experiencing a basking shark entanglement. These species are fished in deeper water and therefore fishing depth was also significantly associated with experiencing a marine animal entanglement with more entanglements reported in by fishers fishing at over 50 metres depths. Slightly more fishers using longer lengths of rope overall (more and/or longer fleets, or greater spacing between creels) experienced an entanglement, suggesting that entanglements occur in between the creels, which is what the evidence suggests particularly for minke whales.

Whilst entanglement has been reported as a rare event for individual fishers through the questionnaire (described by some interviewees as a ‘once in a generation’ occurrence), the level of incidents documented overall was higher than anticipated and the conservation and welfare implications remain. Humpback whale populations may not be recovering as quickly as expected post-whaling due to the level of entanglements in inshore waters (MacLennan et al., 2020; Ryan et al., 2016). Data from stranded entangled whales collected by SMASS demonstrates the long periods of injury and suffering that can occur before death can be extensive, particularly for humpback whales who have the body weight to pick up gear and carry it with them for protracted periods of time (chapter 3 - Understanding the distribution, trends and welfare impacts of marine animal entanglements). Entanglements have been described by an International Whaling Commission Workshop of welfare experts (IWC, 2017) as the most significant global threat to wild marine animal welfare. These incidents can cause great suffering at an individual level and even if rare, do need to be addressed.

Many studies to date have focused on the welfare and conservation consequences of entanglements on species, and potential mitigation methods (e.g. Lebon and Kelly, 2019; Leaper and Calderan, 2018; Dolman and Moore, 2017; Knowlton et al., 2016; Groom and Coughran, 2012; Knowlton et al., 2012). Borggaard et al., (2017) provides a good overview of the guiding principles used to reduce large whale entanglements in the North Atlantic. Over half of the fishers in this study that suggested measures to prevent entanglements listed best practice in general (also see discussion on this in chapter 5 - Coast and socio-economic impacts of marine animal entanglement to the Scottish creel fishery). The majority felt that they were already doing this by ensuring that their ends were adjusted for the depth they were working in and suitably weighted, their gear is well maintained, and they are not shooting their gear if animals are visible nearby.

Fishers clearly represent an invaluable source of information and expertise in entanglement, and possess unique knowledge specific to their own fishing areas, however their opinion and expertise is seldom sought from policy makers. Fishers are qualified to recommend practical measures that could prevent or reduce the risk of entanglements. Several interviewees reported knowing of fishers using excessively long ends as a tactic to ‘mark their territory’ and make it difficult for others to fish near them. One fisher using this method had caught two humpback whales. Both whales were successfully freed alive and so he didn’t see entanglement as an issue. It should be noted that this is an extreme example and we understand this is not representative of normal fishing practice for the vast majority of fishers. A mitigation suggestion from fishers interviewed was the use of weighted or negatively buoyant line (both for ends and/or between the creels) to minimise the amount of floating or looping line at the sea surface and in the water column. This was proposed numerous times during interviews as a potentially acceptable method to prevent marine animal entanglements on certain substrates and has already been introduced in several US pot fisheries in a bid to mitigate entanglements (e.g. ALWTRP, 2007a). Several fishers reported that negatively buoyant rope is significantly more expensive and would not be practical to work with, due to wearing more quickly when in contact with bottom substrate which may also have knock-on effects on biota e.g. sensitive benthic species, it is harder to splice and splinters when cutting. However, fishers already using negatively buoyant rope were not opposed to its wider introduction if this could be subsidised or facilitated through a gear exchange (e.g. old floating rope for new negatively buoyant rope).

Two fishers suggested that reinstating the three-mile limit could help prevent entanglements. The three-mile fishing limit was a historical spatial measure that excluded mobile fishing vessels from coastal waters (Philp and Philp, 2018). Such a management measure would benefit the creel industry in a number of ways, including potentially reducing entanglement risks namely by reducing gear conflict and therefore the amount of lost gear which poses an entanglement threat (Stelfox et al., 2016). However, no association was found between distance from shore and having experienced an entanglement. Therefore unless creel limits accompanied any reinstatement of the three-mile limit, this could lead to an increase in creel fishing effort and hence an increased risk of entanglement.

The general lack of regulation within the creel industry was mentioned by several fishers to be an issue likely influencing marine animal entanglements. Presently there is no limit on the number of boats that can operate (commercial or recreational), the number of creels a boat can fish with, how often gear must be hauled, and no wide-scale separation of the mobile and static sectors. A cap on creel numbers could ensure that all creelers are on an even keel and has already been formally proposed (Marine Scotland, 2017). The Outer Hebrides Regional Inshore Fisheries Group has recently partnered with Marine Scotland to implement a creel limitation pilot to reduce catch effort and gear conflict, restricting the numbers of creels to as few as 800 per vessel within the pilot area (Marine Scotland Science, 2020). The SCFF have proposed that a cap of 1600 creels in the Inner Sound. In the present study only a small number of vessels were using over 1600 creels, and although most of those did report entanglements, assuming our data are representative of the creel industry, limiting vessels to 1600 creels is unlikely to make a notable difference from an entanglement point of view. Those who suggested capping creel numbers via the questionnaires argued that setting such gear limits would ensure that gear is constantly working and therefore checked and maintained regularly, in line with the aforementioned 'best practice'. However, there was concern over how such measures could be policed and penalties enforced for those not abiding by the rules. In addition fishers reported that it is difficult to provide a definitive set of rules or regulations for best practice. It is thought that the fishing area and substrate are often more influential than the number of creels or the total length of the gear worked and so any management measures, such as limits on creel numbers, would need to be set at a local level to ensure they are suitable. Creel limits, if set at levels lower than current levels, would reduce entanglements (see chapter 8 – An industry perspective for more details).

Any future prevention and mitigation methods will only be successful with stakeholder engagement and support from industry. Whilst over three quarters of fishers in the present study said that they would be willing to test ideas that may help reduce entanglements, this was on the condition that the methods are practical e.g. no impact on catch rates, not time consuming and financially supported.

Though seemingly rare, entanglement was not an issue that interviewees shied away from and the majority were happy to discuss their own experiences and insights at length. Most of those interviewed also expressed an interest in helping to better understand and mitigate the entanglement risk posed by their sector through training workshops and events. Though fewer fishers expressed willingness to learn how to sample dead entangled marine animals than how to report these incidents, such sampling could go a long way to improving our understanding of the scale of and species impacted by entanglement, and increase understanding within the fishing community of why such data is valuable. It is understood that collecting the required samples (e.g. skin, blubber and muscle) from a dead animal can be a daunting and emotional experience, especially when the animal is caught in their gear. Nonetheless it is hoped that fishers can be encouraged to participate in future trainings which will be hosted during periods of low fishing activity (e.g. evenings, winter months). Fishers who stated they were not interested in any training events were either close to (or at) retirement age, felt that there was no training that could prepare one for an entanglement, or it was something that they had dealt with before and felt they would be able to deal with again if necessary. Regardless of whether they were open to training or not, it was apparent that fishers need to be reminded that there are no negative repercussions for experiencing an entanglement and that reporting these events could help to prevent entanglements in the future.

All Scottish fishing vessels must be licenced, with conditions that must be adhered to. To date, there are no conditions relating to reporting of entanglements, although there is a requirement under the EU Data Collection Framework for fishers to report sensitive species bycatch in logbooks. As the UK has now left the EU, the Fisheries Act (2020) sets out the environmental and scientific principles and objectives that will inform future policy, including a reference to "minimising and where possible eliminating sensitive species bycatch" in the Act, which would include entanglements. The Scottish Government has also committed to new legislation for the Scottish inshore fisheries. The draft UK

Dolphin and Porpoise Conservation Strategy includes minke whales and is anticipated to have a section on bycatch and entanglement. Under this stream of work, Defra set up a UK bycatch focus group of stakeholders in 2017, with the goal to meet this legal requirement. It is assumed that this strategy will be going out for consultation, once approved by the UK Government. In September 2020, Defra changed the scope of the stakeholder group, to a UK national steering group called 'Clean Catch' to examine and proactively tackle bycatch in a range of species across the UK. New legislation and associated government policy such as the Joint Fisheries Statement (JFS) provide an opportunity to put in place requirements to address marine animal entanglements whilst setting out the mechanisms to achieve the policy outcomes and targets for tackling entanglements, based on best-available evidence and precaution.

Conclusions and recommendations

The number of entanglements documented via fisher interviews was higher than had been previously recorded, involved a wide range of species, and occurred all around the Scottish coastline. There is a significant amount of underreporting and this need to be addressed. The evidence presented within this report and the growing concern about the impact of entanglements indicates the urgent need for solutions, requiring further research into mitigation, development, implementation and policing of management measures, and regulation of the industry (e.g. a cap on the number of creels a boat can fish, how often gear must be hauled, and separation of the mobile and static sectors).

Fishing characteristics potentially influencing entanglements have not been well investigated to date. Further, the collection of more detailed data on the individual vessels, e.g. days at sea, landings, etc., would enable the determination of effort and the number of days that the gear is active, to help to identify part-time fishers and ensure the data collected reflects the make-up of the fishing fleet.

The location of entanglements in the gear appears to be species specific (Table 8). Using abundance data of marine animals in areas with high creel densities could aid the development and implementation of mitigation measures.

Successful prevention and mitigation of entanglements relies on ongoing engagement between policy makers and fishing communities. Any initiatives to prevent and mitigate entanglements in Scotland must be cost-effective and practical for fishers. Development of effective entanglement mitigation measures will also require some understanding of the mechanics by which animals become caught (Northridge et al., 2010). Fishers must be encouraged to report these incidents in the knowledge that they will not be incriminating themselves or their industry. In order to collect robust entanglement data in future, monitoring and reporting should be a condition of fishing licences.

Mitigation trials, e.g. negatively buoyant rope and/or creel limits, should be introduced at a local scale with the aim to scale up implementation to the whole fleet if successful. Initial management measures should focus on 'hot spot' areas. Furthermore, as noted by several fishers, there is a need for overall regulation of the sector. Measures could include limits on creel numbers and soak times.

The project should be extended to investigate marine animal entanglement in other fishing sectors, e.g. trawls, purse-seines and static nets in Scottish waters.

With the Fisheries Act comes the legal requirement for the UK to develop a JFS, providing policy incentive to act. Setting out the mechanisms to achieve the policy outcomes and targets for tackling entanglements, based on best-available evidence and precaution, would be central to this.

Costs and socio-economic impacts of marine animal entanglement to the Scottish creel fishery

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Summary

The New Economics Foundation (NEF) co-developed the questionnaire detailed in chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement, to assess the financial cost to the Scottish creel fishing fleet resulting from marine animal entanglements. The responses to a sub-set of questions were used for an analysis

of the socio-economic impacts of marine animal entanglements on the fleet, in order to calculate the estimated annual cost of these incidents to the sector.

These questions revealed that 27% of fishers had had gear lost or damaged as a result of an entanglement. The average loss of income per event was estimated at nearly £240, with the highest loss of income due to a single entanglement event reported as £2000.

The total cost to the Scottish creel sector as a result of entanglements over a 10 year period is calculated at £755,717, though this is thought to be an underestimate. However, concern for animal welfare is a more important consideration for fishers than financial costs as a result of entanglement.

Introduction

The Scottish inshore fishing industry makes a significant contribution to the national economy and forms the backbone of many small coastal communities. When entanglements occur and are reported, the focus tends to be on the implications of such events to the animals involved in regard to their welfare and/or conservation. However, these interactions can also have detrimental consequences for the fishers whose gear is involved. Not only can entanglements be emotionally distressing and potentially dangerous for those discovering them, the financial cost to individual fishers through damaged or lost gear, lost fishing time, and associated catch can, in rare cases, be significant.

An analysis of the economic costs of entanglements has not previously been done, and therefore as part of the SEA project the New Economics Foundation (NEF) were approached to help in the design of the questionnaire detailed in chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement. NEF submitted six questions for inclusion in the questionnaire which focussed on the causes of gear loss within the creel sector through a range of factors including conflict with other sectors, weather and marine animal interactions. Fishers who had experienced an entanglement were asked to quantify the financial cost of each event through damaged and lost gear, associated catch, and lost fishing time. The results were then analysed to establish what the socio-economic impact of marine animal entanglements on the Scottish creel fishing fleet is, in order to calculate the estimated annual cost of entanglements to the creel sector.

Results

Gear loss

The first financially focussed questions posed to fishers during interviews concentrated on gear loss and damage. The 159 fishers surveyed fished a total of 124,540 creels, with an average of 783 each. Compared to a study by Marine Scotland Science (2017) these results are slightly fewer than those obtained in the west coast Scottish *nephrops* fishery (mean 925, ranging from 50 to 2,500 creels per vessel), but higher than both the average west coast crab and lobster fishery (mean 294, ranging from 40 to 900 creels per vessel) and east coast crab and lobster fishery (mean 455, ranging from 10 to 2,300 creels per vessel).

86% of interviewees had suffered loss or damage to their fishing gear in the last ten years, with the majority (62%, n = 114) experiencing this on over 10 separate occasions. 83% stated that the primary cause of gear loss or damage was mobile fishing vessels (trawler or scallop dredgers) or bad weather (Table 8). Over a third cited trawlers as the primary cause of gear loss or damage, followed by bad weather (28.9%) and scallop dredgers (18.9%). Other less frequent primary causes included leisure boats (1.9%) strong tides (1.9%), poachers (0.6%) and other creel boats (0.6%) (Table 9).

Table 9. Primary causes of gear loss or damage in the last 10 years, including the number of mentions and percentage of respondents who mentioned it as the main cause.

Primary cause of gear damage or loss	Number of mentions	Percentage of respondents who have experienced gear loss or damage
Trawlers	56	35.2%
Bad weather	46	28.9%
Scallop dredgers	30	18.9%

Primary cause of gear damage or loss	Number of mentions	Percentage of respondents who have experienced gear loss or damage
Leisure boats	3	1.9%
Strong tides	3	1.9%
Other creel boats	2	1.3%
Fish farm moorings and vessels	1	0.6%
Gear snagging on the seabed	1	0.6%
Poachers	1	0.6%
Tanker and container ships	1	0.6%
Windfarm boats	1	0.6%
Other (e.g. nomadic/foreign vessels)	1	0.6%

If there was more than one cause of gear loss or damage, respondents were asked to break these down into percentage losses per cause. 54 responses identified trawlers, or trawlers and scallop dredgers as the primary cause of gear loss, attributing between 50% and 100% of losses to this. Of the 28 responses listing other causes, 19 cited bad weather, the remainder ranged from other creelers (2) to trawlers and dredgers (3) and fish farm vessels (1), as well as poachers (1) and off-range submarines. Three responded that the primary cause included other creel vessels, with a secondary cause of bad weather. Marine animal entanglement was cited as a reason for loss or damage by only one respondent (0.63%) and this only represented 5% of the causes of their gear loss breakdown over the 10-year period.

Economic cost of entanglement

Questions 12 and 13 of the questionnaire asked those participants who had experienced an entanglement within the last 10-year period if they could quantify the financial costs of these incidents. Of the 159 responses, 49% had experienced one or more entanglement within this timeframe. 81 participants had not experienced an entanglement, and the most experienced by a single fisher within the timeframe was nine. A total of 146 entanglements were reported via the questionnaires. Of the respondents who said they had experienced one or more entanglements, 58% said they had suffered damage or loss of gear as a result. On average 4% of a fisher's total fishing gear was lost or damaged as a result of entanglement, with a maximum of 20% (i.e. an entire fleet). However, this is viewed as insignificant by the fishers' when compared to the perveived losses by other causes reporting in Table 9.

Table 10 presents the proportion of Scottish creel fishers who experienced an entanglement incident in the last ten years, how many took place and the extent/type of damage or loss income these incidences had. When asked to calculate how much of the days' income, fishing time and gear was lost as a result of an entanglement, the average loss of time as a result of entanglement was 1.8 hours per incident (maximum was two days), totalling 252 hours for all entanglements detailed. The mean estimated loss of income was £240 per incident (maximum £2000 for a single event), totalling £43,050 for all entanglements detailed through the questionnaire. 35 fishers said they lost no income as a result of an entanglement, and the majority of entanglement instances resulted in no subsequent loss of time. The average number of creels lost or damaged and therefore out of use per entanglement was 15 (range 2 to 70), with an average cost per creel quoted as £51. Other costs accounted for included rope that was lost or damaged, and the loss of any weights and buoys. Based on a total number of registered Scottish creel vessels of 1,457, when scaled to a whole-fleet level, the estimated cost of entanglements to the creel sector over a 10 year period was calculated to be £523.886.

Table 10. Summary of creel fleet and survey responses alongside average cost of damage to fishing gear, loss of fishing time and cost to creel fishing fleet over the past ten years.

Total estimated creel vessels in Scotland	**1457**
% Scottish creel fishers experiencing an entanglement incidence in last ten years	48%
% Scottish creel fishers who said entanglement incidences caused damage/gear loss	58%
Average creel damage per incident	£557.13
Average rope damage per incident	£30.85
Average weight damage per incident	£3.78
Average buoy damage per incident	£0.85
Average fishing time lost per incident	1.8 hours
Average fishing income lost per incident	£239.69
Average cost to individual creel fishers over ten years	£518.68
Total cost to creel fleet surveyed over 10 years	**£523,886**

Gear recovery

Question 14 asked participants whether when gear is lost they attempt to retrieve this, regardless of the cause, and if so how successful they were in doing so. Responses were listed as complete, partial, or no recovery of gear. Further, respondents were asked why they did not attempt to retrieve gear if they answered 'no' to the initial question. Only nine of the 159 interviewees did not attempt to recover their gear. 5% of those who did try were not able to recover any, whereas 54 respondents were able to recover 100% of their gear. The remainder estimated they were able to retrieve between 20% and 80%. All of those who did not attempt to retrieve gear stated this had been lost to trawlers and dredgers and that unless these boats share where their gear has been dropped, searching for it is a waste of time as it could be miles from where it was set.

Question 15 asked if fishers felt that marine animal entanglements have a major economic impact on the Scottish creel fishing sector. Responses to this question are detailed in Table 11 and reasons for these responses (open-ended text) are given in Table 12. A coding schema was applied to responses in order to identify themes and measure these quantitatively. The majority of those who 'Strongly disagreed' suggested that entanglements were a rarity, so were not an economic concern (33%), were not costly when they did occur (42%), or they had not experienced an entanglement (28%). Only 22 respondents 'agreed' or 'strongly agreed' (14%) with the statement, with most responses claiming that entanglements are costly and therefore do have a major impact.

Question 16 asked what factors fishers thought influenced both gear loss and damage, and marine animal entanglement. Responses were open-ended and subsequently coded into themes. These are detailed in Table 13 and Table 14.

Table 11. Level of agreement / disagreement with statement that: Marine Animal entanglements are the major economic impact on the Scottish creel fishing sector.

Response	Number of responses	% of responses
Strongly Disagree	53	33.3%

Response	Number of responses	% of responses
Disagree	66	41.5%
Neither Agree nor Disagree	18	11.3%
Agree	20	12.6%
Strongly Agree	2	1.3%

Table 12. Themes identified, number of interview mentions and percentage of respondents who mentioned the theme. Some respondents gave multiple answers.

Theme identified	Number of mentions in interviews	% of respondents who mentioned it
Entanglements are a rarity	72	45%
Entanglements are not costly	66	42%
Never experienced entanglement	44	28%
Entanglements are costly	33	21%
Less costly compared to other problems	25	16%
More about animal welfare/conservation	17	11%
Unsure	4	3%

Table 13. Themes identified for factors influencing gear loss and damage shared by fishers, including the number of mentions during interviews, and percentage of respondents who mentioned that factor. Some respondents gave multiple answers.

Categories	Number of mentions	Percentage of respondents who mentioned it
Weather / tides	92	58%
Towed gear or mobile gear (trawls, dredges)	84	53%
Gear conflict inc. creel-on-creel	44	28%
Bad practice	30	19%
Gear saturation	23	14%

Categories	Number of mentions	Percentage of respondents who mentioned it
Leisure or aquaculture vessels	14	9%
Ghost gear	6	4%
Lack of enforcement	4	3%
Poor gear maintenance	2	1%
Whales	2	1%
No Answer	2	1%
Seals	1	1%

Table 14. Themes identified for factors interviewed fishers thought lead to entanglement, including the number of mentions during interviews, and percentage of respondents who mentioned this theme. Some respondents gave multiple answers.

Categories	2.7	Percentage of respondents who mentioned it
Animal behaviour	50	31%
Bad practice	39	25%
Don’t know	38	24%
Too much creel gear / saturation	36	23%
Bad luck	18	11%
Ghost gear	12	8%
Gear conflict	10	6%
Accidental shooting of creels when animals below	7	4%
Climate change and changing migration routes	4	3%
Bad weather or strong tides	3	2%
Increased animals	2	1%
Shipping noise	2	1%
Netting	1	1%

2.7

Categories		**Percentage of respondents who mentioned it**
Poor gear maintenance	1	1%
Dead animals drifting into gear	1	1%

As Table 14 demonstrates, the fishers surveyed believed the main factor leading to entanglement to be the behaviour of the animals. Examples given included animals feeding near the bottom, deliberately approaching the gear, or becoming disoriented as a result of underwater noise or bad visibility and swimming into gear accidentally. Bad fishing practice of other fishers, for example poor gear maintenance, fishing with excessively long ends, not tending gear regularly, and not respecting others gear e.g. trawlers ignoring or not seeing creel markers, was also given as a possible cause for entanglements.

Discussion

Some key themes have emerged from this analysis including that concern for animal welfare was a more important consideration for fishers than financial costs as a result of entanglement. However, this may indicate that fishers are underestimating the true economic impact of entanglement, which can result in damage to or loss of gear and any associated catch, and subsequent fishing time. For example, while three-quarters of fishers disagreed with the statement ‘marine animal entanglements have a major economic impact on the Scottish creel fishing sector’, 44 fishers (27%) said entanglement had caused damage to or loss of their gear. In addition, while only 22 respondents (14%) agreed or strongly agreed with the above statement and only one fisher interviewed cited animal entanglement as a reason for loss of or damage to gear, almost half of fishers interviewed had experienced at least one entanglement. Six fishers had experienced five or more within the specified timeframe, and the highest number of reported incidents was nine. The highest reported loss to an individual fisher due to a single entanglement was estimated at £2000, therefore we believe that the costs of entanglement detailed here are a conservative estimate.

The questionnaire focussed only on the financial cost of entanglements to individual fishers. While the average amount of gear lost or damaged due to an entanglement was 4%, fishers reported losses to other factors of between 8% and 80% per year and 62% of fishers interviewed stated they had lost gear on 10 or more separate occasions within the last decade. The main causes of gear damage or loss were cited as weather and mobile vessels, however questions regarding the financial implications of losses to such factors were not included in this questionnaire. It would be useful for future work to try to quantify costs of losses to other causes, to allow for comparison and further assessment of whether at an industry-level, entanglements pose a financial concern.

Loss of and damage to fishing gear was reported by 86% of interviewees. Over a third of fishers interviewed reported that they were able to recover 100% of lost gear, however 11% reported that they didn’t retrieve any and the remainder were only able to recover between 20 and 80%. While most entanglements are believed to occur in active fishing gear (Asmutis-Silvia et al., 2017), ALDFG is known to have negative impacts on a wide range of marine environments, wildlife, and the fishing industry (Richardson et al., 2019). Therefore further quantifying these losses in future surveys would allow for assessment of the amount of ALDFG associated with the creel sector in inshore waters, and potential hotspots for lost gear to direct clean-up efforts.

In addition to weather and mobile vessels, 19% and 14% of fishers interviewed suggested bad practise (e.g. poor gear maintenance, fishing with excessively long ends, not tending gear regularly, and not respecting others gear) and gear saturation as causes of gear loss respectively. 25% and 23% also suggested bad practice and gear saturation as possible causes of entanglement. These findings support those detailed in chapter 4 - Capturing fishermen’s knowledge - Fishing activity and experience of entanglement and chapter 8 – An industry perspective.

Conclusions and recommendations

The questionnaire findings suggest multiple reasons for and perceptions regarding marine animal entanglements in Scottish waters and the financial implications of these. These issues need to be addressed at different levels, ranging from top-down policy and regulation, to bottom-up measures the creel fleet can adopt at local and regional levels in terms of best practice, and those that require more data or research to be undertaken.

To better understand both the rates and consequences of entanglement from a financial point of view, a better understanding of the creel fishery in Scotland is essential. Conflict both within (gear saturation and creel-on-creel conflict) and between fishing sectors operating in inshore waters were cited as major causes of gear loss, however without knowing the extent of the fishing effort, the amount of gear lost annually to all causes, and any hot spots where this may be occurring, effective future management to mitigate these losses will not be possible. To limit conflict between sectors, numerous interviewees called for better spatial management regimes and policing of these to separate the static and mobile sectors. Without such measures issues of gear loss, and subsequent impacts for marine life, are likely to worsen. Therefore a census on creel fishing effort, including the amount of both active and abandoned, lost or discarded fishing gear (ALDFG) currently in the water is an urgent next step. In addition, there is currently no formal data collection mechanism or reporting procedure for entanglements despite this being an EU requirement under the Data Collection Framework. Protocols for reporting entanglements need to be put in place that include any financial losses incurred by fishers, and steps taken to ensure fishers feel safe reporting these incidents. These could take the form of a secure online app or portal, or periodic survey for example. Such reports would enable entanglements to be mapped both spatially and temporally, and appropriate mitigations, such as spatial management to reduce risks of both gear loss and entanglement, be put in place.

25% and 24% or interviewees mentioned bad practice and gear saturation as possible reasons why marine animals become entangled in creel gear respectively. Therefore the development and promotion of best-practice gear maintenance standards and codes of conduct for the industry could help reduce entanglement risk and financial losses resulting from these incidents in the future, as well as other causes of gear loss.

Therefore it would be useful in future studies to quantify the cost of other causes of gear loss and damage as a comparison to those losses resulting from entanglement.

Assessing the spatial distribution of entanglement risk to minke whales off the West Coast of Scotland

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Summary

This chapter analyses the distribution of minke whale sightings and the density of vertical lines associated with creel markers recorded off the west coast of Scotland during surveys conducted by the Hebridean Whale and Dolphin Trust. Northridge et al., (2010) developed an index of co-occurrence known as the ‘risk of entanglement measure (REM)’ to identify areas in Scotland where there was the greatest co-occurrence of whales and creels. It is within these areas that interactions between whales and creels are most likely, and therefore represent the highest risk of a whale-creel based interaction occurring that may result in an entanglement. The aim of this chapter was to repeat this analysis using all available data held by HWDT to provide an updated and fine scale assessment of the risk of entanglement and identify any changes that have occurred since the 2010 study.

We found that the risk of entanglement measure (REM) was highest to the east of Harris and north-west of North Uist in the Outer Hebrides. Areas of higher co-occurrence were also widespread to the east of the Outer Isles, and throughout the coastal waters around Skye, Raasay and the Small Isles down to Ardnamurchan.

The results also showed that the use of creels is widespread throughout inshore waters off the west coast of Scotland and the data suggest an increase in the number of creel fleets encountered during surveys in recent years.

Future studies should use the existing data to investigate the fine scale distribution, behaviour and movements of both animals and fishing gear to provide a better understanding of the spatial distribution of entanglement risk, the process of entanglement and the likely efficacy of potential mitigation measures.

Introduction

Entanglement is a global problem and a growing concern in Scottish seas. For minke whales (*Balaenoptera acutorostrata*), entanglement is the single largest cause of death accounting for 40% of all documented fatalities for stranded animals in Scotland (Brownlow et al., 2017; Northridge et al., 2010). Creel fishing for lobster (*Homarus gammarus*), crab and prawn (*Nephrops norvegicus*) is an important source of employment for coastal communities on the west coast of Scotland (Marine Scotland, 2017; Northridge et al., 2010). To better understand entanglement and identify suitable mitigation strategies, it is necessary to identify areas where the risk of entanglement is high i.e. areas where there is the highest chance of a whale-creel based interaction occurring that may result in an entanglement.

With most known entanglement cases identified from necropsies on stranded animals, and many more entangled whales never found or reported (Neilson et al., 2009), it is difficult to accurately identify the areas that pose the highest entanglement risk using data from known entanglement cases alone. Therefore, additional ways of assessing the areas in which entanglements are likely to occur are required.

To address this, a report in 2010 to the Scottish Government, analysed minke whale sightings data and creel location information collected by the Hebridean Whale and Dolphin Trust (HWDT) during the 2008 survey season to identify areas of highest entanglement risk (Northridge et al., 2010). Data were analysed to generate maps showing the areas of highest overlap between minke whales and creels. It was based on the assumption that the risk of entanglement is greatest in areas of high creel use and where there are also high sighting rates of minke whales, and low where there are no reported sightings of creels or whales. The report by Northridge et al*.,* (2010) showed that using sightings data to calculate relative creel densities could provide a useful assessment of fishing effort, which could be used to corroborate data from official sources. Overlaying this with relative minke whale sightings could provide a useful metric to identify areas where there is the greatest overlap in the distribution of creels and whales.

This study updates the previous estimate (Northridge et al., 2010) of the distribution of entanglement risk to minke whales off the west coast of Scotland by analysing the distribution of minke whale sightings and the density of vertical lines associated with creel markers. Updating this analysis with an additional eleven years (2009 to 2019 inclusive) of effort-corrected creel sighting data will provide an updated assessment of entanglement risk and identify any changes in whale and creel distribution that have occurred since the 2010 study. This information will be useful to inform future management decisions.

Methods

Data collection

Effort-based sightings of minke whales and creel buoys were collected off the west coast of Scotland between 2003 and 2019. Data were collected during dedicated visual surveys conducted by the Hebridean Whale and Dolphin Trust (HWDT) on board the 18.5 m research vessel *Silurian*. Surveys took place throughout the coastal waters of western Scotland during daylight hours between April and October each year (Figure 16: survey area ranges from 55.10°N to 58.70°N, and -4.50°W to -8.70°W). In January 2019, a winter survey programme was introduced with surveys taking place between November and March.

During visual surveys, two observers were positioned at the mast, approximately two metres above the water level, and scan the forward 180 degrees with the naked eye and 7x50 mm Opticron Marine binoculars. Observers recorded any sightings of marine wildlife (cetaceans, basking sharks and seals), as well as marine debris and fishing gear (i.e. creel marker buoys) within 500 m and 1000 m from the trackline respectively. Observers attempted to pair up the marker buoys on the endlines to ensure all creel fleets were accounted for, and the position of the marker buoy closest to the vessel was recorded.

Data were collected by trained volunteers and overseen by an experienced marine mammal observer and boat crew. An automatic data logging program, developed by the International Fund for Animal Welfare (IFAW), was run at all times. The vessel's position, speed and heading were automatically recorded from the NMEA feed every 10 seconds, and all other survey data (i.e. sightings, changes to search status) were recorded in real time, using standardised, time-stamped forms. Environmental conditions (sea state using the Beaufort scale, swell, predominant weather, glare, sightability and visibility) were recorded every 15 minutes.

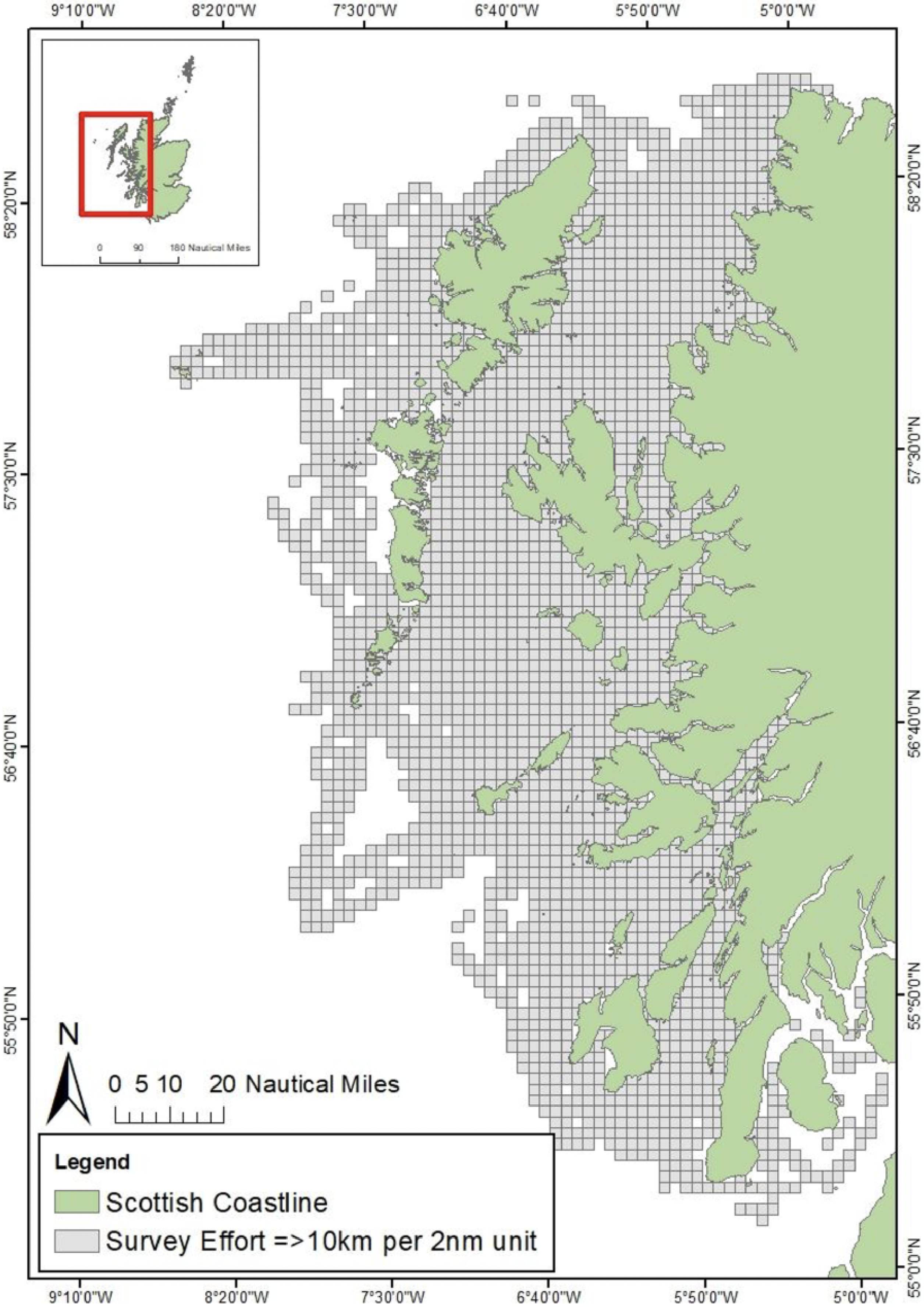

Figure 16. The area surveyed by the Hebridean Whale and Dolphin Trust between 2003 and 2019, displayed on a 2 x 2 nm grid, showing all cells which contain more than 10 km of visual survey effort conducted in sea state ≤3. (Click for a full description)

Map of west coast of Scotland land from Firth of Clyde up to the tip of Outer Hebrides. Grey squares cover the seas of the inner Hebrides, West of the outer Hebrides out to St Kilda, a few squares are in the Firth of Clyde.

Contains data collected by Hebridean Whale and Dolphin Trust and Ordnance Survey data © Crown Copyright 2020.

Data analysis

The ability to detect surfacing cetaceans is affected by sea state (Evans and Hammond, 2004). For this study, it was also necessary to consider the observer's ability to detect creel marker buoys within a 1 km radius of the vessels track. Buoys were recorded up to Beaufort Sea state six. However, at sea states greater than three it can become difficult to spot creels. Therefore, any effort or sightings collected in sea states greater than three have been excluded here to ensure comparable detectability.

The HWDT survey protocol was designed to achieve non-biased spatial coverage throughout the survey area but inevitably locations near to rendezvous locations (Tobermory, Kyle of Lochalsh and Ullapool) have received higher coverage. Areas west of the Outer Hebrides were surveyed the least due to limited weather windows to survey the area (Hebridean Whale and Dolphin Trust, 2018). To account for this variability, the survey area was divided into a grid of 2 x 2 nm cells and the total amount of effort (kilometres surveyed) during dedicated visual surveys from all years was calculated for each cell. Cells where the total survey effort was less than 10 km were excluded to reduce small sample effects.

Since the previous study was published (Northridge et al., 2010), HWDT have continued their long-term monitoring in the region and have now compiled a more comprehensive dataset. This has allowed us to analyse these data at a finer spatial resolution than Northridge et al., (2010). Here a 2 x 2 nm grid has been used rather than the 10 nm grid cells used previously.

Minke whale and creel sightings data from all years were compiled (minke whales 2003-2019, creels 2008-2019). The total number of creel and whale sightings recorded during visual surveys in sea states ≤3 were calculated for each grid cell and corrected for search effort. Sighting rates were calculated for whales and creels as the number of sightings per 10 kilometres of visual survey effort.

In order to compare the distribution of minke whales and creel fleets, an index of co-occurrence, referred to as the 'risk of entanglement measure' (REM), was calculated following the method outlined in Northridge et al., (2010). The REM can be used to identify the areas where there is the greatest co-occurrence of minke whales and creels, which is assumed to be related to the likelihood of a whale-creel interaction occurring that may result in an entanglement. The mean sighting rates for minke whales ($\hat{W}$) and creels ($\hat{C}$) across all grid cells were calculated from the sighting rates for minke whales (W) and creels (C) assigned to each 2 nm grid cell in the survey area. The difference from the mean sighting rate was then calculated for each cell by dividing the sighting rate for each cell by the mean sighting rate ($W/\hat{W}$ for minke whales and $C/\hat{C}$ for creels). These two measures were multiplied to calculate the REM.

$$Risk\ of\ Entanglement\ Measure\ (REM) = \left(\frac{W}{\hat{W}}\right) \times \left(\frac{C}{\hat{C}}\right)$$

Risk of entanglement measure (REM) (Click for a full description)
The mean sighting rates for minke whales ($\hat{W}$) and creels ($\hat{C}$) across all grid cells were calculated from the sighting rates for minke whales (W) and creels (C) assigned to each 2 nm grid cell in the survey area. The difference from the mean sighting rate was then calculated for each cell by dividing the sighting rate for each cell by the mean sighting rate ($W/\hat{W}$ for minke whales and $C/\hat{C}$ for creels). These two measures were multiplied to calculate the REM.

Results

Survey effort

Over a seventeen-year period from 7th April 2003 to 20th December 2019, 110,847 km of dedicated visual surveys were conducted on the west coast of Scotland on board HWDT's research vessel *Silurian*. Effort varied between years as a result of weather conditions, participant numbers and vessel maintenance (Hebridean Whale and Dolphin Trust, 2018) with an average 6,520 km surveyed per year (Figure 17). During these surveys, 691 minke whale sightings and 42,313 creel fleets were recorded.

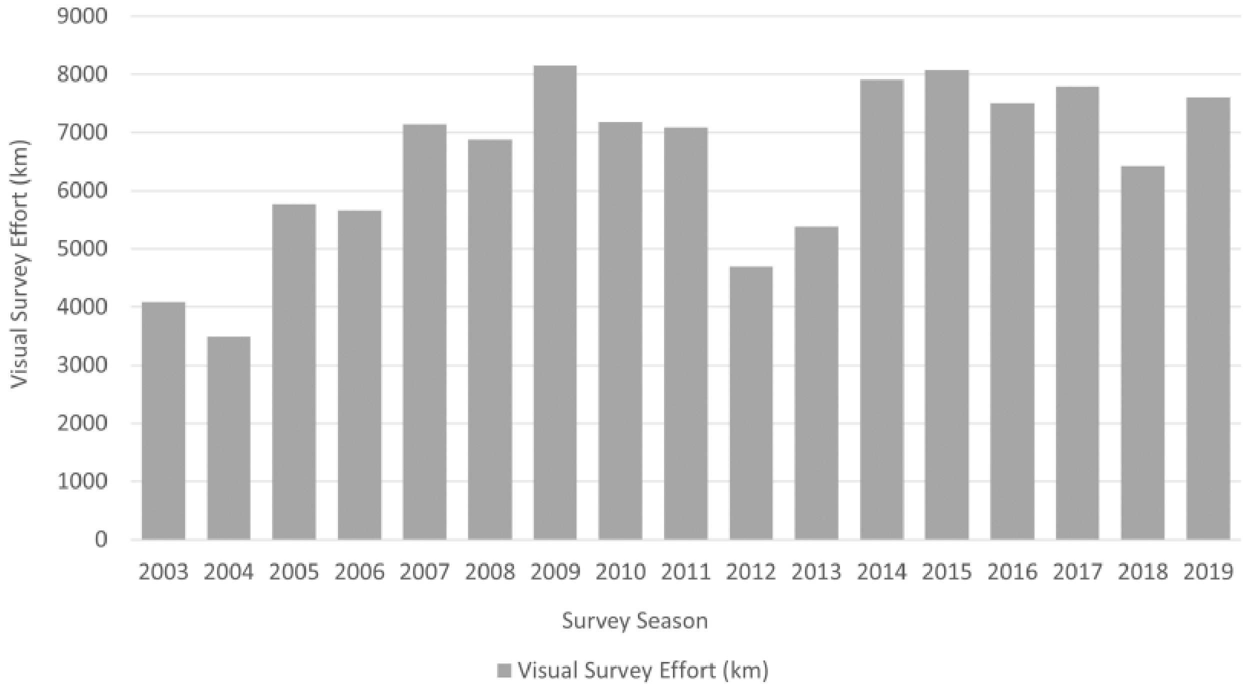

Figure 17. Total visual survey effort (km) conducted by the Hebridean Whale and Dolphin Trust each year covering the period from April 2003 to December 2019. (Click for a full description)
Survey effort varies seasonally between 2003 to 2019. Effort varied between years with an average of 6,500 km surveyed per year.

Survey effort varied seasonally and was highest between June and August (Figure 18). Winter surveys began in January 2019, which explains the comparatively low amount of effort during winter months (November to March).

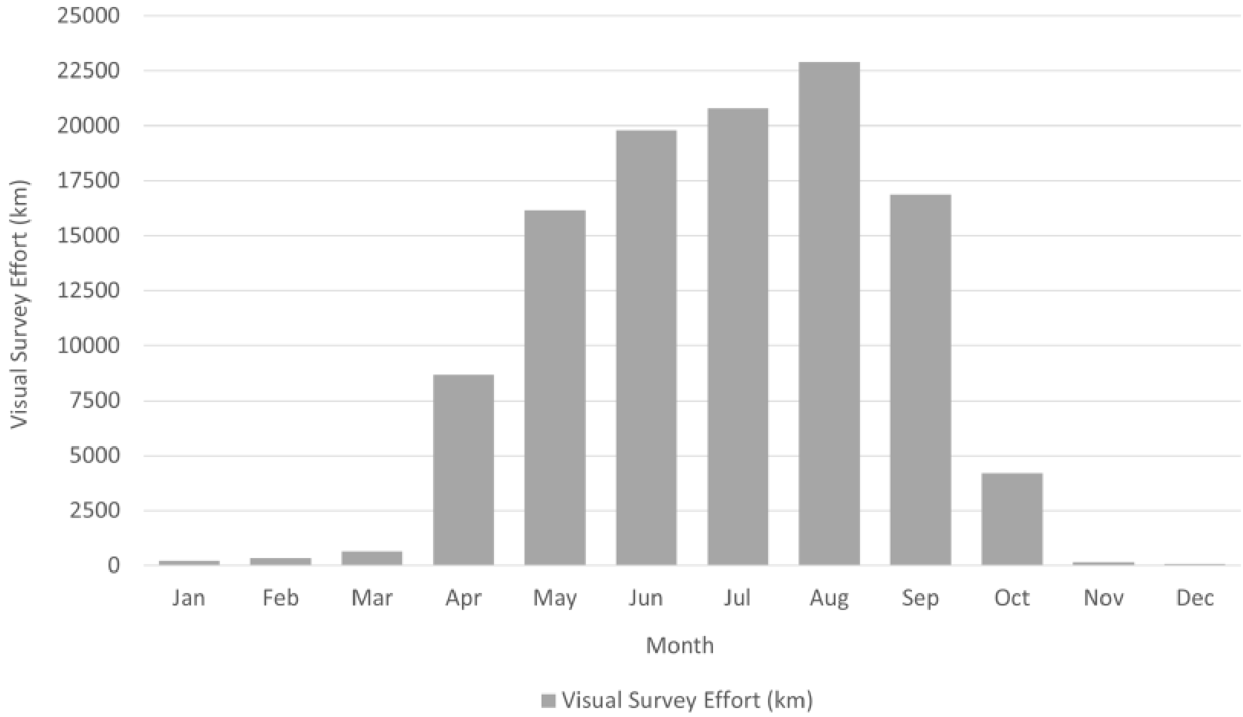

Figure 18. Total visual survey effort (km) per month. Data for all years (2003-2019) has been compiled and is displayed as the total distance (km) surveyed during dedicated visual surveys per month. (Click for a full description)
Survey effort varied seasonally and was highest between June and August and lowest in the winter months.

Minke whale distribution

Minke whales were recorded in all years from 2003 to 2019. The sightings rate per year ranges from 0.026 sightings per 10 km surveyed in 2005 to 0.093 in 2003 (Figure 22, mean = 0.062, SD = 0.016). Sightings rates for all other years show some variability.

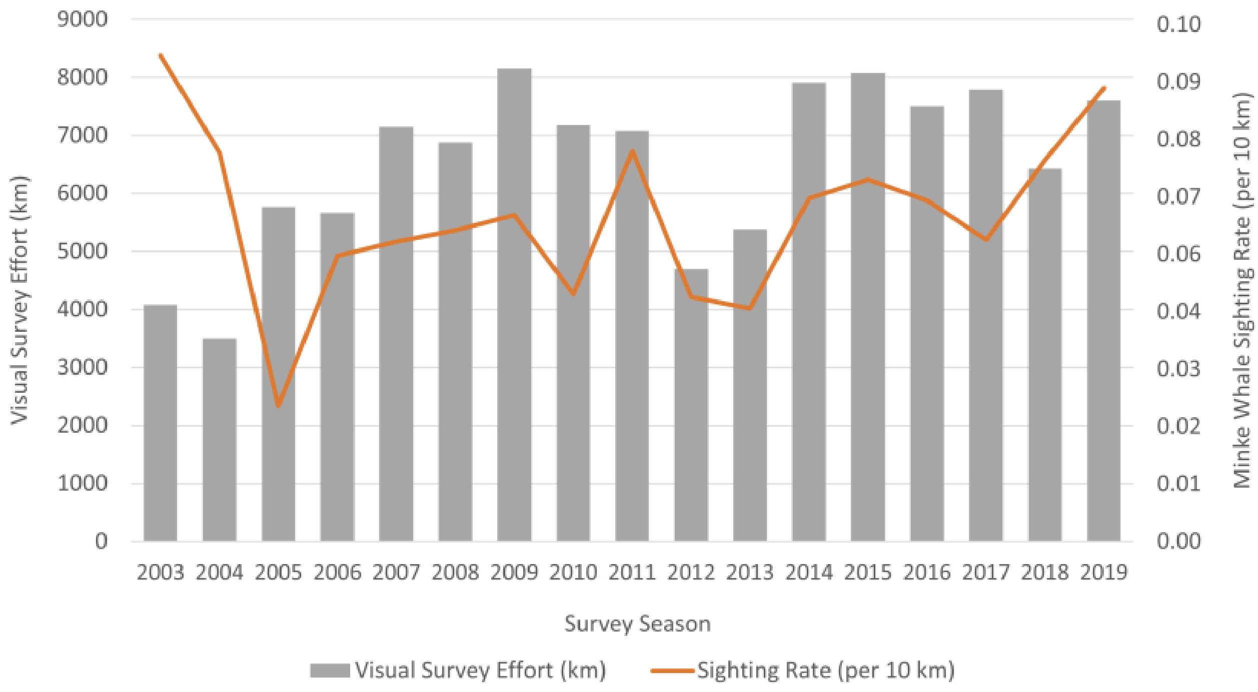

Figure 19. Minke whale sighting rates per year (2003-2019) overlaying the total visual survey effort (km). (Click for a full description)

Minke whales were recorded in all years from 2003 to 2019. There is variability in the sighting rates per year.

Minke whales are a highly mobile species but their migration patterns are poorly understood (Anderwald et al., 2007). During HWDT surveys, on the west coast of Scotland, they were recorded in all months between April and November. Sightings rates were highest in June (0.088 sightings per 10 km surveyed), July (0.086) and August (0.072) (Figure 20).

Limited, spatially restricted survey data were available for the winter months (November to March) therefore, reliable sightings rates could not be calculated for this period. Minke whales were recorded during HWDT winter surveys conducted in 2019. Data collected through HWDT's community sightings network, Whale Track and by the national sightings scheme run by the Sea Watch Foundation (Anderwald et al., 2007), also show that some minke whales are present in the region during the winter months.

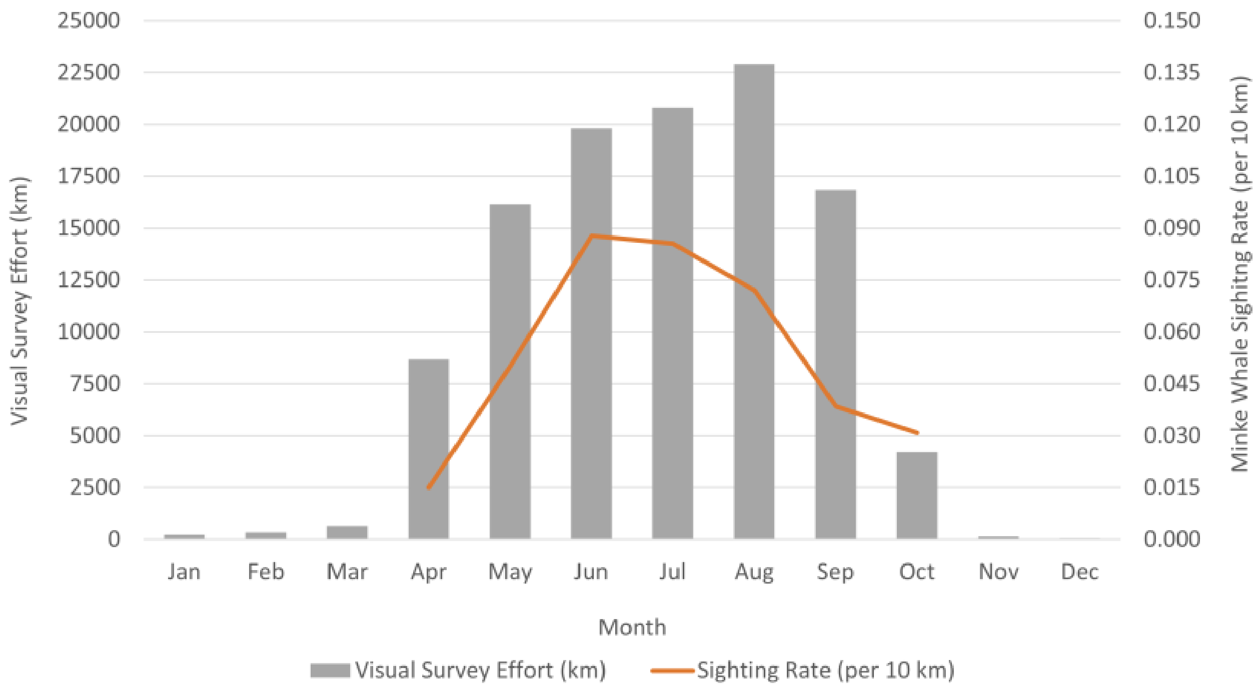

Figure 20. Minke whale sighting rates per month (April to October) overlaying the total visual survey effort (January to December). (Click for a full description)

Sightings of minke whales were recorded in all months between April and November. Sighting rates were highest in June, July and August. Sighting rates are not shown for November to March because limited survey data were available for these months. Data were compiled for all years (2003-2019).

Minke whale sightings were distributed throughout the survey area from Cape Wrath and the Butt of Lewis, to the Kintyre peninsula and out to Stanton Banks and the Flannan Islands in the west (Figure 21). The highest sightings rates are seen throughout the Minch, the Sea of Hebrides, down to Stanton Banks, and to the north west of North Uist.

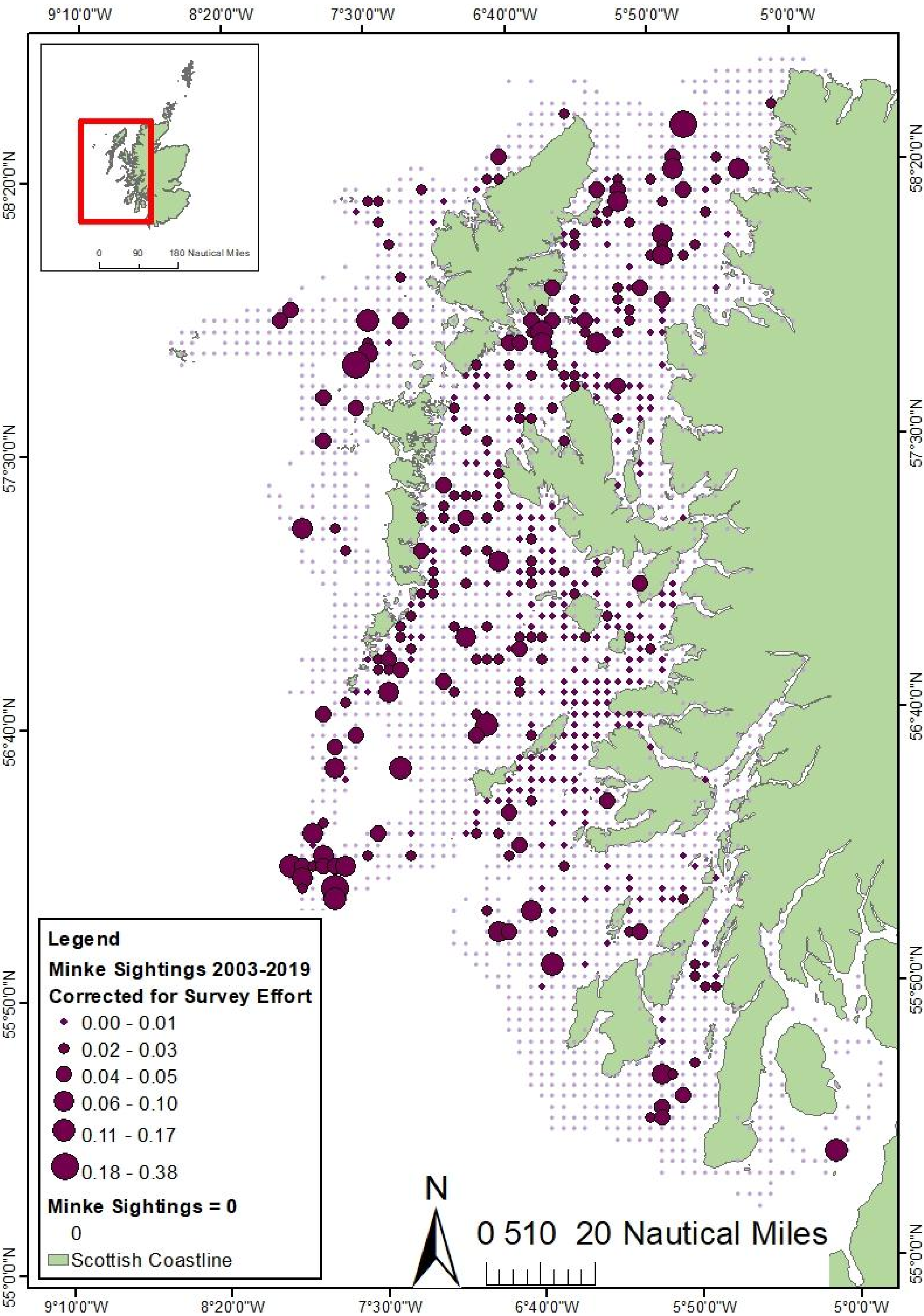

Figure 21. Minke whale sighting rates 2003 to 2019. Only cells where the total visual survey effort conducted in sea state ≤3 was greater than 10 km were included. (Click for a full description)
Red dots of varying sizes cover the seas of the Inner Hebrides and West of the Outer Hebrides to St Kilda. Contains data collected by Hebridean Whale and Dolphin Trust and Ordnance Survey data © Crown Copyright 2020.

Creel fishery distribution

Sightings locations of creel fleets were recorded in surveys from 2008 onwards. The creel sighting rate shows a general upward trend indicating that the number of creels being deployed on the west coast of Scotland is increasing (Figure 22). The sighting rate is lowest in 2010 with 3.47 creel fleets recorded per 10 km of survey effort and peaks in 2017 with 6.41 creel fleets recorded per 10 km of survey effort.

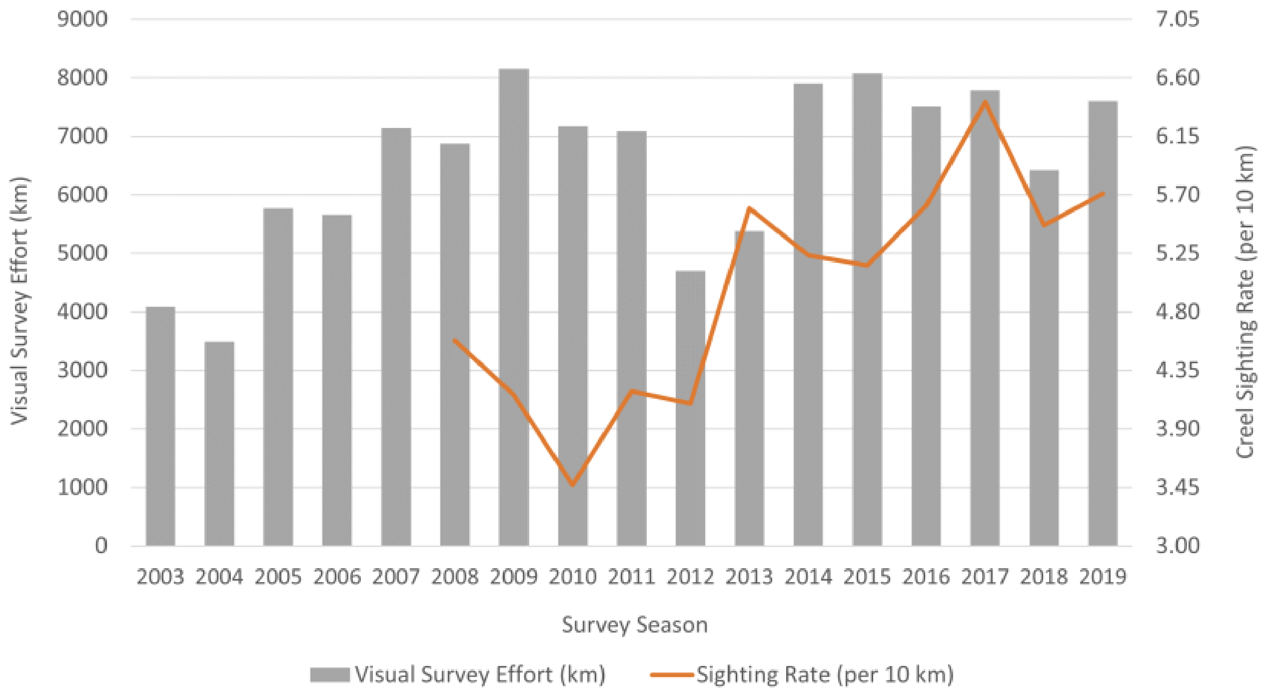

Figure 22. Creel sighting rates per year (2008-2019) overlaying the total visual survey effort (km). (Click for a full description)

Sightings locations of creel fleets were recorded in surveys from 2008 onwards. The creel sighting rate shows a general upward trend indicating that the number of creels being deployed on the west coast of Scotland is increasing. The sighting rate is lowest in 2010 with 3.47 creel fleets recorded per 10 km of survey effort and peaks in 2017 with 6.41 creel fleets recorded per 10 km of survey effort.

Creels are widespread throughout coastal waters off the west coast of Scotland (Figure 24). The highest densities were recorded between the Summer Isles and Loch Broom, Stoer and Handa, Raasay and the mainland, as well as waters near the islands of Scalpay, Berneray and Scarp in the Outer Hebrides.

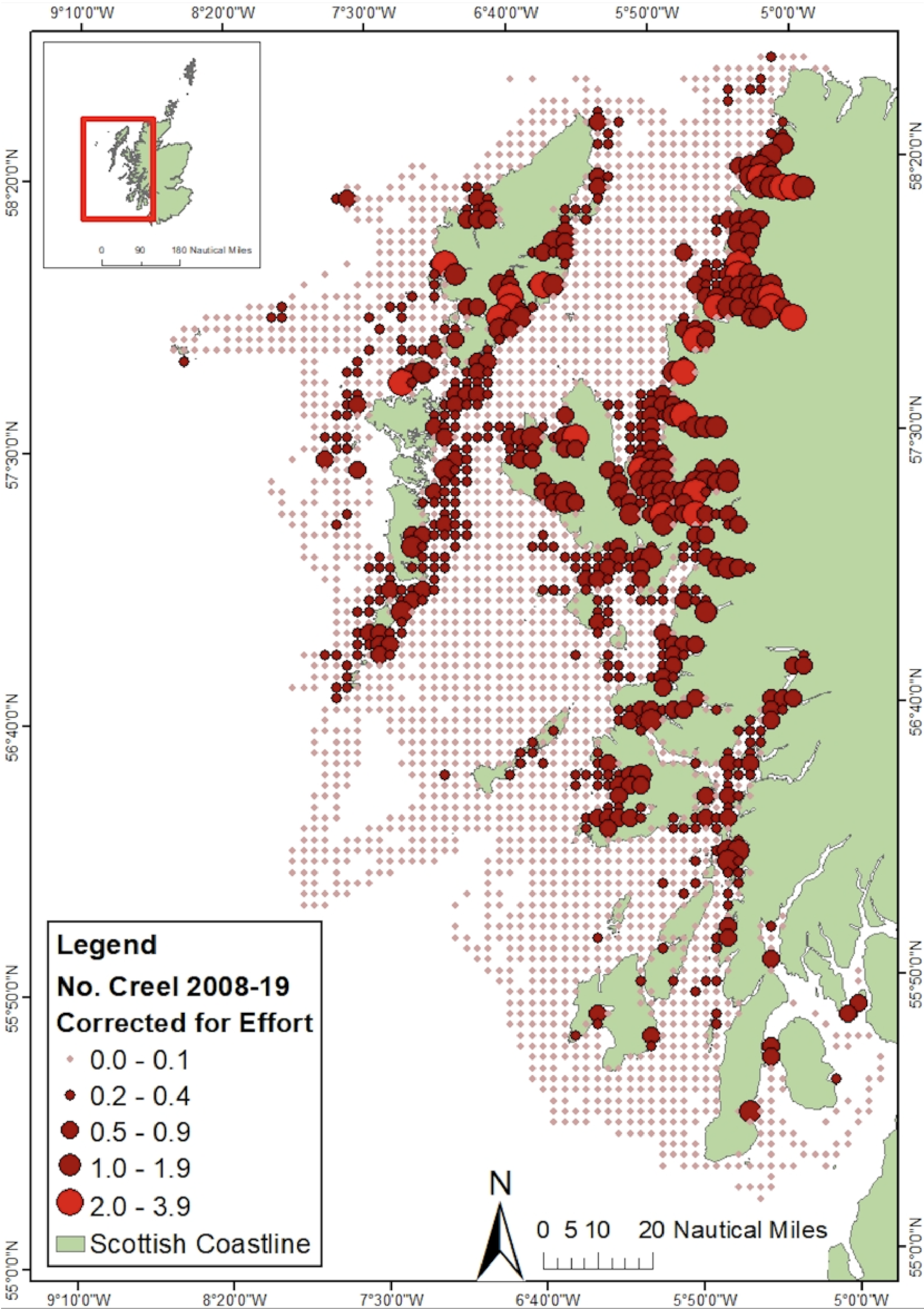

Figure 23. Creel sighting rates 2008-2019. Only cells where the total visual survey effort conducted in sea state ≤3 was greater than 10 km were included. (Click for a full description)

Creels are widespread throughout coastal waters off the west coast of Scotland. The highest densities were recorded between the Summer Isles and Loch Broom, Stoer and Handa, Raasay and the mainland, as well as waters near the islands of Scalpay, Berneray and Scarp in the Outer Hebrides. Contains data collected by Hebridean Whale and

Dolphin Trust and Ordnance Survey data © Crown Copyright 2020.

Risk of entanglement

The risk of entanglement measure (REM) was highest to the east of Harris and north-west of North Uist in the Outer Hebrides (Figure 25). Higher REM values were also widespread to the east (Barra to Benbecula) of the Outer Isles, throughout the coastal waters around Skye, Raasay and the Small Isles down to Ardnamurchan.

These areas show the greatest overlap between minke whale sightings and creel fishing, and therefore represent the areas where there is the highest chance of a whale-creel based interaction occurring that may result in an entanglement.

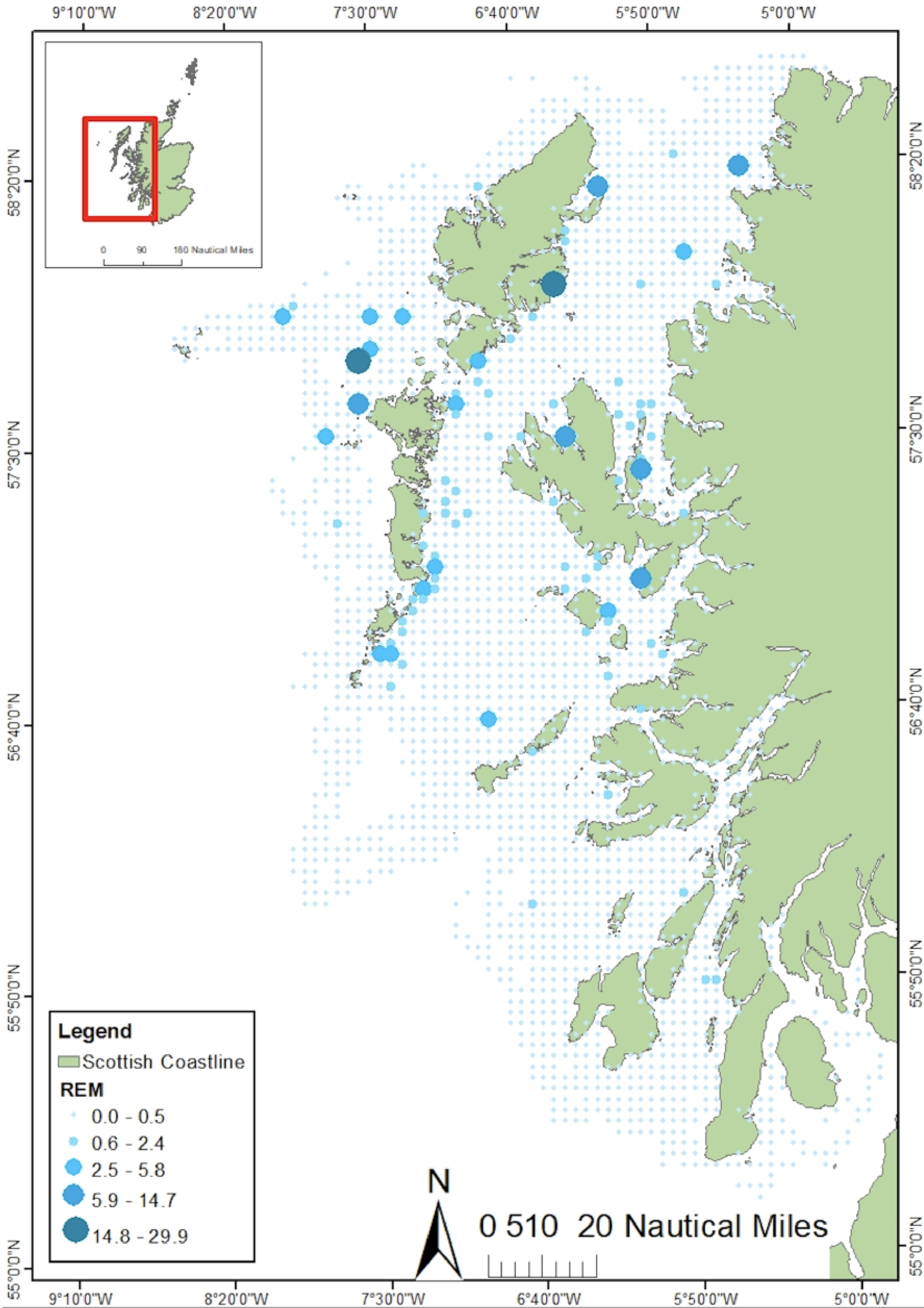

Figure 24. Risk of entanglement measure (REM) displayed on a 2 x 2 nm grid. (Click for a full description)

The risk of entanglement measure (REM) was highest to the east of Harris and north-west of North Uist in the Outer Hebrides. Higher REM values were also widespread to the east (Barra to Benbecula) of the Outer Isles, throughout the coastal waters around Skye, Raasay and the Small Isles down to Ardnamurchan. These areas show the greatest overlap between minke whale sightings and creel fishing, and therefore represent the areas where there is the highest chance of a whale-creel based interaction occurring that may result in an entanglement. Contains data collected by Hebridean Whale and Dolphin Trust and Ordnance Survey data © Crown Copyright 2020.

Discussion

Here we utilised a method developed by Northridge et al., (2010), which used existing observations of minke whales and creel fleets collected by the Hebridean Whale and Dolphin Trust (HWDT) to identify where the areas of highest co-occurrence of minke whales and creels are off the west coast of Scotland. The analysis by Northridge et al. (2010) showed that the HWDT data provided a useful way to demonstrate the fine scale density of creel fishing on the west coast of Scotland and a method to identify areas where interactions between minke whales and creels were most likely.

Here we have repeated the Northridge et al., (2010) methodology with an additional 11 years of sightings data, which allowed us to analyse these records at a higher resolution. This showed the areas with the greatest co-occurrence of minke whale sightings and creel fishing occurred to the east of Harris and north-west of North Usit in the Outer Hebrides. Areas of high co-occurrence were also widespread to the east of the Outer Isles, and throughout the coastal waters around Skye, Raasay and the Small Isles down to Ardnamurchan.

There is some similarity to the results of the analysis by Northridge et al., (2010) who found 'the overlap of minke whales and creels greatest in coastal waters from Loch Broom to the Ardnamurchan peninsula, coastal waters of Skye, North Uist and the Atlantic side of South Uist.'

It is worth noting that some of the high-risk areas are within the newly designated Sea of the Hebrides Nature Conservation Marine Protected Area (NC MPA) for minke whales. Habitat modelling has also been used to identify consistent areas of high entanglement risk to minke whales in the Hebrides (Rayner, 2016). This is a concern for the conservation objectives of the site, which are to conserve these features to make a long-lasting contribution to the MPA network (NatureScot, 2019b). However, the introduction of fishing restrictions within the MPA would need to be carefully considered to ensure fishing effort is not shifted into other areas with high densities of vulnerable animals, or around the MPA boundary, which may further compound the issue for this highly mobile species.

It is unclear whether this analysis provides a reliable predictor for where most entanglements will occur but there is some overlap between the areas where there was the greatest co-occurrence of whales and creels (Figure 25) and areas where minke whales are known to have been entangled from stranding data (Figure 3).

Furthermore, the analysis of the questionnaire data (chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement) showed three quarters of fishers (75.7%) that saw minke whales in their fishing area had experienced a minke whale entanglement (see section 4.4.3 for full results). This observation indicates that fishers who see minke whales in their fishing area are more likely to experience an entanglement, which supports using the rate of co-occurrence of sightings of whales and creels to provide a measure of entanglement risk. This method does not, however, account for other significant factors affecting the chances of experiencing an entanglement including the depth of water being fished and the frequency the gear is hauled. These factors should be included in future assessments.

The results show that the use of creels is widespread throughout inshore waters off the west coast of Scotland (Figure 24). In the questionnaire (see chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement), several fishers raised concerns over the increasing number of creels being deployed and referenced the fact that there are no official sources of data to support this. The data analysed here suggest there has been a general increase in the number of creel fleets encountered during HWDT surveys since 2010 (Figure 22).

Data were combined for all years, but the distribution of whales and creels are not fixed, and we would expect some variability between years and by season. Minke whales are most frequently seen between April and October, with some remaining in the region through the winter. Even though the minke whales in the Hebrides are considered part of the same population, they display individual variability in their distribution and site faithfulness. Some individuals return year after year and others are only ever seen once. Different animals may use different feeding strategies, which could be specific to the individual or indeed the area in which they are feeding. All of these factors will affect the level of risk an individual animal will be exposed to and will put some individuals significantly more at risk of a fatal entanglement. It is important that work continues to further understand the impacts of entanglement on Scottish marine wildlife and to prevent, monitor and review this threat. It has been 10 years between the work conducted by Northridge et al., (2010) and this research led by the Scottish Entanglement Alliance and we must not wait another 10 years for the next review. Entanglement has important implications for the conservation of marine animals in Scotland and must be considered in future management, including of MPA's and fishing industry.

Conclusions and recommendations

Here we have shown that creels are widespread throughout coastal waters, which in some cases overlaps with minke whale distribution, posing an entanglement risk. Measures to prevent entanglements should be a future priority. To inform suitable mitigation strategies, future assessments should:

- Investigate the fine scale distribution, behaviour and movements of both animals and fishing gear using existing data to provide a better understanding of the spatial distribution of entanglement risk, the process of entanglement and the likely efficacy of potential mitigation measures.
- Extend the analysis to cover other areas. Data to allow this type of assessment to be conducted were only available for the west coast of Scotland.
- Extend the analysis to include data from the winter months. HWDT began a winter monitoring programme in January 2019, therefore limited data from the winter months were available for use in this study. With some minke whales recorded in the region during the winter months, year-round monitoring should continue to build a better baseline for winter months and provide more reliable data on creel and minke whale distributions during this time.
- Investigate changes over time. All available data were collated for this assessment, but future studies should look in more detail at trends and changes over time.
- Extend the analysis to other species affected by entanglement. With the number of entanglements increasing, and the number of species affected also increasing (MacLennan et al., 2019), the types of analysis outlined here should be performed for other protected species that are commonly entangled e.g. basking sharks. This would also be important for informing the management measures for the Sea of the Hebrides MPA.
- Consider cumulative impacts. Anthropogenic impacts are often considered in isolation but increasing pressures on the marine environment coupled with wider environmental change as a result of climate change are likely to have cumulative impacts. Future studies should consider cumulative impacts on protected species and this should also be considered in management strategies. This is particularly pertinent to the development of an ecologically coherent network of MPA's designed to protect critical areas of habitat for mobile species, like minke whales, who rely on these areas for feeding. It is vital that we continue to monitor and protect these important places as well as the cetaceans and sharks that use them. It is important that any measures introduced to prevent minke whale entanglements do not have negative effects on other species.

Entanglement survivors – assessing the extent of non-lethal entanglement

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Summary

Entanglement, which is defined by the International Whaling Commission (2010) as 'wraps of line, netting or other materials around body areas' and 'may include cases in which animals are towing gear or anchored by gear', causes distinct scars and tissue damage. This chapter examines the prevalence of entanglement related scars in live minke whales recorded off the west coast of Scotland between 1990 and 2017. Building on the analysis by Northridge et al*.,* (2010), an additional 10 years' worth of data were analysed here extending the sampling period to 27 years. The aim was to provide an updated assessment of the number of animals that show evidence of a previous entanglement and identify any changes that have occurred since the 2010 study.

In this study, photo-identification records for 256 catalogued minke whales were analysed. Encounters were graded based on image quality and marks and scars were categorised. Every sighting of catalogued individuals was assigned an entanglement status. The entanglement status ranged from animals that were or clearly had been entangled in line, netting or other material to those with insufficient photographic evidence to determine whether the individual had any entanglement related scars.

The types of entanglement related scars varied from extensive tissue damage or deformation through to linear scars, wounds or indentations that often wrapped around parts of the body. In total, 22.3% (n = 57) of the individuals assessed had entanglement related marks. This comprises of 4.7% of animals (n = 12) that showed clear evidence of a current or previous entanglement (i.e. gear was visible and/or the animal had extensive tissue damage highly consistent with entanglement), and 17.6% (n = 45) had marks that showed they were likely to have previously been entangled in fishing gear (i.e. linear scars wrapping around the body). The proportion of animals showing evidence of a previous entanglement has therefore remained consistent with the previous estimate (30 out of 133 individuals, 22.5% in Northridge et al*.,* 2010).

Effort should continue to increase the photographic coverage of individual animals to allow assessments of entanglement related scars. Future assessments must continue to include information about the number of live animals that show evidence of entanglement to better understand the implications these types of interactions have on individual animals. Using these data alongside data on mortalities will provide better estimates of the effects of entanglement on minke whale mortality rates.

Introduction

In order to assess the population and conservation consequences of entanglement and develop and monitor suitable management measures, the mortality rate and the number of animals that experience serious injuries from fisheries interactions must be assessed, but with many entangled whales never found or reported, it is difficult to accurately evaluate the scale of entanglement (Neilson et al., 2009). However, because the injuries caused by entanglement in fishing gear (e.g. line, netting, rope or other materials) are distinct, and scars and/or tissue damage remain visible long after the event, it is possible to examine live individuals in the population for evidence of previous entanglement to provide an assessment of the frequency of these types of interactions (Knowlton et al., 2012; Neilson et al., 2009; Robbins and Mattila, 2001; Kraus, 1990).

Records collected by Sea Life Surveys, a whale-watching operator based on the Isle of Mull, and the Hebridean Whale and Dolphin Trust between 1990 and 2008 were analysed in a study by Northridge et al*.,* (2010). Their analyses showed up to 20% of minke whales in the Inner Hebrides carried marks indicating they may have been entangled by fishing gear, and of these at least 5% of animals had clearly been entangled.

Since this analysis, the minke whale catalogue for the west coast of Scotland has almost doubled in size (127 individuals in 2008 to 256 individuals in 2017). These photo-identification records have been re-analysed to provide an updated assessment of the prevalence of entanglement in minke whales off the west coast of Scotland.

Methods

The Hebridean Whale and Dolphin Trust maintains a catalogue of photographs and associated sightings information for minke whales on the west coast of Scotland. These photographic records have been collected by Tobermory based whale-watch operator Sea Life Surveys since 1990 and by HWDT on board research vessel *Silurian* since 2002 (under Scottish Natural Heritage research licence 159755). Photographs are also submitted by contributors to HWDT's long-standing community sightings network Whale Track.

Prior to 2002, most sightings were within the Inner Hebrides and since then the coverage has increased with photographic encounters now captured along the whole of the west coast from Cape Wrath in the north, to the Kintyre peninsula in the south, with the most westerly sighting at Stanton Banks.

Between 1990 and 2003 only identifiable individuals were catalogued following the method outlined in Gill (1994), and Gill & Fairbairns (1995). From 2003, all photographs were catalogued. Photographs focussed on parts of the animal's bodies showing identifiable features e.g. dorsal fins, but from 2007 onwards photographers were asked to photograph all animals and as much of the animal's body as possible to reduce any bias towards photographing only well-marked animals and to allow a more accurate assessment of entanglement events.

Photographs are stored by year, encounter and then by individual. The photographs from every encounter are compared against the catalogue of known individuals. If a match can be made, the best photographs showing each body part (head, dorsal fin, flank and tailstock, as shown in Figure 26) of both sides of the animal are added to the catalogue along with ancillary information about the encounter (date, location, image copyright).

Figure 25. Body regions for photographic classifications a) Head, b) Flank, c) Dorsal fin, d) Tailstock. © HWDT.org.

Since 2016, the catalogue has been stored and maintained using the photographic data-management system Discovery (Gailey and Karczmarski, 2012). Animals in the catalogue are identified by a unique alpha-numeric code, which describes the key distinguishing feature(s) used to identify the animal (Table 15) and the number of whales previously identified with that mark type.

Table 15. Classification of mark types for catalogued minke whales.

Code	Classification	Definition
FD	Distinctive fin notches	Individuals identified primarily by large indentations in the trailing or leading edge of the dorsal fin.

FD27 - Knobble (HWDT.org)

Code	Classification	Definition
FS	Distinctive fin nicks	Individuals identified primarily by small indentations in the trailing or leading edge of the dorsal fin.

FS01 – Top Notch (HWDT.org)

Code	Classification	Definition
FSH	Unusual fin shapes	Individuals identified primarily by dorsal fin shapes considered to be distinctive enough to allow future recapture.

FSH08 – Sickle (HWDT.org)

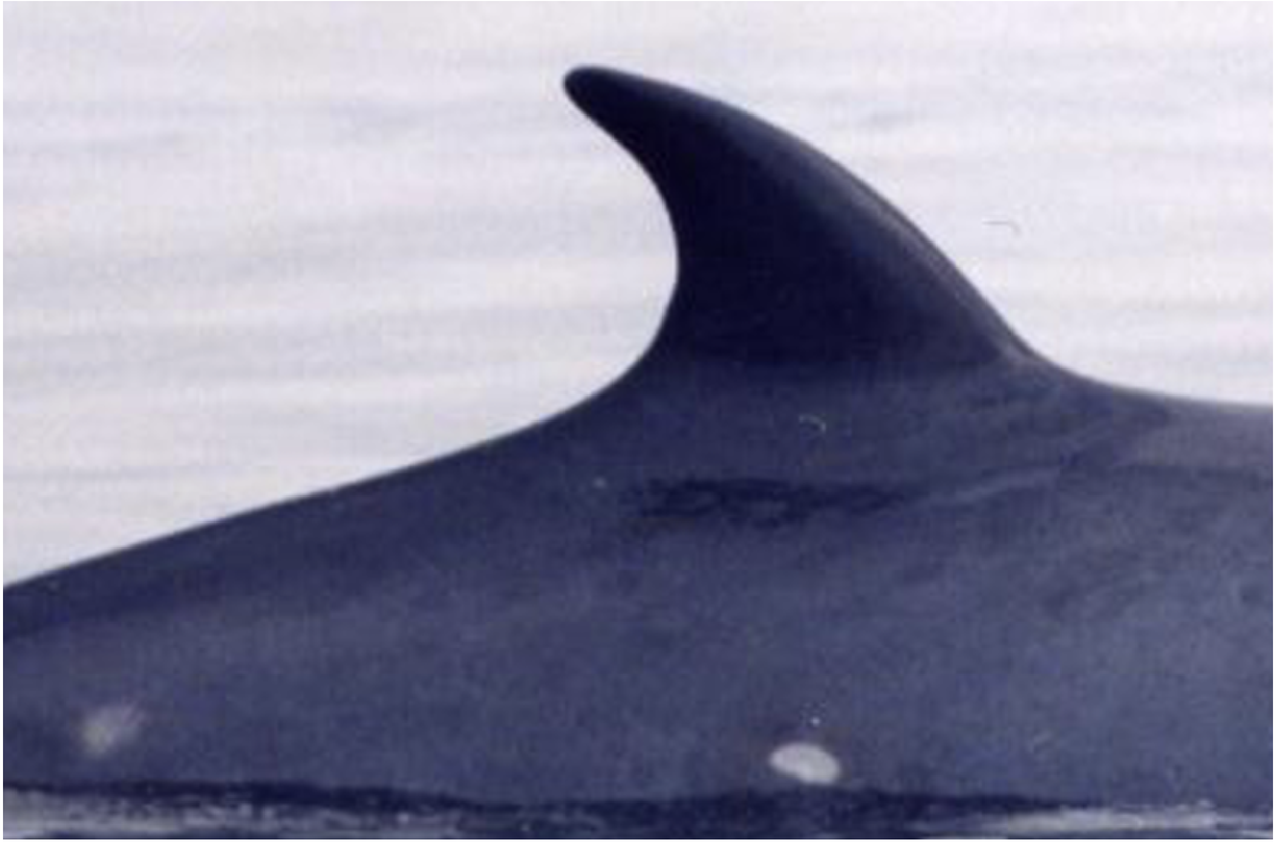
Code	Classification	Definition
FM	Distinctive fin marks	Individuals identified primarily by lesions and scars on the surface of the dorsal fin.

FM02 – Snowy (Sea Life Surveys)

Code	Classification	Definition
BS	Distinctive body scars	Individuals identified primarily by lesions, scars and indentations on the animal's flank, and other body surfaces

BS33 – Scar (Sea Life Surveys)

Code	Classification	Definition
BW	White oval scars	Individuals identified primarily by the presence of small white oval scars, considered to be caused by parasites, present on the animal's body surface.



BW08 - Sweep (Sea Life Surveys)

To provide a comparative and updated analysis, photographs of all catalogued encounters were assessed for evidence of entanglement using the method outlined in Northridge et al., (2010) as described below. Catalogued encounters up to 2008, which had been included in the previous assessment by Northridge et al., (2010) were independently reassessed here. Photos were analysed by an experienced photo-ID researcher, and classifications checked with pathology experts at the Scottish Marine Animal Stranding Scheme (SMASS).

The photographic quality (Q) of each catalogued photograph was assessed and assigned independently of how recognisable the marks on the individual were (Table 16). The quality rating was based on a scale of 0 to 3, where 0 was a very poor-quality image and 3 was a very high-quality image.

Table 16. Photographic quality (Q) classifications based on definitions in Northridge et al. (2010).

Classification	Description	Criteria
Q3 – Good	Any marks are clearly visible.	Image is well lit, in focus and has good resolution and exposure.
Q2 – Acceptable	Any marks can be seen but with less clarity than Q3.	In focus but potentially less well lit or lower resolution or lower image sharpness.
Q1 – Poor	Large nicks in the dorsal fin can be seen but little other detail.	Image is either out of focus, poorly lit (glare/the animal is silhouetted), low resolution or poor image definition.
Q0 – No good	Body part can be identified but no detail can be seen.	Meets more than one of the criteria outlined for Q1.

The visible marks on the animal's body were examined to assess the likelihood that they were entanglement-related (Table 17). Each photograph was assigned a scar classification (S) using criteria based on the study by Robbins and Mattila (2001) and adapted from Northridge et al., (2010).

Table 17. Scar classifications (S) based on definitions in Robbins and Mattila (2001) and Northridge et al. (2010).

Classification	Description	Criteria
S4 – Severe	Clear evidence of a current or previous entanglement.	Gear visible and/or extensive tissue damage or deformation consistent with entanglement.
S3 – Significant	Marks suggest animal has previously been entangled.	Linear scars, wounds or indentations, which wrap around the feature.
S2 – Minor	The origin of the marks is unclear.	Noticeable nicks in the trailing edge of the dorsal fin or small indentations in the leading edge
S1 – Slight	Marks are caused by parasites, conspecific or interspecific interactions etc.	Slight, non-linear, randomly arranged marks or small indentations on the trailing edge of the dorsal fin.
S0 – None	No evidence of any natural or anthropogenic interactions.	No visible marks.

An overall entanglement status was assigned to each encounter based on the image quality rating and scar code assigned to each aspect of the animal's body (Table 18). It was based on the method outlined in Northridge et al., (2010), which had been adapted from the descriptions in Robbins and Mattila (2001) and Neilson et al., (2009).

Table 18. Entanglement status based on the descriptions in Northridge et al. (2010).

Classification	Description	Criteria
EC4 – High	The animal is or has been entangled	Any animal with S4 marks
EC3 – Moderate	The animal has likely been entangled.	Any animal with S3 marks
EC2 – Low	The animal exhibits no marks or scars that are indicative of entanglement.	Any animal with $S<3$ and $Q\geq2$ for each region of the body
EC1 – Unknown	Insufficient photographic evidence to determine entanglement status.	

These classifications were used to provide an assessment of the proportion of individuals that showed evidence of entanglement and to assess which regions of the body most frequently show evidence of entanglement.

Results

Between 1990 and 2017, 256 individual animals were identified during 567 encounters. 72.3% of catalogued animals had insufficient photographic coverage or the images taken were too poor quality for an entanglement assessment to be made (n = 185, EC1-unknown). From the images that were captured, there was no evidence of entanglement, however, entanglement marks or scars may have been present on body parts that were not photographed or in images that were too poor quality for scars to be seen.

5.5% of individuals (n = 14) received good photographic coverage and showed no marks or scars that were indicative of entanglement (EC2-Low). Some of these animals showed marks caused by parasites, or conspecific or interspecific interactions, which corroborates our assumption that entanglement marks would be seen if they had been present.

17.6% of individuals (n = 45) had marks or scars which suggested the animal may have previously been entangled (EC3-moderate). These animals had linear scars, wounds or indentations wrapping round the body part.

The remaining 4.7% (n = 12) showed clear evidence of a current entanglement (e.g. ropes/straps still visible) or clear tissue damage from a previous entanglement (EC4-high). Three animals showed evidence of a current entanglement and in all cases they had plastic packing straps embedded around the rostrum (Figure 27). A further seven animals showed marks consistent with entanglement around the upper rostrum. The remaining two had scars and indents wrapping round the body between the blow hole and the dorsal fin, which were indicative that the animal had been entangled in ropes and had been freed.

Table 19. Entanglement status for 256 animals photographed between 1990 and 2017.

Entanglement status	Number of animals	Percentage of catalogue
EC1 – Unknown	185	72.3%
EC2 – Low	14	5.5%
EC3 – Moderate	45	17.6%
EC4 – High	12	4.7%

Figure 26. Minke whale (BW30 taken on 10/07/2010) with fish packing strap embedded round the upper rostrum. © HWDT.org.

Discussion

To provide an assessment of non-lethal entanglement rates, photographs of individual animals were assessed for scarring from interaction with ropes, strapping and other gear associated with fishing. The types of marks varied from those that had extensive tissue damage or deformation associated with entanglement to less severe linear scars or wounds that wrapped around parts of the body, indicating they may have previously been entangled. Some cases showed evidence that they had been entangled in ropes or line, whereas others had been ensnared by straps associated with fish packing.

Five percent of animals sampled (n = 12) off the west coast of Scotland were either still entangled or had severe scars from previous entanglements. A further 17.6% had less severe marks that indicated they may have previously been entangled in fishing gear.

Building on the analysis by Northridge et al., (2010), an additional 10 years' worth of data were added and analysed here extending the sampling period to 27 years. This resulted in the number of animals in the sample almost doubling in size (133 to 256 individuals), yet the proportion of animals showing evidence of a previous entanglement has remained consistent with previous estimates with 22.3% of individuals showing high to moderate evidence of a previous entanglement (22.5% in Northridge et al., (2010)).

The analysis of photographs to screen cetacean populations for evidence of entanglement has been used in a number of studies (Neilson et al., 2009; Knowlton et al., 2003; Robbins and Mattila, 2001; Woodhead et al., 2001). The estimates presented here are lower than the rate of entanglement seen in studies using similar methods for north Atlantic right whales and humpback whales off America where 82.9% (Knowlton et al., 2012) and 48-68% (Neilson et al., 2009) of whales photographed were affected respectively. However, as documented by others using this method (Northridge et al., 2010; Neilson et al., 2009), entanglement estimates like these are likely to underestimate the true frequency of non-lethal entanglement events for a number of reasons as outlined below.

High quality photographs of all parts of an animal's body are required to accurately assess whether an animal has experienced an entanglement. In this study, an assessment could not be made for 72% of animals in the catalogue due to insufficient photographic coverage of the animal body and/or poor photo quality (EC1-Unknown entanglement status). Some of the animals assigned to this category may have entanglement related marks on parts of the body that had not been photographed or could not be seen due to photo quality. In addition to this, some of the animals assigned to the EC2-Low classification had marks in the trailing or leading edge of the dorsal fin. Because marks in the dorsal fin are common, it is difficult to accurately determine how they were caused and it is possible therefore that some of these marks may have also been caused by entanglement. Both of these factors will result in the number of animals experiencing an entanglement being underestimated.

The analysis is also based on the assumption that any interaction with fishing gear will result in identifiable marks. This may well not be the case, which would mean the true entanglement rate would be higher than has been estimated here. Conversely, once an animal has acquired distinct marks, such as those caused by entanglement, it becomes more identifiable even in poor quality photos, which biases the results towards well-marked individuals. Including only well-marked animals will result in the prevalence of entanglement marks being overestimated in the general population.

Furthermore, there is also an assumption that entanglement marks will be seen on the upper part of the body. Northridge et al., (2010) estimated that only 37% of entanglement marks would be visible above the water line. Analysis of stranding data shows minke whales were most commonly entangled by gear wrapping round the tailstock (64% of cases). In half the cases (46%), the entanglement marks on the tailstock were the only lesions seen, there were no marks on the rest of the body (see section 3.4.3 for full results). Northridge et al., (2010) also showed that this was the most common area for entanglement in this species in Scotland. When minke whales surface, their flukes or tailstock are rarely seen, and as a result, we lack adequate full photographic coverage for 72% of the animals in the catalogue. Therefore, the estimates generated here could be vastly underestimating the entanglement mark rate. Other studies investigating entanglement rate in species that do not frequently fluke have concluded that aerial imagery is a preferred method for estimating entanglement rates for these species (Ramp et al., 2021; Ramp et al., 2019). To overcome this knowledge gap, future studies should consider using drones to capture aerial photographs of minke whales to provide a more accurate assessment. These novel technologies should be used alongside those that can be easily used in the long-term e.g. photo-identification and laser photogrammetry on Silurian. Even though limited data were available for minke whales during this study period, photogrammetry data should continue to be collected and catalogued by HWDT because over time these records will build an important data set providing valuable information on body condition and growth, which can provide an assessment of the health and fitness of individual animals, as well as population demographics (Cheney et al., 2018).

Over the 27-year study period, only two whales showed clear marks and scars that were highly indicative of a previous entanglement in ropes. This may indicate that most entanglements in ropes are fatal for minke whales, and this was also shown in the questionnaire data in which fishers reported finding minke whales dead in 84% of cases, whereas humpbacks were released alive in 73% of cases (see chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement for more detail). One study examining entanglement along the East Coast of the United States of America found that minke whales were found dead entangled in the gear having likely been anchored to the sea bed unable to break free from the ropes in all cases (Knowlton et al., 2016). While larger whales like humpback and right whales, are often able to swim trailing fishing gear, minke whales, which are much smaller, may be unable to do so (Song et al., 2010) and it has been estimated that entanglement in minke whales is fatal in 70% of cases (Lien, 1994).

Even though the more severe cases of non-fatal entanglement affect a small proportion of the live population, such events are still likely to represent an energetically costly unnatural life-history stage for large whales (Van de Hoop et al., 2016). The impact these interactions and injuries have on the fitness of the affected individuals is poorly understood and has received relatively little attention compared to mortalities (Kot et al., 2009). With many of the animals that had been entangled showing tissue damage and deformation to the rostrum and through the baleen, it is likely that the feeding success and welfare of the individuals sustaining these type of chronic injuries may be compromised (Cassoff et al., 2011; Kot et al., 2009). This would have wider implications at the individual and population level as it may lead to reduced reproductive success, and comprise the animal’s overall health and fitness, ultimately increasing the risk of mortality.

On the other hand, there is evidence that some minke whales are able to survive these non-fatal events and may even adapt their feeding behaviour to compensate for the impairment from their injuries (Kot et al., 2009). From the data compiled for this study, most animals assigned to the highest entanglement classification showed entanglement related marks that had already healed, indicating the animals had been able to survive with their injuries for some time. However, with the majority of animals only ever seen once, it is difficult to make any conclusions about the fitness of the animals seen in this study. The long-term impacts and implications on welfare are poorly understood (see a href="#Introduction">chapter 2 - Introduction). Nevertheless, they are likely to be substantial. Future management strategies should consider not only measures to prevent entanglement, but should also consider the implications on the long-term welfare, health and fitness of individuals that may survive a non-fatal incident (Cassoff et al., 2011).

Conclusions and recommendations

We have shown that at least 22% of minke whales seen off the west coast of Scotland since 1990 showed evidence that they may have previously been entangled. These results provide a conservative assessment of non-lethal entanglement in Hebridean minke whales. Effort should continue to catalogue individual animals and effort should be made to increase the photographic coverage of individual animals to allow an assessment of entanglement related scars to be made for a higher proportion of animals. Future studies should consider using drones to capture aerial photographs of minke whales to provide a more accurate assessment of scarring and hence prevalence of entanglement.

Future assessments must continue to include information about the number of live animals that show evidence of entanglement to better understand the implications these types of interactions have on individual animals. Using these data alongside data on mortalities, will provide better estimates of the effects of entanglement on minke whale mortality rates.

We have only focussed on minke whales here, but with recent evidence generated by the SEA project showing the incidence and range of species affected by entanglement is increasing (MacLennan et al., 2019), the methods for assessing entanglement outlined here should also be applied to other species commonly affected by entanglement e.g. basking sharks for which HWDT also hold long-term photo-identification and sightings in the Hebrides.

An industry perspective

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Summary

Various mitigations have been introduced in a bid to reduce the entanglement risk elsewhere around the world, with differing degrees of success or industry approval. The Scottish Creel Fisherman’s Federation (SCFF) consider entanglement to be one of the biggest environmental issues facing its sector and has worked collaboratively with the other SEA partner organisations throughout this project to better understand the issue. In this chapter we have reviewed the evidence, technologies and possible mitigation measures available to reduce the entanglement risk. These include negatively buoyant rope, ropeless technologies and creel limits and their potential suitability for the Scottish creel sector.

Introduction

The impacts of large whale entanglement have been the focus of much research over the last few decades, especially in the USA and Canada where the critically endangered North Atlantic Right Whale (*Eubalaena glacialis*) is particularly vulnerable to entanglement in creel and pot fisheries (Knowlton et al., 2012; Moore and van der Hoop 2012). Various mitigations have been introduced in a bid to reduce the entanglement risk, with differing degrees of success or industry approval, including the use of negatively buoyant ropes and weak links, trials of ropeless gears, and seasonal area closures. Such mitigations have been reviewed by Leaper and Cauldran (2018), Hamilton and Baker (2019) and Lebon and Kelly (2019).

SCFF consider entanglements to be one of the biggest environmental issues facing their sector, and the SEA programme has shown entanglement to be a more significant concern for both conservation and industry than previously thought (chapter 3 - Understanding the distribution, trends and welfare impacts of marine animal entanglements and chapter 7 - Entanglement survivors - assessing the extent of non-lethal entanglement). As a founding partner of SEA, SCFF has worked collaboratively with the other organisations involved to assess and review the evidence, technologies and possible solutions, including mitigation measures available to reduce the entanglement risks posed by their sector, and assess their suitability in Scottish waters. It is imperative that any such measures be proportional to the identified problem and ensure both the conservation of marine species and the safety and economic security of fishers.

It should be noted that while this project has focused exclusively on entanglements in creel fishing gear, and accordingly the potential mitigation measures discussed in this chapter focus on this sector, entanglements are known to occur in a variety of active and ghost mobile and static fishing gears, as well as various forms of marine debris (Stelfox et al., 2016).

Entanglement configurations

Creel gear presents two distinct opportunities for entanglement; the vertical endline, which attaches the creel fleet to a surface marker buoy; and the horizontal groundline to which the creels are attached at set intervals (Figure 28).

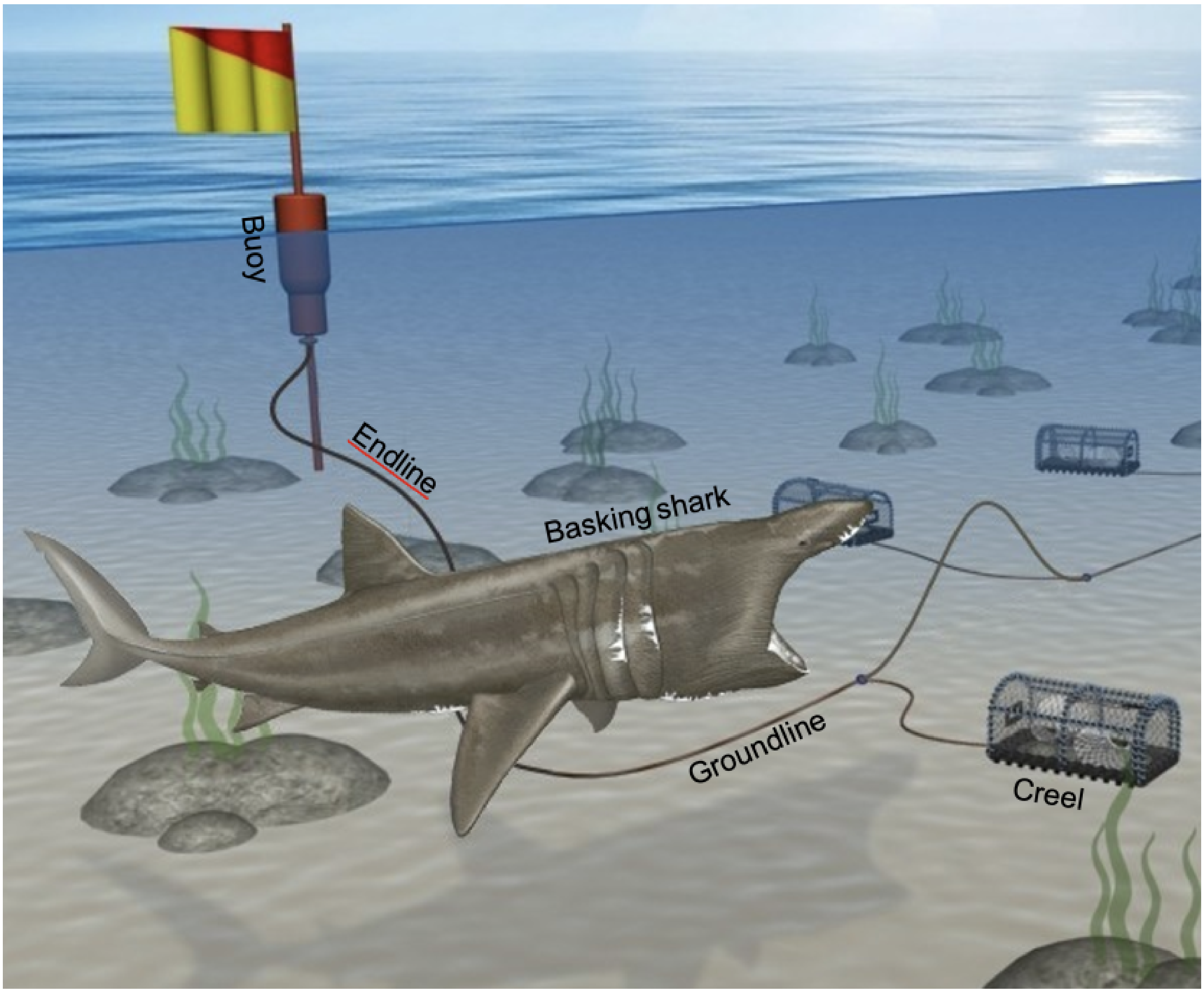

Figure 27. A typical creel fleet. Adapted from Seafish (2020) (see Figure 1).

At least 12 different species of large marine animals were reported entangled by fishers through the SEA questionnaires (chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement), and configurations varied from ropes being caught through the mouth, to around the body, fins and flukes (Figure 29). Entanglement configurations and survival varied between species, suggesting some species are more vulnerable to entanglement than others, depending on their behaviours, physiology, and seasonal abundance.

Identifying and understanding species-specific spatial and temporal movements and variations in both the animals (including behaviour and abundance) and fishing gears affected, and the most common entanglement scenarios, is vital in order to target and maximise the benefits of any proposed mitigation methods. It is also important to note that creel fishing around Scotland is not uniform. A range of practices and preferences are employed, for example the number of creels per fleet and spacing between these, depending on the depth, seabed type, tidal conditions, target species and local agreements. Therefore, any proposed management measures should be considered at a local level to ensure these are suitable for the area.

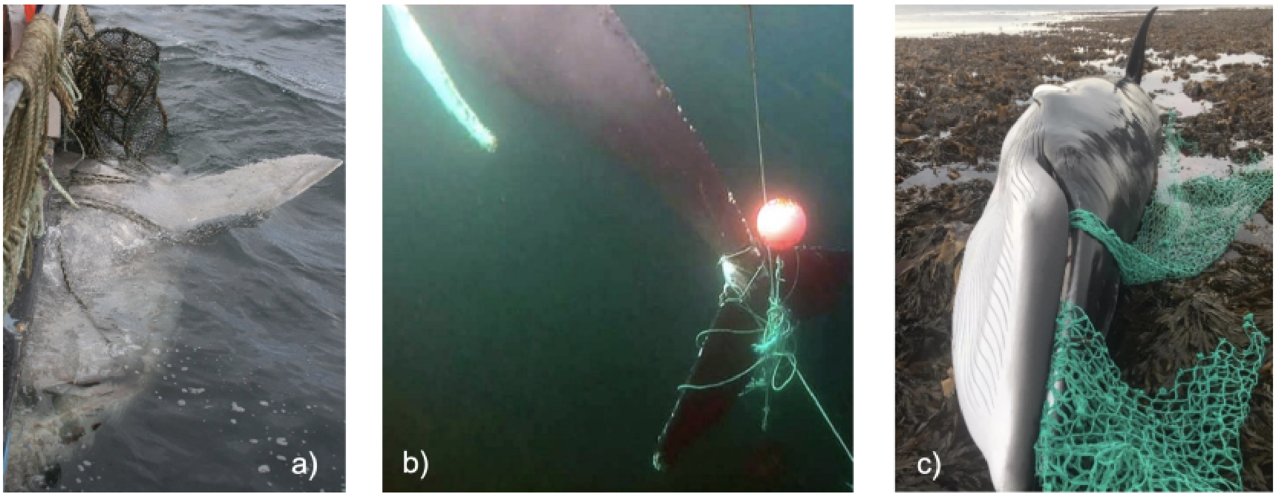

Figure 28. Examples of entanglement cases involving fishing gear in Scotland. (Click for a full description)
a) A basking shark caught in the groundline entangled through the mouth and around the pectoral fins. © Anon. b) A humpback whale caught by the tail in an endline. © BDMLR. c) A pregnant minke whale entangled in a section of netting. © SMASS.

Proposed mitigation measures

Negatively buoyant rope

Within the Scottish inshore creel fishery floating rope is most commonly used to rig fleets, largely because it is cheaper and easier to work with compared to negatively buoyant alternatives. Existing best practise within the sector to reduce entanglement risk includes adjusting end lines for the depth being fished, and weighting these at regular intervals. This avoids excess floating rope at the sea surface, minimising the risk of fouling passing propellers or entangling marine animals. At the seabed little is known about how the groundline behaves (How et al., 2015), however, the assumption is that self-shooting creels and shooting with the tide tightens the groundline, minimising the amount of rope looping above the seabed between creels. These measures were suggested by several interviewees as best practice to minimise entanglement risk (chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement.

The use of negatively buoyant rope was also suggested as a potential entanglement mitigation measure by numerous interviewees, many of whom were already using this in some sections of their endlines. Several suggested that it may be workable on groundlines on soft ground but also highlighted the disadvantages including increased cost, wear, and that this type of rope is heavier and therefore harder to work with. Furthermore, a move to negatively buoyant rope may simply not be safe in some scenarios. For example, for those working over rocky ground, rope designed to lay flat on the seabed is liable to snag or become 'fast', whereby the gear is no longer able to be hauled to the surface. Becoming fast can result in serious safety concerns, excessive loads suddenly being applied to the machinery and ropes can damage hydraulics, break ropes, endanger the vessel and crew, and result in a capsize scenario if operating in large swells.

Negatively buoyant groundlines have been mandated in some static fisheries in the USA after floating ropes were identified as posing a high entanglement risk (ALWTRP, 2007b; Johnson et al., 2005). In 2006, in a bid to reduce the threat of entanglement in static pot fisheries to the North Atlantic right whale, Massachusetts inshore lobster fishers participated in a funded gear exchange, where they could swap floating rope for negatively buoyant rope. The scheme helped alleviate the initial financial burden of complying with the new gear regulations and removed approximately 3,000 miles of floating rope from the water column (MLA, 2009; McKiernan, 2004). In neighbouring Maine, where negatively buoyant rope on the groundlines is a requirement in the lobster fishery, some fishers have reported abandoning traditional grounds characterised by rocky substrate and strong currents, citing increased snagging and chaffing of ropes combined with higher gear losses (McCarron and Tetreault, 2012).

SCFF would support further study to understand the behaviour of floating groundline near the seabed, the feasibility, costs and other implications associated with a move toward negatively buoyant ropes including the potential for this to scour and damage sensitive seabed features, and any positive impact such a move could have in reducing risks of marine animal entanglement. SCFF also recommends fishers be encouraged, potentially through subsidised exchanges and disposal schemes, to transition to negatively buoyant rope when replacing worn lines where safe and practical.

Ropeless technologies

‘Ropeless’ or ‘on-call’ fishing gears include a suite of technologies that remove the requirement for an end line to be present in the water column at all times, instead keeping this coiled at the seabed until it is released via either a timer or acoustic signal in order to be hauled (Figure 30 and Figure 31). Such systems have been used globally in a variety of non-fisheries related marine applications since the 1960s, and over the last 20 years fisher-led adaptations of these devices for use within creel and trap fisheries to reduce risks of both marine animal entanglements and costly gear loss have gained momentum (Myers et al., 2019; Trippel, 2019).

Much like negatively buoyant rope, ropeless or ‘on-call’ technologies have several issues both in practicality and price, however the potential for these systems to eliminate entanglement risk in vertical lines is infinite, and trials are ongoing in USA and Canadian pot fisheries in a bid to reduce this threat (Trippel, 2019; Shester, 2018).

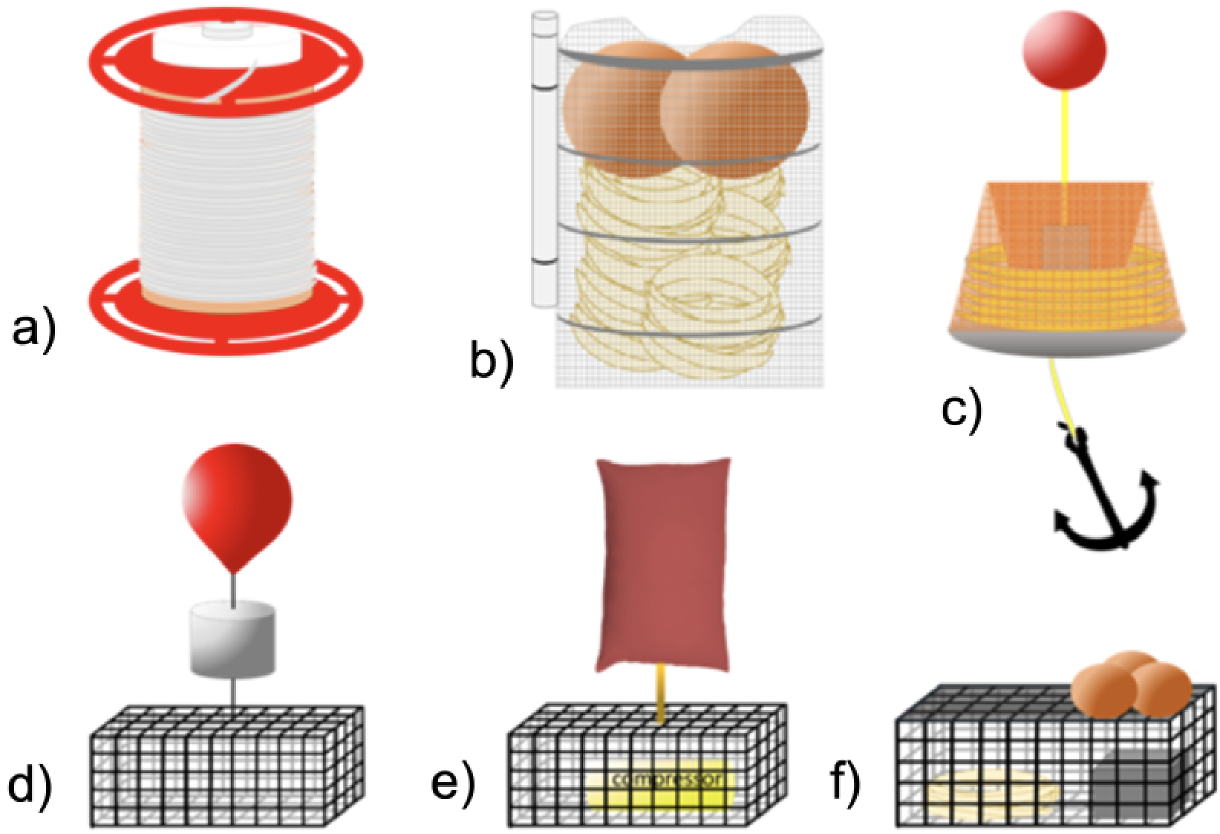

Figure 29. Ropeless or ‘on-call’ gear designs currently being developed. (Click for a full description)
Top L to R: a) Fiobuoy, b) DesertStar ARC-1, c) Ashored-Mobi. Bottom L to R: d) LobsterLift, e) SMELTS LobsterRaft, f) EdgeTech 5112. © Kim Sawicki.

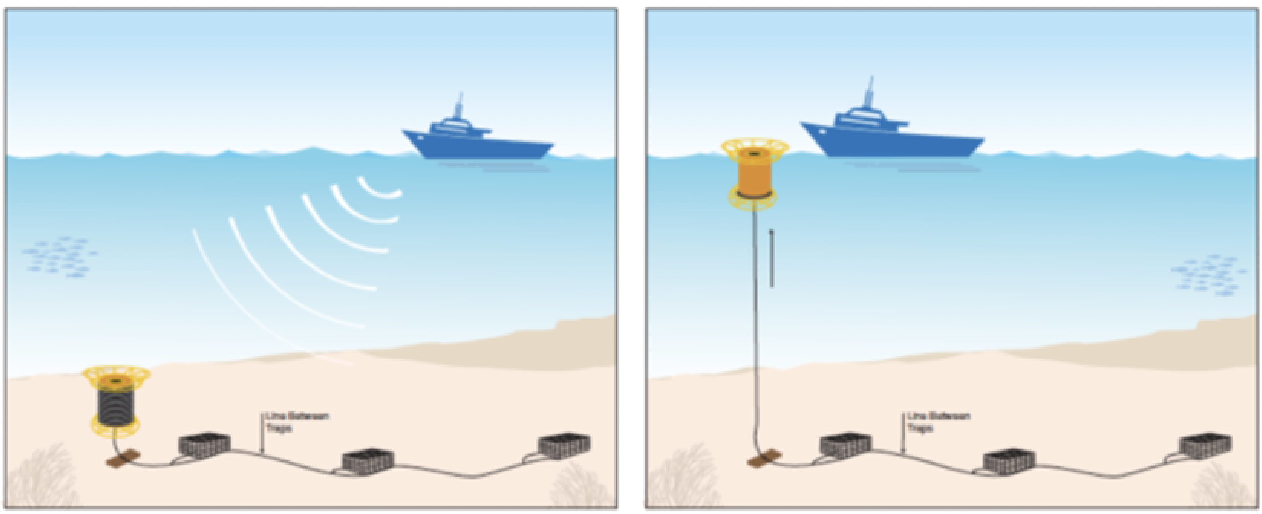

Figure 30. An illustration of a ropeless fishing system using a flotation spool. © Tim Werner/New England Aquarium.

The principal concern associated with ropeless technologies at present is cost, as most systems are still in development and production is not yet at a commercial scale. In addition, these systems will not mitigate entanglement risk in groundlines where the majority of basking sharks and minke whales reported by fishers were caught and the removal of any surface marker to indicate gear location is not only illegal in some areas, but a huge departure from current fishing practise where a visual indication of gear location and orientation is essential to prevent fishers setting or towing over each other’s gear. These systems come with apps designed to allow for virtual gear marking using integrated GPS, which log gear locations and display these to other fishers operating within a pre-set radius (e.g. Desert Star). These systems are not dissimilar to vessel tracking systems currently being deployed by Marine Scotland across the Scottish fishing fleet (e.g. SIFIDS) and could facilitate future use of ropeless technologies in these waters. Informal trials of two ropeless prototypes were conducted during the SEA programme in collaboration with Sustainable Seas (Figure 32) and support exists to formalise these. SCFF believe that as the technology develops Scottish fishers should participate in refining this to suit their own needs, and recommend trials of ropeless fishing gears be continued in defined areas to determine if these systems could realistically be deployed.

Figure 31. Kim Sawicki of Sustainable Seas demonstrating two ropeless systems to Inner Sound fishers. © Ellie MacLennan.

Effort regulation

Ropeless technologies and negatively buoyant rope both require rigorous testing and consultation to assess whether either option could offer a practical, economically feasible solution to the entanglement issue. However, one of the most obvious mitigations is to regulate creel fishing effort, and therefore the density of gear in the water. There is currently no restriction on the number of creel vessels in operation, the amount of gear each vessel can deploy, or creel densities per unit area and there is very little mapping data available on creel fishing activity. Scotmap provides a snapshot, however this data is already several years old and although the creel densities vary by area, overall fishing effort is increasing (Marine Scotland, 2014; Marine Scotland Science, 2017). There are also concerns over the practice of wet storage of creels, where gear is left untended for prolonged periods of time, the use of creels to mark territory and the deliberate disposal of spent gear at sea. Available (limited) evidence suggests large marine populations including humpback whales and basking sharks are beginning to recover from historic over-exploitation (O’Neil et al., 2019; Witt et al., 2012). In combination with increases in creel gear densities this will, without counter measures, likely result in a continuing increase in entanglement incidents (Ryan et al., 2016; Myer et al., 2012).

Pilot schemes exploring creel limits and/or separation of mobile and static vessels have been proposed and are in the early stages of development by Marine Scotland, the Outer Hebrides Regional Inshore Fisheries Group (RIFG), the Arbroath and Montrose static gear association, the Mull Fishermen’s Association and the Shetland Shellfish Management Organisation (SSMO). A 2017 study into creel fishing effort by Marine Scotland highlighted that industry support for better regulation of fishing effort exists, and that current shellfish management needs to be reviewed. Creel saturation has been voiced as the key concern for shellfish fisheries on both the east and west coasts of Scotland, and exploring the options of creel limits is widely supported (Marine Scotland, 2017). These concerns were echoed in the SEA fisher interviews, where a reduction in fishing effort and gear densities by area was frequently given as an entanglement mitigation measure that fishers would support (chapter 3 - Understanding the distribution, trends and welfare impacts of marine animal entanglements).

SCFF have been advocating for a creel limit per vessel and a mechanism to limit the amount of vessels in any given area to regulate fishing effort. To inform this process, we recommend the prevalence of species known to be susceptible to entanglement be mapped and compared to areas of highest creel densities (and therefore potential highest entanglement risk, depending on factors such as fishing depth, see chapter 3 - Understanding the distribution, trends and welfare impacts of marine animal entanglements and chapter 5 - Coast and socio-economic impacts of marine animal entanglement to the Scottish creel fishery), and this risk be considered in setting creel limits. The Scottish Government's new Fleet Modernisation Program (Scottish Government 2020), which will require all Scottish vessels to use tracking systems will potentially lend itself well to developing trials of some suggested mitigation measures by mapping fishing effort.

Disentanglement training

A major hurdle to overcome in understanding the extent of the entanglement issue in Scottish waters and potential solutions to this is engagement with the fishing community, which to date has been lacking. Without the necessary data, it is impossible to ensure that mitigation measures are applied at a scale appropriate to the scale of the problem. From the available data only a fraction of entanglement incidents may be being reported (as few as 2%) by fishers and other marine users (chapter 3 - Understanding the distribution, trends and welfare impacts of marine animal entanglements and chapter 4 - Capturing fishermen's knowledge - Fishing activity and experience of entanglement). Reasons for this may include a lack of understanding of the relevant legislation surrounding marine animal protection, not knowing who to report these incidents to or why this information may be useful, and fear of negative repercussions against individuals or their respective industry. What did become very clear through fisher interviews is that although fishers may not be reporting entanglement events, when live animals are encountered, many have been able to successfully release these. Scotland does have a team trained in large whale disentanglement run by SEA partner British Divers Marine Life Rescue (BDMLR). SEA partners felt that there was an obligation to support fishers by ensuring that they have access to the knowledge, skills and assistance available if required, and similarly facilitate opportunities for existing disentanglement teams to learn from fisher's experiences and expertise.

In October 2019, 20 inshore creel fishers took part in a disentanglement training course (Figure 33). The first of its kind to be held in Europe, fishers travelled to Ullapool from as far as the Clyde to Shetland to work alongside SEA project partners including BDMLR. The course was delivered by David Mattila, Technical Advisor to the International Whaling Commission (IWC) on Entanglement Response and Ship Strike Reduction, and co-ordinator of the Global Whale Entanglement Response Network. Since 1984, David has helped to develop unique rescue tools, techniques and training programs and has to date trained more than 1200 responders in 34 countries.

Figure 32. David Mattila demonstrating some of the bespoke tools designed for freeing entangled whales. © Ellie MacLennan.

The two-day course comprised a full day of on-water training in assessing and approaching both free-swimming and anchored whales using local fishing and support vessels (Figure 34). The aim was to inspire better relationships between fishers to SEA partners, encourage better reporting of entanglements, widen Scotland's existing entanglement response network, and share insights to better understand, mitigate and respond to these incidents.

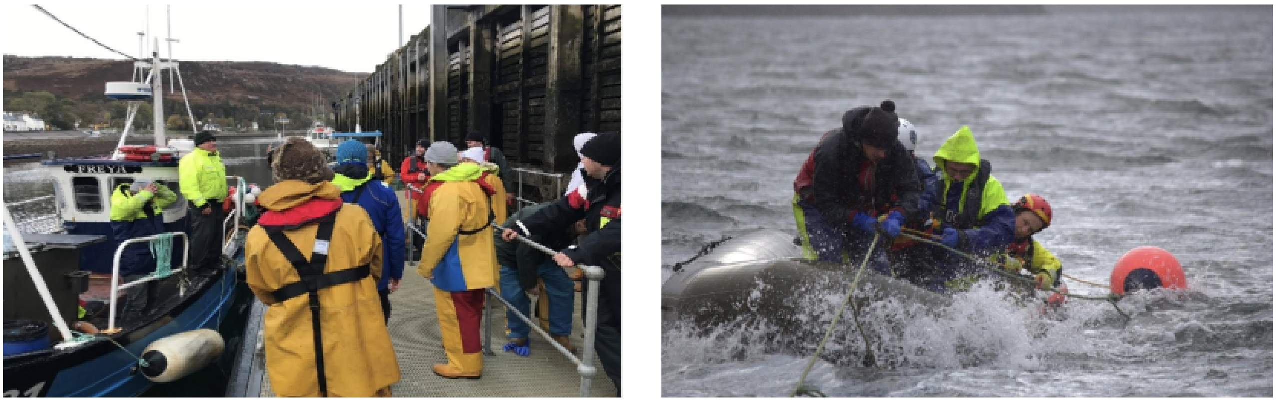

Figure 33. a) David Mattila briefing fishers on methods of assessing and approaching entangled whales. b) Fishers and BDMLR large whale disentanglement team members practicing a Nantucket sleighride © Ellie MacLennan. (Click for a full description)
Nantucket sleighride is a technique originally developed by whalers and adapted to safely attach to and approach free-swimming entangled whales.

The course received very positive feedback and further training events were planned throughout 2020 however, given the restrictions that arose as a result of COVID-19, these have been postponed until further notice. In the interim online resources are available at: www.scottishentanglement.org and www.bdmlr.org.uk.

Disentanglement is not a long-term solution; the ultimate goal is to prevent entanglements but until suitable measures can be put in place to eliminate the risk, disentanglement is a vital interim measure. However, every effort must be made to ensure that such tasks are conducted as safely and efficiently as possible.

Conclusions and recommendations

Marine animal entanglement in creel gear has been identified as a concern in Scottish waters, and the available evidence suggests that not only is creel fishing effort increasing, but so too are the incidence and range of species being affected by entanglement.

This phase of SEA focussed on assessing whether an entanglement problem exists in Scottish waters, and has found that many more incidents are occurring than are being reported. It has also identified numerous potential measures to reduce entanglement risk. All of these will require a change in fishing behaviours and/or techniques and therefore we recommend a second SEA phase be launched, to start trialling these mitigation measures and assess which, if any could be feasible in Scotland. A key component of any trials will be to maintain input from the fishing industry, and ensure fishers continue to be encouraged to report entanglement incidents in order to improve knowledge and data required to initiate effective change. SCFF recommend the following to form part of a SEA phase two programme of research:

- Compiling detailed temporal and spatial maps of creel fishing effort and density by all vessels and comparing this to sites of known presence and movement patterns of species vulnerable to entanglement (baleen whales, basking sharks and marine turtles) and previous entanglement events.
- Developing systems of virtual vessel and gear tracking to allow these maps to be updated in near real-time.
- Consulting on and developing clear and enforceable creel density limits at regional and local levels.
- Producing educational and outreach materials to encourage and facilitate better engagement from industry in reporting entanglement events.
- Continuing a programme of disentanglement training events specifically for fishers.
- Formalising, funding and developing fisher-led trials of negatively buoyant ropes and ropeless technologies, initially within the prawn fishery and potentially using newly designated Nature Conservation Marine Protected Areas (MPAs) for minke whale and basking shark features as research and development sites.
- Inviting other fishing sectors that may also pose a bycatch and/or entanglement risk to participate in these measures.

These recommendations are based on feedback from the Scottish creel fishing community gained through interviews, workshops, and gear demonstrations.

References

ALWTRP, 2007a. Final environmental impact statement: broad-based gear modifications. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, US Department of Commerce, Washington, DC.

ALWTRP, 2007b. Atlantic Large Whale Take Reduction Plan: Final environmental impact statement - broad-based gear modifications.

Anderwald, P. and Evans, P.G.H. 2007. Minke whale populations in the North-Atlantic – an overview with special reference to UK Waters. In: an integrated approach to non-lethal research on minke whales in European waters (Editors K.P. Robinson, P.T. Stevick and C.D. MacLeod). *European Cetacean Society Special Publication Series*, 47, 8-13.

Asmutis-Silvia, R., Barco, S., Cole, T., Henry, A., Johnson, A., Knowlton, A., Landry, S., Mattila, D., Moore, M., Robbins, J. and van der Hoop, J. 2017. Rebuttal to published article '*A review of ghost gear entanglement amongst marine mammals, reptiles and elasmobranchs'* by M. Stelfox, J. Hudgins, and M. Sweet. Marine Pollution Bulletin. 117 (1-2), 554–555.

Borggaard, D.L., Gouveia, D.M., Colligan, M.A., Merrick, R., Swails, K.S., Asaro, M.J., Kenney, J., Salvador, G. and Higgins, J. 2017. Managing US Atlantic large whale entanglements: Four guiding principles. *Marine Policy,* 84, 202-212.

Brownlow, A., Davison, N., ten Doeschate, M., Ryan, C. and Leaper, R. 2017. Knot a problem? Distribution and pathology of fatal entanglements in large marine animals in Scotland. *Proceedings of the 31st Annual Conference of the European Cetacean Society, Middlelfart, Denmark,* pp. 69.

Cassoff, R.M., Moore, K.M., McLellan, W.A., Barco, S.G., Rotstein, D.S. and Moore, M.J. 2011. Lethal entanglement in baleen whales. *Diseases of Aquatic Organisms*, 96,175–185.

Cheney, B., Wells, R.S., Barton, T.R. and Thompson, P.M. 2018. Laser photogrammetry reveals variation in growth and early survival in free‐ranging bottlenose dolphins. *Animal Conservation*, 21, 252-261.

Cole, T., Hartley, D. and Garron, M. 2006. Mortality and serious injury determinations for baleen whale stocks along the eastern seaboard of the United States, 2000−2004. Northeast Fisheries Science Center Reference Document 06–04, Gloucester, MA. 26 pp.

Czaja, R. and Blair, J. 2005. Designing surveys: a guide to decisions and procedures. Pine Forge Press: Thousand Oaks, California.

Doherty, P.D., Baxter, J.M., Godley, B.J., Graham, R.T., Hall, G., Hall, J., Hawkes, L.A., Henderson, S.M., Johnson, L., Speedie, C. and Witt, M.J. 2019. Seasonal changes in basking shark vertical space use in the north-east Atlantic. *Marine Biology*, 166, 1-12.

Dolman, S.J. and Moore, M.J. 2017. Welfare implications of cetacean bycatch and entanglements. In: Butterworth, A. (ed) *Marine Mammal Welfare*. Springer International Publishing, Cham, pp. 41–65.

Evans, P.G.H. and Hammond, P.S. 2004. Monitoring cetaceans in European waters. *Mammal Review*, 34, 131–156.

Fulton, G. 1998. Fishery audit and assessment for the Loch Torridon Area, Minch project. In: McGoodwin, J.R. Understanding the cultures of fishing communities: A key to fisheries management and food security. Rome: FAO Fisheries Technical Paper 401.

Gailey, G. and Karczmarski, L. 2012. DISCOVERY: Photo-identification data-management system for individually recognizable animals.

Gill, A. 1994. The photo-identification of the minke whale (*Balaenoptera acutorostrata*) off the Isle of Mull, Scotland. MSc Thesis, Aberdeen University. 67 pp.

Gill, A. and Fairbairns, R. 1995. Photo-Identification of the minke whale (*Balaenoptera acutorostrata*) off the Isle of Mull, Scotland. In *Whales, Seals, Fish and Man* (ed. A.S. Blix, L.Walløe and Ø. Ulltang). Netherlands: Elsevier Science. 129-132.

Groom, C.J. and Coughran, D.K. 2012. Entanglements of baleen whales off the coast of Western Australia between 1982 and 2010: patterns of occurrence, outcomes and management responses. *Pacific Conservation Biology*, 18, 203-214.

Hamilton, S. and Baker, G.B. 2019. Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. *Reviews in Fish Biology and Fisheries*, 29, 223–247.

Hebridean Whale and Dolphin Trust, 2018. Hebridean Marine Mammal Atlas. Part 1: Silurian, 15 years of marine mammal monitoring in the Hebrides. A Hebridean Whale and Dolphin Trust Report, Scotland, UK. 60 pp.

How, J., Coughran, D., Smith, J., Double, M., Harrison, J., McMath, J., Hebiton, B. and Denham, A. 2015. Effectiveness of mitigation measures to reduce interactions between commercial fishing gear and whales. FRDC Project No 2013/03. Fisheries Research Report No. 267.

IWC, 2010. Report of the workshop on the welfare issues associated with the entanglement of large whales IWC/62/15.

IWC, 2017. Report of the Workshop to Support the IWC's Consideration of Non-Hunting Related Aspects of Cetacean Welfare. IWC/66/WKM&WI Rep 01. 34 pp.

Johnson, A., Salvador, G., Kenney, J., Robbins, J., Kraus, S., Landry, S. and Clapham, P. 2005. Fishing gear involved in entanglements of right and humpback whales. *Marine Mammal Science*, 21, 635-645.

Kot, B.W., Ramp, C., and Sears, R. 2009. Decreased feeding ability of a minke whale (*Balaenoptera acutorostrata*) with entanglement-like injuries. *Marine Mammal Science*, 25, 706-713.

Knowlton, A. R., M. K. Marx, H. M. Pettis, P. K. Hamilton, and S. D. Kraus. 2003. Analysis of scarring on North Atlantic right whales (Eubalaena glacialis): Monitoring rates on entanglement interaction. Available from the Centre for Coastal Studies, Box 1036, Provincetown, MA 02657.

Knowlton, A.R., Hamilton, P.K., Marx, M.K., Pettis, H.M. and Kraus, S.D. 2012. Monitoring North Atlantic right whale (*Eubalaena glacialis*) entanglement rates: a 30-year retrospective. *Marine Ecology Progress Series*, 466, 293-302.

Knowlton, A.R., Robbins, J., Landry, S., McKenna, H.A., Kraus, S.D. and Werner, T.B. 2016. Effects of fishing rope strength on the severity of large whale entanglements. *Conservation Biology*, 30, 318-328.

Kraus, S.D. 1990. Rates and potential causes of mortality in North Atlantic right whales (*Eubalaena glacialis*). *Marine Mammal Science*, 6, 278–291.

Lien, J. 1994. Entrapments of large cetaceans in passive inshore fishing gear in Newfoundland and Labrador (1979-1990). Report to the International Whaling Commission, Special Issue 15, pp. 149-157.

Leaper, R. and Calderan, S. 2018. Review of methods used to reduce risks of cetacean bycatch and entanglements. CMS Series. 38, 76 pp.

Lebon, K.M. and Kely, R.P. 2019. Evaluating alternatives to reduce whale entanglements in commercial Dungeness Crab fishing gear. *Global Ecology and Conservation*, 18, 1-12.

MacLennan, E., Leaper, R., and Dolman, S. 2019. Interim report from the Scottish Entanglement Alliance (SEA) on previously undocumented fatal entanglements of minke whales (*Balaenoptera acutorostrata*) in Scottish inshore waters. Paper presented to the International Whaling Commission Scientific Committee. SC/68A/HIM/02. 4 pp.

MacLennan, E., Leaper, R., Brownlow, A.C., Calderan, S. Jarvis, D., Hartny-Mills, L. and Ryan, C. 2020. Estimates of humpback and minke whale entanglements in Scotland. Paper presented to the International Whaling Commission Scientific Committee. SC/68B/HIM/01. 15 pp.

Marine Scotland, 2014. ScotMap Inshore fisheries mapping project in Scotland.

Marine Scotland Science, 2017. Creel fishing effort study. A Marine Scotland Science Report produced by the Marine Analytical Unit. 47 pp.

Marine Scotland, 2020. Outer Hebrides inshore fisheries pilot.

Meÿer, M.A., Best, P.B., Anderson-Reade, M.D., Cliff, G., Dudley, S.F.J. and Kirkman, S.P. 2012. Trends and interventions in large whale entanglement along the South African coast. *African Journal of Marine Science*, 33(3), 429-439.

McCarron, P. and Tetreault, H. 2012. Lobster pot gear configurations in the Gulf of Maine. 36 pp.

Mckiernan, D. 2004. Lobstermen gear-up with whale-safe lines. *DMF News*, 25, 1-2.

Mellor, D.J. 2017. 'Operational details of the five domains model and its key applications to the assessment and management of animal welfare', *Animals*, 7, 60.

Minton, G. 2008. *Megaptera novaeangliae*, Arabian Sea subpopulation. IUCN Red List of Threatened Species.

MLA, 2009. Massachusetts lobster fishing – the right way.

Moore, M.J. and van der Hoop, J.M. 2012. The painful side of trap and fixed net fisheries: chronic entanglement of large whales. *Journal of Marine Biology*, 12, 1-4.

Myers, H. J., Moore, M. J., Baumgartner, M. F., Brillant, S. W., Katona, S. K., Knowlton, A. R., Morissette, L., Pettis, H.M., Shester, G. and Werner, T.B. 2019. Ropeless fishing to prevent large whale entanglements: ropeless Consortium report. *Marine Policy*, 107.

NatureScot, 2019a. European protected species.

NatureScot, 2019b. Conservation and Management Advice, Sea of the Hebrides possible MPA.

Neilson, J. L., Straley, J.M., Gabriele, C.M. Hills, S. and Bellwood, D. 2009. Non-lethal entanglement of humpback whales (*Megaptera novaeangliae*) in fishing gear in northern Southeast Alaska. *Journal of Biogeography*, 36, 452-464.

Nicol, C., Bejder, L. Green, L. Johnson, C. Keeling, L. Noren, D. Van der Hoop, J. and Simmonds, M. 2020. Anthropogenic threats to wild cetacean welfare and a tool to inform policy in this area. *Frontiers in Veterinary Science*, 7, 1-12.

Northridge, S., Cargill, A., Coram, A., Mandleberg, L., Calderan, S. and Reid, R. 2010. *Entanglement of minke whales in Scottish waters: an investigation into occurrence, causes and mitigation*. Contract Report. Final Report to Scottish Government CR/2007/49. 57 pp.

O'Neil, K.E., Cunningham, E.G. and Moore, D.M. 2019. Sudden seasonal occurrence of humpback whales *Megaptera novaeangliae* in the Firth of Forth, Scotland and first confirmed movement between high-latitude feeding grounds and United Kingdom waters. Marine Biodiversity Records, 12(12), 1-5.

Parton, K.J., Galloway, T.S. and Godley, B.J. 2019. Global review of shark and ray entanglement in anthropogenic marine debris. *Endangered Species Research*, 39, 173-190.

Philp, A. and Philp, M. 2018. The 3 mile limit. The case for a sustainable fishery.

Ramp, C., Gaspard, D., Gavrilchuk, K., Unger, M., Schleimer, A., Landry, S. and Sears, R. 2019. Perception bias: How aerial imagery revealed underrated threat of entanglement in large rorquals. Proceedings of the World Marine Mammal Conference, Barcelona, Spain, pp. 585.

Ramp, C., Gaspard, D., Gavrilchuk, K., Unger, M., Schleimer, A., Delarue, J., Landry, S. and Sears, R. 2021. Up in the air: drone images reveal underestimation of entanglement rates in large rorqual whales'. *Endangered Species Research*, 44, 33-44.

Rayner, J.E. 2016. Minke whale entanglement in creel fishing gear: Identifying consistent areas of high risk in the Hebrides. MRes Thesis, Plymouth University, 58 pp.

Read, A.J. 2008. The looming crisis: interactions between marine mammals and fisheries. *Journal of Mammalogy*, 89, 541-548.

Richardson, K., Asmutis-Silvia, R., Drinkwin, J., Gilardi, K.V.K., Giskes, I., Jones, G., O'Brien, K., Pragnell-Raasch, H., Ludwig, L., Antonelis, K., Barco, S., Henry, A., Knowlton, A., Landry, S., Mattila, D., MacDonald, K., Moore, M., Morgan, J., Robbins, J., van der Hoop, J. and Hogan, E. 2019. Building evidence around ghost gear: Global trends and analysis for sustainable solutions at scale. *Marine Pollution Bulletin*, 138, 222-229.

Robbins, J. and Mattila, D.K. 2001. Monitoring entanglements of humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine on the basis of caudal peduncle scarring. Paper presented to the International Whaling Commission Scientific Committee. SC/53/NAH25. 14 pp.

Robbins, J. and Mattila, D. 2004. Estimating humpback whale (*Megaptera novaeangliae*) entanglement rates on the basis of scar evidence. Final report Northeast Fisheries Science Center, Woods Hole, Massachusetts.

Robbins, J., Landry, S. and Mattila, D. 2009. Estimating entanglement mortality from scar-based studies. Paper presented to the International Whaling Commission Scientific Committee. SC/61/BC3.

Ryan, C., Leaper, R., Evans, P.G.H., Dyke, K., Robinson, K.P., Haskins, G.N., Calderan, S., van Geel, N., Harries, O., Froud, K., Brownlow, A. and Jack, A. 2016. Entanglement: an emerging threat to humpback whales in Scottish waters. Paper presented to the International Whaling Commission Scientific Committee. SC/66b/HIM/01. 11 pp.

Seafish, 2020. Fishing gear database.

Scottish Entanglement Alliance, 2018. Understanding marine animal entanglement in Scottish waters. A Scottish Entanglement Alliance Product, Scotland, UK, 16 pp.

Scottish Government, 2020. Support for inshore fisheries.

Shester, G. 2018. Initial Ropeless Gear Trials in the California Dungeness Crab Fishery. Oceana.

SMASS, 2019. The Scottish Marine Animal Stranding Scheme.

Song, K.J., Kim, Z.G., Zhang, C.I. and Kim, Y.H. 2010. Fishing gears involved in entanglements of minke whales (*Balaenoptera acutorostrata*) in the East Sea of Korea. *Marine Mammal Science*, 26, 282-295.

Stelfox, M., Hudgins, J. and Sweet, M. 2016. A review of ghost gear entanglement amongst marine mammals, reptiles and elasmobranchs. *Marine Pollution Bulletin*, 111, 6-17.

Teng KT-Y, Devleesschauwer B, Maertens De Noordhout C, Bennett P, McGreevy PD, Chiu P-Y, Toribio, J-A.,L.M.L. and Dhand, N.K. 2018. Welfare-Adjusted Life Years (WALY): A novel metric of animal welfare that combines the impacts of impaired welfare and abbreviated lifespan. *PLoS ONE,* 13: e0202580.

Trippel, E. 2019. Canadian Support for Ropeless Fishing and Gear Innovation Summit. Fisheries and Oceans Canada.

Van der Hoop, J., Corkeron, P. and Moore, M. 2016. Entanglement is a costly life-history stage in large whales. *Ecology and Evolution,* 7, 92-106.

Vanhatalo, J., Vetemaa, M., Herrero, A., Aho, T. and Tiilikainen, R. 2014. By-catch of grey seals (*halichoerus grypus*) in baltic fisheries - a bayesian analysis of interview survey. *PLoS ONE,* 9, 1-16.

White, P.C.L., Jennings, N.V., Renwick, A.R. and Barker, N.H.L. 2005. Questionnaires in ecology: a review of past use and recommendations for best practice. *Journal of Applied Ecology*, 42, 421-430.

Williams, C. and Carpenter, G. 2016. The Scottish nephrops fishery: applying social, economic, and environmental criteria. New Economics Foundation. 73 pp.

Witt, M.J., Hardy, T., Johnson, L., McClellan, C.M., Pikesley, S.K., Ranger, S., Richardson, P.B., Solandt, J., Speedie, C., Willaims, R. and Godley, B.J. 2012. Basking sharks in the Northeast Atlantic: spatio-temporal trends from sightings in UK waters. *Marine Ecology Progress Series*, 459, 121-134.

Woodhead, C., M. Weinrich, J. Robbins, and S. Brault. 2001. A technique to screen humpback whale populations for risk of serious entanglement using fluke photographs. Paper presented to the International Whaling Commission's Scientific Committee. SC/55/BC3. 15 pp.