Vol. 49: 217–232, 2022
https://doi.org/10.3354/esr01214

ENDANGERED SPECIES RESEARCH
Endang Species Res

Published December 22

Estimates of humpback and minke whale entanglements in the Scottish static pot (creel) fishery

Russell Leaper[1,*], Ellie MacLennan[2], Andrew Brownlow[2], Susannah V. Calderan[3], Katie Dyke[4], Peter G. H. Evans[5], Lauren Hartny-Mills[6], Dan Jarvis[7], Lauren McWhinnie[8], Alistair Philp[9], Fiona L. Read[4], Kevin P. Robinson[10], Conor Ryan[11]

[1]International Fund for Animal Welfare, London SE1 8NL, UK
[2]Scottish Marine Animal Stranding Scheme, Institute of Biodiversity, Animal Health & Comparative Medicine, College of Medical, Veterinary & Life Sciences, University of Glasgow, Glasgow G12 8QQ, UK
[3]Scottish Association for Marine Science (SAMS), Argyll PA37 1QA, UK
[4]Whale and Dolphin Conservation, Spey Bay, Fochabers IV32 7PJ, UK
[5]Sea Watch Foundation, Ewyn Y Don, Bull Bay, Amlwch, Anglesey LL68 9SD, UK
[6]Hebridean Whale and Dolphin Trust, 28 Main Street, Tobermory, Isle of Mull PA75 6NU, UK
[7]British Divers Marine Life Rescue, Lime House, Regency Close, Uckfield TN22 1DS, UK
[8]Institute of Life and Earth Sciences, Heriot-Watt University, Edinburgh EH14 4AS, UK
[9]Scottish Creel Fishermen's Federation, 5 Queen Elizabeth Cottages, Furnace, Inveraray PA32 8XX, UK
[10]Cetacean Research & Rescue Unit (CRRU), PO Box 11307, Banff AB45 3WB, UK
[11]2 Shore Street Close, Tobermory PA75 6NT, UK

ABSTRACT: Entanglement in static fishing gear (pots, or creels as they are called in Scottish fisheries) is a major cause of anthropogenic mortality and morbidity in large whales globally; in northeastern Atlantic waters around the coast of Scotland, entanglement is a particular welfare and conservation concern for minke whales *Balaenoptera acutorostrata* and humpback whales *Megaptera novaeangliae*. Reports from strandings, live disentanglements and interviews with Scottish inshore creel fishers were gathered to estimate entanglement rates. Considerably more whale entanglements occur in the Scottish creel fishery than previously thought based on strandings alone, with estimates of 6 humpback whales and 30 minke whales becoming entangled each year. Where entanglement type was reported, 83 % of minke and 50 % of humpback whales were caught in groundlines between creels. There was a positive correlation between the average amount of gear set by a vessel and the number of minke whale entanglements. For the west coast of Scotland, the estimated annual fatal entanglement rate of minke whales is 2.3 % of a recent abundance estimate, suggesting a risk of localised depletion. There are very low densities of humpback whales in Scottish waters, but opportunistic observations suggest numbers are increasing. The estimated number of annual humpback whale entanglements also shows an increasing trend. There are few entanglement estimates for static pot fisheries globally; this study provides an indication of how such data might be derived. Scottish creel fishers have shown a willingness to engage in entanglement mitigation, with suggestions such as the introduction of sinking groundline to the sector, and these options should be urgently pursued.

KEY WORDS: Minke whale · Humpback whale · Entanglement · Bycatch · Creel fishery · Scotland

1. INTRODUCTION

Whale entanglement in static pot/trap fishing gear has been identified globally as a major cause of large whale mortality (Hamilton & Baker 2019). It has been documented in areas such as western Australia (humpback whales *Megaptera novaeangliae*, How et al. 2021), the Republic of Korea (minke whales *Balaenoptera acutorostrata*, Song et al. 2010) and the northeastern USA (North Atlantic right whales

*Corresponding author: russell@rcleaper.com

Publisher: Inter-Research · www.int-res.com

Eubalaena glacialis; Knowlton et al. 2012). Entanglement in pot and trap fishing gear is also the largest cause of non-natural mortality in baleen whales stranded around Scotland (where pots are known locally as creels) (Northridge et al. 2010); however, the issue is not well understood. Data collected by the Scottish Marine Animal Stranding Scheme (SMASS) and from media reports suggest both the incidence and diversity of megafauna species which become entangled in creel gear are increasing. The creel fishing industry in Scotland primarily targets *Homarus gammarus* (lobster), *Nephrops norvegicus* (langoustine, known locally as prawns, referred to hereafter as *Nephrops*), *Cancer pagurus* (brown crab) and *Necora puber* (velvet crab). A typical deployment of creels is shown in Fig. 1. Creels are set in a fleet which comprises a number of creels attached to connecting rope. The Marking of Creels (Scotland) Order 2020 (https://www.legislation.gov.uk/ssi/2020/168/made/data.pdf) requires any fleet of more than 10 creels to have at least 1 marker buoy fixed to each end of the fleet. The length of line between creels and number of creels in a fleet vary between areas, between vessels and by target species. A typical setup for a small (12 m long) inshore vessel fishing for *Nephrops* would be a fleet of 55 to 60 creels with 14 to 15 m of groundline between each creel (Fig. 1). The creels are joined to the groundline with leg lines, which would be around 2 m in length for such a setup. Lines are made from polypropylene, which is buoyant (0.905 g cm^{-3}), and are typically 10 or 12 mm in diameter.

The cetacean species most frequently reported entangled in Scottish waters are minke whales and humpback whales (MacLennan et al. 2019, 2021). However, estimates of the total numbers of entanglement events have not been available, and reported cases are known to represent only a small percentage of total incidents due to underreporting, logistical challenges in recovering carcasses for post-mortem examinations and the low likelihood of at-sea carcasses making landfall.

Here, we combine a range of data sources to provide estimates of the numbers of minke and humpback whale entanglements in Scottish waters over the last 10 yr. We present information provided by the creel fishing community on the nature of entanglements encountered and possible ways of reducing future entanglement risks. These data originate primarily from the Scottish Entanglement Alliance (SEA) (www.scottishentanglement.org), which was established to generate a better understanding of the extent of entanglement within the creel sector. It is a partnership between 6 marine research, industry, conservation and welfare bodies aiming to provide a coordinated comprehensive monitoring and engagement programme to better understand the scale and impact of marine animal entanglements in Scottish

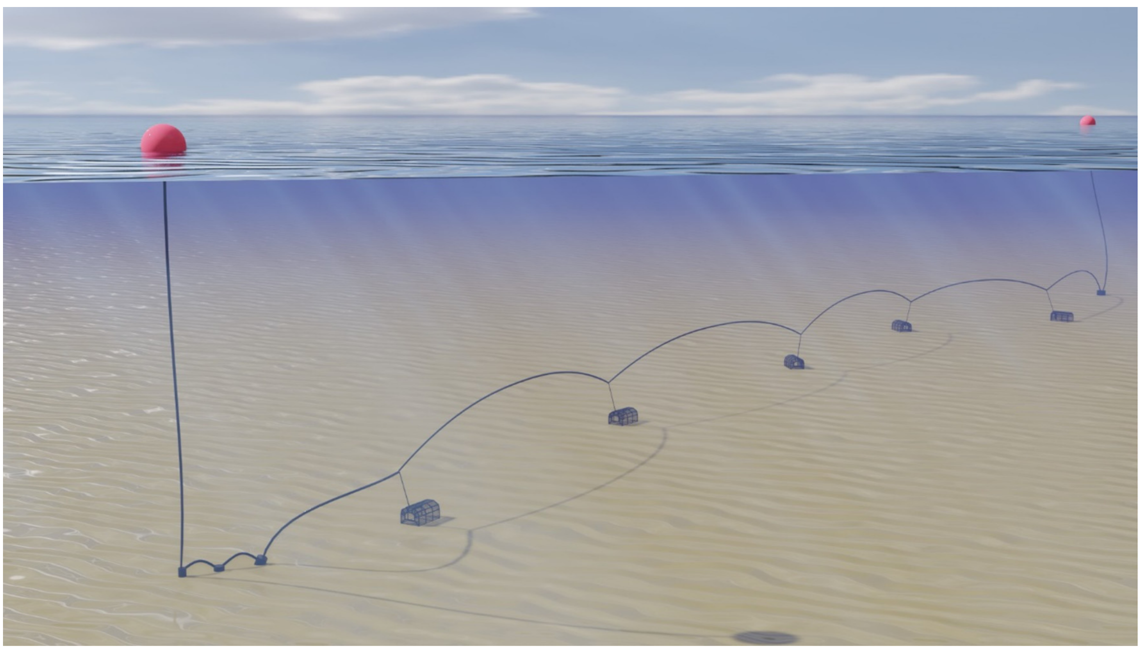

Fig. 1. Typical configuration of creels in Scotland comprising a buoy at each end; a vertical line to weights on the sea bed; and a main groundline with leg ropes attaching the creels to the groundline, both of which float. The number of creels joined together in this way varies, but around 50 to 60 would be typical

waters, including economic implications and conservation and welfare impacts. We present estimates for total entanglements of minke and humpback whales, which would include both fatalities and whales which were disentangled and released but not individuals which managed to break free from the gear by themselves. Analysis of scars on living whales in areas of the northwestern Atlantic has shown that a high proportion of whales have entanglement-related scars, which indicates that they have become sufficiently entangled to generate such scars but have been able to break free from gear (Robbins & Mattila 2004, Ramp et al. 2021). In Scottish waters, entanglement-related scarring has also been observed on living minke whales (Northridge et al. 2010, MacLennan et al. 2021). However, these scarring rates are low compared to those of larger whales in other areas, as minke whales are often not strong enough to break free from gear (Song et al. 2010). Situations where whales are entangled and cannot free themselves present serious welfare and conservation concerns, as even if these whales are released alive, the survival rate of released animals is unknown. Further, live releases can present a risk to human safety due to the dangers involved in disentanglement attempts (https://iwc.int/entanglement).

Minke whales are sufficiently abundant in Scottish waters that they are regularly detected on systematic sighting surveys (Robinson et al. 2007, 2009, Hammond et al. 2013, 2021), which allows estimates of abundance. There have also been studies reporting on distribution patterns in relevant areas (Leaper et al. 1997, Macleod et al. 2004, Evans & Waggitt 2020, Waggitt et al. 2020). However, humpback whales are rarely recorded during systematic surveys. Minke whale entanglement risk can therefore be related to whale distribution and abundance from other studies, but for humpback whales, we present additional analysis of sighting reports to compare estimated numbers of entanglements to humpback whale presence. We examine results from the large systematic survey effort of the Hebridean Whale and Dolphin Trust (HWDT) off the west coast of Scotland, although the small number of humpback sightings precludes reliable estimation of effective strip width. The much larger sample sizes from opportunistic sightings provide some information on seasonal patterns and annual trends. However, there is considerable heterogeneity in the probability that a whale will be reported. In well-observed areas, the same whales may be reported several times in the same day. The large numbers of reports of particular individuals can bias any analysis of spatial or temporal trends. We try to overcome this by grouping sightings into visits, allowing estimates of trends that are less influenced by the presence of just a few individuals reported on multiple occasions. A period during which there were repeated sightings of an individual or group of humpback whales within a limited area was classified as a visit for the purposes of this analysis.

2. MATERIALS AND METHODS

2.1. Entanglement data sources

Between June 2018 and September 2019, 159 commercial creel fishers from different vessels were interviewed as part of the SEA project. These fishers operated from 67 different Scottish harbours and represent approximately 11% of the registered inshore fleet.

Semi-structured interviews based on a standard list of questions were conducted face to face and were all undertaken by the same interviewer to maintain consistency. The design met the 4-point approach to sampling in qualitative interview-based research described by Robinson (2014), including specifying criteria for participation, deciding on a sample size and selecting a sampling strategy. The questionnaire comprised 22 questions, most of which were closed, but some were more open ended. The closed questions related to the interviewees' experiences of whale entanglement within the last 10 yr, with more open-ended questions regarding their suggestions for modifications to gear or fishing practices which might mitigate the problem. Details of the questions are provided in MacLennan et al. (2021). Prior to the interviews being carried out, the questionnaire was submitted for ethical review to the University of Aberdeen, adapted accordingly and piloted. The selection of fishing harbours was made following discussions with regional inshore fisheries groups and the Scottish Creel Fishermen's Federation (SCFF) and was based on the distribution and density of creel fishers around the Scottish coastline.

In addition to the interview dataset, data on entanglements were also obtained from a number of other sources: stranded animals opportunistically reported to SMASS and subsequently evaluated as showing clear evidence of entanglement, live animal disentanglements by British Divers Marine Life Rescue (BDMLR) and reports from fishers at the time of incidents (collectively referred to here as reported incidents). The combined reports from all these sources provide a minimum estimate of the number of incidents but are likely negatively biased because many incidents may not be reported. Stranding data, for example, are restricted to the subset of cases which float and are detected, reported and investigated.

2.2. Extrapolating interview results based on fishing effort

Entanglement prevalence can be estimated based on extrapolations from the interview data. To enable this, interviews were divided by regions and districts to allow for some stratification whilst maintaining sample sizes. The probability that a particular entanglement would be revealed through interviews would depend on a number of factors but principally on the proportion of fishers in that region who were interviewed. This allows for a Horvitz-Thomson type approach (Horvitz & Thompson 1952), which allows for unequal sampling probability, to estimate the total number of entanglements based on stratified interview results. Within Scotland, fisheries are divided into districts (https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=527), with statistics reported annually for each district. The numbers of registered vessels are reported by gear type (https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2017/pages/49/), but this also includes vessels that may not be active. An indication of the number of active vessels may be given by the number of people in full-time employment (https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2017/pages/52/), but these data are not reported by fishery type. To obtain an approximate estimate of the number of active pot and creel vessels based on the employment data, we used the reported mean number of crew members for each vessel size category to predict the number of fishers employed in each district. For vessels 10 m and under, this was 1.5; for shellfish vessels over 10 m, this was 3; for demersal vessels over 10 m, this was 4.7 (https://www.gov.scot/publications/scottish-sea-fisheries-employment-2015/pages/10/#Table6). Linear regression of predicted employment against reported employment by district showed no evidence of bias ($y = 0.97x$, $R^2 = 0.56$). The ratio of actual employment divided by predicted employment was used as an estimate of the proportion of vessels within each district that were active (Table 1). This suggests that the median proportion of active vessels by district was around 71%. The estimated total number of active creel vessels for Scotland was 1017 of 1431 registered vessels. Northridge et al. (2010) estimated that around 300 vessels fished for more than 50 d a year, suggesting that many vessels may go to sea less than once a week. In terms of estimating the proportion of effort included in the interviews, the main factor is whether the vessels included in the interviews were representative of the creel fleet in that district rather than the total fishing effort.

Two forms of stratification were used to generate estimates of the total numbers of entanglements based on the proportions of vessels that were included in the interviews. Interviews were stratified geographically into 18 districts, which were then grouped into 3 distinct regions (see Fig. 2). These were defined as West, from Cape Wrath to the Clyde including the Outer Isles; North, comprising the coast between Cape Wrath and Duncansby Head and from Duncansby Head to Helmsdale, Orkney and Shetland; and East, the coast from Helmsdale to Berwick Upon Tweed. These larger strata gave sufficient samples to allow estimation of variance but also captured some of the geographical variation in entanglement risk.

Table 1. Reported number of vessels in 2017 by fisheries district and estimated numbers of active vessels

District	Region	Creel vessels ≤10 m	Creel vessels >10 m	Estimated active proportion	Estimated total active creel vessels
Aberdeen	E	77	5	0.5	43.1
Anstruther	E	82	1	0.6	46.7
Buckie	E	52	1	0.5	28.4
Eyemouth	E	76	2	0.9	70.4
Fraserburgh	E	95	1	1.0	94.8
Peterhead	E	60	2	1.0	62.0
Scrabster	N	84	8	0.9	81.6
Orkney	N	84	26	0.9	99.2
Shetland	N	119	3	0.6	72.4
Stornoway	W	162	13	0.7	118.9
Ayr	W	68	4	1.0	72.0
Campbeltown	W	86	6	0.8	76.6
Kinlochbervie	W	15	0	0.8	11.5
Lochinver	W	10	1	1.0	11.0
Mallaig	W	29	1	0.7	21.0
Oban	W	66	14	1.0	76.0
Portree	W	84	10	0.7	69.6
Ullapool	W	74	10	0.8	66.8

The total number of active vessels V across j strata was calculated by:

$$V = \sum_{i=1}^{j} v_i \tag{1}$$

where v_i is the number of active vessels in stratum i.

The estimated total number of entanglements $\hat{N}$ is then given by:

$$\hat{N} = \sum_{i=1}^{j} \frac{v_i}{k_i} n_i \tag{2}$$

where k_i is the number of interviews by stratum i, and n_i is the number of reported entangled whales in stratum i.

The variance of $\hat{N}$ is given by:

$$var\left(\hat{N}\right) = K \sum_{m=1}^{s} \left(\frac{n_m}{k_m} - \frac{n}{K}\right)^2 \Big/ (s-1) \tag{3}$$

where K is the total number of interviews, with k_m being the number in each stratum m of s strata, resulting in n_m reported entanglements, and n is the total number of entanglement reports.

The log-normal CI (Buckland et al. 1993) can then be given by $\left(\frac{\hat{N}}{C}, \hat{N} \times C\right)$ where:

$$C = \exp\left[z_\alpha \sqrt{\hat{\text{var}}(\log_e \hat{N})}\right] \tag{4}$$

where $z_\alpha = 1.96$ for a 95% CI, and

$$\hat{\text{var}}\left(\log_e \hat{N}\right) = \log_e\left[1 + \frac{\text{var}\left(\hat{N}\right)}{\hat{N}^2}\right] \tag{5}$$

2.3. Identifying factors affecting entanglement risk

The total amount of gear multiplied by time in the water is likely to be a good predictor of the entanglement risk for a whale in the fishing area, but the actual risk will depend on the distribution of whales in relation to the deployed gear. Data on fishing effort recorded in interviews included total length of all gear when deployed (i.e. average length of rope used per fleet [a string of creels joined together] multiplied by the number of fleets), retrieval time (i.e. number of days between gear being set and hauled) and number of creels, which relate to the risk associated with the gear itself. Other data included information on target species and fishing area such as distance of the grounds from shore and depth of the water in which gear was typically set. Although there will be differences between fishers who reported whether they were full or part time in terms of the frequency that they haul their gear, in some cases, non-baited creels are left at sea (wet storage) and will thus pose a similar level of entanglement risk. All fishers interviewed, both full time and part time, were operating commercially. No recreational (hobby) fishers were included in the interviews; these unlicenced fishers are legally restricted to small daily catches (1 lobster, 10 *Nephrops*, 5 crabs) (https://www.legislation.gov.uk/ssi/2017/57/contents/made), so the amount of gear deployed and hence entanglement risk would be expected to be small.

The target species will determine the type of benthic habitat where the gear was set. *Nephrops* are found on soft substrate, whereas crabs and lobsters are more often found on rocky bottoms. Risk would be expected to increase with increased amount of gear, but fishers operating in deeper water also tend to use more gear, so these parameters are highly correlated. Depth may affect entanglement risk in a number of ways, including whale distribution, the likelihood of whales diving close to the seabed and the length of vertical lines. In addition, the areas (North, East and West) have many different characteristics, ranging from the shallow exposed coasts of the North Sea, the island groups of Orkney and Shetland and the complex bathymetry of the west coast. Generalized additive models (GAMs) were used to explore relationships between entanglements and risk parameters, with Area and Target Species as factors. In addition to questions about the number of entanglement incidents they had experienced, fishers were also asked for details of the entanglement and where it occurred within the fishing gear to distinguish between entanglements in the groundlines between the creels along the seabed and the end lines leading to surface marker buoys (Fig. 1).

2.4. Temporal and spatial distribution of humpback whales

Because humpback whales are not sufficiently abundant in Scottish waters to be regularly detected on systematic sighting surveys (unlike minke whales), humpback whale sighting data were collated from several sources in Scotland. Separate analyses were conducted using sighting data with quantified effort and incidental sightings (some of which were from surveys but covered a limited area). Effort-based systematic sighting data were collected around the Hebrides (Scottish west coast) during dedicated marine mammal surveys conducted by HWDT from their research vessel, the SV 'Silurian', in Beaufort sea state <5 from April to October 2003 to 2019 inclusive. Two observers scanned the sea using the naked eye during daylight hours from a platform 2 m above sea level, with surveys conducted along track lines distributed as evenly as possible within the constraints of weather and suitable anchorages (Booth et al. 2013). From 2008, the distribution of creels was also recorded by observers by identifying pairs of buoys within 2 km of the vessel's track.

The small number of humpback whale observations precluded strip width estimation, so it was not possible to estimate absolute density. Compared to other survey vessels, the observation platform on the SV 'Silurian' is low; thus, estimated strip widths would be expected to be smaller than those from larger vessels. However, because humpback whales are usually detected by their blows, detection distances are less sensitive to observation height than for species detected by seeing the body.

Incidental or opportunistic sighting records of humpback whales were gathered from a number of different sources, including public sighting schemes coordinated by the Sea Watch Foundation (SWF), HWDT, Whale and Dolphin Conservation (WDC) Shorewatch and the Cetacean Research & Rescue Unit (CRRU); dedicated research cruises (HWDT, CRRU and SWF); and whale rescue callouts (BDMLR and CRRU) in Scottish waters between 2001 and 2019. Plots of inter-sighting distances against inter-sighting times were examined to select distance and time criteria for assessing whether reported sightings should be assumed to be of the same individual or group and thus allocated to the same visit.

In a few cases, photographic evidence permitted individual identification and matches between different sightings on different days. For example, one whale was identified in the Firth of Forth (east coast) over a 2 mo period in 2017 and again for a 1 mo period in 2018 (O'Neil et al. 2019). However, individual identification was only possible in less than 5% of all cases. In 2 such cases, the identifying feature was entangled gear.

The majority of Scottish creel fishing effort takes place within 3 nautical miles (nmi) of the coast, and more than 90% of the opportunistic sightings of humpback whales were also within 3 nmi. The systematic surveys by HWDT cover areas at greater distances from land but are largely within an area of 48 710 km^2 defined by Marine Scotland as internal waters plus territorial sea out to 3 nmi (https://marine.gov.scot/data/facts-and-figures-about-scotlands-sea-area-coastline-length-sea-area-sq-kms).

2.5. Distribution of creel fishing effort for the west coast area

The surveys conducted by HWDT on the west coast also included observations of creel marker buoys from 2008 to 2019. These were analysed based on a grid of 0.25 min of arc (approximately 463 × 250 m). Relative creel density was estimated as the total number of fleets observed (assuming the standard practice of surface markers at both ends) divided by the total surveyed effort.

3. RESULTS

3.1. Locations and numbers of entanglements

The number of reported entanglements (reported incidents) and those obtained from interviews for both species are summarised in Table 2. The stratified estimates by fisheries district are given in Table 3 and by region in Table 4. Sample sizes in some fisheries districts were too small to allow variance estimates, so variance was only calculated for the 3 regions. The regional estimates and associated CIs for a 10 yr period were 301.8 (95% CI 227.0–469.0) minke whale entanglements and 64.0 (95% CI 36.9–134.1) humpback whale entanglements (i.e. annual entanglement rates of 30 minke whales and 6 humpback whales). Stratification by fisheries district gave an estimate of 329.3 minke whale and 59.4 humpback whale entanglements for a 10 yr period. Thus, the different stratifications used gave estimates within 10% of each other.

The locations of both reported incidents and the ports where entanglements were recorded in interviews are shown in Fig. 2 for humpbacks and Fig. 3 for minke whales, showing that entanglements appear to occur throughout Scottish waters, although in

Table 2. Reports of humpback and minke whale entanglements from different sources. SMASS: Scottish Marine Animal Stranding Scheme; BDMLR: British Divers Marine Life Rescue

	Humpback whale	Minke whale
No. of entanglement records from SMASS, BDMLR and other sources within the period of the interview surveys (2008–2019)	10	24
No. of entanglement records from SMASS, BDMLR and other sources outwith the period of the interview surveys (before or after)	6	4
Other non-creeling entanglement incidents (aquaculture)	1	0
No. of entanglements from interviews	11	51

Table 3. Stratified estimates (Est.) of number of entanglements by district for the 10 yr covered by interviews

District	Region	Interviews		Avg. depth (m)	Avg. gear length (km)	Entanglements			
		n	Active vessels included (proportion)			Minke whales		Humpback whales	
						Reports	Est. total	Reports	Est. total
Aberdeen	E	12	0.28	37	18.5	0	0.0	0	0.0
Anstruther	E	7	0.15	49	8.1	0	0.0	0	0.0
Buckie	E	2	0.07	38	11.7	0	0.0	0	0.0
Campbeltown	W	15	0.20	80	16.7	10	51.1	2	10.2
Eyemouth	E	12	0.17	30	11.3	1	5.9	0	0.0
Fraserburgh	E	6	0.06	42	1.9	1	15.8	0	0.0
Lochinver	W	1	0.09	146	26.5	2	22.0	0	0.0
Oban	W	11	0.14	105	25.7	3	20.7	0	0.0
Orkney	N	12	0.12	56	22.8	8	66.1	2	16.5
Peterhead	E	4	0.06	46	10.9	1	15.5	0	0.0
Portree	W	28	0.40	146	25.8	12	29.8	3	7.5
Scrabster	N	23	0.27	47	20.9	4	14.2	2	7.1
Shetland	N	8	0.11	55	15.9	3	27.1	2	18.1
Stornoway	W	11	0.08	54	12.5	3	32.4	0	0.0
Ullapool	W	7	0.10	145	35.5	3	28.6	0	0.0
Total		**159**				**51**	**329.3**	**11**	**59.4**

Table 4. Stratified estimates of number of entanglements by region for the 10 yr covered by interviews. 95%CI: 95% log-normal CI

Region	No. of interviews	Estimated no. of active vessels	Minke whale entanglements			Humpback whale entanglements		
			Reported	Total		Reported	Total	
				Estimated	95% CI		Estimated	95% CI
E	43	345.4	3	24.1	8.7–66.7	0	0.0	0.0–0.0
N	43	253.1	15	88.3	44.2–176.2	6	35.3	17.2–72.4
W	73	418.9	33	189.4	121.1–296.0	5	28.7	9.9–83.5
Total	**159**	**1017.4**	**51**	**301.8**	**227.0–469.0**	**11**	**64.0**	**36.9–134.1**

the case of humpbacks, the absence of any patterns could be obscured by the fact that humpbacks are capable of towing gear great distances away from the site of entanglement (Knowlton et al. 2016).

For humpback whale incidents, it was possible to identify 2 definite duplicates between the reports and the interviews. It was also possible to determine 7 incidents reported in the interviews which could not have been duplicate records with the reports. An approximate date was available for 26 cases of the 51 minke whale incidents identified in the interviews. For all 26 cases, it was possible to eliminate any duplicates with the 24 records from SMASS, BDMLR and other sources within the period of the interview surveys.

The interviews integrated fishers' experiences over a 10 yr period and thus were not well suited to examining trends over time. However, the reports from other sources shown in Table 2 (16 humpback whale and 28 minke whale entanglement events) were examined. Annual reports varied from 0 to 3 for minke whales and from 0 to 4 for humpback whales. Most years had 1 or zero, so these were grouped into 5 yr blocks. There was no significant or obvious trend in entangled minke whale reports, but entangled humpback whale reports increased significantly (linear regression of ln(reports) ~ year, $R^2 = 0.96$), showing an increase rate of 16% a year (Fig. 4a).

3.2. Factors affecting entanglement risk

All the fishers interviewed indicated that they had always used a marker buoy at each end of the fleet of creels and confirmed that this was standard practice to avoid gear conflicts.

Of 51 entangled minke whales reported in interviews, 7 were reported to be entangled in vertical (end) line, 33 were in groundline and 11 were unknown, i.e. in the 33 of 40 cases where the nature of entanglement was known (83%), entanglement was in the groundline. Of 11 reported humpback

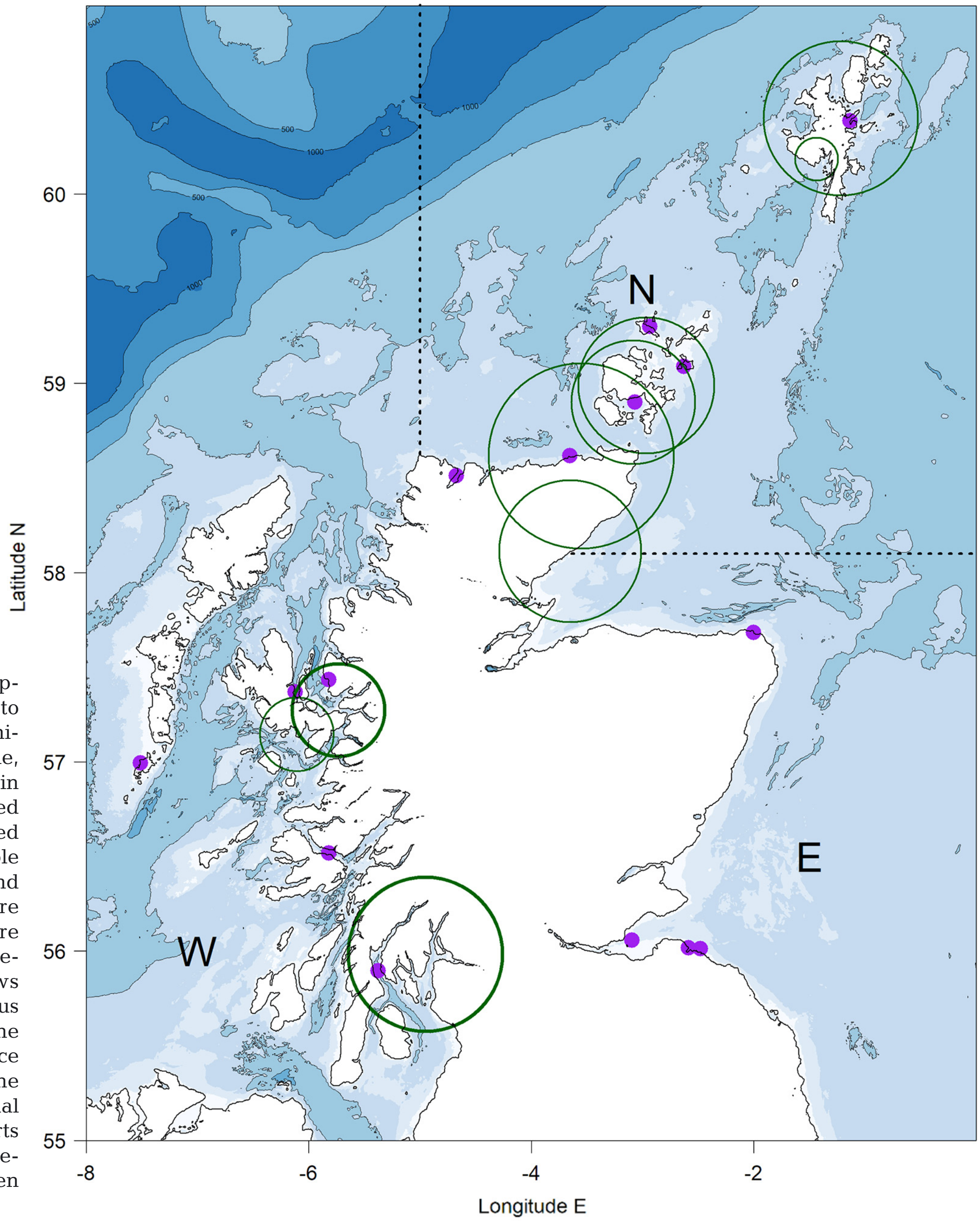

Fig. 2. Locations of humpback whales, reported to the Scottish Marine Animal Stranding Scheme, that were entangled in rope known or suspected to have been associated with creel fishing (purple dots) between 2008 and 2019. Green circles are centred on ports where an entanglement was reported from interviews with creel fishers. Radius of the circle indicates the reported fishing distance from the port, and the line thickness is proportional to the number of reports (1–2). Dashed lines represent boundaries between N, E and W regions

whale entanglements, 4 were in vertical line, 4 were in groundline and 3 were unknown, i.e. 4 of 8 cases of known cause (50%) involved the groundlines.

The numbers of reported entanglements and interviews by main target species are given in Table 5. In the West area, most (79%) of the interviews were with fishers primarily targeting *Nephrops*, with almost all of the *Nephrops* fishing occurring on the west coast. The highest reported numbers of minke entanglements were 27 from *Nephrops* fisheries on the west coast and 13 from brown crab fisheries in the North area.

The best fitting model of risk based on the minimum Akaike's information criterion was with Area and Target Species as factors and the number of entanglements per vessel as a smooth of the length of the gear (Fig. 5). This model explained 28% of the deviance and showed the expected increase of entanglements with longer gear. There was a significant effect of gear length ($p < 0.01$). Of the 51 entangled minke whales reported in interviews, 43 (84%) were found dead, compared with humpback whales, where 3 of 11 (27%) were found dead.

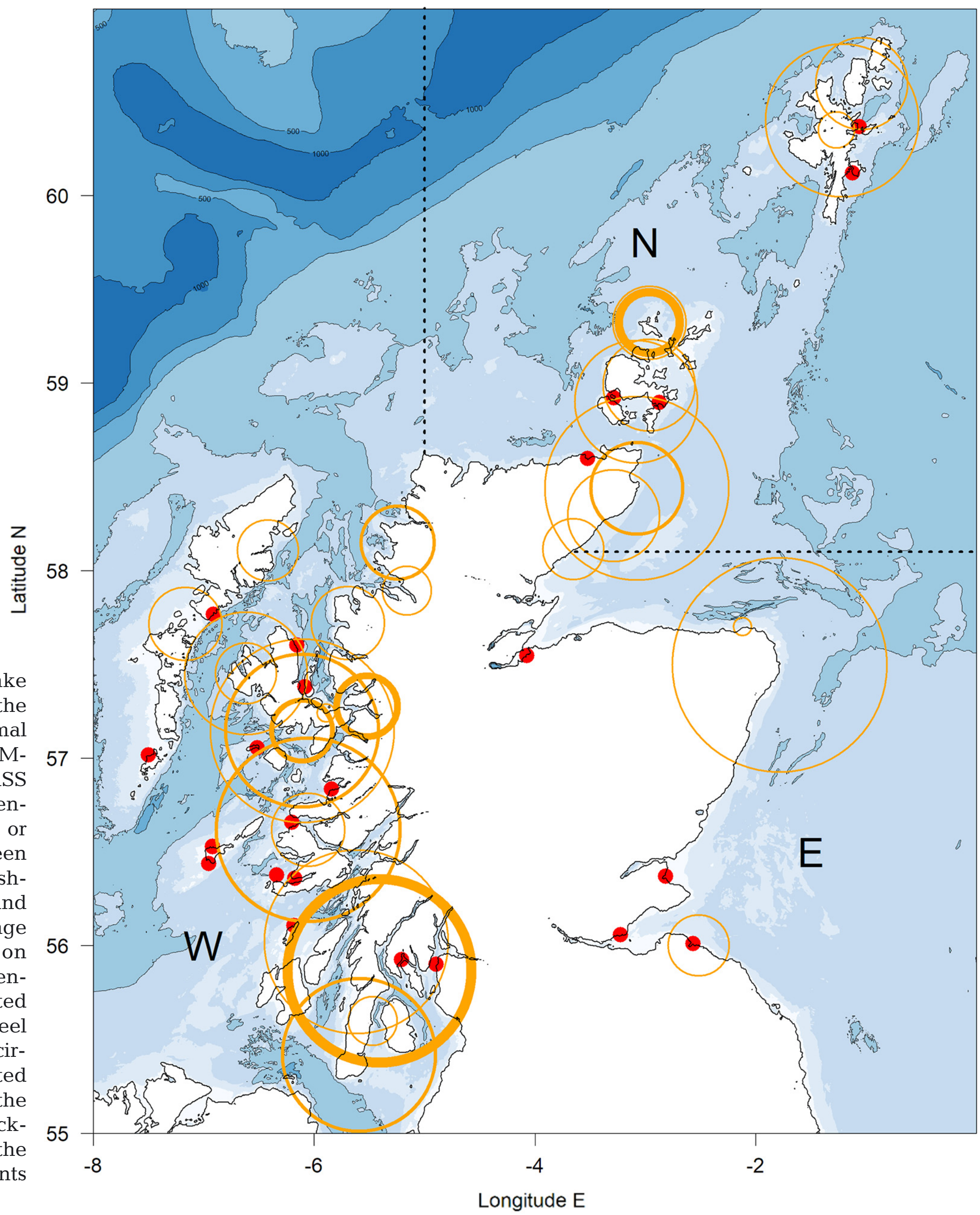

Fig. 3. Locations of minke whales, reported by the Scottish Marine Animal Stranding Scheme (SMASS) from the SMASS database, that were entangled in rope known or suspected to have been associated with creel fishing between 2008 and 2019 (red dots). Orange circles are centred on ports where 1 or more entanglement was reported from interviews with creel fishers. Radius of the circle indicates the reported fishing distance from the port, and the line thickness is proportional to the number of entanglements reported (1–6)

3.3. Temporal and spatial distribution of humpback whales

HWDT conducted 108 800 km of survey effort from the SV 'Silurian' in sea state <5 between 2003 and 2019 inclusive. The distribution of this effort was limited to the west coast mainly to the east of the Outer Hebrides (tracks are shown in pale blue in Fig. 6), covering an area with regular effort of around 30 000 km^2. The majority of the survey effort was during summer. There were sightings of 7 individual humpback whales during the systematic visual search effort.

Surveys with dedicated cetacean observers on ferries on the west coast of Scotland covered 8951 km of effort between 2017 and 2019, with no sightings of humpback whales (L. Babey pers. comm.). If the sighting probability from the ferry observers is assumed to be the same as that from the HWDT surveys, then based on the sighting rate from the HWDT surveys, the expected number of humpback whale sightings from 8951 km of effort from ferries would be less than 1. Zero sightings are therefore consistent with the HWDT surveys and also indicate a low density of humpback whales. Opportunistic sightings

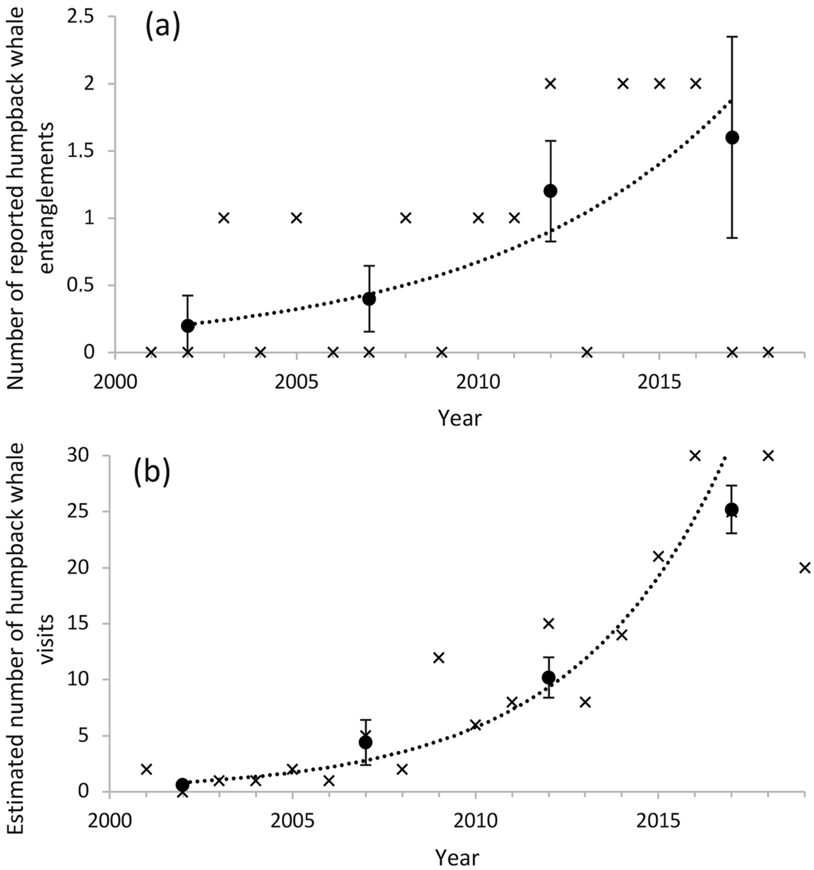

Fig. 4. Number of (a) reported humpback whale entanglements (not including interview results) and (b) estimated humpback whale visits by year. Crosses show yearly values, dots with error bars show 5 yr mean ± SE. Dotted line indicates fitted regression

Table 5. Number of interviews and reported entanglements by main target species

Main target species	No. of interviews	Reported entanglements Minke	Humpback	Gear parameters (avg.) Length (km per vessel)	Depth (m)
Brown crab	53	20	5	18.8	53
Lobster	38	4	1	11.4	39
Nephrops	59	27	5	26.2	129
Velvet crab	9	0	0	11.8	29

Table 6. Parameter estimates resulting from assumed maximum time difference and maximum separation distance for classifying sightings into visits

Assumed max. time difference (d)	Assumed max. separation distance (km)	No. of visits	Mean days between first and last observation	Unique days
5	37	279	2.6	560
9	65	201	5.2	549
15	130	160	7.9	543

were divided into 3 regions: West, North and East.

Between 2001 and 2019, there were 860 humpback whale sighting reports (comprising 1253 animals). For the period covered by the interviews with fishers (2008–2019), there were 845 reports (1237 animals). Examination of surface plots of all inter-sighting distances against inter-sighting times showed some patterns but did not provide any clear indication of values to select distance and time criteria for allocating these to visits. Hence, a range of plausible values of 5 to 15 d and 20 to 70 nmi (37–130 km) were examined (Table 6). The unique days on which humpback whales were reported are the number of distinct days when there was a report, or if 2 reports on the same day were classified as different visits (on the basis of distance), then the number of visits on that day was added to the total.

Based on this examination, we chose the same criteria as Ryan et al. (2016b), being close to the middle of the range considered: a time difference <9 d and a separation distance <65 km. Using this grouping by visits, the monthly distribution is shown in Fig. 7. Overall, visits peaked in the summer months (June–September), but this was mainly driven by sightings in the West area.

There was a significant increase in visits over time. Regression of ln(visits) ~ year ($R^2 = 0.96$) gave the best fit, suggesting an exponential increase of 25% a year (Fig. 4b). There has also been an increase in reported sightings of humpback whales in the southern North Sea. The first humpback whale was sighted in the southern North Sea in 2001, and the annual number of sightings has steadily increased over the subsequent decades (Leopold et al. 2018).

For both systematic and opportunistic sightings, the median group size was 1. During the systematic surveys, all sightings except 1 group of 2 were of single individuals (mean group size

1.17). Mean group size reported from opportunistic sightings was 1.46, but there were a few reports of unrealistically high group sizes (>10 individuals). A report was assumed to be an outlier if a single report from a visit had a group size considerably greater than all of the others. Removing the most obvious outliers (1% of total reports) reduced the mean group size to 1.42.

3.4. Creel distribution

Results from the interviews (Section 3.2) support the assumption of paired buoys to identify fleets of creels and thus creel distribution. A total of 82 274 km of survey effort from the SV 'Silurian' where creel observations were recorded was conducted between 2008 and 2019. There was generally a good correspondence between the distribution by depth of creels observed from surveys and the distribution of average fishing depths reported from interviews (Fig. 8). This supports the assumption that the interview sample was representative at least with respect to fishing effort in relation to depth.

There were higher rates of reported entanglements for creel fishing gear deployed in deeper water (Fig. 8). Based on the observations from the SV 'Silurian', 50% of the creels on the west coast are deployed in water less than 50 m deep, but only 20% of the reported minke whale entanglements were reported in depths less than 50 m. In addition, 50% of the reported minke whale entanglements were in depths greater than 100 m, but the survey results indicated that only 25% of the creels are set in depths greater than 100 m. Although these results do suggest an increasing entanglement rate with depth, the GAMs using reported depth from interviews indicated that this is more likely explained by the amount of gear that is set rather than the depth itself. There was no obvious relationship between the proportion of entangled whales reported in groundlines and the depth of deployment of the gear.

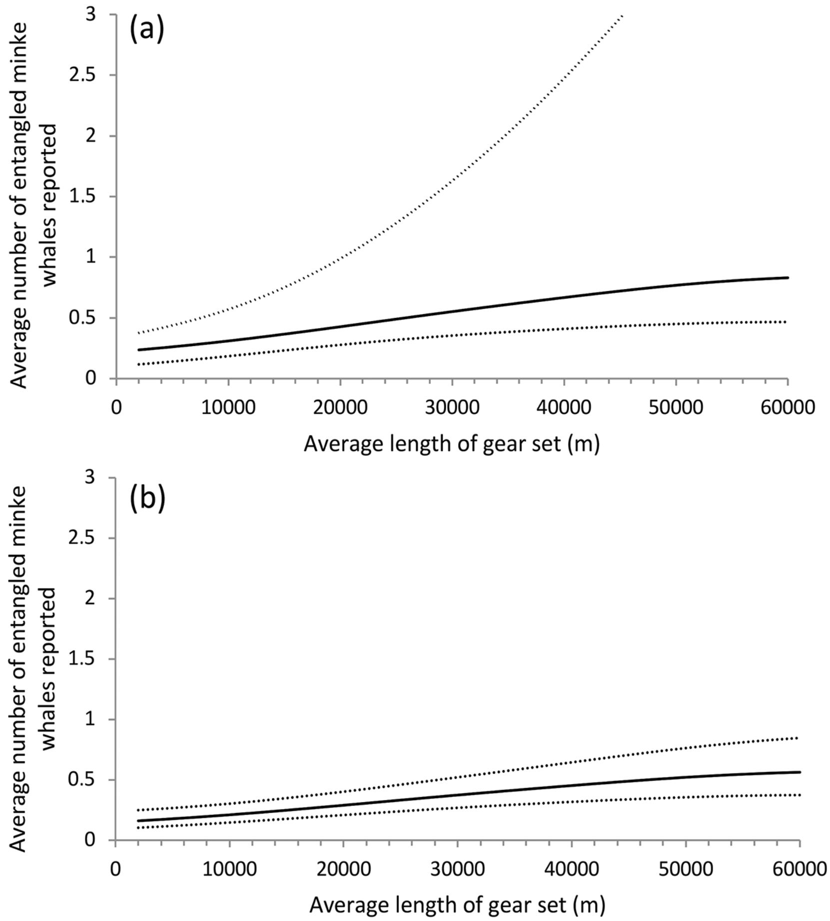

Fig. 5. Smoothed generalized additive model prediction of average number of reported entangled minke whales per vessel by length of gear set for vessels in (a) the West area targeting *Nephrops* and (b) the North area targeting brown crab. Dotted lines indicate 95% CIs

4. DISCUSSION

Cryptic mortality is a major impediment to the accurate estimation of cetacean bycatch (Pace et al. 2021). The estimated numbers of entanglements presented here are considerably higher than those previously reported, including those reported to the International Whaling Commission (IWC) in national progress reports. For the years 2009 to 2019 inclusive, the UK reported 5 minke whale and 5 humpback whale entanglements to the IWC (https://iwc.int/scientific-research/reports/scprogress). This demonstrates a significant degree of underreporting and suggests that creel fishing in Scotland may be having a greater impact on whale welfare and conservation than has previously been recognised. The reports of entangled whales from interviews with fishers used to generate the annual entanglement estimates were all in actively fished gear. Going for-

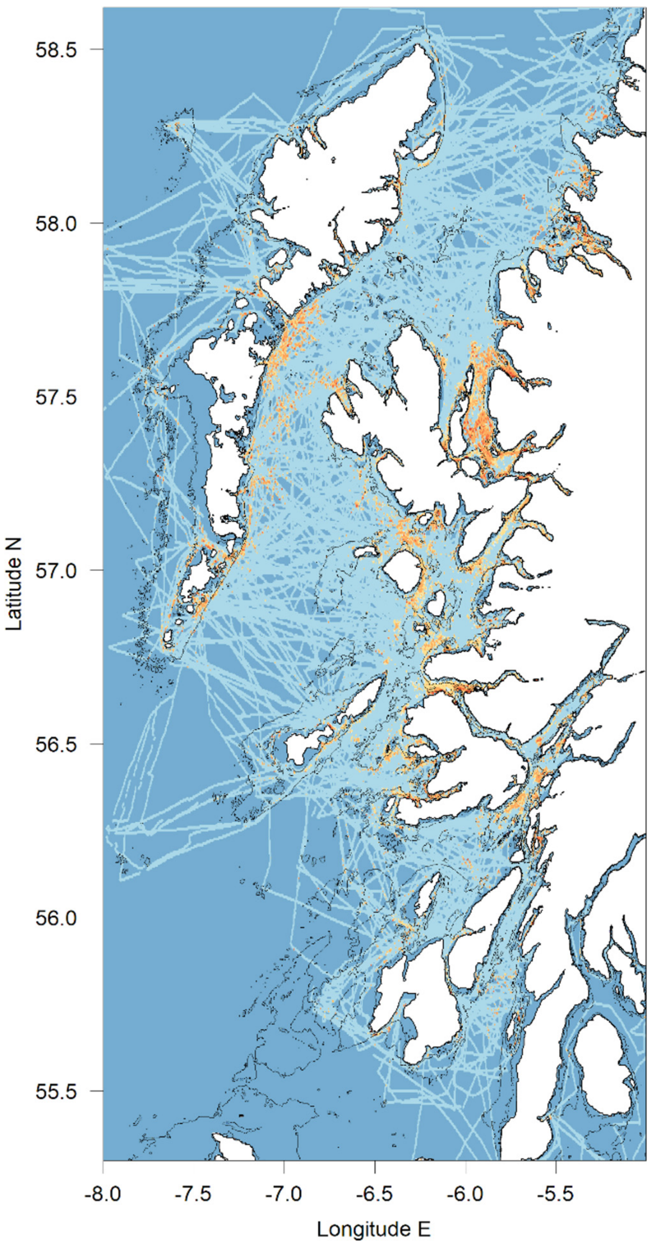

Fig. 6. Density of creels from Hebridean Whale and Dolphin Trust surveys on the west coast. Dark blue indicates unsurveyed areas, and pale blue indicates survey tracks of the SV 'Silurian'. Yellow-red shading indicates increasing density of creel observations adjusted for the survey effort

ward, new conditions introduced for fishing licences in the UK in 2021 require all bycatch of marine mammals to be reported within 48 h of the end of the fishing trip, but whale entanglements will still be underreported if whales break free or animals are caught in abandoned, lost or otherwise discarded fishing gear. The results here double the number of reported entanglements of humpbacks in Scotland from the 12 identified by Ryan et al. (2016b) to 24, all but 3 of which have occurred since 2010. We estimate a total over the last 10 yr of 64 humpback whale entanglements, and there is also evidence of an increasing entanglement rate, with 2019 having the greatest number of incidents (4) for any year in the SMASS database, which probably provides the most consistent reporting rate over time.

Observed densities for minke whales are much higher than those for humpbacks (Robinson et al. 2009, Ryan et al. 2016b, Hammond et al. 2021); estimates of the numbers of entangled whales are also higher. Minke whale entanglements were also much more likely to be acutely fatal; 84 % of the entangled minke whales found by fishers were already dead, suggesting minke whale entanglement locations are more informative in terms of understanding the geography of the entanglement issue in Scottish waters.

There are a number of potential biases which might occur with estimates based on extrapolation of the interview results to the whole fleet. There will be a negative bias associated with whales either breaking free from the gear or swimming away with entangling gear. Consequently, a fisher may just see that the gear has been lost and attribute this not to a whale entanglement but rather to the effects of weather or other vessels snagging gear, for example. Whales swimming away with gear is much more likely to occur with humpback whales than minke whales, as humpbacks are known to be powerful swimmers capable of towing gear over great distances (Knowlton et al. 2016); therefore, the true entanglement rate, in terms of both mortality and morbidity for humpback whales, will likely be higher. The extrapolation from the interviews assumes that those interviewed were representative of the commercial inshore fleet as a whole for either the district or the region (and does not take account of the behaviour of non-commercial creel fishers, who were not interviewed).

The fishers involved in this study have expert knowledge of the entanglement issue based on the definition of Martin et al. (2012, p. 29) that 'expert knowledge is substantive information on a particular topic that is not widely known by others'. However, in terms of estimating entanglements, the experts were only asked to quantify their personal experience rather than make any inferences. Thus, some of the biases such as anchoring and groupthink related to expert elicitation described by Hemming et al. (2018) are not a concern. Nevertheless, there will be potential sources of bias associated with availability and representativeness. For example, a positive bias would result if fishers who had experienced entan-

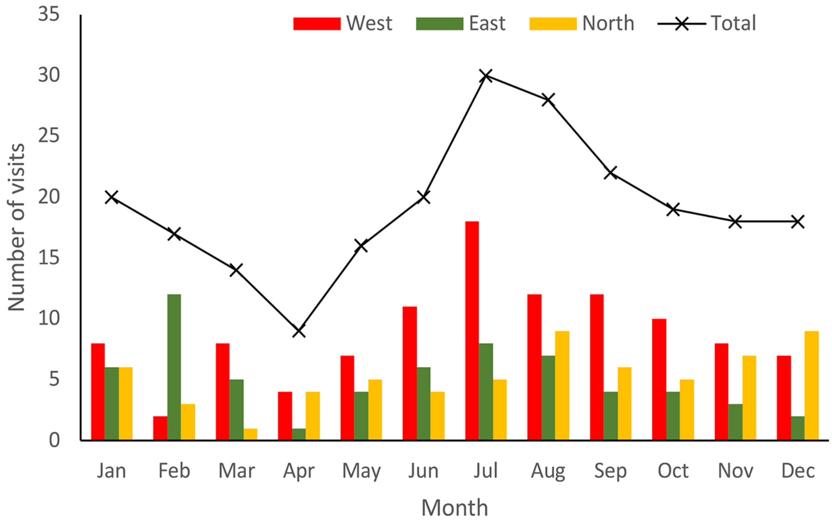

Fig. 7. Numbers of humpback whale visits by month

glements were more likely to be interviewed, whereas a negative bias would result if an entanglement experience had left them less willing to discuss their experience. Of fishers who had experienced entanglements, 79% reported that they had experienced just 1 or 2 incidents. This supported the assumption that entanglements were experienced sufficiently rarely as to make a large impression and such that fishers would recall any entanglement events within the previous 10 yr. Questions relating to mitigating entanglement risks do rely more on expert judgement and predictions and will be the subject of further research and consultation.

Although there was a correlation between the depth of the water where the gear was set and the number of minke whale entanglements, the amount of gear set by each vessel also increases with depth. The best fit model indicated that the increased risk associated with more gear could explain the observed correlation with depth. The significant correlation between the total amount of gear set and the entanglement rate confirms the potential for reducing entanglement from effort limitation schemes such as that being trialled by the Outer Hebrides Regional Inshore Fisheries Group (https://rifg.scot/news/oh-pot-limitation-pilot) in an attempt to improve catch per unit effort and reduce gear conflicts.

Our estimates suggest that at least 6 humpback whales and 30 minke whales are entangled in Scottish waters each year. These numbers are a concern from both a welfare and a conservation perspective. The abundance estimate for the blocks of the SCANS III survey covering the west coast of Scotland inside of the Outer Hebrides (I and G), equivalent to the West region in this study, was 695 minke whales with a coefficient of variation of 0.51 (Hammond et al. 2021). We estimate 15.9 fatal entanglements per year in this region (based on a 10 yr estimate of 189 and 84% of entanglements proving fatal), which is 2.3% of the regional abundance estimate. Potential biological removal (PBR), defined within the US Marine Mammal Protection Act (Wade 1998), is a commonly used threshold for assessing the conservation implications of bycatch. With a recovery factor of 0.5 and maximum productivity rate of 0.04 as used in US stock assessments for minke whales (NOAA 2022), the PBR for the region would be 4.6 individuals, less than a third of the estimated annual number of fatal entanglements. This suggests a risk of localised depletion for minke whales. Risch et al. (2019) describe a range of threats to minke whales, including commercial whaling on the northeastern Atlantic population, and note that cumulatively these threats may lead to severe impacts on populations. Thus, mortality estimates for Scotland will need to be included in assessments for the northeastern Atlantic population as a whole.

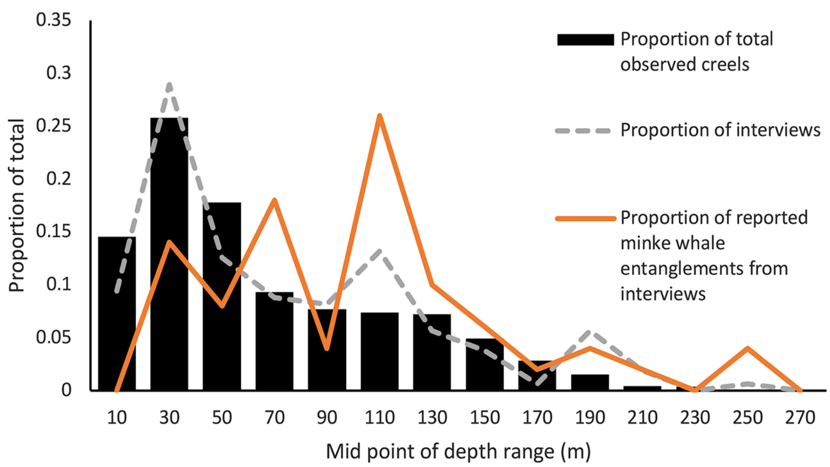

Fig. 8. Proportion of observed creels in area surveyed by the Hebridean Whale and Dolphin Trust from the SV 'Silurian' (filled columns), proportion of interviews and proportion of minke whale entanglements from interviews, by depth category

Two known breeding populations of humpback whales in the North Atlantic occur in Cape Verde and the West Indies, with some interbreeding (Palsbøll et al. 2017). Wenzel et al. (2020) recently reported that the Cape Verde population remains precariously small (n = 272, SE = 10). There are photo-identification matches to the Cape Verde Islands and to the southeastern Caribbean portion of the West Indies (Jones et al. 2017) from Scottish waters (n = 22 individuals compared to the North Atlantic Humpback Whale Catalog [NAHWC]), although this is based on a small sample size, and research is still ongoing (NAHWC at Allied Whale unpubl. data). Therefore, any entanglements occurring in Scottish waters could potentially impact these small populations in the northeastern Atlantic. There is a larger number of individually identified humpback whales from Irish waters compared to Scotland, and there have been 3 matches between Ireland and Cape Verde but none to the Caribbean (Berrow et al. 2021).

Densities of humpback whales are so low that many systematic surveys (e.g. the 3 SCANS surveys) and observations from ferries have not detected any, and the estimate of density from these surveys would be zero. Sighting rates of humpback whales from the SV 'Silurian' are also less than 1% of those of minke whales, despite humpback whales being more conspicuous. This highlights the relative susceptibility to entanglement of humpback whales, which has also been observed in other areas (Robbins & Mattila 2004, Johnson et al. 2005, Neilson et al. 2009). Humpback whale visits peaked over the summer months. Higher reporting probabilities in summer would be expected due to several factors, including more people out watching, longer daylight hours and better sighting conditions. Thus, it is difficult to know whether this peak reflects actual whale presence. However, all areas showed a minimum in spring (March–May), which would be expected to have a higher reporting probability than late autumn and winter (October–February), so there is evidence of fewer humpback whales in spring compared to the rest of the year. The seasonal pattern of humpback whale sightings off western and northern Scotland with the lowest numbers in spring and higher numbers in late summer into autumn is similar to that observed off Ireland from effort-corrected data (Ryan et al. 2016a). The July peak in west coast reports in this study is also consistent with peak whale catches on the west coast during Scottish industrial whaling during the early twentieth century (Ryan et al. 2022).

The use of Scottish inshore waters by humpback whales and the numbers of entanglements are both increasing rapidly. We estimated that humpback visits are increasing by around 25% per year, which is higher than could be explained by population growth. This shift in distribution into the area is also reflected in the increasing trend in entanglements (around 16% a year). The lack of any similar trend in minke whale entanglements suggests that this observed increase in humpback entanglements is not related to reporting effort. The increasing trends in humpback whale numbers and the associated increasing trend in entanglements suggest that the problem will continue to get worse. This highlights the need from both the whales' and the fishers' perspectives to implement measures to reduce entanglement risk.

Although disentanglement efforts have been successful for several of the incidents involving humpback whales, this was not the case for the majority of minke whale entanglements, with 84% already dead when they were discovered. For both species, the issue of entanglement can only be effectively addressed through reducing risk of entanglement occurring in the first place. In addition to the conservation and welfare implications for whales, there are economic and safety considerations for fishers, particularly if disentanglement attempts, which can be hazardous, become more common.

Reports showed 83% of minke and 50% of humpback entanglements occurred in the groundlines between creels. Whales become entangled in groundline because the rope used is buoyant and floats in loops between pots rather than lying on the seabed (McKiernan et al. 2002). In the Republic of Korea, 97% of entangled minke whales were also in groundline, and all were found dead (compared to 84% found dead in this study) (Song et al. 2010).

Some of the interview questions related to how entanglements might be addressed and showed a willingness on the part of the fishers interviewed to address the problem. Of those who provided suggestions (83% of those interviewed), 36% suggested negatively buoyant groundline, and 31% suggested less gear in the water. The suggestions from fishers of using sinking lines could greatly reduce entanglement risk for both species. This was identified by fishers as being the most practical in areas of soft, muddy bottom (i.e. *Nephrops* fishing areas), because sinking lines might be more vulnerable to snagging and abrasion on rocky ground, which can also potentially raise safety issues. Sinking groundline has been used in fisheries off the east coast of the USA, where fixed-gear fisheries are required to use sinking or neutrally buoyant ropes for their groundlines (NMFS et al. 2007). Therefore, a first step for addressing this issue in Scottish waters could be to examine creel effort by bottom type and investigate typical heights of loops of line between creels to compare to other areas (e.g. Brillant & Trippel 2010). This would help inform areas where sinking line could be implemented most effectively. Further research may be needed to determine which sinking groundlines can be used most efficiently on rocky bottoms. Entanglement risk could be further reduced through removal of the end lines to surface marker buoys. Informal trials of on-call or ropeless gear types in Scotland have progressed well to date, and the technologies have been embraced by those fishers employing them.

Acknowledgements. First and foremost, we extend our thanks to all the creel fishers who participated in the SEA project. Their contributions to this work have been invaluable, and we are very grateful to them for sharing their time, knowledge and expertise. We also thank the European Maritime and Fisheries Fund for funding SEA and the project partners for their contributions: Kirstie Dearing (NatureScot), Sarah Dolman (WDC) and Alistair Sinclair (SCFF). We also thank IFAW for funding much of this analysis. Finally, we thank Jonathan Gordon and Nienke van Geel for reviewing and improving earlier drafts of this paper. We also thank all of the volunteers who contributed to the HWDT, SWF, WDC Shorewatch and CRRU sighting schemes.

LITERATURE CITED

Berrow S, Massett N, Whooley P, Jann B, Lopez-Suarez P, Stevick P, Wenzel F (2021) Resightings of humpback whales (*Megaptera novaeangliae*) from Ireland to a known breeding ground: Cabo Verde, West Africa. Aquat Mamm 47:63–70

Booth CG, Embling C, Gordon J, Calderan SV, Hammond PS (2013) Habitat preferences and distribution of the harbour porpoise *Phocoena phocoena* west of Scotland. Mar Ecol Prog Ser 478:273–285

Brillant SW, Trippel EA (2010) Elevations of lobster fishery groundlines in relation to their potential to entangle endangered North Atlantic right whales in the Bay of Fundy, Canada. ICES J Mar Sci 67:355–364

Buckland ST, Anderson DR, Burnham KP, Laake JL (1993) Distance sampling: estimating abundance of biological populations. Chapman & Hall, London

Evans PGH, Waggitt JJ (2020) Impacts of climate change on marine mammals, relevant to the coastal and marine environment around the UK. MCCIP Sci Rev 2020: 421–455

Hamilton S, Baker GB (2019) Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. Rev Fish Biol Fish 29:223–247

Hammond PS, Macleod K, Berggren P, Borchers DL and others (2013) Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biol Conserv 164:107–122

Hammond PS, Lacey C, Gilles A, Viquerat S and others (2021) Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys. https://scans3.wp.st-andrews.ac.uk/files/2021/06/SCANS-III_design-based_estimates_final_report_revised_June_2021.pdf

Hemming V, Burgman MA, Hanea AM, McBride MF, Wintle BC (2018) A practical guide to structured expert elicitation using the IDEA protocol. Methods Ecol Evol 9: 169–180

Horvitz DG, Thompson DJ (1952) A generalization of sampling without replacement from a finite universe. J Am Stat Assoc 47:663–685

How JR, de la Mare WK, Coughran DK, Double MC, de Lestang S (2021) Gear modifications reduced humpback whale entanglements in a commercial rock lobster fishery. Mar Mamm Sci 37:782–806

Johnson A, Salvador G, Kenney J, Robbins J, Kraus S, Landry S, Clapham P (2005) Fishing gear involved in entanglements of right and humpback whales. Mar Mamm Sci 21:635–645

Jones LS, Bouveret L, Stevick PT, Thomason B, Wenzel FW, Whooley P (2017) First humpback whale resighting from the British Isles to a breeding ground. Poster presented at the 22nd Bienn Conf Biol Mar Mamm, Halifax, 23–27 October 2017

Knowlton AR, Hamilton PK, Marx MK, Pettis HM, Kraus SD (2012) Monitoring North Atlantic right whale *Eubalaena glacialis* entanglement rates: a 30 yr retrospective. Mar Ecol Prog Ser 466:293–302

Knowlton AR, Robbins J, Landry S, McKenna HA, Kraus SD, Werner TB (2016) Effects of fishing rope strength on the severity of large whale entanglements. Conserv Biol 30:318–328

Leaper R, Fairbairns R, Gordon J, Hiby A, Lovell P, Papastavrou V (1997) Analysis of data collected from a whalewatching operation to assess relative abundance and distribution of the minke whale (*Balaenoptera acutorostrata*) around the Isle of Mull, Scotland. Rep Int Whaling Comm 47:505–511

Leopold MF, Rotshuizen E, Evans PGH (2018) From nought to 100 in no time: how humpback whales (*Megaptera novaeangliae*) came into the southern North Sea. Lutra 61:165–188

MacLennan E, Leaper R, 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 SC/68A/HIM/02 presented to the International Whaling Commission Scientific Committee, Nairobi

MacLennan E, Hartny-Mills L, Read FL, Dolman SJ and others (2021) Scottish Entanglement Alliance (SEA): understanding the scale and impacts of marine animal entanglement in the Scottish creel fishery. NatureScot Res Rep 1268

Macleod K, Fairbairns R, Gill A, Fairbairns B, Gordon J, Blair-Myers C, Parsons ECM (2004) Seasonal distribution of minke whales *Balaenoptera acutorostrata* in relation to physiography and prey off the Isle of Mull, Scotland. Mar Ecol Prog Ser 277:263–274

Martin TG, Burgman MA, Fidler F, Kuhnert PM, Low-Choy S, McBride M, Mengersen K (2012) Eliciting expert knowledge in conservation science. Conserv Biol 26: 29–38

McKiernan DJ, Pol M, Malkoski V (2002) A study of the underwater profiles of lobster trawl groundlines. Massachusetts Division of Marine Fisheries. https://www.mass.gov/files/2017-08/groundline-report.pdf

Neilson JL, Straley JM, Gabriele CM, Hills S (2009) Non-lethal entanglement of humpback whales (*Megaptera novaangliae*) in fishing gear in northern Southeast Alaska. J Biogeogr 36:452–464

NMFS (National Marine Fisheries Service), NOAA (National Oceanic and Atmospheric Administration), US Dept of Commerce (2007) Taking of marine mammals incidental to commercial fishing operations; Atlantic Large Whale Take Reduction Plan Regulations. Fed Reg 72:57103–57194

NOAA (2022) Marine mammal stock assessment reports by species/stock. Common minke whale (*Balaenoptera acutorostrata acutorostrata*): Canadian East Coast Stock. May 2022. https://media.fisheries.noaa.gov/2022-08/Com%20Minke%20Whale-Can%20E%20Coast%20Stock_SAR%202021.pdf (accessed 14 December 2022)

Northridge SP, Cargill A, Coram A, Mandleberg L, Calderan S, Reid R (2010) Entanglement of minke whales in Scottish waters: an investigation into occurrence, causes and mitigation. Final Report to Scottish Government CR/2007/49, University of St Andrews

O'Neil KE, Cunningham EG, Moore DM (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. Mar Biodivers Rec 12:12

Pace RM III, Williams R, Kraus SD, Knowlton AR, Pettis HM (2021) Cryptic mortality of North Atlantic right whales. Conserv Sci Pract 3:e346

Palsbøll P, Bérubé M, Ryan C, Lopes-Suarez P and others (2017) A post-whaling legacy: differential post-whaling recovery rates resulting in the genetic extinction of native Cape Verde humpback whales. Abstract from 22nd Bienn Conf Biol Mar Mamm, Halifax, 23–27 October 2017

Ramp C, Gaspard D, Gavrilchuk K, Unger M and others (2021) Up in the air: drone images reveal underestimation of entanglement rates in large rorqual whales. Endang Species Res 44:33–44

Risch D, Norris T, Curnock M, Friedlaender A (2019) Common and Antarctic minke whales: conservation status and future research directions. Front Mar Sci 6:247

Robbins J, Mattila DK (2004) Estimating humpback whale (*Megaptera novaeangliae*) entanglement rates on the basis of scars evidence. Report to the National Marine Fisheries Service. Order no. 43ENNF030121

Robinson O (2014) Sampling in interview-based qualitative research: a theoretical and practical guide. Qual Res Psychol 11:25–41

Robinson KP, Baumgartner N, Eisfeld SM, Clark NM and others (2007) The summer distribution and occurrence of cetaceans in the coastal waters of the outer southern Moray Firth in northeast Scotland (UK). Lutra 50:19–30

Robinson KP, Tetley MJ, Mitchelson-Jacob EG (2009) The distribution and habitat use of coastally occurring minke whales (*Balaenoptera acutorostrata*) in northeast Scotland. J Coast Conserv 13:39–48

Ryan C, Whooley P, Berrow S, Barnes C and others (2016a) A longitudinal study of humpback whales in Irish waters. J Mar Biol Assoc UK 96:877–883

Ryan C, Leaper R, Evans PGH, Dyke K and others (2016b) Entanglement: an emerging threat to humpback whales in Scottish waters. Paper SC/66b/HIM/01 presented to the International Whaling Commission Scientific Committee, Bled

Ryan C, Calderan S, Alison C, Leaper R, Risch D (2022) Historical occurrence of whales in Scottish waters inferred from whaling records. Aquat Conserv Mar Freshw Ecosys 32:1657–1692

Song K, Kim Z, Zhang CI, Kim YH (2010) Fishing gears involved in entanglements of minke whales (*Balaenoptera acutorostrata*) in the East Sea of Korea. Mar Mamm Sci 26:282–295

Wade PR (1998) Calculating limits to human-caused mortality of cetaceans and pinnipeds. Mar Mamm Sci 14: 1–37

Waggitt JJ, Evans PGH, Andrade J, Banks AN and others (2020) Distribution maps of cetacean and seabird populations in the North-East Atlantic. J Appl Ecol 57: 253–269

Wenzel F, Broms F, Lopez-Suarez P, Freire Lopes K and others (2020) Humpback whales (*Megaptera novaeangliae*) in the Cape Verde Islands: migratory patterns, resightings, and abundance. Aquat Mamm 46:21–31

Editorial responsibility: Eric Gilman, Honolulu, Hawaii, USA
Reviewed by: M. J. Moore, A. Read and 1 anonymous referee

Submitted: April 4, 2022
Accepted: October 24, 2022
Proofs received from author(s): December 18, 2022