ESTIMATES OF HUMPBACK AND MINKE WHALE ENTANGLEMENTS IN SCOTLAND.

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ABSTRACT

Entanglement in static fishing gear has been identified as the largest anthropogenic cause of mortality in minke (*Balaenoptera acutorostrata*) and humpback whales (*Megaptera novaeangliae*) in Scottish waters, and is of increasing concern from both a welfare and conservation perspective. However a thorough understanding of the scale and impacts of these incidents is lacking. To address this, data from a number of sources including strandings, live disentanglement reports and interviews with inshore creel fishermen were gathered to provide estimates of entanglements, using a capture-recapture type approach and extrapolation of interview data. The findings suggest that the Scottish creel fishery may be responsible for considerably more whale bycatch than previously thought, with estimates of around five humpback whales and 30 minke whales becoming entangled each year. Entanglements occurring in Scottish waters could potentially impact small populations of humpback whales in the NE Atlantic. For the west coast of Scotland, the estimated fatal entanglement rate of minke whales is 2.2% of the estimated abundance from the SCANSIII survey suggesting a risk of localised depletion. Scottish fishermen have exhibited willingness to engage in mitigation strategies and research, with suggestions such as the introduction of leaded line to the sector. Some have also been participating in informal trials of ropeless technologies. To date these trials have been successful and we recommend that continued support for such mitigations, which could greatly reduce entanglement risk, be considered with urgency.

INTRODUCTION

Entanglement in pot and creel fishing gear has been identified as the largest cause of non-natural mortality in baleen whales stranded around Scotland (Northridge et al., 2010). Data collected by the Scottish Marine Animal Stranding Scheme (SMASS) and through media reports suggest both the incidence and range of affected species is increasing. However, estimates of the total numbers of entanglement events have not been available and previously reported cases are known to represent only a small percentage of total incidents due to under-reporting by fishers, limitations of post-mortem examinations, and the low likelihood of retrieving carcasses. The cetacean species most frequently reported entangled in Scotland are minke (*Balaenoptera acutorostrata*) and humpback (*Megaptera novaeangliae*) whales (MacLennan et al. 2019).

In order to generate a better understanding of the entanglement problem, the Scottish Entanglement Alliance (SEA) was established in April 2018. SEA is a two-year European Maritime and Fisheries Fund (EMFF)-funded partnership between six marine research, industry, conservation and welfare bodies. SEA partners aim to provide a co-ordinated, comprehensive monitoring and engagement programme to better understand the scale and impact of marine animal entanglements in Scottish waters. Importantly, this includes economic and human safety implications in addition to conservation and welfare impacts.

The aims of SEA include raising awareness of marine animal entanglements amongst fishers and other marine users; improving reporting rates of marine animal entanglements; providing a platform for fishers to suggest solutions to this problem and opportunities for them to become involved in entanglement prevention, research and disentanglement efforts; assessing the risk and impact of entanglements to marine animals at an individual and population level; and improving understanding of the socio-economic impact of marine animal entanglements on the Scottish fishing fleet. More information on the initiative is available here: www.scottishentanglement.org

This paper provides estimates of the numbers of minke and humpback whale entanglements in Scotland over the last ten years and reports on information provided by the creel fishing community on the nature of the entanglements and suggestions for ways to reduce entanglement risk. The analysis includes data from Ryan et al. (2016) and MacLennan et al. (2019). We present estimates for total entanglements, including both whales which are released alive and those that die. All situations where whales are entangled present serious welfare concerns, and even whales released alive may give rise to conservation concerns, as their fate post- release is rarely known. Further, live release can present a risk to human safety because of the dangers involved in disentanglement[1].

METHODS

SEA interviews

Between June 2018 and September 2019, 157 commercial creel fishers from different vessels were interviewed as part of the SEA project. These fishers were operating 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 conducted by the same interviewer. The questionnaire comprised 22 questions and included both closed and open-ended questions. Prior to implementation, questions were 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 (RIFGs) and the Scottish Creel Fishermen's Federation (SCFF), and was based on the distribution and density of creel fishers around the Scottish coastline.

The majority of interviews were opportunistic, however prior to visiting each harbour, the interviewer made contact with the Harbour Master and/or local fisheries association representatives. This often resulted in 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. 'Snowball' sampling was used whereby interview participants were asked if they could recommend other fishers who might also be willing to participate.

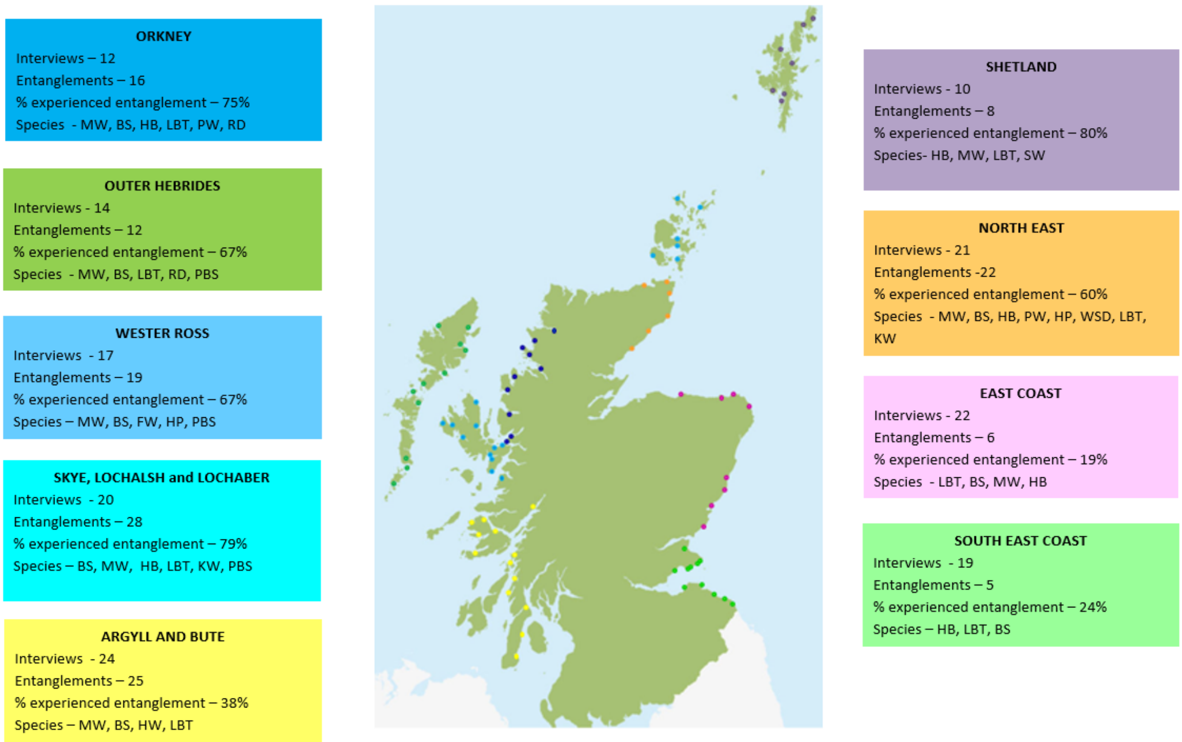

Figure 1. Locations and numbers of interviews with fishers (MW: minke whale; BS: basking shark; HB: humpback whale; LBT: leatherback turtle; PW: pilot whale; RD: Risso's dolphin; FW: fin whale; HP: harbour porpoise; PBS: porbeagle shark; KW: killer whale; SW: sei whale; WSD: white-sided dolphin). (MacLennan et al. in preparation)

Data on entanglements can be derived from a number of sources: stranded animals reported to SMASS, live animal disentanglements by BDMLR, and reports from fishers at the time of incidents (these are referred to here

[1] https://iwc.int/entanglement

as *reported incidents*). The combined reports from all these sources provide a minimum estimate of the number of incidents but are negatively biased because there are many incidents that are not reported. The structured interviews with fishers provide another, independent, source of reports for comparison (referred to as *interviews*). If duplicates can be identified between these two data sets then it should be possible to estimate the total number of entanglements using a capture-recapture type approach. One of the simplest estimators that can be applied to survey data is the Chapman modification of the Lincoln–Petersen estimator (Brittain and Böhning, 2008).

The key challenge in this study is identifying potential and definite duplicates. The reported incidents generally had quite specific locations and dates, whereas the interview responses just had a port of operation and included any incidents over the previous 10 years, although in many cases an approximate year and season were available, or in some cases an actual date.

Potential duplicates were examined by looking first at the spatial distribution of direct reports and reports from interviews.

The Chapman estimate for total entanglements, N is given by:

$$\widehat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1 \qquad (1)$$

With variance

$$var(\widehat{N}) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \qquad (2)$$

Where n_1 is the number of from combined reports, n_2 is the number from interviews and m_2 is the number of duplicate incidents common to both data sources.

If there are no duplicates then a point estimate may not be valid, but it is possible to estimate a lower bound N_{min} such that there is a 95% probability that $N > N_{min}$

$$\left(\frac{N_{min}-n_1}{N_{min}}\right)^{n_2} < 0.05 \qquad (3)$$

Extrapolating interview results based on fishing effort

Entanglement prevalence can alternatively be estimated solely on interview data. Interviews were divided up by regions and districts in order to allow for some stratification, while maintaining sample sizes. The probability that a particular entanglement would be revealed through interviews would depend on a number of factors, but principally the proportion of fishers in that district who were interviewed. This allows for a Horvitz-Thomson type estimator for the total number of entanglements based on stratified interview results. In Scotland, fisheries are divided up into districts[2] and statistics reported annually for each district. The numbers of registered vessels are reported by gear type[3] but this includes vessels that may be inactive. An indication of the number of active vessels may be given by the number of people in full-time employment[4], however 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 crewmembers for each vessel size category to predict the number of fishers employed in each district. For vessels under 10m, this was 1.5, for shellfish vessels over 10m this was 3, and for demersal vessels over 10m this was 4.7 [5]. The predicted employment plotted against reported employment by district is shown in Figure 2. 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 out of a total of 1431 registered vessels. Northridge et al. (2010) estimated that around 300 vessels fished for more than 50 days a year, suggesting that many vessels only 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.

[2] https://marinescotland.atkinsgeospatial.com/nmpi/default.aspx?layers=527
[3] https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2017/pages/49/
[4] https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2017/pages/52/
[5] https://www.gov.scot/publications/scottish-sea-fisheries-employment-2015/pages/10/#Table6

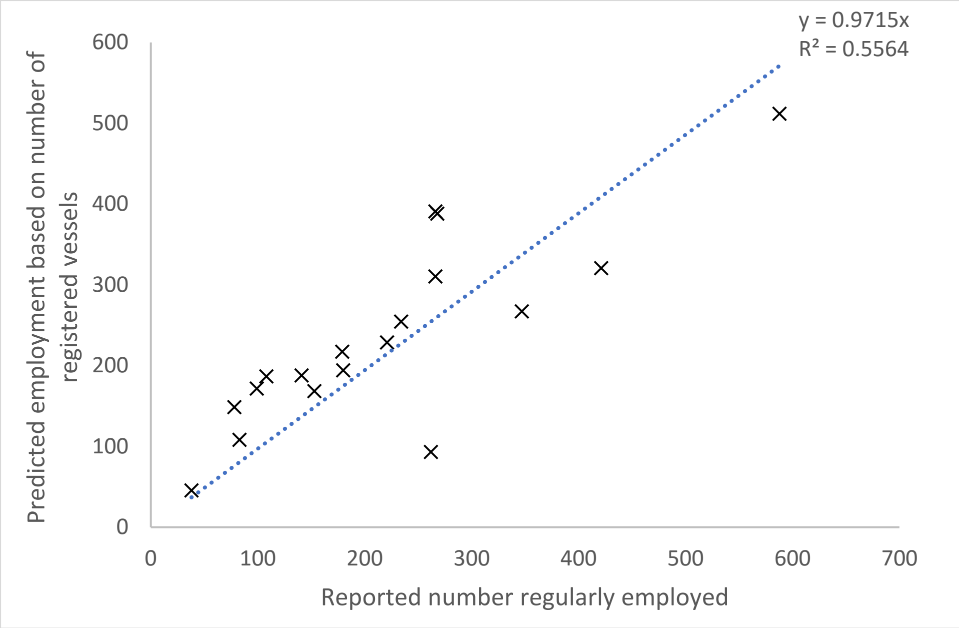

Figure 2. Predicted employment against reported number regularly employed by fisheries district (districts are listed in Table 2).

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

District	**Region**	**Under 10m Creel fishing**	**Over 10m creel fishing**	**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

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 three distinct regions. These were defined as ‘West’ from Cape Wrath to the Clyde including the Outer Isles, ‘North’ comprising of the north coast between Cape Wrath and Duncansby Head and East coast from Duncansby Hd. To Helmsdale, Orkney and Shetland, and ‘East’ 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.

The total number of active vessels *V* across *j* strata were calculated by

$$V = \sum_{i=1}^{j} v_i \qquad (4)$$

Where v_i = number of active vessels in strata *i*

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

$$\widehat{N} = \sum_{i=1}^{j} \frac{v_i}{k_i} n_i \qquad (5)$$

Where:

k_i = number of interviews by strata *i*

n_i = number of reported entangled whales in strata *i*

With variance

$$var\left(\frac{\widehat{N}}{V}\right) = \frac{\sum_{i=1}^{j} v_i^2 \, var\left(\widehat{n_i}/v_i\right)}{V^2} \qquad (6)$$

If K_i is the total number of interviews in stratum *i* with k_m being the number in each sub-strata *m* out of *s* sub-strata, resulting in n_m reported entanglements. n_i is the total number of entanglement reports in stratum *i* then the variance can be expressed as (following Buckland et al. 1993):

$$\widehat{var}(n_i) = K_i \sum_{m=1}^{s} k_m \left(\frac{n_m}{k_m} - \frac{n}{K_i}\right)^2 /(s-1) \qquad (7)$$

If each interview is treated as a sampling unit (i.e. there are no sub-strata) then k_m=1 giving a standard calculation of $\widehat{var}(n_i)$

The log-normal confidence interval (Buckland et al. 1993) can then be given by $\left(\frac{\widehat{N}}{C}, \widehat{N}.C\right)$

Where

$$C = exp\left[z_\alpha \sqrt{\widehat{var}(log_e \widehat{N})}\right] \qquad (8)$$

and

$$\widehat{var}\left(log_e \widehat{N}\right) = log_e \left[1 + \frac{var(\widehat{N})}{\widehat{N}^2}\right] \qquad (9)$$

Identifying factors affecting entanglement risk

The total amount of gear multiplied by time in the water is likely to be a good predictor of risk for a whale in the fishing area, but the actual entanglement risk will depend on the distribution of whales in relation to the fishing gear. Data on fishing effort recorded in interviews included total length of all gear when deployed (i.e. fathoms of rope used per fleet), soak 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 fishing area such as distance of grounds from shore and depth of water in which gear was typically set. In order to allow for differences between fishers who reported whether they were full and part time, we used an estimate of 'risk' that was proportional to gear length for full time fishers and gear length/2 for part time. All fishers interviewed, both full time and part time, were operating commercially. No recreational ('hobby') fishers were included in interviews but were cited during interviews as being less likely to employ best practice e.g. regular gear maintenance, weighting gear properly or adjusting ends for depth due to a lack of experience and/or concern.

Gear length, number of creels, fishing 0-6nm or >6nm from shore and water depth are all correlated to some extent. So choosing the most appropriate model of risk is a challenge. The sample size of 157 interviews was not large enough to allow for stratification and so risk factors were investigated using the full data set.

RESULTS

The locations of reported entanglements and the ports where entanglements were recorded in interviews are shown in Figure 3 for humpbacks and Figure 4 for minke whales. These show that entanglements occur throughout Scottish waters.

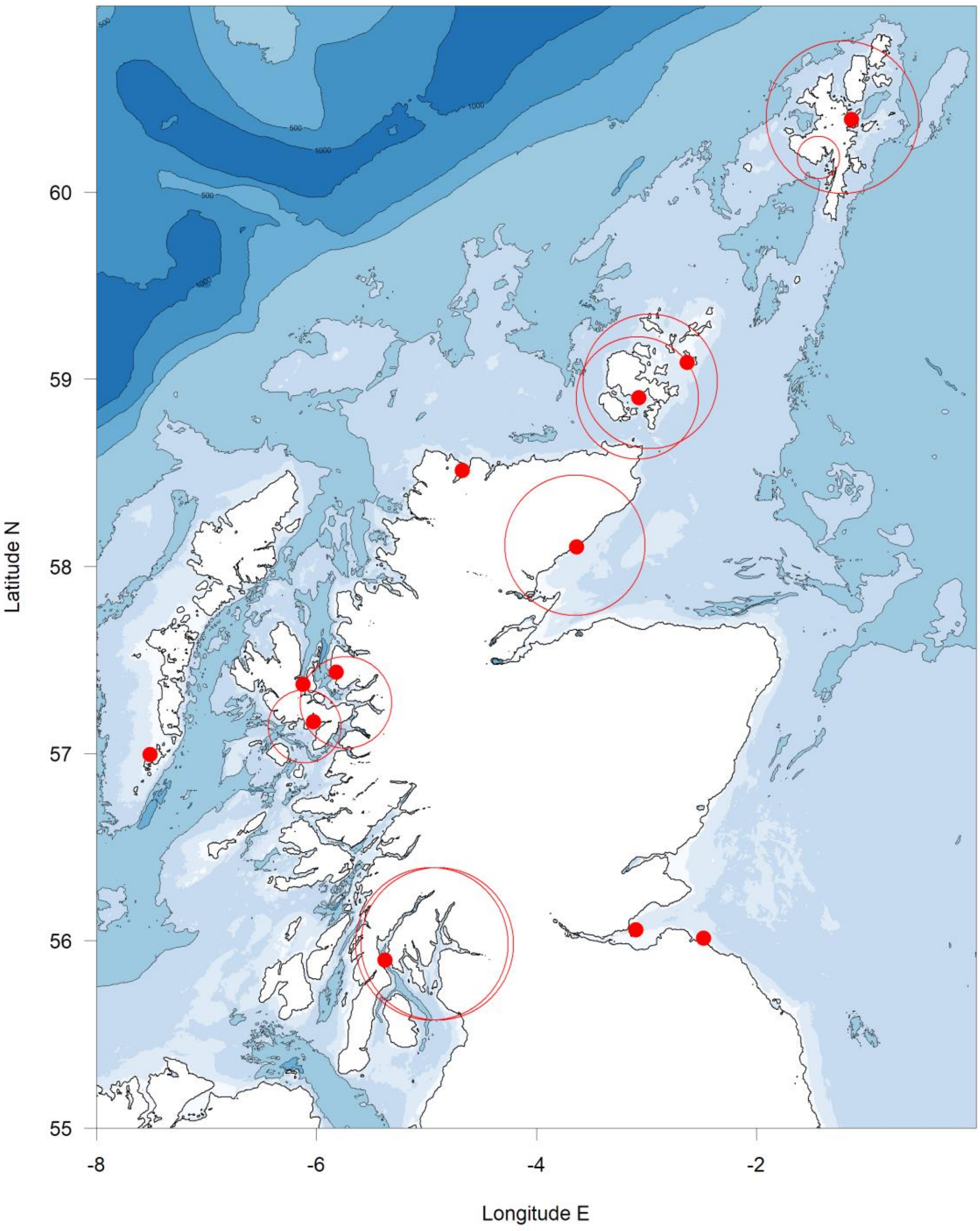

Figure 3. Locations of humpback whales reported to SMASS entangled in rope known or suspected to have been associated with creel fishing (red dots) between 2008 and 2019. Red circles are centred on ports where an entanglement was reported from interviews with creel fishers. Radius of the circle indicates the reported fishing distance from the port.

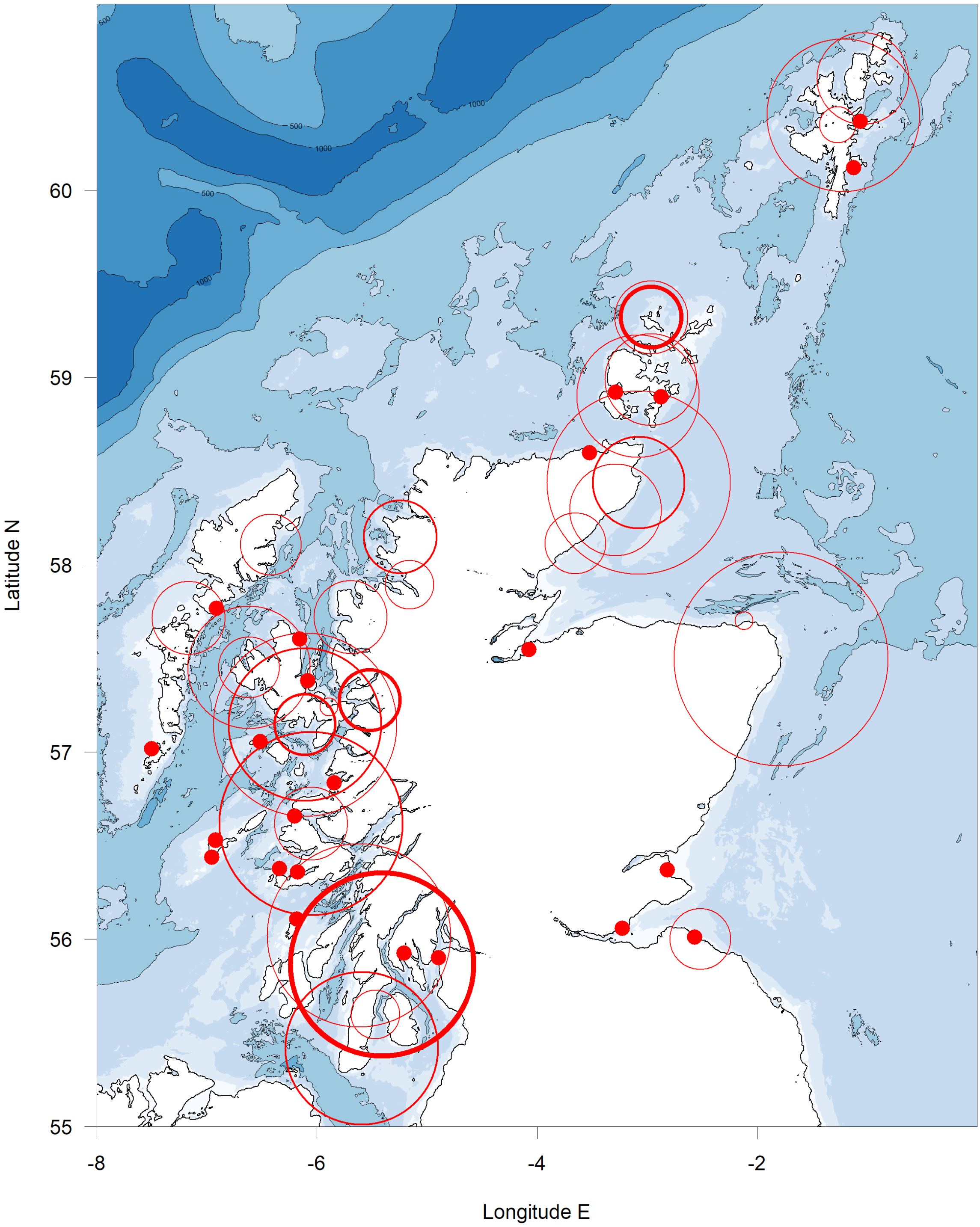

Figure 4. Locations of entangled minke whales from the SMASS database between 2008 and 2019 (red dots). Circles indicate locations of port interviews reporting at least one minke whale entanglement. The radius of the circle indicates the distance from the port where fishing operations occur, and the width of the circle is proportional to the number of entanglements reported (1-6).

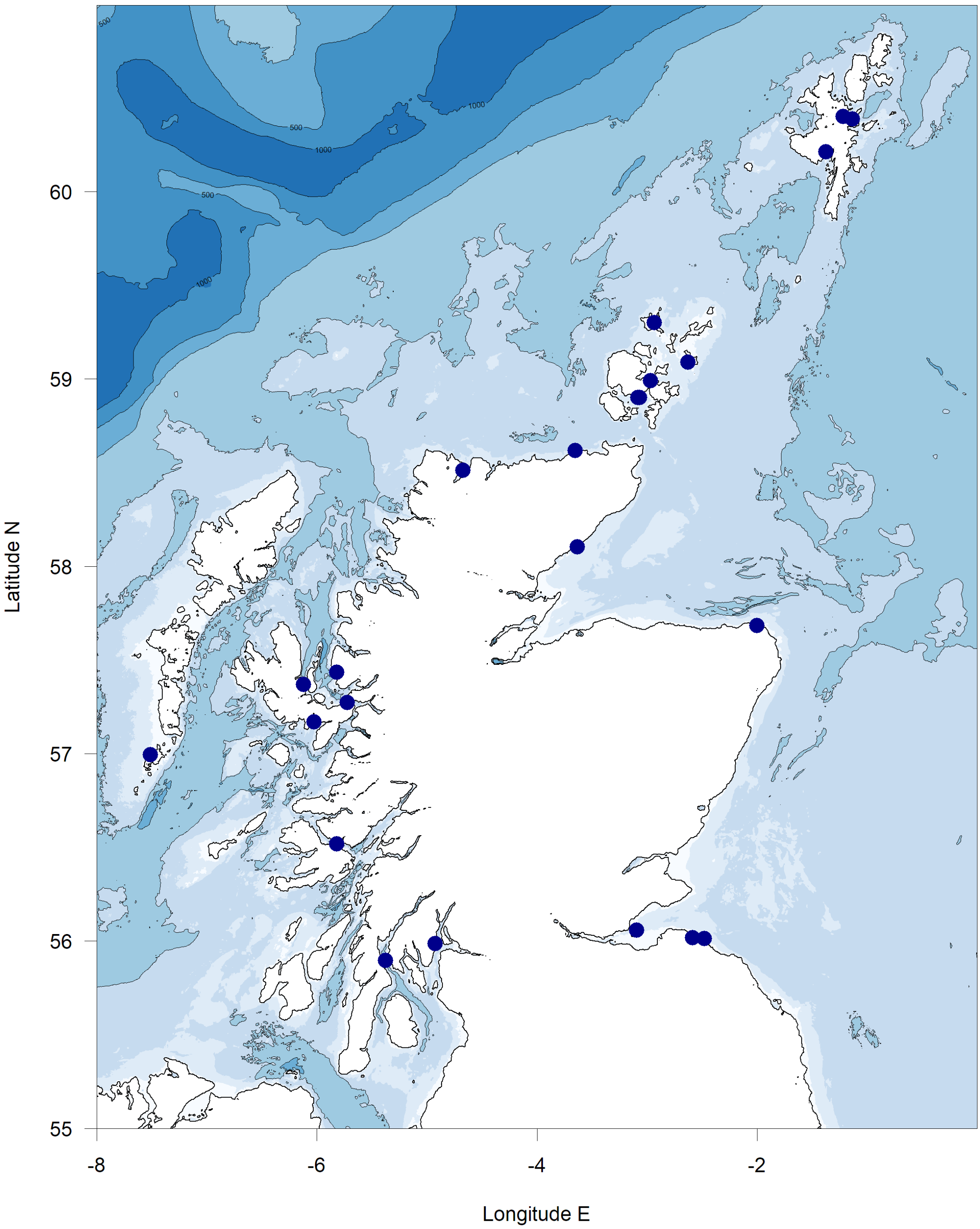

Figure 5. Indicative locations of all known humpback entanglements. Dots indicate either reported entanglement location, reported stranding location or port where interview reported an entanglement if no additional information was available.

For humpback whale incidents it was possible to identify two definite duplicates between the reports and the interviews. It was also possible to determine that none of the other seven incidents reported in the interviews could have been duplicate records with the reports.

It was much harder to determine duplicates for minke whales because of the larger number of reports from interviews (50) and their density and distribution throughout Scottish waters (Figure 3). An approximate date was available for 26 cases of the 50 minke whale incidents identified in the interviews. For all these 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 lack of identified duplicates effectively precludes calculation of a point estimate but the lower bound based on equation 3 was 220 (i.e. there was a 95% probability that the actual number was greater than this).

Results for both species are summarised in Table 2. The distribution of the unique humpback entanglements (or strandings following entanglement) is shown in Figure 5. This indicates entanglements may occur throughout Scottish waters with no obvious concentrations, however the absence of any such patterns could be obscured by the fact that humpbacks are capable of towing gear great distances away from the site of entanglement (Lyman 2014).

Table 2. Reports of humpback and minke whale entanglements from different sources and estimates of total numbers.

	Humpback	Minke	Minke with approximate date to identify duplicates
Number of records from SMASS, BDMLR and other sources within the period of the interview surveys (2008-2019)	10	24	
Number of records from SMASS, BDMLR and other sources before or after the period of the interview surveys (2008-2019)	6	4	
Other incidents (aquaculture)	1	0	
Number of cases from interviews	9	50	26
Number of duplicates	2	-	0
Minimum total creel estimates (sum of other sources and interviews less possible duplicates)	23	-	-
Chapman estimate for period of interview surveys	35.7 (10.0 – 61.3)	-	-
Estimated total using correction factor from Chapman estimate for those reports outside of period of surveys	57.1 (16.0 - 98.1)	-	-
Estimate of total creels + aquaculture	58	-	-

The stratified estimates by district are given in Table 4 and by region in Table 5. Sample sizes in some districts were too small to allow variance estimates and so these were only calculated for the three regions.

Table 4. Stratified estimates by district for the 10 years covered by interviews

District	Region	Number of interviews	Proportion of active vessels included in interviews	Average Depth (m)	Average gear length (km)	Total minke reports	Estimated minke total	Total humpback reports	Estimated humpback 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	2	5.0
Scrabster	N	22	0.27	47	20.9	4	14.8	1	3.7
Shetland	N	8	0.11	55	15.9	3	27.1	2	18.1
Stornoway	W	10	0.08	54	12.5	2	23.8	0	0.0
Ullapool	W	7	0.10	145	35.5	3	28.6	0	0.0
Total		**157**				**50**	**321.3**	**9**	**53.5**

Table 5. Stratified estimates by region for the 10 years covered by interviews

Region	Number of interviews	Estimated number of active vessels	Number of entangled minke whales reported	Estimate of total minke whale entanglements	Variance of entangled minke reports	95% log-normal CI of estimated total entanglements
E	43	345.4	3	24.1	2.8	8.7 - 66.7
N	42	253.1	15	90.4	29.5	45.4 - 179.9
W	72	418.9	32	186.2	58.7	117.2 - 295.7
Total	**157**	**1017.4**	**50**	**300.7**	**541.9**	**258.7 - 350.2**

Region	Number of interviews	Estimated number of active vessels	Number of entangled humpback whales reported	Estimate of total humpback whale entanglements	Variance of entangled humpback reports	95% log-normal CI of estimated total entanglements
E	43	345.4	0	0.0	0.0	0.0 - 0.0
N	42	253.1	5	30.1	4.3	13.8 - 65.9
W	72	418.9	4	23.3	5.7	7.9 - 68.8
Total	**157**	**1017.4**	**9**	**53.4**	**59.4**	**40.4 - 70.9**

Factors affecting entanglement risk

Of 50 minke whales, seven were reported to be entangled in vertical line, 31 in ground or back line, and 12 were unknown, i.e. in the 31 out of 38 (82%) cases where the nature of entanglement was known, entanglement was in the ground or back lines.

Of nine humpbacks, two were in vertical line, three in ground line, and four unknown, i.e. three out of five (60%) cases of known cause involved the ground or back lines.

Because of the correlations between all the risk related variables it was not possible to include more than one co-variate in a modelling approach. Instead, simple linear regression models were used to investigate relationships. For humpback whales, no significant relationships were found between entanglements per interview and any of the factors, but this is most likely due to small sample sizes.

For minke whales, the strongest relationship was with the depth in which the gear was set, with entanglement rates increasing with greater depth (Figure 6), but there was also a significant increase in entanglement rates with 'risk' (gear length adjusted for full or part time).

Table 5. Linear regressions of entanglement rates, with depth, gear length and 'risk'.

Regression	r-squared	p value
Minke entanglements ~ AverageDepth	0.40	**0.01**
Minke entanglements ~ AverageGearLength	0.21	0.08
Minke entanglements ~ AverageRisk	0.34	**0.02**
Humpback entanglements ~ AverageDepth	0.00	0.91
Humpback entanglements~ AverageGearLength	0.01	0.70
Humpback entanglements ~ AverageRisk	0.00	0.81

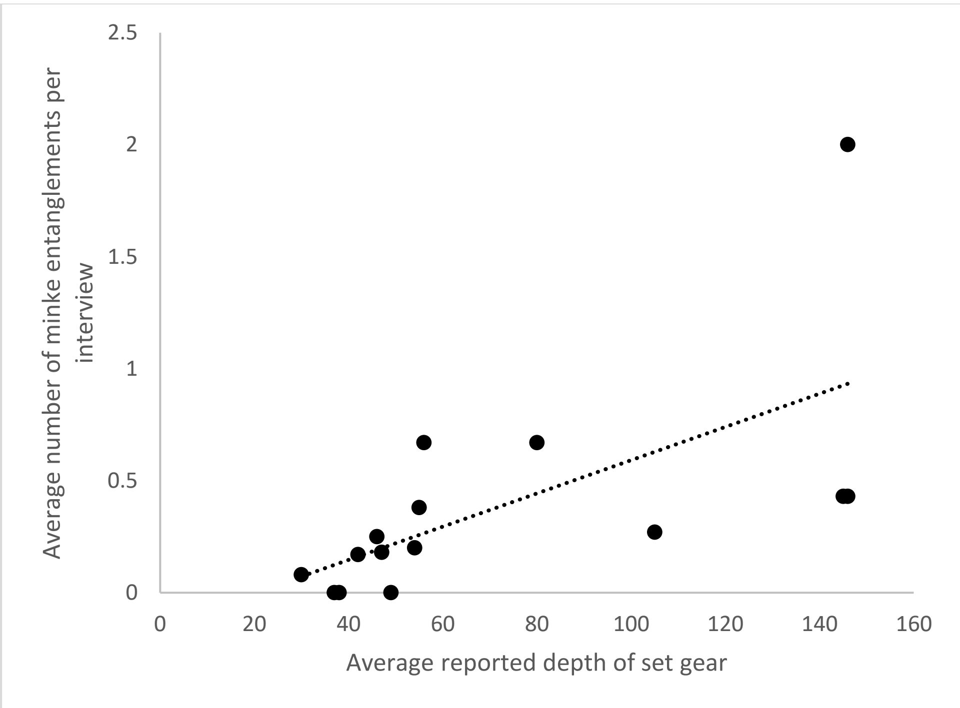

Figure 6. Mean number of minke entanglements per interview by fisheries district against average reported gear depth.

Of the 50 entangled minke whales from the interviews, 41 (82%) were found dead, compared with humpback whales where three out of nine (33%) were found dead.

DISCUSSION

The estimates and numbers of reports presented here are considerably higher than have been previously reported, including to IWC in National Progress reports. They demonstrate a significant degree of historic underreporting and suggest that the Scottish creel fishery may be having a much greater impact on whale welfare and conservation than has previously been recognised. Previous analysis of entanglement rates for humpback whales led by Ryan et al. (2016) concluded that 'Scottish inshore waters could not support a population of humpback whales and these waters currently act as a high mortality sink for the species in the NE Atlantic'. The results here double the number of reported entanglements of humpbacks in Scotland from the 12 identified by Ryan et al. (2016) to 24, all but three of which have occurred since 2010. We estimate a total over the last ten years of 53 humpback whale entanglements, but there is also evidence of an increasing entanglement rate in recent years with 2019 having the greatest number of incidents (four) 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 for humpbacks (Ryan et al. 2016, Hammond et al. 2017); estimates of numbers of entangled whales are also higher. Minke whale entanglements were also much more likely to be fatal; 82% 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. The total estimate of 300 (95% CI 259-350) from extrapolated interview surveys was not very sensitive to the stratification chosen.

There are a number of potential biases that could occur for both the capture-recapture approach to estimates and extrapolation of the interview results to the whole fleet but the sources of bias for the two approaches will generally be different. However, both methods will be subject to negative bias associated with either whales breaking free from the gear or swimming away with entangled gear, such that the fisher may just see that the gear has been lost and not attribute this to a whale entanglement, but rather the effects of weather or other vessels towing gear for example. The latter situation is much more likely to occur with humpback whales, which are known to be powerful swimmers sometimes carrying gear for great distances (Knowlton et al. 2016) and therefore the true entanglement rate, both in terms of mortality and morbidity for humpback whales will be higher. The capture-recapture approach will be most sensitive to any heterogeneity in the probability that an incident will be reported. For example, some entangled whales and disentanglement efforts attract considerable media attention whereas others are only witnessed by the fisher involved. This may lead to a negative bias if highly publicised incidents were more likely to be reported by both methods. The extrapolation from the interviews assumes that those interviewed were representative of the fleet as a whole for either the district or the region. A positive bias would result if fishers who had experienced entanglements were more likely to be interviewed, or a negative bias if an entanglement experience had left them less willing to talk.

The consistency of the results of the two approaches does give some confidence in the numbers. For humpback whales the two estimation methods for the period of the interview surveys did not give significantly different results (36 from the capture-recapture approach and 53 from the extrapolation from the interviews). Although the capture-recapture approach could not provide a point estimate for minke whale entanglements because there were no identified duplicates, it can give an indication of a lower bound. This lower bound of 220 (i.e. there was a 95% probability that there were more entanglements than this) was consistent with the lower 95% confidence interval of 259 from extrapolation of the interview surveys.

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, 20% thought that the situation could be improved through setting gear with less line, 5% identified self-shooting gear (i.e. where creels are deployed automatically off the deck rather than by hand) as a way to keep greater tension on the ground lines and reduce floating loops, 32% suggested the use of weights or sinking line, and 28% thought that there should be less gear in the water overall.

Our estimates suggest that around five humpback whales and 30 minke whales are entangled in Scottish waters each year. These numbers are a concern from both a welfare and conservation perspective and could pose a risk of localised depletion for minke whales. The abundance estimate for the blocks of the SCANS III survey covering the west coast of Scotland inside of the Outer Hebrides, equivalent to the W region in this study was 695 minke whales (Hammond et al. 2017). We estimate 15.3 fatal entanglements per year in this region (based on a ten year estimate of 186 and 82% of entanglement proving fatal) which is 2.2% of the abundance estimate.

Two known breeding populations of humpback whales in the North Atlantic occur in Cape Verde and West Indies, with some interbreeding (Palsbøll et al., 2017). Wenzel et al. (2020) recently reported that the Cape Verde population remains precariously small (272, 10 SE). There are photo-ID matches to the Cape Verde Islands and to the southeast Caribbean portion of the West Indies (Jones et al 2017) from Scottish waters (n=22 individuals compared to the NAHWC), although this is based on a small sample size and research is still ongoing (North Atlantic Humpback Whale Catalog at Allied Whale, unpublished data).Therefore any entanglements occurring in Scottish waters could potentially impact these small populations in the NE Atlantic.

Given that 82% of minke and 60% of humpback entanglements were reported to have occurred in the ground lines between creels, the suggestions from fishers of using leaded line could greatly reduce entanglement risk. This was identified by fishers as more practical in areas of soft, muddy bottom because sinking lines would be more vulnerable to snagging and abrasion on rocky ground. Sinking ground line has been used in fisheries off the east coast of the US where all fixed-gear fisheries are required to use sinking or neutrally buoyant ropes for their groundlines (ALWTRP, 2007). Therefore a first step in Scotland 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. Brilliant et al. 2010). This would help inform areas where sinking line could be implemented most effectively.

In addition, informal trials of on-call or 'ropeless' gear types in Scotland have gone well to date, and the technologies have been embraced by those fishers employing them. Formalising and expanding these trials, particularly in areas identified as high risk could also reduce entanglement risk in vertical end lines and should be considered with urgency, particularly given the willingness exhibited by fishers to engage in mitigation strategies and research.

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