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WHALING COMMISSION

ENTANGLEMENT: AN EMERGING THREAT TO HUMPBACK WHALES IN SCOTTISH WATERS

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Abstract

Entanglement in static fishing gear, especially shellfish creels (pots), is a known source of mortality and injury for humpback whales (*Megaptera novaeangliae*) with an apparent rise in recent entanglements of this species in Scottish coastal waters. All available sighting records in Scottish waters from 1992 to 2016 were collated to determine the distribution of the species. A subset of sightings with associated boat-based search effort from the west of Scotland indicated the relative abundance of humpback whales in this region was very low (just four sightings from 86,000 km of search effort). Of the 213 incidental sighting records from 1992 to 2016, 5.6 % (n = 12) comprised known entanglements. For the five most recent years (2012 to 2016), this proportion was higher 7.5 % (n = 10). Over half of the known entanglements (n = 7) involved creels, three others were of ropes consistent with creels, and one involved an aquaculture (salmon) pen. Rescue responses to six of the 12 entangled whales resulted in successful disentanglements, although their long-term survival remains unknown. Three of the 12 entanglement cases (i.e. 25%) were fatal. A gamma distribution was fitted to the frequency of humpback whale 'visits' based on the number of different days on which humpbacks were reported. From this, the number of unreported visits in inshore Scottish waters was estimated. Based on the minimum number of reported entanglements, the daily probability that a whale that is present in the area would become entangled was estimated at 0.0017. An independent estimate of entanglement risk, using a subset of effort-related sightings and an assumed effective strip half-width, also suggested the same daily entanglement probability. If a whale were to be resident year-round, these estimates would equate to an annual entanglement probability of 0.46. Based on this probability and the observed proportion of fatal entanglements would suggest a fatal entanglement probability of 0.12. This source of mortality alone is an order of magnitude higher than sustainable levels. A positive correlation between the annual estimates of the number of visits and reported entanglements ($r=0.79$, $df=22$, $p<0.001$) suggests that the method for estimating humpback whale days is a valid approach for assessing risk. In the present scenario, 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 entanglement issue is also a concern for other species, particularly minke whales. Measures to reduce entanglement risk could also benefit the creel fishing industry by minimising the loss of gear.

Introduction

Following two centuries of over-exploitation globally, the recovery of humpback whales (*Megaptera novaeangliae*) in some parts of the world is well documented (e.g. Paterson *et al.*, 1994; Stevick *et al.*, 2003). However, recovery rates in the only known breeding ground in the eastern North Atlantic (Cape Verde Islands) and feeding areas around Western Europe appear to be slow (Ryan *et al.*, 2014, In Press). Relative abundances in UK waters remain very low (Reid *et al.*, 2003), which is reflected in the lack of published data on the presence and distribution of this species in these waters (Evans et al., 2003; Clapham & Evans, 2008).

Entanglement in static fishing gear, namely crab and lobster creels (pots), is the largest source of anthropogenic mortality and injury for this species in the western North Atlantic (Johnson *et al.*, 2005; Benjamins *et al.* 2012; Moore and Van der Hoop, 2012; Van der Hoop *et al.*, 2013; Pace *et al.*, 2014). Recent observations of entangled humpback whales in Scottish waters prompted us to investigate this emerging issue. Pathological evidence consistent with entanglement in shellfish creels has already been documented in as many as 50% of stranded minke whales (*Balaenoptera acutorostrata*) in Scottish waters (Northridge *et al.*, 2010). Creel fisheries are carried out throughout Scotland, although estimating fishing effort is not possible for the majority of the fleet as they are below the 12 m length obliged to transmit vessel monitoring system (VMS) data. Even where vessels do transmit VMS data, quantifying creeling effort is problematic as the soak time of the creels is not known (Lee *et al.*, 2010). Using data collected by field researchers and members of the public, the present study is the first attempt to estimate the risk of humpback whale entanglement in Scotland or the UK.

Methods

Temporal and Spatial Distribution of Sightings and Entanglements

Humpback whale sighting data were collated from several databases in Scotland. Separate analyses were conducted using sighting data with quantified effort and incidental sightings.

Effort-based sighting data were collected around the Hebrides, Scotland during dedicated marine mammal surveys conducted from the sailing research vessel *Silurian* in Beaufort sea state < 5 from April to October 2003 to 2015 inclusive. Two observers scanned the sea using the naked eye during daylight hours from a platform 2m above sea level along pre-defined track-lines as evenly as possible within the constraints of weather and suitable anchorages (Embling *et al.*, 2009). The distribution of creels was also recorded by observers by identifying pairs of buoys within 2 km of the vessel's track. The total number of creels and humpback whales recorded during visual survey effort was subsequently mapped to determine whether or not high-density areas of co-occurrence were evident.

Incidental sightings records of humpback whales were gathered from a number of different sources, including: public sighting schemes coordinated by Sea Watch Foundation (SWF), Hebridean Whale and Dolphin Trust (HWDT), Whale and Dolphin Conservation (WDC); and the Cetacean Research and Rescue Unit (CRRU); dedicated research cruises (HWDT, CRRU and SWF); and whale rescue call-outs (British Divers Marine Life Rescue (BDMLR) and CRRU)) in Scottish waters between 1992 and 2016. In a few cases, photographic evidence permitted individual identification and matches between different sightings on different days. However, this was only possible in a very few (<5%) number of cases. In two such cases, the identifying feature was entangled gear. All records were mapped to visually assess if the entanglement issue was widespread or geographically confined.

Estimating Entanglement Risk

Relating whale density to the number of entanglements was challenging, owing to the low density of humpback whales and small number of observations. However, several crude assumptions were used to provide some insight into the level of risk. A useful metric, if it can be estimated, is the average density over time or number of 'humpback whale days' in inshore Scottish waters (the Territorial Sea within 12nm of the coast including the Minch and Sea of the Hebrides). A reasonable assumption is that Scottish inshore waters are not currently a key habitat for any humpback whale population in the NE Atlantic, but that individual whales, or small groups, 'visit' for varying lengths of time. These individuals or groups would likely be seen a number of times and reported, but there will be many days when they are present but not seen. Each visit carries a probability of entanglement.

An estimate for the number of 'humpback whale days' can be obtained from the number of visits, the mean duration of a visit and the mean group size. The number of reported visits was estimated by considering the time and distance intervals between sightings, assuming that many records were in fact re-sightings of individual whales. Once sightings were grouped into visits the frequency of the number of days on which each estimated visit was reported were examined. As a validation of the groupings of sightings into visits, the total sum of the variance in the observed group size estimates partitioned by each visit was calculated.

Simulations were conducted to examine the most likely form of this frequency distribution. For the simulations it was assumed that the duration of a visit could be modelled by a lognormal distribution with a constant probability of detection for each day of the visit. For a range of plausible parameters this gave a very good fit to an exponential distribution (one-sample K–S test, $p<0.001$). Hence an exponential distribution was fitted to the observed sighting frequencies for reported visits (i.e. seen once or more) in order to estimate the expected number for zero, giving probability that a visit would not be detected.

An alternative estimate of average humpback whale density in Scottish inshore waters calculated independently of the incidental sightings was derived using survey data from the west of Scotland from the research vessel *Silurian*. The small number of observations precluded strip width estimation, so this was assumed based on other survey results. Compared to other surveys, the observation platform on Silurian is low (eye-height *ca.* 3m) and so estimated strip widths would be expected to be less. Based on similar surveys for humpback whales (e.g.

Findlay *et al.*, 2011) and a review of strip widths for large whales (Leaper *et al*., 2015) a strip half width of 1.5km would seem to be a reasonable assumption for a very approximate estimate.

Results

Temporal and Spatial Distribution of Sightings and Entanglements

Dedicated visual surveys conducted from Silurian between 2003 and 2015 amounted to 86,569 km of effort resulting in sightings of four humpback whales, 609 minke whales and 25,468 fleets of creels (Figure 1). Evidently, humpback whale relative abundance was very low in the west of Scotland when compared for example with minke whales. Creels were widespread in coastal areas and in waters shallower than 100m (Figure 1). None of the four humpback whales encountered showed signs of entanglement.

All incidental sightings of humpback whales were within Scottish territorial seas (Figure 2). Most were in coastal waters, reflecting the distribution of observers. Known entanglements were widely distributed in coastal waters (Figure 2). One entanglement case involved a recently weaned calf becoming caught beneath an aquaculture pen and drowning. Seven cases were entanglements in sets of creels or ropes and one case was unknown, although fresh (pink) scars on the leading edge of the tail stock were consistent with recent entanglement in ropes (Table 1). Although based on a low sample size, there was no apparent season where known entanglements occurred in greater numbers (Table 1). There were more sightings of humpback whales reported between June and August, with fewer records in both December and April (Figure 3). However, there is much lower sighting effort over the winter and so it is not possible to conclude that there are more whales in summer than in winter.

Of all the sighting records available from 1992 to 2016 (n=213), 5.6% (n=12) were known entanglement cases, of which six were disentangled by fishermen, volunteer rescue teams or divers, three (25%) were confirmed to be fatal, two apparently escaped unaided, and the fate of one remains unknown (Table 1). When the most recent five years of data were considered (n=133), the proportion of all sightings comprising entangled whales increased to 7.5 % (n=10).

Estimating Entanglement Risk

Reported incidental sightings were clustered in time as shown by the plot of waiting time intervals in days between sightings (Figure 5). Apart from same day reports, the most frequent interval was just one day. However, these intervals did not suggest any clear number to select to separate clusters of sightings that were likely to be the same individual.

In order to estimate whether a sequence of observations could be attributed to the same 'visit', the distance between observations was also taken into account. It can be seen from Figure 6a that regardless of the maximum distance between successive sightings chosen as a criterion for observations to be classified as the same visit, there is an inflexion at maximum interval between sightings of seven days. Similarly, regardless of the number of days between successive sightings that are assumed to be the same visit there is a point of inflexion at a distance of around 35nm (Figure 6b).

This suggests criteria for classifying whether a series of observations belong to the same visit of ≤7 days since the last sighting and <35nm distance between successive sightings. This would result in a total estimate of 155 observed visits up until the end of 2015. Of these 11 (7.1%) resulted in entanglement. Sensitivity tests for the estimated number of visits suggests that it is not overly sensitive to the assumptions chosen and that a plausible range would be 130-200 visits. Observed group size varied from 1-6 but was dominated by single animals (82% of visits) with a mean group size for a visit of 1.2. The chosen classification of visits also resulted in the minimum total variance of observed group size. Although this adds further support to the classification being appropriate, this same minimum variance occurred whatever value in a range of 6-18 days was chosen for the criteria of the number of days with no sightings for a new sighting to be classified as a new visit. The number of reported sightings each year has increased over time but with considerable inter-annual variability (Figure 4). When sightings are classified into visits, this variability is reduced considerably (Figure 4) but still with a clear increasing trend over time.

In order to estimate the probability that a visit will be reported at least once, the fitted exponential distribution to the frequency of the number of days on which each estimated visit was reported (Figure 7) was extrapolated to estimate the number of visits that were not reported (689 or 81.6% of total). This gave a probability that a visit would be reported of 18.4%. During the period 2003-2015 there were 142 observed visits, 11 of which resulted in reported entanglement (7.7%). With an estimated reporting probability of 18.4% this would suggest 783 visits during this period. If the mean length of a visit were 7 days with a mean number of whales of 1.2 then this would result in around 6600 humpback whale days during this period.

An alternative way to estimate the total number of 'humpback whale days' for Scottish inshore waters is using sightings data from *Silurian* surveys. If it is assumed that the ESHW from Silurian is 1.5km then an approximate density for inshore waters of Scotland (within 12nm) based on Silurian data would be 0.015 individuals per 1000 km^2. This would correspond to an average of 1.4 humpback whales present at any one time in Scottish inshore waters (Territorial sea measuring 90,404km^2 in area). If the ESHW were assumed to be 1km then the mean abundance estimate would be around 2.1 individuals. Assuming an ESHW of 1.5km and the same density of whales throughout the year, this would suggest around 6600 humpback whale days over the 13-year period giving a probability of entanglement of 0.0017 per day (an ESHW of 1.0km would suggest around 9900 humpback whale days).

The estimates of the number of humpback whale days and hence the probability of entanglement are similar using both approaches, but this is likely just coincidence given the approximate nature of the estimates and the required assumptions. An entanglement probability of 0.0017 per day would result in a probability of entanglement of 0.46 for an animal, which was resident year round (however we acknowledge that humpback whales are unlikely to be resident year round, given they are seasonal migrants).

Finally, there was a strong correlation between the number of estimated visits in any year and the number of reported entanglements (Pearson $r=0.79$, $df=22$, $p<0.001$).

Discussion

Temporal and Spatial Distribution of Sightings and Entanglements

Effort-based data from surveys on board *Silurian* confirm that humpback whales occur in very low abundances among a high abundance of creels in inshore waters off the West of Scotland. A similarly low relative abundance was also found in offshore waters of north-western Europe, e.g. only one humpback whale was seen during SCANS I and II and CODA surveys following a total of 65,000 km of search effort since 1994 (Phil Hammond, pers. com.). Evidently, generating data with a view to assessing risk of entanglement for humpback whales using effort-based data is not currently feasible. Records submitted by members of the public combined with occasional sightings by researchers are thus currently the best available methods by which to investigate humpback whale presence and the relationship with entanglement risk.

Considering their low relative abundance in Scottish waters, the proportion of all humpback whale records involving entanglement was high (5 – 7%) suggesting the species is particularly prone to entanglement in the present creel fishery. Among 303 incidental sightings of humpback whales in Irish waters between 1999 and 2013 (Ryan *et al.*, In Press), only three entanglement cases were recorded (Simon Berrow, *pers comm*). These sighting rates together with somewhat larger group sizes in Irish waters of up to 8 whales (mean group size 1.7 ± 1.0 SD, Ryan *et al.*, In Press) suggest that humpback whales are more abundant there than in Scottish waters (mean group size 1.2 ± 0.6 SD, present study) yet the incidence of entanglement appears to be either much lower or under-recorded off Ireland. Although drawing comparisons between proportions of entangled to non-entangled whales comes with many caveats, the apparent incidence of whale entanglement in Scotland is high compared to adjacent waters.

The geographical distribution of entangled humpback whales around Scotland indicates that the issue of entanglement is widespread. Considering that most sighting and entanglement records were reported by members of the public, those data presented here may be biased in favour of coastal waters, so it is probable that humpback whales are also occurring or becoming entangled elsewhere. In Scotland, the vast majority of cases of minke whales found with evidence of entanglement involved dead whales with creels no longer attached (Northridge *et al.*, 2010). Most humpback entanglement cases examined in the present study, however, involved fleets of creels still attached to live whales. Disentanglement of whales by fishermen and trained rescuers has apparently been successful in releasing whales in half of the known cases; however, prevention of entanglement in the first place would be a far more favourable solution. To our knowledge, there are currently no measures being implemented to attempt to reduce risk of cetacean entanglement in Scottish creel fisheries.

Probability of Entanglement

From the limited data available, it is difficult to estimate the probability that a humpback whale present within Scottish inshore waters will be seen on any day or any visit. The estimates of the number of humpback whale days for Scottish waters made here must be considered very approximate. However, the two approaches of using incidental sightings categorised into 'visits' and systematic survey data (with only four sightings) do give similar results. The categorisation into visits is also supported by coinciding with the minimum variance in the observed group sizes partitioned into visits and by the reduced inter-annual variability when comparing number of visits to the number of reported sightings. The correlation between the annual estimates of the number of visits and reported entanglements also suggests that estimating humpback whale days is a valid approach for assessing risk.

If a substantial proportion of entanglements are fatal (e.g. 25% of known entanglement cases, n = 4) then the annual fatal entanglement probabilities (0.12) if an animal were resident year round would be an order of magnitude greater than what could be considered sustainable, e.g. contemporary sustainable human-caused annual mortality for humpback whales in the northwest Atlantic is 0.014 ±0.007 SD (Van der Hoop *et al.*, 2013). It is also important to acknowledge that not all entanglements will be reported. Fatal entanglements may be more likely to be reported than non-fatal interactions but situations where there has been a disentanglement effort are also more likely to be reported than ones which are just observed by fishermen. Hence the proportion of potentially fatal entanglements where disentanglement is successful is likely to be overestimated. This analysis has attempted to correct for sightings that are not reported but no attempt has been made to estimate the proportion of entanglements that are reported, meaning that our estimates of entanglement risk and fatality rate are negatively biased. In the Gulf of Maine, despite well-established reporting and response networks it has been estimated that fewer than 10% of humpback whale entanglement events are witnessed and only a fraction of all deaths are detected (Robbins et al. 2009).

Hence it is reasonable to assume that, at present, Scottish inshore waters could not support a population of humpback whales, and they currently act as a potential high mortality sink for populations in the NE Atlantic. This is of concern for the recovery of humpback whale populations if whales should increasingly inhabit Scottish waters. In addition, the high entanglement risk for humpback whales emphasises current concerns for minke whales, which occur at much higher densities in Scottish waters. Minke whale entanglements have a higher fatality rate and are less likely to be noted ante-mortem because minke whales are not such powerful swimmers as humpbacks and may be less likely to reach the surface to breathe whilst entangled (Knowlton *et al.* 2016). Thus many entangled minke whales are likely to die and sink without being reported. It is not known whether minke whales are more prone than humpbacks to creel entanglement. Furthermore, the risk of entanglement for minke whales is unknown in Scottish waters. Off the east coast of the USA there are fewer reported cases of minke entanglements than for humpback or right whales (Knowlton et al. 2016), but it is unclear whether this is due to lower entanglement risk or lower reporting probability. Globally, minke whales are the most frequently reported species of baleen whale killed by gear entanglement, although they are also more abundant than other species. In South Korea there is a well-developed reporting system, as the meat from reported entangled whales can subsequently be sold legally. Here, 67 reported minke whale deaths were reported between 2004 and 2007 in pot gear similar to that set on the west coast of Scotland (Song *et al.* 2010).

From the incidental sighting data presented, it is difficult to determine whether the increased number of reported humpback sightings is indicative of a genuine increase in whale abundance, of increased reporting, or both. From dedicated effort-based data in the west of Scotland, there are too few records to determine any trends in relative abundance but an increasing trend is apparent from incidental sightings data. It is not known how abundant humpback whales were in Scottish waters prior to large-scale whaling. Humpback abundance in many areas of the North Atlantic likely reached a minimum around 1900 (Punt et al., 2006). Thus by the time whaling started from the station on the Isle of Harris in 1904, the humpback whale population was already severely depleted. Humpback whales were caught west of the Outer Hebrides and around the Shetland Islands from 1903-1929 but formed less than 1% of the total Scottish catch for the period 1908-1914. Catches were dominated by males (74%) and were mainly in July and August (Thompson, 1928). A total of 18 animals were landed off the Outer Hebrides between 1904 and 1910 with only one animal between 1911 and 1928 (Brown, 1976).

The correlation between reported entanglement rates and the estimated use of Scottish waters by humpback whales confirm the expected relationship that entanglement rates will increase if whale numbers increase. The emerging issue of creel entanglement in humpback whales is undoubtedly a cause for concern for this species which remains rare in Scottish waters. Our findings indicate that mitigation measures ought to be implemented in the interest of conservation and the welfare of humpback and minke whales in Scottish waters. Measures to reduce entanglement risk could also benefit the creel fishing industry by minimising the loss of gear.

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Figures and Tables

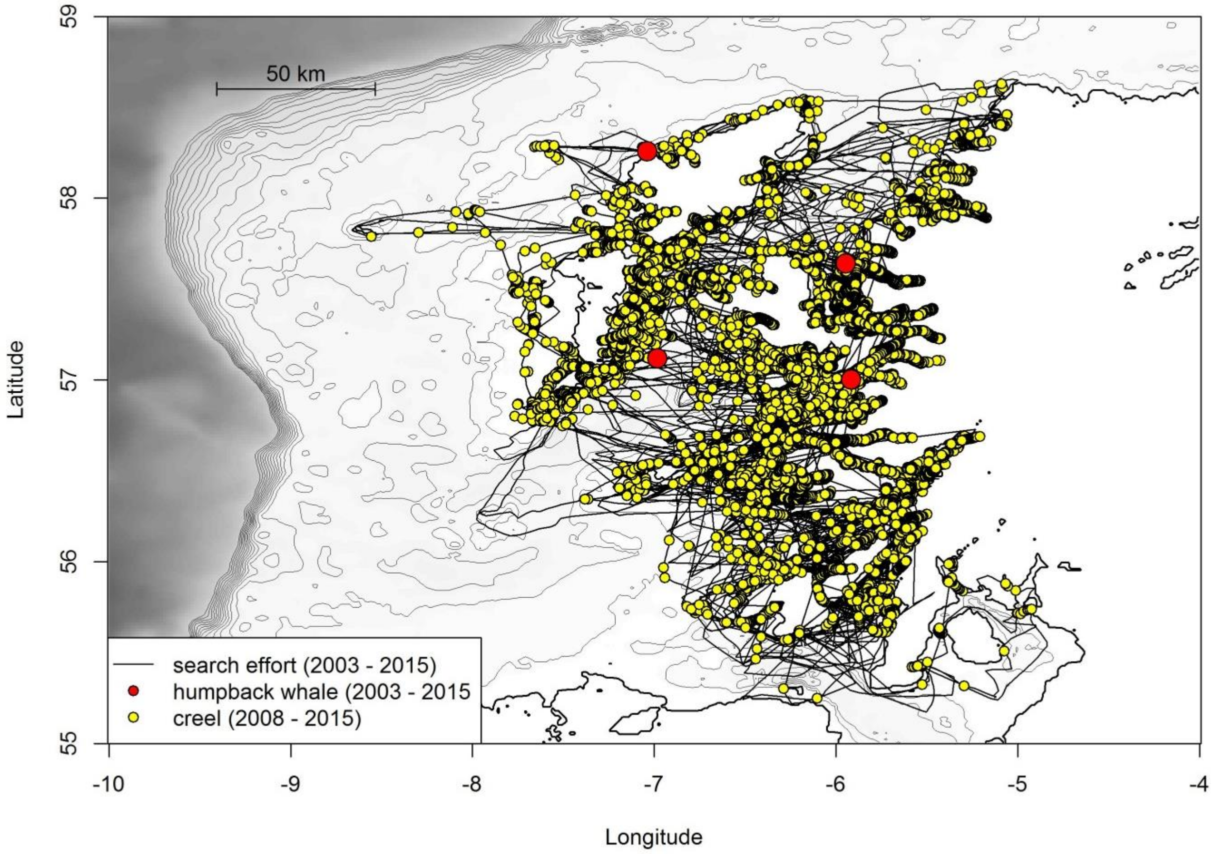

Figure 1. Distribution of creels and humpback whales recorded from research vessel Silurian during visual line-transect surveys (track-line in black) conducted annually during April to October from 2008 – 2015.

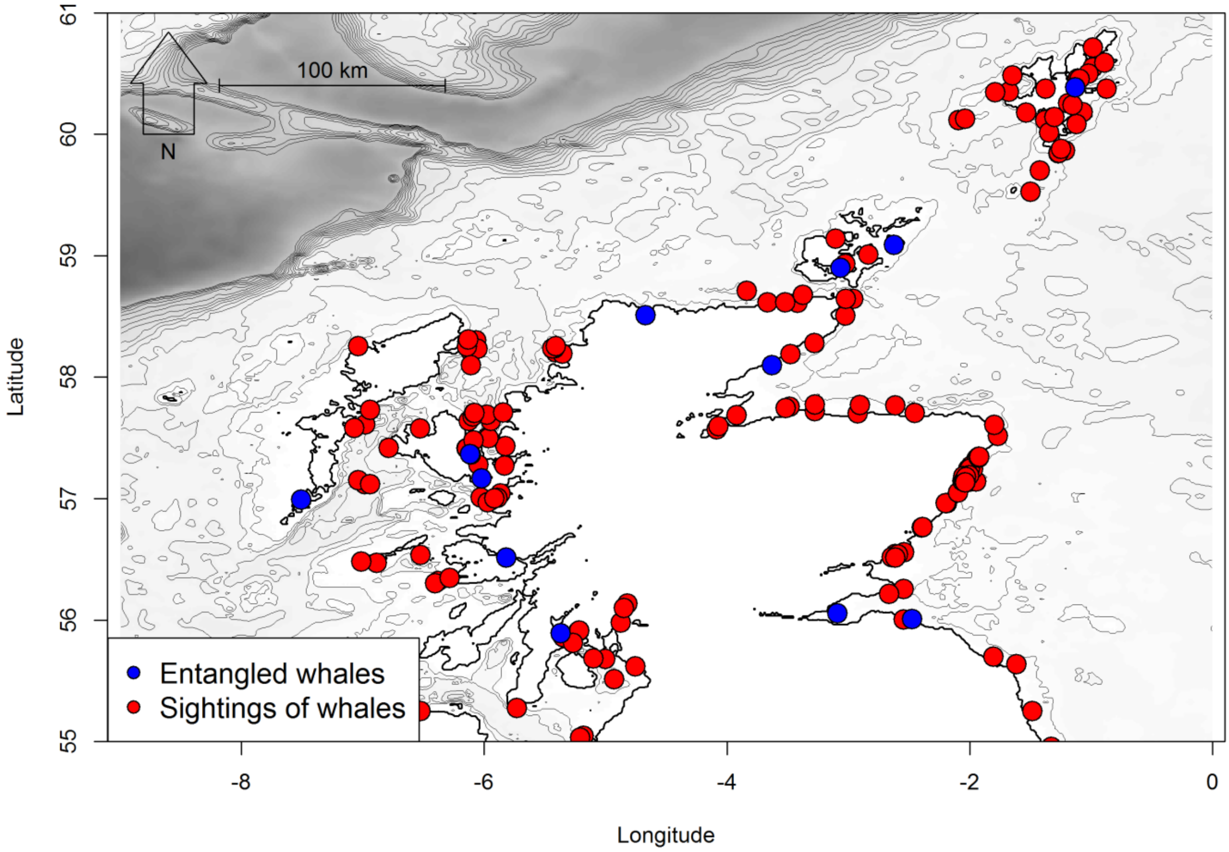

Figure 2. Humpback whale records from 1992 - 2016 in Scottish waters, verified by photographs or a description including diagnostic features.

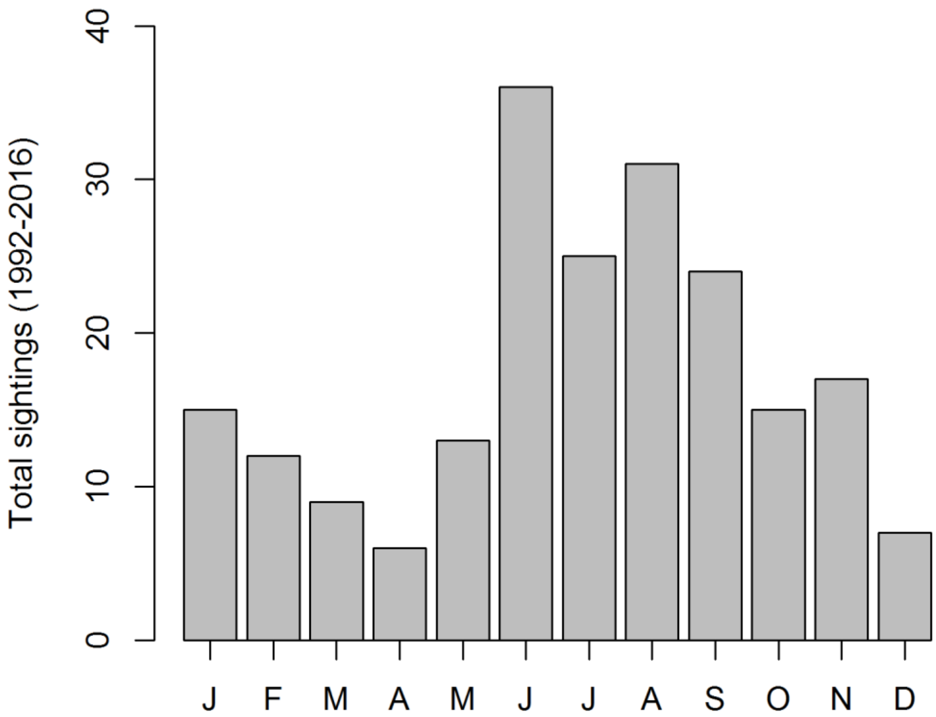

Figure 3. Seasonal distribution of all humpback whale records used in this study

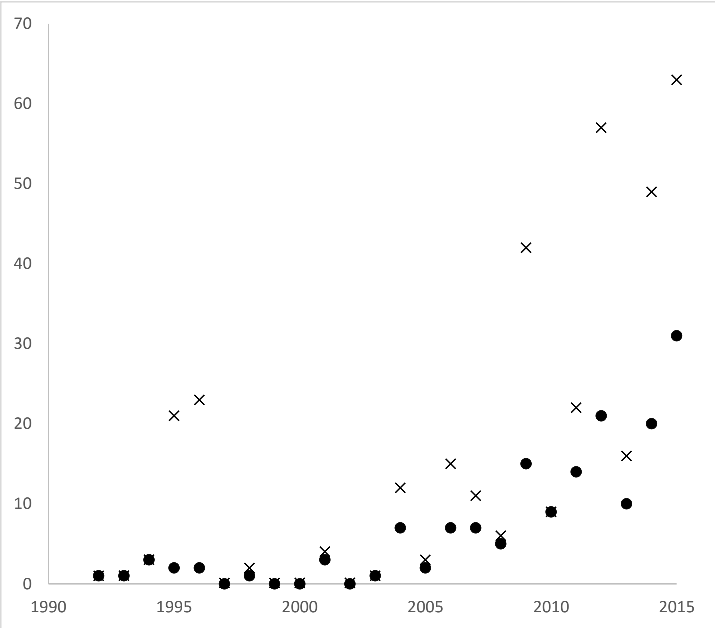

Figure 4. Reported number of sightings (crosses) and estimated number of visits (filled circles). Grouping sightings into visits considerably reduces the inter-annual variability.

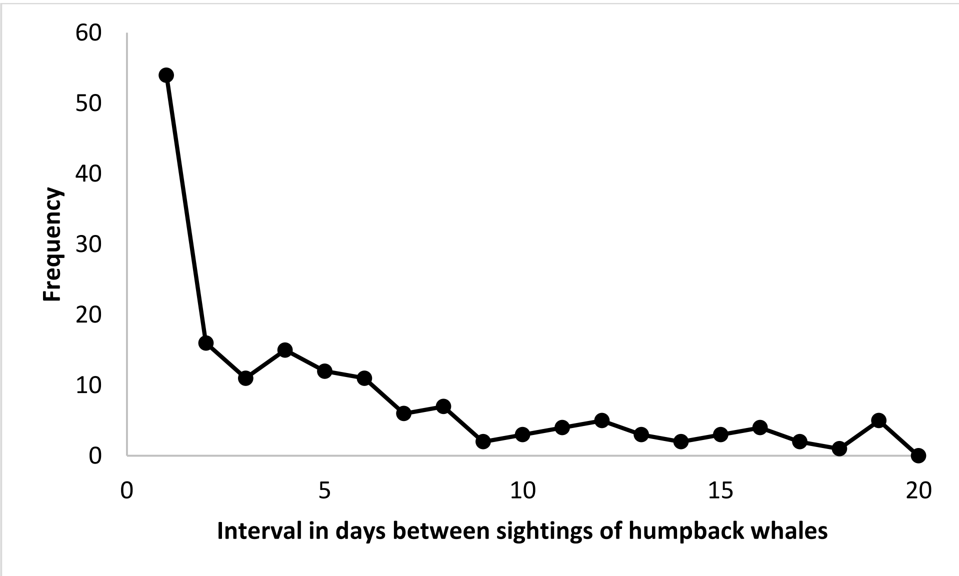

Figure 5. Observed frequency of waiting times between sightings of humpback whales (all data 1992-2015).

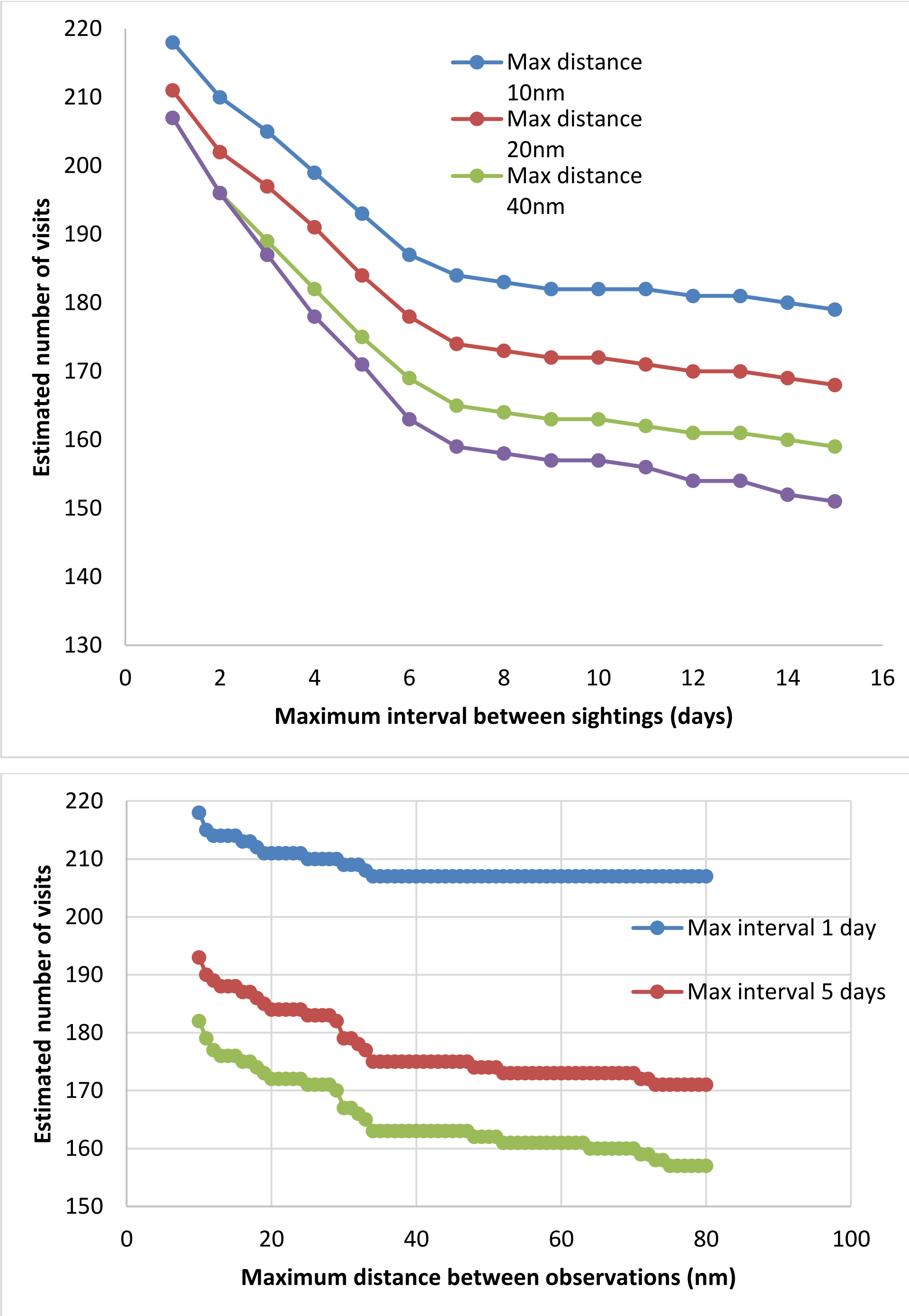

Figure 6. Estimated number of visits by humpback whales to Scottish inshore waters from incidental sighting data. Irrespective of the maximum set distance or time considered, points of inflexion at 7 days and 35 nm indicate that these criteria can be used to classify separate 'visits'.

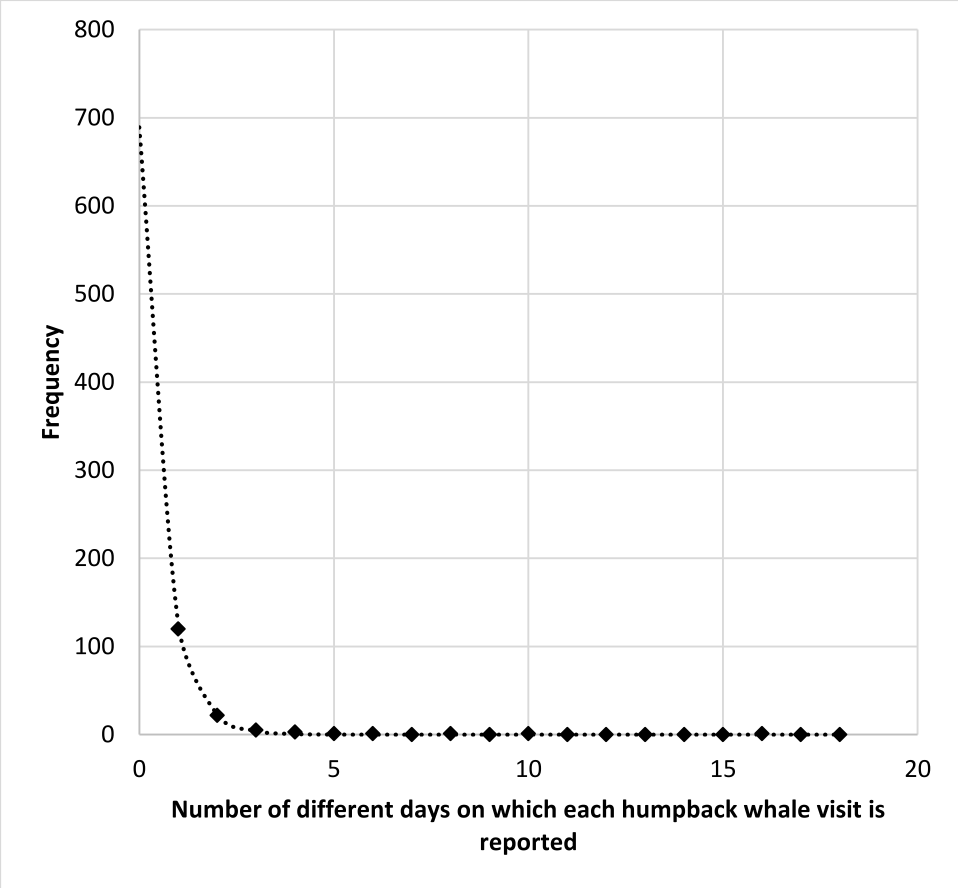

Figure 7. The frequency of number of visits by the number of different days on which each one was seen (filled diamonds). Dotted line shows fitted exponential distribution extrapolated to x=0.

Table 1. Details of all known entanglement cases involving humpback whales in Scotland from 1992 - 2016

Date	Latitude	Longitude	Entangled in	Photos or Video?	Alive When Found?	Rescue Attempt?	Fate	Source
15/02/2003	56.057012	-3.094020	Ropes/Creels	Y	Y	N	Disentangled itself, alive	CRRU
22/05/2008	59.089496	-2.626796	Creels	Y	Y	Y	Disentangled by fishermen, alive	Northridge *et al.* 2010
09/09/2010	60.38616667	-1.1335	Ropes/Creels	N	Y	Unknown	Unknown	SWF
16/11/2011	56.012058	-2.478404	Creels	Y	Y	Y	Disentangled by BDMLR, alive	BDMLR
27/03/2012	55.8951	-5.373283333	Creels	Y	Y	Y	Disentangled by fishermen, alive	SWF
18/05/2012	58.900966	-3.06565	Creels	Y	Y	Y	Disentangled by diver, alive	BDMLR
25/06/2014	56.517581	-5.818556	Aquaculture pen	Y	N	N	No disentanglement attempt, Died	HWDT/SMASS
31/10/2014	57.36903284	-6.118011475	Ropes	Y	Y	N	Disentangled itself, alive	HWDT
04/06/2015	58.101804	-3.632655	Creels	Y	Y	Y	Disentangle attempt (BDMLR), died	BDMLR
14/12/2015	57.169149	-6.022477	Creels	Y	Y	Y	Disentangled by fishermen, alive	BDMLR
09/01/2016	58.511247	-4.671485	Creels	Y	Y	Y	Disentangled by BDMLR, alive	BDMLR
01/03/2016	56.993949	-7.5087466	Ropes/Creels	Y	N	N	Stranded dead	HWDT/SMASS