Non-Lethal Entanglement of Minke Whales (*Balaenoptera acutorostrata*) in Fishing Gear in the Hebrides

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1. Acknowledgements

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2. Abstract

There is a large amount of evidence to show that entanglement can cause injury and mortality in many baleen whale species. The Hebrides, off the West coast of Scotland, have a particularly high risk of entanglement for minke whales compared with other areas around the UK due to high concentrations of creel lines and high numbers of minke whales in this area. This report examined photographic records of live minke whales in the Hebrides from 1990-2010 for evidence of scarring indicative of previous entanglement, to estimate the proportion of minke whales that had been previously non-lethally entangled. In addition, the subjectivity of photo identification techniques and scar analysis, the methods used in this study for estimating the proportion of minke whales that had been previously non-lethally entangled, were assessed. This was done by comparing two photo librarians' identifications of whales, and two photo analysts' scar codes and entanglement codes assigned to whales to calculate the inter-observer agreement. Furthermore, this report aimed to identify areas of the Hebrides where the risk of entanglement for minke whales is elevated, by mapping creel and minke whale sightings rates from research cruises conducted by the research vessel the Silurian, in the summer months of 2009, 2010 and 2011. The analysis in this study showed that as many as 17.7% of identified minke whales in the Hebrides show some evidence of previous entanglement. Additionally, a conservative estimate was made of 2.4% of minke whales. The analysis also demonstrated that the head is the body region most commonly found with scars indicative of entanglement in identified minke whales photographed between 1990 and 2010 in the Hebrides. This suggests that minke whales may become entangled in fishing gear whilst feeding. It was found that even though the methods used in scar analysis are subjective they are unlikely to greatly affect the analysis conducted in this report. The errors associated with scar analysis will however affect scar accumulation rates on cetaceans, but due to a lack of data this was not calculated in this report. Mapping of creel and minke whale sightings rates showed that the North of the Isle of Skye and South Uist consistently pose an elevated entanglement risk for minke whales between 2009 and 2011. Therefore, perhaps future mitigation methods should focus on these areas. It is important to stress that this report is merely a preliminary study on minke whale entanglement. Future work needs to focus on expanding the photographic database to allow scar accumulation studies to be conducted on minke whales in the Hebrides. In addition, future studies should research the feeding behaviour of minke whales to identify how they become entangled. Furthermore, small scale movements of minke whales in areas deemed to have higher entanglement risk need to be assessed. It is important that future research looks at these issues so that appropriate mitigation methods are created and implemented if necessary.

3. Introduction

3.1 Entanglement of minke whales

Entanglement from static fishing gear (for instance lobster creel fisheries and gillnets) is a common cause of injury and mortality in baleen whales (Neilson et al., 2009 and Woodward et al., 2006). For example, there is much evidence to show that humpback whales (*Megaptera novaeangliae*) frequently become entangled in fishing gear. Robbins et al. (2004) found that photographs of humpback whales in the Gulf of Maine taken between 2000 and 2002 showed that between 48% and 57% of the population had previously been non-lethally entangled. Neilson et al. (2009) found that photographs of humpback whales in northern SE Alaska taken between 2003 and 2004 showed that 71% of the population displayed evidence of previous entanglement.

Entanglement has also been documented in North Atlantic right whales (*Eubalaena glacialis*) (Krause et al., 1990), gray whales (*Eschrichtius robustus*) (Bradford et al., 2009) and minke whales (Song et al., 2010).

It is important to estimate entanglement rates of baleen whales since entanglement can be a conservation concern (Song et al., 2010). The Scientific Committee of the International Whaling Commission (IWC) needs estimates of lethal entanglement rates in order to set sustainable quotas for whaling (International Whaling Commission, 2010).

The minke whale (*Balaenoptera acutorostrata*) is the smallest and most common balaenopterid in Scottish waters (Gill et al., 2000). The most up-to-date population estimate of minke whales in the NE Atlantic is 174,000 individuals (International Whaling Commission, 2010). The records from the UK cetacean strandings investigation programme show that minke whales are more frequently found stranded around the UK than other large cetaceans, and that three quarters of these have occurred in Scotland. A high proportion of these carcasses have been diagnosed as having died due to entanglement (Northridge et al., 2010).

Creel fishing for lobsters, crabs and prawns (nephrops) is widespread and locally intense in Scottish waters. Although there is no current evidence to suggest that entanglement of minke whales in creel fisheries around Scotland is a major conservation concern (Northridge et al., 2010), mortality levels of minke whales need to be estimated to address national obligations required under the Habitats Directive, article 12, which states that accidental capture or mortality of minke whales must be monitored (Council of the European Community, 1992). In addition, annual Icelandic and Norwegian hunts of minke whales occur from the same biological stock and adjacent waters. Therefore, mortality levels from entanglement would be useful for establishing whaling quotas (Northridge et al., 2010).

3.2 Aims

The objectives of this report were to:

1. Examine photographic records of live minke whales in the Hebrides for scarring indicative of entanglement to determine the proportion of whales that have been previously non-lethally entangled.
    i. In addition, the subjectivity of the techniques used in the examination of entanglement was assessed.
2. Identify areas of the Hebrides where the risk of entanglement for minke whales is elevated.

3.3 Approach

Photo identification is a procedure used to recognise individual marine mammals. Individual animals are photographed and later studied for unique markings which can be used for identification (Wilson et al., 1999). Dorsey (1983) found photo identification was suitable for minke whales in the waters of Washington, and Gill et al. (2000) found this technique can also be used for identifying minke whales around the Hebrides. Photo identification is not only important in cetacean studies for estimating population sizes and investigating life histories (Tetley et al., 2006), but can also be used in entanglement studies of whales. It allows the extent of entanglement in a population, as well as scar accumulation rates of individuals, to be estimated (Northridge, 2011). However, this is a subjective method that requires time consuming visual determination of scars (Burdett et al., 2007). It is therefore important to understand the measurement errors associated with this method and how they may affect entanglement studies.

Scar analysis of live whales is commonly used to calculate non-lethal entanglement rates in humpback (Robbins et al., 2004) and right whales (Krause, 1990). Additionally, a small amount of work has been conducted on gray (Bradford et al., 2009) and minke whales (Northridge et al., 2010). Entanglement of whales in fishing gear often results in injuries that are visible on the animal after the fishing gear is removed. The injuries can therefore be studied to calculate non-lethal entanglement rates (Robbins et al., 2009). Scar based analysis is a suitable methodical approach for calculating non-lethal entanglement rates of whales since it allows a large sample size to be recorded over an extended time period, and identifies entanglement events that would otherwise go unrecorded or be badly documented (Robbins et al., 2009 and Neilson et al., 2009). However, similar to photo identification techniques, scar analysis is subjective and so it is important to understand the measurement errors associated with the technique (Burdett et al., 2007).

Northridge et al. (2010) explain that scar analysis only calculates non-lethal entanglements, yet entanglement events that result in mortality are of primary concern from a conservation perspective. Robbins et al. (2009) have shown that scar based investigations in combination with other data (for instance recordings of reported entanglement events) can be used to infer entanglement related mortality. However, this is a simplistic, preliminary method for estimating entanglement mortality and the ratio of entanglement survival to mortality was calculated from a small amount of data that has unknown biases (Robbins et al., 2009). Nevertheless, Northridge et al. (2010) argue that non-lethal entanglement rates are probably correlated with lethal entanglement rates, and areas where there is evidence of high non-lethal entanglement rates are likely to be areas with high entanglement mortality rates.

Scar analysis can estimate the overall extent of entanglement in a population, entanglement related mortalities and scar accumulation rates of individuals. However, it does not give any indication as to where these entanglements are taking place and if there are areas where entanglement events are of high occurrence. It is important to establish if there are areas where there is a high risk of entanglement for minke whales in the Hebrides as they should be a focus of further research and possibly of mitigation measures.

Fishing effort and live minke whale sightings can be mapped to determine the likelihood of co-occurrence and therefore the risk of entanglement. The sightings of creel marker buoys and minke whales from the research vessel the Silurian provides suitable data to do this. Northridge et al. (2010) mapped the creel buoy sightings from the Silurian in 2008 and compared this to the minke whale sightings between 1979 and 1998 to determine areas of high entanglement risk. Since then, creel buoy sightings have been collected in the summer months of 2009, 2010 and 2011 and these can now be compared with the minke whale sightings within these years to calculate further annual risk of entanglement maps. The years can be compared to see if areas of high risk are consistent between 2009 and 2011.

4. Methods

4.1 Assessing the subjectivity of photo identification techniques

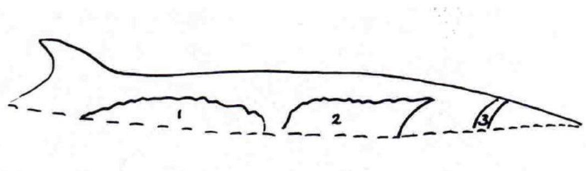
Photographs of minke whale encounters taken by the Hebridean Whale and Dolphin Trust (HWDT) between 1990 and 2010 onboard the Silurian were used. The photographs were filed by encounter and individuals within an encounter by HWDT. There were 463 individual whale encounters photographed. Between 1990 and 2003 only photographs of identified individuals were saved and catalogued. However, from 2003 onwards all photographs were saved and catalogued. Originally photographers were told to concentrate their effort on areas of the whales that would be most easily used for identification purposes, particularly the dorsal fin. However, since 2007 photographers were told to try and photograph as much of the whales as possible to increase the probability of observing scarring indicative of previous entanglement (Northridge et al., 2010).

The minke whales in the photographic database had already been identified by HWDT. However, the purpose of this part of the investigation was to separately identify the minke whales in the photographs, and compare the identifications made with those already given by HWDT, to see if there is consistency amongst different photo librarians when identifying minke whales sighted around the Hebrides. In addition, a number of photo librarians have been used by HWDT over the 20 year project; therefore a new photo librarian was needed to go through all photographs of minke whale encounters to ensure there was consistency amongst the different photo librarians used by HWDT. Furthermore, conventional photo identification methods usually involve two or more judges for final identifications of whales; however this was not done with the HWDT photographic database (Wells, 2009).

The photographs were studied (by FM) to see if the individual whales had appropriate markings that could be used for identification. The methods used were those described by Gill et al. (2000). Each individual in each encounter was either given an identification code based on some distinguishing mark or feature, or the whale encounter was termed 'unidentifiable'.

The features that are stable over time and can therefore be used for identification include (Gill et al., 2000):

1. Distinct notches or nicks in the dorsal fin. However it should be remembered that an individual may gain new notches or nicks over time.
2. Unusual dorsal fin shapes.
3. Unusual body scars.
4. Lateral body pigmentation consisting of the flank patch, thorax patch and crescent-shaped grey streak (figure 1) can be used for identification and as reference points for scars.



1. Flank Patch
2. Thorax Patch
3. Grey Streak

Figure 1: Lateral body pigmentation of minke whales (From Gill et al., 2000)

The identifications given by the two photo librarians (HWDT and FM) to the whales were compared. First, to see if both readers classified the same whales as 'identifiable' (where an identification was given) or 'unidentifiable'. This was done using an inter-rater reliability analysis through use of the Cohen's kappa statistic. Appendix table 1 gives a guide for how to interpret kappa. A z-score must be calculated to work out the significance of kappa; appendix table 2 shows the significance of z-score values. A low strength of agreement between the two librarians implies that the method is subjective (Wood, 2007).

In addition, it was calculated how often: both librarians gave the same identification to whales; librarians gave different identifications to the whales; both librarians classified whales as 'unidentified'; where HWDT classified whales as 'unidentified' but FM gave an identification; and where HWDT identified the whales but FM classified them as 'unidentified'.

4.2 Assessing the subjectivity of scar analysis techniques

The methods used for scar analysis were those used by Northridge et al. (2010). The same photographs were used as those in section 4.1 of this study.

Photographs were classified by the body part of the whale that was photographed. They were classified as either the right or left side of the animal followed by the body segment: the head (A), abdomen (B), dorsal fin (C) or peduncle (D) (figure 2).

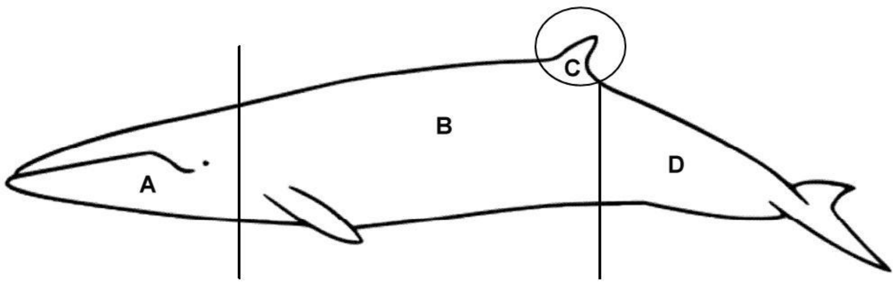


Figure 2: Anatomical regions of minke whales for photographic analyses (From Northridge et al., 2010).

The quality of every photograph was determined for each body part in the photograph using the photographic quality (PQ) code as described by Northridge et al. (2010):

3: "Photo in focus, well lit such that any marks on the skin would be easily visible."

2: "Poorly lit photograph. Nicks and scratches can still be seen but with much less clarity."

1: "Out of focus or silhouetted. Body part and large nicks from dorsal fin can be seen, but little other detail."

0: "Unusable."

Next the photographs were studied to see if there was any scarring on each of the body parts photographed that may be indicative of entanglement using the scar code (SC) following Northridge et al. (2010) where:

4: "Obvious evidence of previous/current entanglement. Ropes/straps visible."

3: "Linear scars or wounds which wrap around the feature."

2: "Noticeable nicks or chunks missing from the trailing edge of the dorsal fin, or small indentations on the leading edge."

1: "Slight, non-linear, apparently randomly arranged marks, or small indentations on the trailing edge of the dorsal fin."

Finally an entanglement code (EC) was assigned to each individual at each encounter as used by Northridge et al. (2010):

High: "An animal with any SC4 code photos indicating that the animal is or has been entangled."

Ambiguous: "Any SC3 marks- suggesting the animal has likely been injured or entangled by fishing gear or some other anthropogenic interaction."

Low: "No marks of SC3 or above and at least one complete side of the animal with a PQ value of 2 or more in all sections. The animal apparently exhibits no marks or scars that might be indicative of entanglement. Previous serious entanglement deemed unlikely."

Unknown: "PQ is not 2 or more for all body sections of at least one side of the animal. Photographic evidence is insufficient to make assumptions about entanglement marks."

The ECs and SCs assigned to minke whales in this study (FM) were compared to those already assigned by AC from the University of St Andrews Sea Mammal Research Unit. An inter-rater reliability analysis using Cohen's kappa statistic was also performed here to determine if there was consistency among the two photo analysts when assigning ECs and SCs.

4.3 Analysing photographic records of live minke whales for evidence of previous entanglement

The SCs and ECs assigned to each minke whale sighting from section 4.2 (by FM) were used in this part of the study.

The proportion of individual identified minke whales with 'unknown', 'low', 'ambiguous' and 'high' ECs was calculated.

In addition, the SCs assigned to the different body sections of identified minke whales were compared to see if some areas of the body exhibited more SC3s and SC4s. A chi-squared test was conducted to see if the different body regions of identified minke whales photographed between 1990 and 2010 significantly differed in their amount of scarring indicative of previous non-lethal entanglement.

4.4 Identifying areas in the Hebrides where risk of entanglement of minke whales is high

The data used to identify where in the Hebrides the risk of entanglement of minke whales is elevated was collected during research cruises, made by the Silurian, in the Hebrides during the summer months of 2009, 2010 and 2011. Observers on board the Silurian collected sightings records of minke whales and creel buoys that mark the ends of creel lines. In addition, the area the Silurian covered (trackline) was recording using a Global Positioning System (GPS). Furthermore, the ease at which whales could be sighted due to environmental conditions (sightability) and whether observers were actively looking for whales (search status) were recorded during the research cruises.

Raw creel sightings were split into 20km^2 grid cells using Manifold System 8, a Geographic Information System (GIS). The amount of trackline and the number of creel buoys sighted in each cell were used to calculate a creel sightings rate for each cell.

The same was done to calculate a minke whale sightings rate for each grid cell. Raw minke whale sightings and associated effort trackline were split into 20km^2 grid cells. The amount of trackline and the number of minke whales sighted in each cell were used to calculate a minke whale sightings rate for each cell.

The sightings rate of minke whales and creel buoys were then used to generate a risk of entanglement measure (REM) as described by Northridge et al. (2010). REM is an index of co-occurrence of minke whales and creels used to detect areas of high risk of entanglement. Areas of mean whale or creel sightings have a value of one, and areas of relatively high sightings and high creel density will have a higher risk of entanglement and a REM value greater than one.

$$REM= W/\hat{W}*C/\check{C}$$

Where W= minke whale sightings rates; Ŵ= mean sightings rates of minke whales over all surveyed grid cells; C= creel buoy sightings rates and Č= mean sightings rates of creel buoys over all surveyed grid cells.

5. Results

5.1 Assessing the subjectivity of photo identification techniques

The two photo librarians generally agreed when identifying minke whales from photographs of live sightings. There was a good strength of agreement between the two photo librarians (k=0.744, z=15.43, p<0.01) when assigning minke whale sightings as 'identifiable' or 'unidentifiable' (appendix table 3).

In addition, out of the 463 minke whale sightings, photo librarians agreed on identifications 390 times (84%). There were 16 sightings (3%) where photo librarians gave different identifications. Furthermore, there were four sightings (0.9%) where FM gave individuals an identification but HWDT said they were 'unidentifiable' and 53 sightings (11.4%) where FM said individuals were 'unidentifiable' whilst HWDT gave them an identification (table 1).

Table 1: Number of cases where: both librarians gave the same identification to whales; librarians gave different identifications; both librarians classified whales as 'unidentified'; where HWDT classified whales as 'unidentified' but FM gave an identification and where HWDT identified the whales but FM classified them as 'unidentified'.

Classification of Readers	Number of Cases
Both readers gave the same identification	238
Readers identified the whales as different individuals	16
Both readers classified the whales as 'unidentified'	152
HDWT classified the whale as 'unidentified', FM gave an identification	4
HWDT identified the whales, FM classified it as 'unidentified'	53

5.2 Assessing the subjectivity of scar analysis techniques

Appendix figure 1 shows that the two photo analysts generally agreed when assigning SCs and ECs to photographed minke whales. There was a very good strength of agreement (k=0.951, z=13.676, p<0.01) between the two photo analysts' entanglement classifications of whales as either 'previously entangled' (EC3/4), 'not previously entangled' (EC1/2) or 'unknown' (EC0) (appendix table 3). Table 2 shows that there are only seven sightings (out of 463) where the analysts disagree on the entanglement classifications of whales. The main disagreement is the four sightings where AC classified whales as 'previously entangled' but FM classified them as 'unknown'. There are also two sightings where FM classified whales as 'entangled' but AC classified them as 'not previously entangled' or 'unknown'.

There was a very good strength of agreement between the two photo analysts' assignment of ECs to minke whales (k=0.95, Z=13.71, p<0.01). The differences in ECs assigned by the two photo analysts are similar to that of the entanglement classifications since the ECs were used for assigning entanglement classifications.

The photo analysts seemed to agree when assigning SCs to different body regions of minke whales. For the head there was a very good strength of agreement between the two analysts (k= 0.81, z= 6.24, p<0.01). The only real difference between the two analysts was the six minke whale head sightings (out of 92) where AC gave a SC1 but FM gave a SC0 (table 2).

There was a lower strength of agreement between analysts for SCs assigned to the abdomen (k= 0.65. z= 11.22, p<0.01) compared with the head. Out of the 582 minke whale abdomen sightings there were 48 cases where AC assigned a SC1 but FM assigned the same sightings of minke whales' abdomens with a SC0, and there are 13 cases where FM assigned a SC1 but AC assigned the same sightings with a SC0.

There was a very good strength of agreement between the two photo analysts in their assignments of SCs to the dorsal fin of minke whales (k=0.87, Z=27.36, p<0.01). However, table 2 shows that there are some differences in SC0, SC1 and SC2 assigned to dorsal fins by the two photo analysts. Out of the 645 minke whale dorsal fin sightings there are 52 cases where the analysts do not agree on SC0s, SC1s and SC2s. Appendix figure 1 shows that FM is more likely to assign a SC0, whilst AC is more likely to assign a SC1 or SC2.

There was a much lower strength of agreement between photo analysts in their assignment of SCs to the peduncle of minke whales (k=0.25, Z=2.31, p<0.05). Out of the 448 minke whale abdomen sightings there are 53 cases where AC assigns peduncles with a SC1, whilst FM assigns the same sightings of peduncles with a SC0.

Table 2: Comparisons of entanglement classifications (A) and ECs (B) assigned to photographed minke whale sightings by two photo analysts, and comparisons of SCs assigned to the head (C), abdomen (D), dorsal fin (E) and peduncle (F) of photographed minke whale sightings by two photo analysts. The numbers marked in red are where the two analysts disagree and the numbers in bold show were the two analysts agree.

A.		**Entanglement Classification**		
		FM's Coding		
		Previously Entangled	Not Previously Entangled	Unknown
AC's Coding	'Previously Entangled'	**36**	1	4
	'Not Previously Entangled'	1	**42**	0
	'Unknown'	1	0	**378**

B. **ECs**

		FM's Coding			
		'Unknown'	'Low'	'Ambiguous'	'High'
AC's Coding	'Unknown'	**378**	0	1	0
	'Low'	0	**42**	1	0
	'Ambiguous'	4	1	**33**	0
	'High'	0	0	0	**3**

C. **Head Region SCs**

		FM's Coding				
		0	1	2	3	4
AC's Coding	0	**67**	0	0	0	0
	1	6	**5**	0	0	0
	2	0	0	**0**	0	0
	3	1	0	0	**10**	0
	4	0	0	0	0	**3**

D. **Abdomen Scar SCs**

		FM's Coding				
		0	1	2	3	4
AC's Coding	0	**431**	13	0	1	0
	1	48	**66**	3	0	0
	2	0	0	**0**	0	0
	3	0	5	0	**14**	0
	4	0	0	0	0	**1**

E. **Dorsal Fin SCs**

		FM's Coding				
		0	1	2	3	4
AC's Coding	0	**359**	5	2	0	0
	1	23	**61**	5	0	0
	2	6	11	**224**	0	0
	3	0	0	1	**5**	0
	4	0	0	0	0	**0**

F. **Peduncle SCs**

		FM's Coding				
		0	1	2	3	4
AC's Coding	0	**383**	0	0	0	0
	1	53	**0**	0	0	0
	2	0	0	**1**	0	0
	3	1	0	2	**8**	0
	4	0	0	0	0	**0**

5.3 Analysing photographic records of live minke whales for evidence of previous entanglement

In a large number of cases photographic coverage of minke whales between 1990 and 2010 was inadequate to assign an EC. Table 3 shows that between 1990 and 2010, 124 different minke whales were identified through photo identification, 63.70% (n=79) of these were given an 'unknown' EC due to lack of photographic coverage. Over this 20 year period 2.5% were assigned a 'high' EC (n=3), while 15.3% (n=19) were assigned an 'ambiguous' EC and 18.5% (n=23) were assigned a 'low' EC.

Between 1990 and 2003 only photographs of identified minke whales were kept and photographers were told to focus on areas of the whale that could be used for identification. There were 66 identified minke whales photographed in this time period; 74.2% (n=49) of these were assigned an EC of 'unknown'. However, a larger percentage of identified whales photographed between 1990 and 2003 showed evidence of entanglement compared with other year categories; 4.5% (n=3) were assigned an EC of 'high'. This was the only time period where whales were assigned an EC of 'high'. An EC of 'low' was assigned to 15.1% (n=10) of identified whales photographed between 1990 and 2003, the lowest out of the different year categories. An EC of 'ambiguous' was assigned to 19.7% (n=13) of identified whales photographed between 1990 and 2003; this was much higher than that of the other year categories.

Between 2003 and 2007, ECs assigned to identified minke whales were relatively similar to those of 1990-2003. However, no identified whales photographed between 2003 and 2007 were given a 'high' EC. In addition, a slightly smaller percentage of identified whales were given an 'ambiguous' EC (11.1%, n=3), and a higher percentage were given an 'unknown' EC (77.8%, n=21).

Identified whales photographed between 2007 and 2010 had a lower percentage assigned with an 'unknown' EC (60.5%, n=23). ECs of 'low' were assigned to 26.8% (n=10) of the identified whales photographed in this time period and ECs of 'ambiguous' were assigned to 13.2% (n=10) of identified whales photographed. This was similar to other time periods.

Table 3: Number and percentage of identified minke whales with each EC for all identified minke whales photographed between 1990 and 2010 (A), n is the number of identified whales in each time period. The number and percentage of identified minke whales with each EC is also given for different time periods where the data collection methods varied: 1990-2003 (B) when only photographs of identified whales were kept and photographers focused on areas of the whale used for identification, 2003-2007 (C) when all photographs of minke whales were kept and photographers focused on areas for photo identification, and 2007-2010 (D) when all photographs were kept and photographers tried to photograph as much of the whale as possible.

A.

1990-2010 (n=124)		
Entanglement Code	Number of individuals	Percentage
Unknown	79	63.7%
Low	23	18.5%
Ambiguous	19	15.3%
High	3	2.4%

B.

1990-2003 (n=66)		
Entanglement Code	Number of individuals	Percentage
Unknown	49	74.2%
Low	10	15.1%
Ambiguous	13	19.7%
High	3	4.5%

C.

2003-2007 (n=27)		
Entanglement Code	Number of individuals	Percentage
Unknown	21	77.8%
Low	3	11.1%
Ambiguous	3	11.1%
High	0	0%

D.

2007-2010 (n=38)		
Entanglement Code	Number of individuals	Percentage
Unknown	23	60.5%
Low	10	26.3%
Ambiguous	5	13.2%
High	0	0%

Table 4 shows that the severity of scarring on identified minke whales varies with body region. A chi-squared test showed that the different body regions of identified minke whales photographed between 1990 and 2010 significantly differed in their amount of scarring indicative of entanglement (X^2=8.154, df=3, p< 0.005).

Between 1990 and 2010, 34 identified whales had photographs of their head taken. Of these individuals, 20.6% were assigned a SC3 and 5.90% were assigned a SC4. The abdomen seems to be the next most severely scarred with 9.4% of identified whales with photographs of their abdomen assigned a SC3 and 0.90% assigned a SC4. The peduncle is less severely scarred, with 1.55% of photographed identified whales' peduncle assigned a SC3 whilst none were assigned a SC4. The dorsal fin seems to be the least severely scarred body section with only 0.71% of photographed identified whales' dorsal fin being assigned a SC3 and none being assigned a SC4.

This variation of severity in scarring across body regions was also seen between 1990 and 2003. Photographs of identified minke whales taken between 1990 and 2003 had the most severe scarring compared with other time periods. Out of the 35 identified whales that had their head photographed, 25.71% had a SC3 assigned to their head and 8.57% had a SC4. The abdomen was the next most severely scarred with 4.57% of identified whales with their abdomens photographed exhibiting SC3s, SC4s were found on 0.46% of identified whales with their abdomens' photographed. The peduncle was the next most severely scarred. The dorsal fins of identified whales in this time period had no SC3s or SC4s.

Photographs of identified minke whales taken between 2003 and 2007 showed a different variation in severity of scarring across body regions of minke whales than other time periods. Unlike other time periods, photographs of identified whales taken between 2003 and 2007 showed that the dorsal fin had the most severe scarring. Of the 24 identified minke whales that had their dorsal fin photographed, 8.3% were assigned a SC3 and none were assigned a SC4. Out of the identified whales that had their peduncle photographed, 3.8% were assigned a SC3 on their peduncle and none were assigned a SC4. The head and abdomen had no SC3s or SC4s.

Photographs of identified whales taken between 2007 and 2010 showed that the abdomen had the most severe scarring. This differed from other time periods. Of the 29 identified minke whales that had their abdomen photographed, 10.3% were assigned a SC3 and none were assigned a SC4. The head was the next most severely scarred with 7.1% of photographs of identified whales' heads having SC3s assigned to them. Photographs of identified whales' peduncles had SC3s assigned to 3.4% of them. The dorsal fins had no SC3s or SC4s assigned to them.

Table 4: Percentage of scars found on photographed identified minke whales that are SC3 and SC4 for each body region between: 1990-2003 (A), 2003-2007 (B), 2007-2010 (C) and 1990-2010 (D). n indicates the number of identified whales with each body section photographed in the different time periods.

A.

1990-2003	SC3	SC4
Head (n=18)	27.8%	11.1%
Abdomen (n=66)	12.1%	1.5%
Dorsal Fin (n=66)	0%	0%
Peduncle (n=64)	4.7%	0%
All areas (n=66)	21.2%	4.5%

B.

2003-2007	SC3	SC4
Head (n=5)	0%	0%
Abdomen (n=26)	0%	0%
Dorsal Fin (n=24)	8.3%	0%
Peduncle (n=26)	3.8%	0%
All areas (n=27)	11.1%	0%

C.

2007-2010	SC3	SC4
Head (n=14)	7.1%	0%
Abdomen (n=29)	10.3%	0%
Dorsal Fin (n=32)	0%	0%
Peduncle (n=29)	3.4%	0%
All areas (n=38)	10.5%	0%

D.

1990-2010	SC3	SC4
Head (n=34)	20.6%	5.9%
Abdomen (n=106)	9.4%	0.9%
Dorsal Fin (n=106)	1.9%	0%
Peduncle (n=99)	4.0%	0%
All areas (n=124)	15.3%	2.4%

5.4 Identifying areas in the Hebrides where risk of entanglement of minke whales is high

Table 5 shows that the survey area covered by the Silurian differed between years. The 2010 survey period did not extend as far South or West as other year periods. In addition, the 2011 period surveyed further North than other years, however it failed to survey as far East as other periods, but did survey further West (table 5).

Table 5: Mean, standard deviation and mean ± two standard deviations of the latitude (A) and longitude (B) co-ordinates of the Silurian GPS trackline for 2009, 2010 and 2011.

A. Latitude

Year	Mean	Standard Deviation	Mean (±2SD)
2009	56.98152	0.633227	55.71498 - 58.24806
2010	57.05432	0.548155	55.95801 - 58.25984
2011	57.16353	0.662349	55.838832 - 58.488228

B. Longitude

Year	Mean	Standard Deviation	Mean (±2SD)
2009	-6.35322	0.524312	-7.401844 - (-5.304597)
2010	-6.41542	0.544011	-7.053442 - (-5.327398)
2011	-6.35067	0.588715	-7.5281 - (-5.17324)

Figure 3 shows the REM of minke whales in 20km^2 grid cells for 2009, 2010 and 2011. It can be seen that the North of the Isle of Skye and South Uist consistently posed as an entanglement risk for minke whales in 2009, 2010 and 2011.

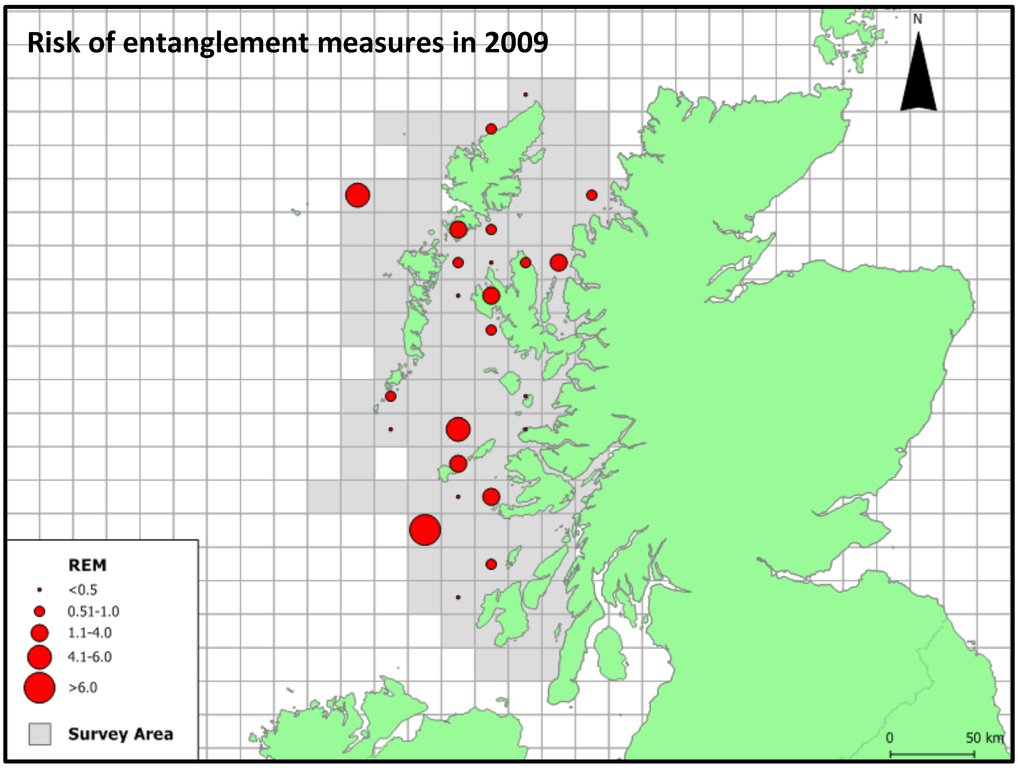
The maps can be compared to show how the REM changed across the years, however it is important to note that the survey area also changed throughout the years. Despite this, when comparing REM values for 2009, 2010 and 2011, it can be seen that there was an increase in REM around South Uist from 2009 (0.51-1), to 2010 (>6) and that the REM value in this area remained high for 2011 (>6).

In the North East of the Isle of Skye an increase of REM occurred from 1.1-4 in 2009 and 2010 to 4-6 in 2012.

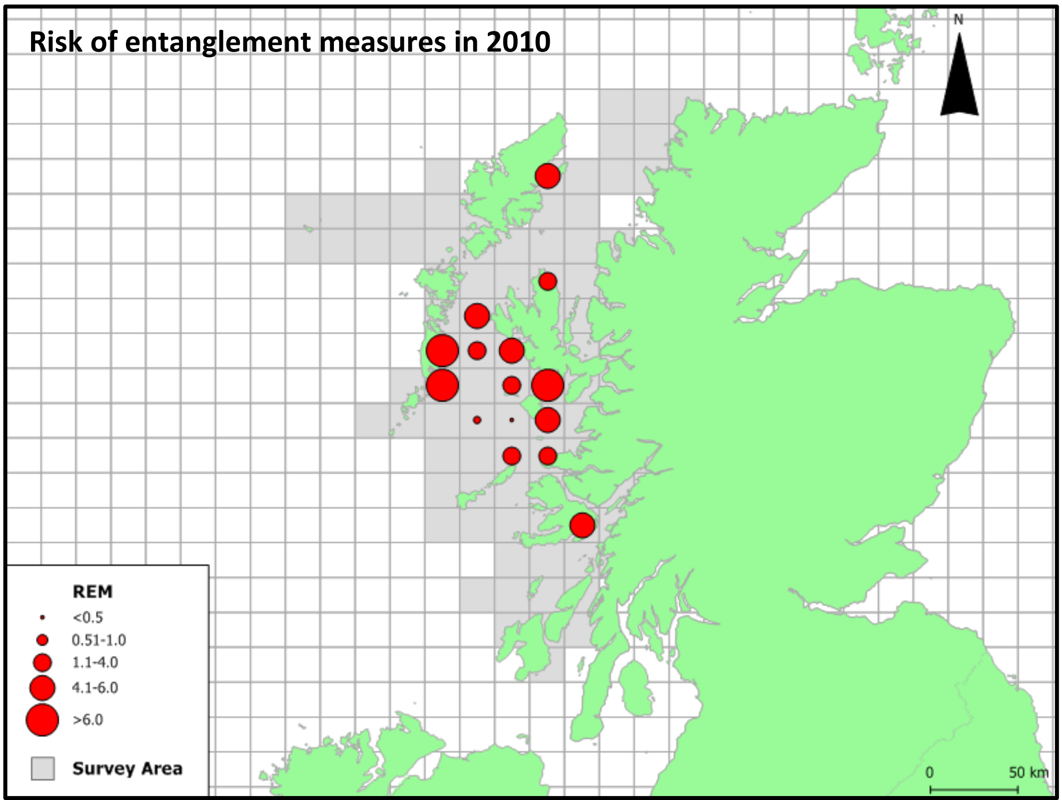
The REM around Coll and Tiree decreased from 2009 (4.1-6) to 2010 (1.1-4.0), and further decreased in 2011 to an REM of 0.51-1.

In the South of Lewis, there was a high REM value in 2011 (>6), and a significantly smaller one for 2009 (0.51-1). There was no elevated risk of entanglement in the South of Lewis in 2010, however 2010 showed a higher REM (4.1-6) in the North East of Lewis than other years.

A.



B.



C.

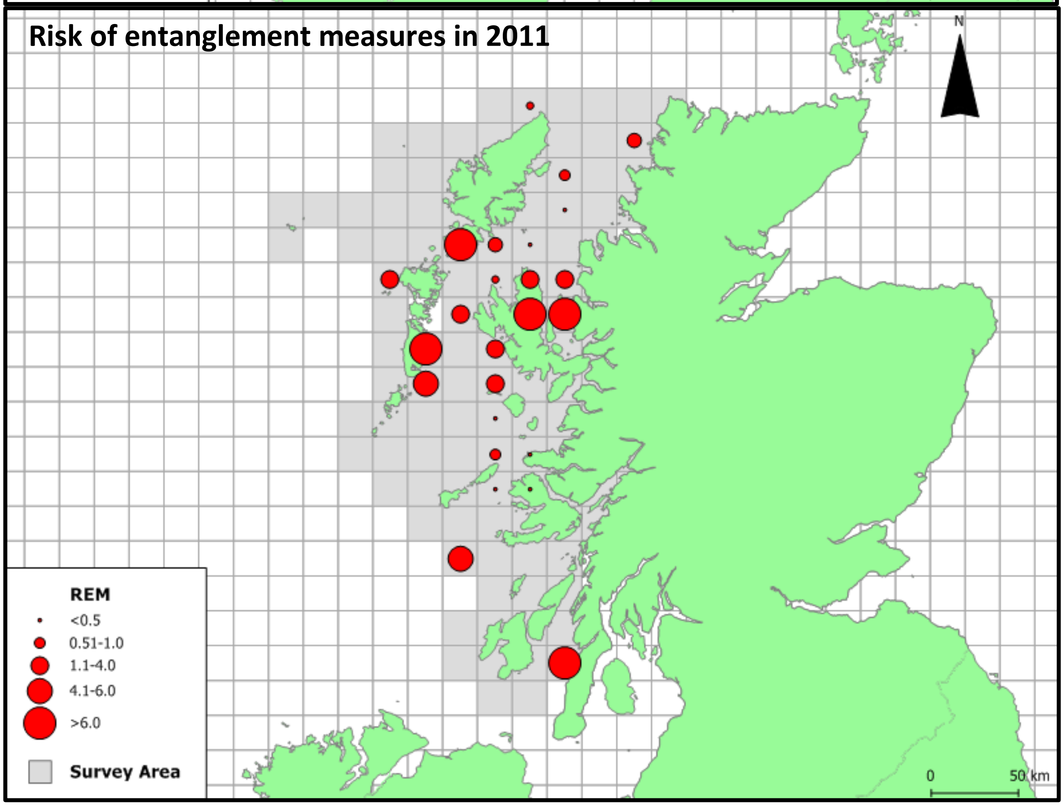


Figure 3: Maps showing the risk of entanglement measures for each 20km^2 grid cell for 2009 (A), 2010 (B) and 2011 (C). The shaded grey area shows the survey area.

6. Discussion

6.1 Assessing the subjectivity of photo identification techniques

The Cohen's kappa statistic shows that there was generally a high agreement between photo librarians when classifying minke whale sightings as 'identifiable' or 'unidentifiable'. However, the HWDT photo librarian was more likely to classify whales as 'identifiable' than FM. This may be due to the fact that HWDT is a more experienced photo librarian.

The lower number of individuals identified by FM than the HWDT photo librarian could affect the proportion of identified individuals with each EC. Of the 463 minke whale sightings photographed between 1990 and 2011 there were 53 cases (11%) where HWDT identified minke whale sightings but FM said that the same whale sightings were unidentifiable. Of these 53 cases there are 36 different identified individuals. This would alter the proportion of identified minke whales that show evidence of previous entanglement. However, it would most likely be a relatively small change that would not greatly affect the overall results of this report.

It is probable that the errors associated with photo identification are most significant in scar analysis studies when estimating scar accumulation rates of identified minke whales. For instance the large number of sightings where HWDT identified whales but FM classified them as 'unidentifiable', as well as the 16 cases where the two librarians gave different identifications to whale sightings, could affect scar accumulation rates. However, this was not an issue for this study as there was a lack of data to estimate this.

Photo identification studies could be improved by ensuring that experienced photo librarians are used as inexperienced photo librarians may be less likely to spot identifying features on minke whales. In addition, standard photo identification techniques of using two or more judges for final identifications of minke whales should be used. This would mean that identifying features would be less likely to be missed by photo librarians and would result in an increase of the reliability in the photo identifications given.

Therefore, it can be concluded that although photo identification is a subjective method with associated errors, these errors are unlikely to greatly affect the entanglement estimates conducted in this report.

6.2 Assessing the subjectivity of scar analysis techniques

The Cohen's kappa statistic shows that there was a very good strength of agreement between the two photo analysts when assigning ECs to minke whales in the Hebrides. However, there are six cases (out of 463) where analysts disagree on EC classifications. These disagreements are all where one analyst has classified a minke whale sighting with an EC of 'ambiguous' whilst the other has classified it as 'unknown' or 'low'. This suggests that the assignment of ECs of 'ambiguous' is one of the more subjective aspects of scarring analysis of minke whales.

Assigning SC0s and SC1s to the peduncle of minke whales is one of the most subjective aspects of scar analysis of minke whales, as shown by the comparisons of SCs assigned to the peduncle by the two photo analysts. This means photo analysts need to take extra care when assigning SC0s and SC1s to the peduncle. In addition, scar analysis of the abdomen of minke whales was shown to be particularly subjective, suggesting that special attention should be paid to this area when assigning SC0s and SC1s. Furthermore, it was found that extra care should be taken by analysts when assigning SC0s, SC1s and SC2s to dorsal fins of minke whales as they also seem to have a high level of subjectivity

In a similar fashion to the photo identification section of this report, it was shown that AC, a more experienced photo analyst, is more likely to see scars indicative of entanglement. Therefore this method could also be improved by using experienced photo analysts. In addition, if more than one person assigns ECs to sightings of minke whales, evidence of previous entanglement of whales is less likely to be missed. Burdett et al. (2007) suggest that GIS can be used to create maps showing marks on cetaceans left by fishing gear. Burdett argues that the maps can provide a less subjective and more efficient way to assess impressions on marine mammals than conventional methods. This method could greatly improve scar based analysis and lead to identification of the fishing gear that resulted in the entanglement event.

To conclude, there are some areas of scar analysis of minke whales that are more subjective that photo analysts need to pay particular attention to. There are a larger number of disagreements for SCs assigned to different body regions than of ECs assigned to individual minke whales. ECs assigned to live sightings of minke whales by the two photo analysts are extremely similar, and therefore are unlikely to greatly affect estimates of the proportion of minke whales with evidence of previous non-lethal entanglements.

6.3 Analysing photographic records of live minke whales for evidence of previous entanglement

Overall the analysis suggests that around as many as 17.7% of minke whales in the Hebrides show some evidence of previous entanglement. However, a very conservative method of solely using ECs of ‘high’ would suggest only 2.4% show some evidence of previous entanglement. Nonetheless, this method assumes that all entanglement events cause visible scarring on whales, which is not necessarily the case, therefore entanglement rates could be higher than suggested by this analysis (Northridge et al., 2010).

Currently there is insufficient data to estimate scar accumulation rates of individual minke whales. However, future work could look at integrating the HWDT minke whale photo identification database with others held by different organisations to increase the availability of data, which may allow work to be conducted on scar accumulation rates of minke whales in the Hebrides (Northridge et al., 2010).

Evidence of previous non-lethal entanglement of minke whales in the Hebrides is of low occurrence compared with humpback whales. For instance, photographs of humpback whales in the Gulf of Maine taken between 2000 and 2002 showed that between 48% and 57% of the population had previously been non-lethally entangled (Robbins et al., 2004).

The entanglement related scarring found on minke whales in the Hebrides is more similar to that of Western gray whales found off North Eastern Sakhalin Island, Russia. Bradford et al. (2009) showed that of the 150 individual gray whales photographed between 1995 and 2005 18.7%, had scars indicative of previous non-lethal entanglement.

However, it is important to make these comparisons between species in a conservative manner. This comparison may not actually indicate that minke whales become entangled less frequently than humpback whales, but may signify that there is a higher entanglement mortality for minke whales. In fact, Glass et al. (2008) showed that minke whales suffered the highest mortality from entanglement compared with other baleen whale species along the US eastern seaboard between 2003 and 2007.

Throughout the 20 year period, the head seems to have had a relatively high proportion of SC3s and SC4s assigned to it compared with other body regions. This suggests that fishing gear may become entangled in minke whales' open mouths whilst they are feeding (Northridge et al., 2010). If this is true then more detailed information on minke whale feeding habits could shed some light on where minke whales are most vulnerable to entanglement. However, no SC3s or SC4s were seen on the identified minke whales' heads photographed between 2003 and 2007. This may be explained by the fact that there were only five instances where identified whales had their head photographed. 2007-2010 saw a decrease of identified minke whales with heads exhibiting SC3s and SC4s; this may be because of a change of feeding patterns in minke whales.

In addition, the analyses showed that there was a relatively high proportion of whales with SC3s and SC4s on their abdomen. This suggests that minke whales can also become entangled by fishing gear wrapping around their abdomen.

It is important to note that this analysis of photographs of live sightings of minke whales has a lot of potential interpretation errors as previously stated in this report. The analysis relied on the skill and interpretation of photo librarians and the judgement of the photo analysts (Northridge et al., 2010). However, it is encouraging that in this study the two photo librarians and photo analysts came to very similar conclusions. Additionally, it is challenging to distinguish between entanglement from fishing gear and entanglement from other materials.

Before 2007 photographers focused on areas of the whales used for identification, causing a number of biases. This analysis shows that the head is the body region that was most frequently marked with SC3s and SC4s. However, since the head is not required for photo identification, photographers did not attempt to photograph this area. This means that the proportion of whales with scarring indicative of entanglement could be higher than that seen in this analysis. On the other hand, it can be difficult to photograph these areas since fluking and breaching are rare in minke whales (Jefferson et al., 2008).

It is important to stress that this work on entanglement of minke whales is just a preliminary study. Although the analysis suggests that there is no prior evidence that entanglement of minke whales in the Hebrides is a conservation threat, it may be a number of years before this can be stated with any certainty. However, the IWC should still consider these implications when setting catch limits of minke whales (Northridge et al., 2010).

6.4 Identifying areas in the Hebrides where risk of entanglement of minke whales is high

The areas of highest risk of entanglement for minke whales in the Hebrides tend to have been in the central Hebrides, where the Silurian does most of its research cruises. The North of the Isle of Skye and South Uist seem to consistently have had a higher risk of entanglement. Perhaps future work on entanglement of minke whales could focus on these two areas.

In some of the areas of elevated entanglement risk, the minke whale sightings rates were relatively low; however high creel densities increase the risk of entanglement. For instance, in 2010 the minke whale sightings rates are significantly lower than those of other years (appendix figure 3) but the REM is similar to that of 2009 and 2010 due to the high creel sightings rates. The amount of trackline covered by the Silurian for this year is actually higher than other years (appendix table 4) so the lower minke whale sightings rates are not due to a lack of surveying. In addition, the percentage of time the research cruise spent with each sightability code is very similar for the three years (appendix table 5), so this cannot explain the lower minke whale sightings rates in 2010 either. Furthermore, the proportion of time observers spent on visual surveys is very similar between years (appendix table 6). It may just be that there were fewer minke whales sighted in the Hebrides in 2010, possibly due to a change in food availability.

The areas of greatest entanglement risk in 2010 and 2011 were around the coastline; whilst in 2009 areas of higher entanglement risk were further offshore. However the area the Silurian surveyed differed between years. In 2010, the survey period was more confined to the central Hebrides which would explain why higher risks of entanglement were not seen further offshore in this year.

It is impossible to suggest any significant changes to creel fisheries to reduce entanglement events as the scale of the problem and ways that minke whales become entangled is not yet known (Northridge et al., 2010). It is therefore important that future work looks at minke whale movements and feeding behaviour in the areas where creel are used in large quantities to fully understand the risk of entanglement. In addition, future investigations should look at elevations of creel lines to allow new mitigation methods to be formed.

These new mitigation strategies could therefore be implemented in areas of higher risk to reduce the mortality and injury to minke whales. In addition, these mitigation methods would reduce economic problems for fishermen through loss and destruction of fishing gear which occurs during entanglement events (Northridge et al., 2010).

Furthermore, future work could look at mapping minke whale sightings by the ECs they have been assigned to see if there are certain areas where whales with ECs ‘high’ and ‘ambiguous’ are more frequently found.

To conclude, mapping of creel and minke whale sightings rates provides an important basis for future work. The mapping exercise has clearly shown that the Isle of Skye and South Uist have an elevated entanglement risk for minke whales and that if mitigation methods are created, they should be employed in these areas of higher entanglement risk.

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8. Appendix

Appendix Table 1: A guide of how to interpret Cohen's kappa (From Wood, 2007).

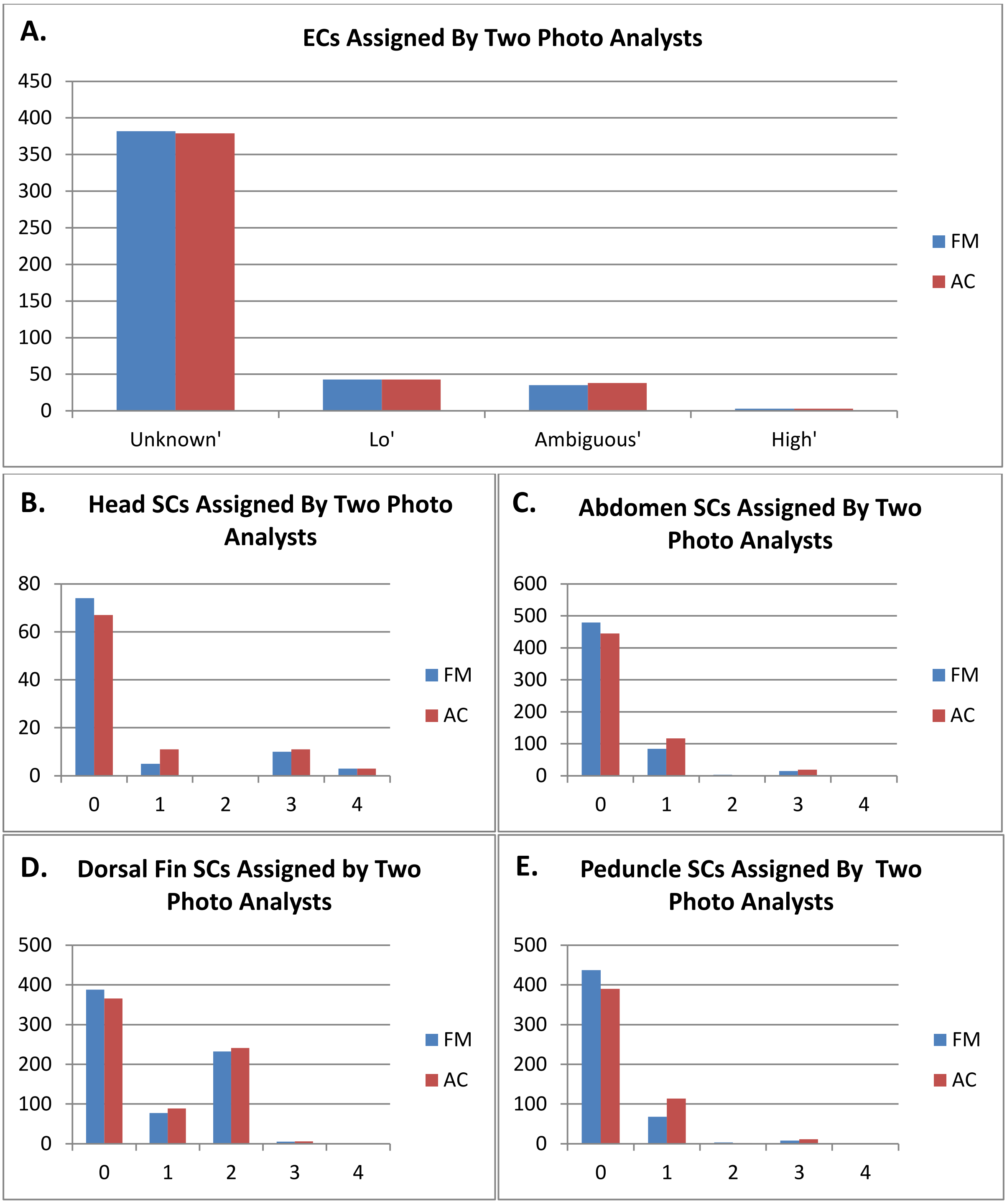
Value of Kappa	Strength of agreement
<0.2	Poor
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Good
0.81-1.0	Very Good

Appendix Table 2: Significance of z-score values (From Stewart, 2010 and Wood, 2007).

Z-score	p-value	Confidence
>1.96	<0.05	95%
>2.57	<0.01	99%

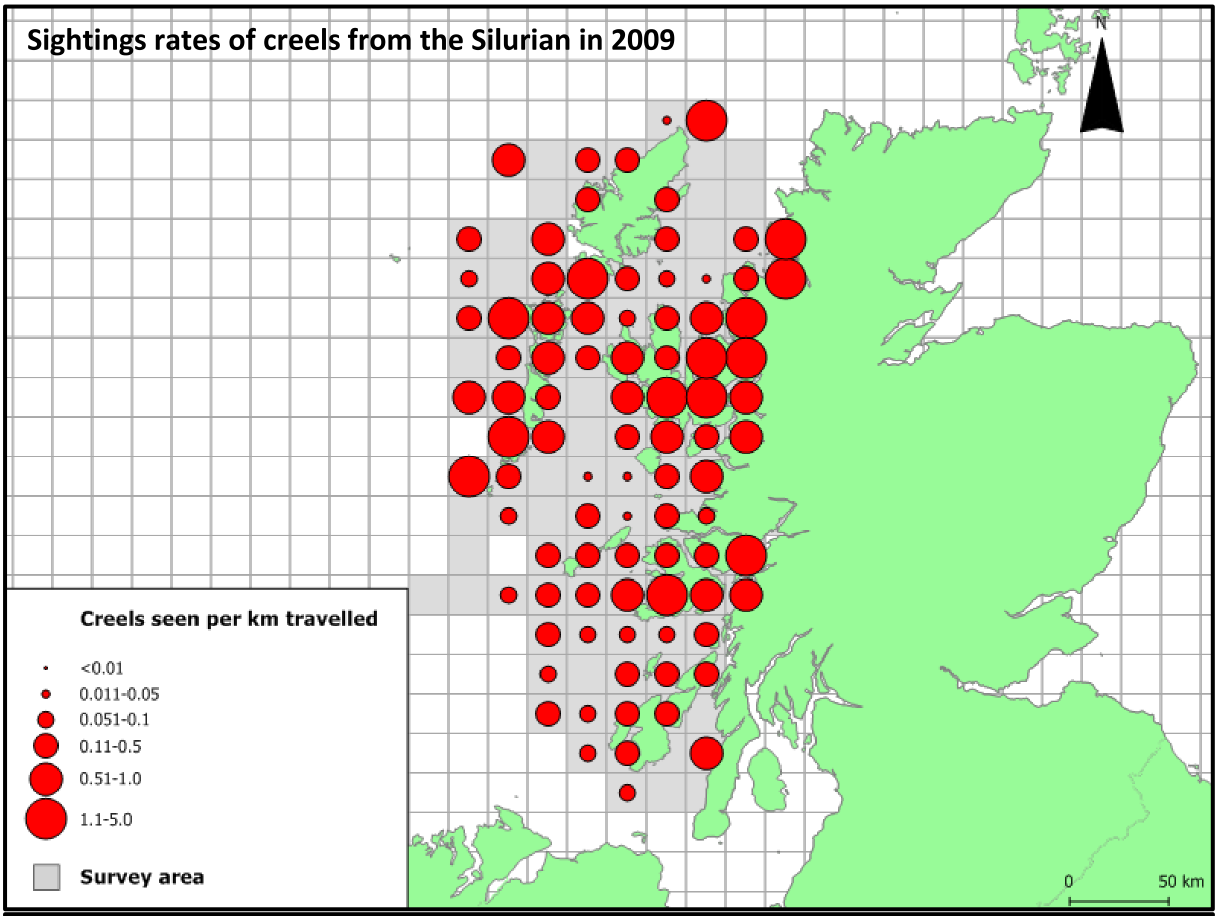
Appendix Table 3: Cohen's kappa statistic, z score, significance, standard error and confidence levels for the comparisons of sightings where minke whales were: classified as 'identifiable' by two different librarians; deemed 'entangled' by two photo analysts, and the comparisons of the ECs assigned to photographed minke whales and SCs assigned to the head region, abdomen, dorsal fin and peduncle of photographed minke whales by two readers.

Aspect of scar analysis that photo librarians/analysts conduct	Kappa	Z score	Significance	Standard Error	95% Confidence Level (Lower Limit)	95% Confidence Level (Upper limit)
Identifiable Classification	0.744	15.43	P<0.01	0.0317	0.682	0.8064
Entanglement Classification	0.9510	13.676	P<0.01	0.0184	0.9150	0.9870
ECs	0.9512	13.711	P<0.01	0.0183	0.9153	0.9871
Head SCs	0.8067	6.235	P<0.01	0.0702	0.6691	0.9943
Abdomen SCs	0.6471	11.227	P<0.01	0.0396	0.5696	0.7246
Dorsal Fin SCs	0.8708	27.360	P<0.01	0.0171	0.8374	0.9042
Peduncle SCs	0.2453	2.313	P<0.05	0.0943	0.0604	0.4302

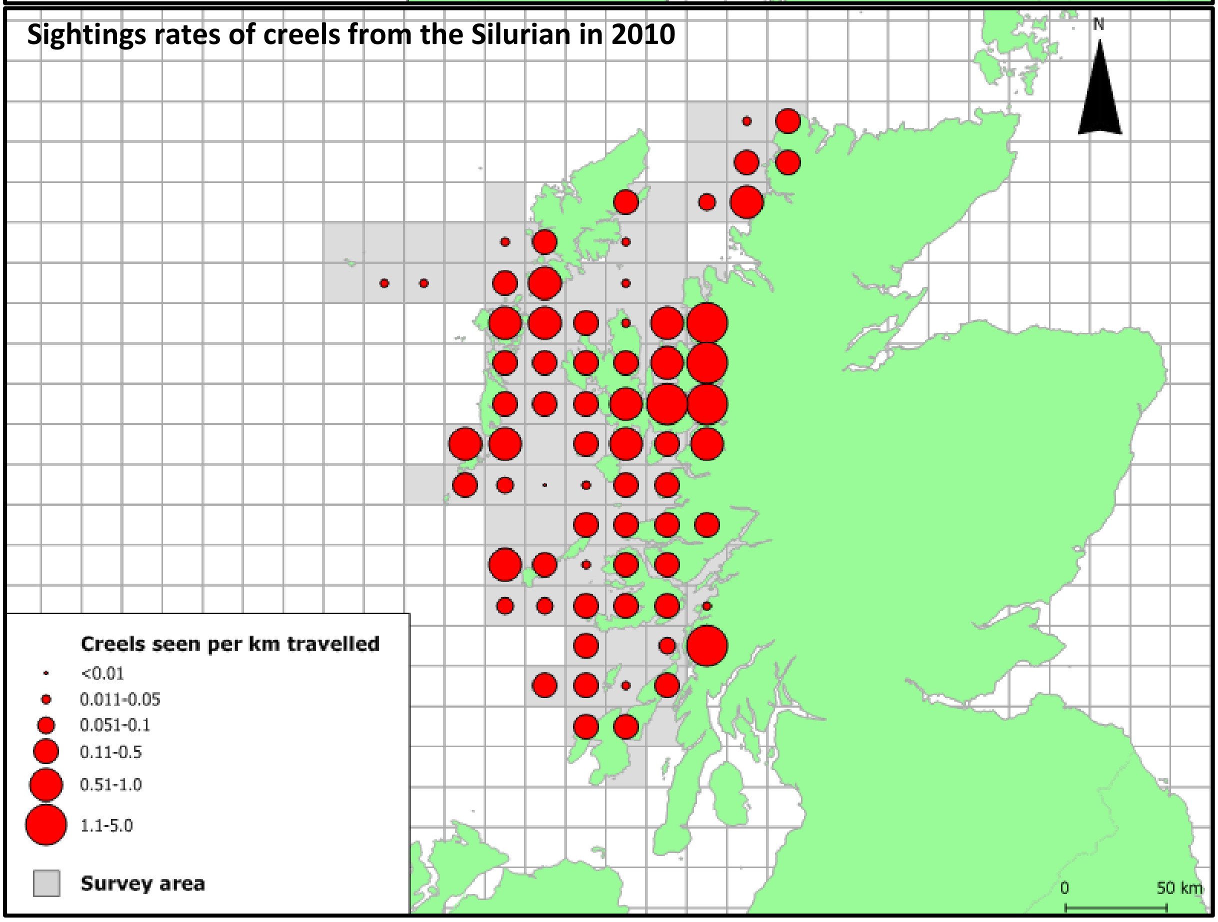


Appendix Figure 1: Comparison of ECs assigned to minke whales (A) and SCs assigned to the head (B), abdomen (C), dorsal fin (D) and peduncle (E) of photographed minke whales by two photo analysts (AC and FM).

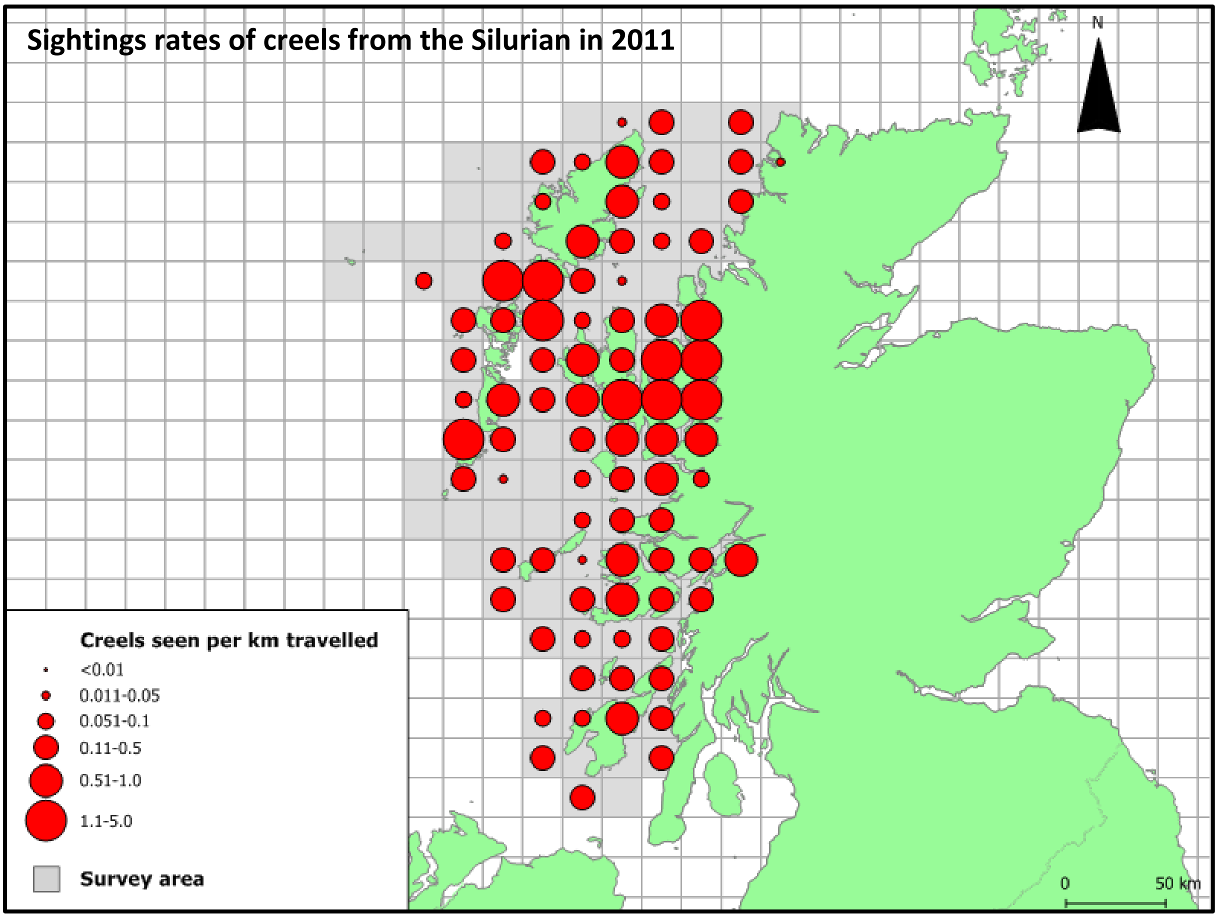
A.


Sightings rates of creels from the Silurian in 2009
N
Creels seen per km travelled
<0.01
0.011-0.05
0.051-0.1
0.11-0.5
0.51-1.0
1.1-5.0
Survey area
0
50 km

B.

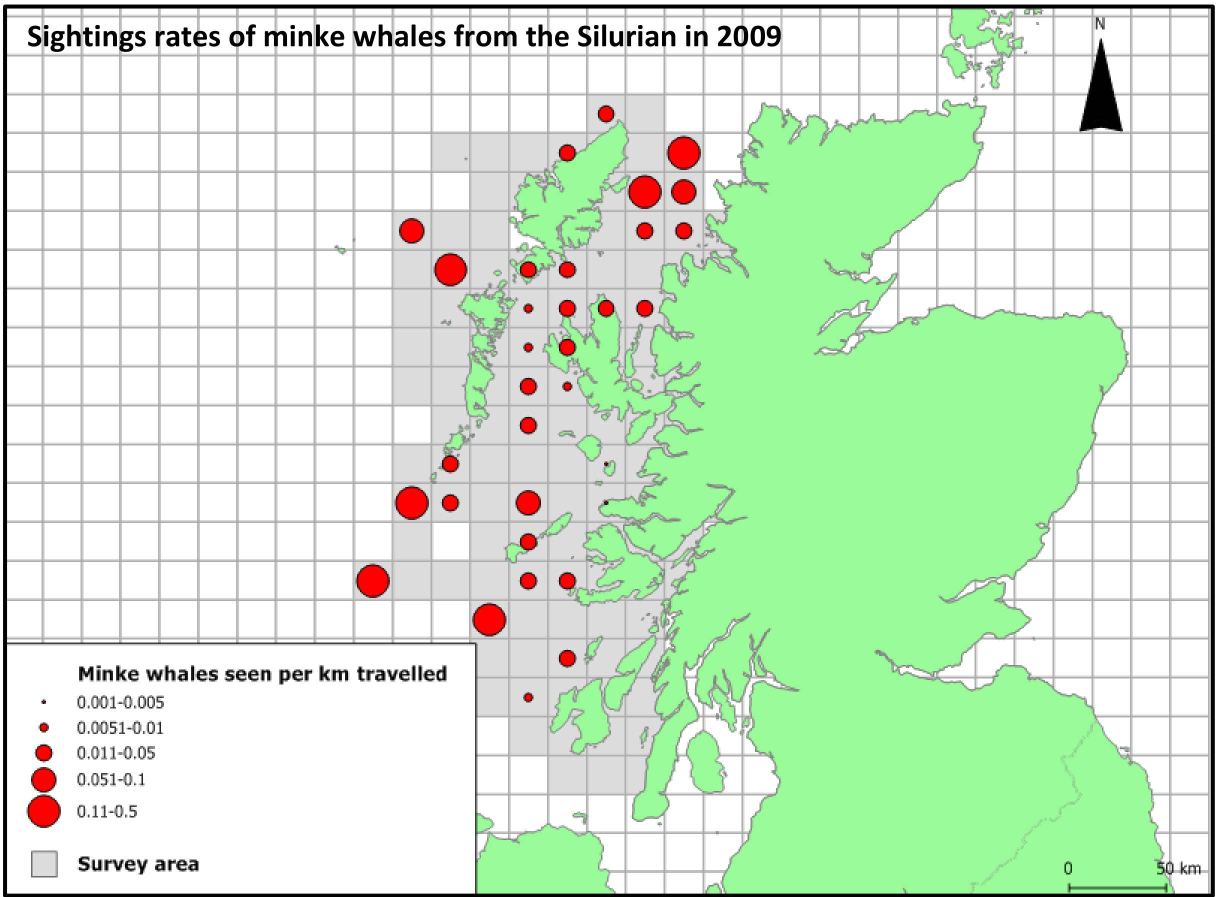

Sightings rates of creels from the Silurian in 2010
N
Creels seen per km travelled
<0.01
0.011-0.05
0.051-0.1
0.11-0.5
0.51-1.0
1.1-5.0
Survey area
0
50 km

C.

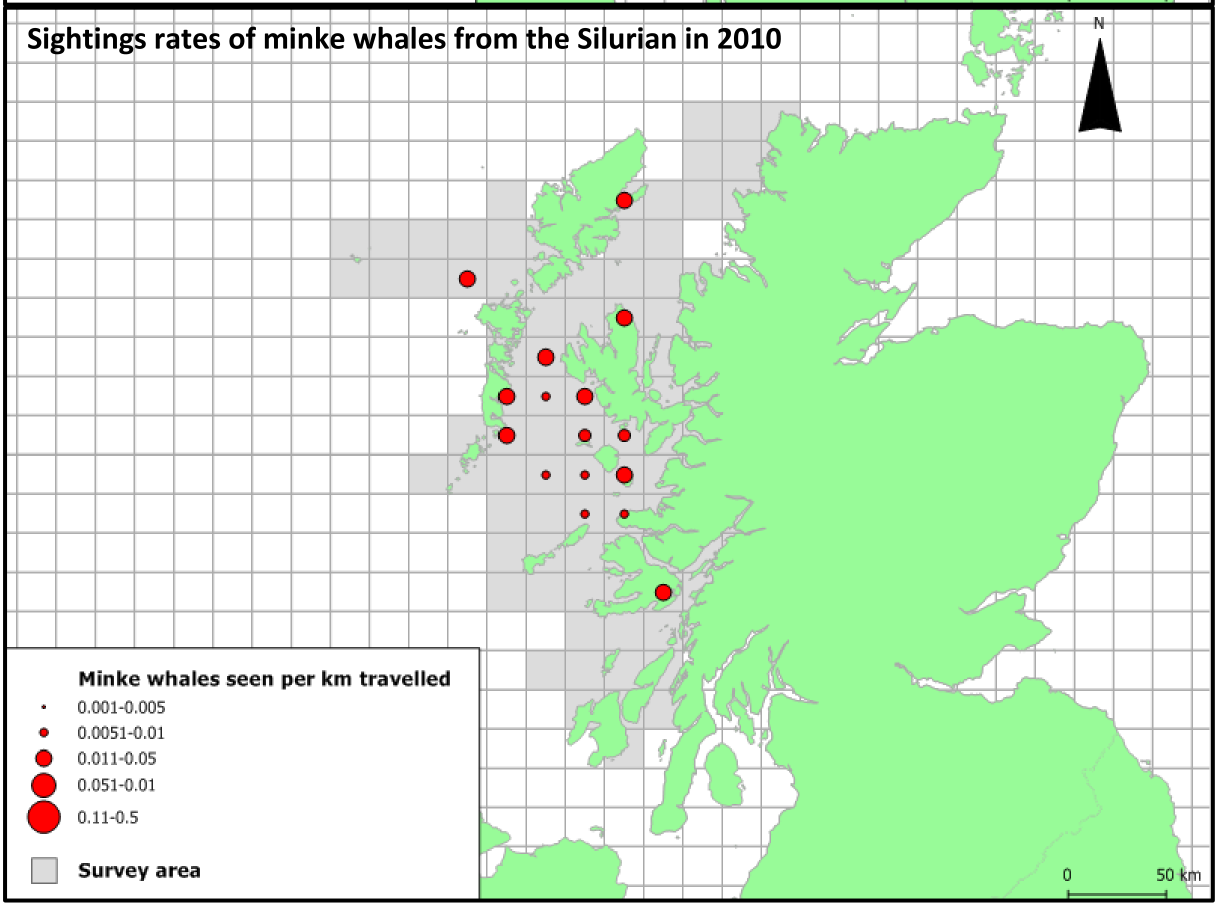


Appendix Figure 2: Maps showing sightings rates of creel marker buoys from the Silurian for each 20km^2 grid cell in 2009 (A), 2010 (B) and 2011 (C) . The shaded grey area shows the survey area.

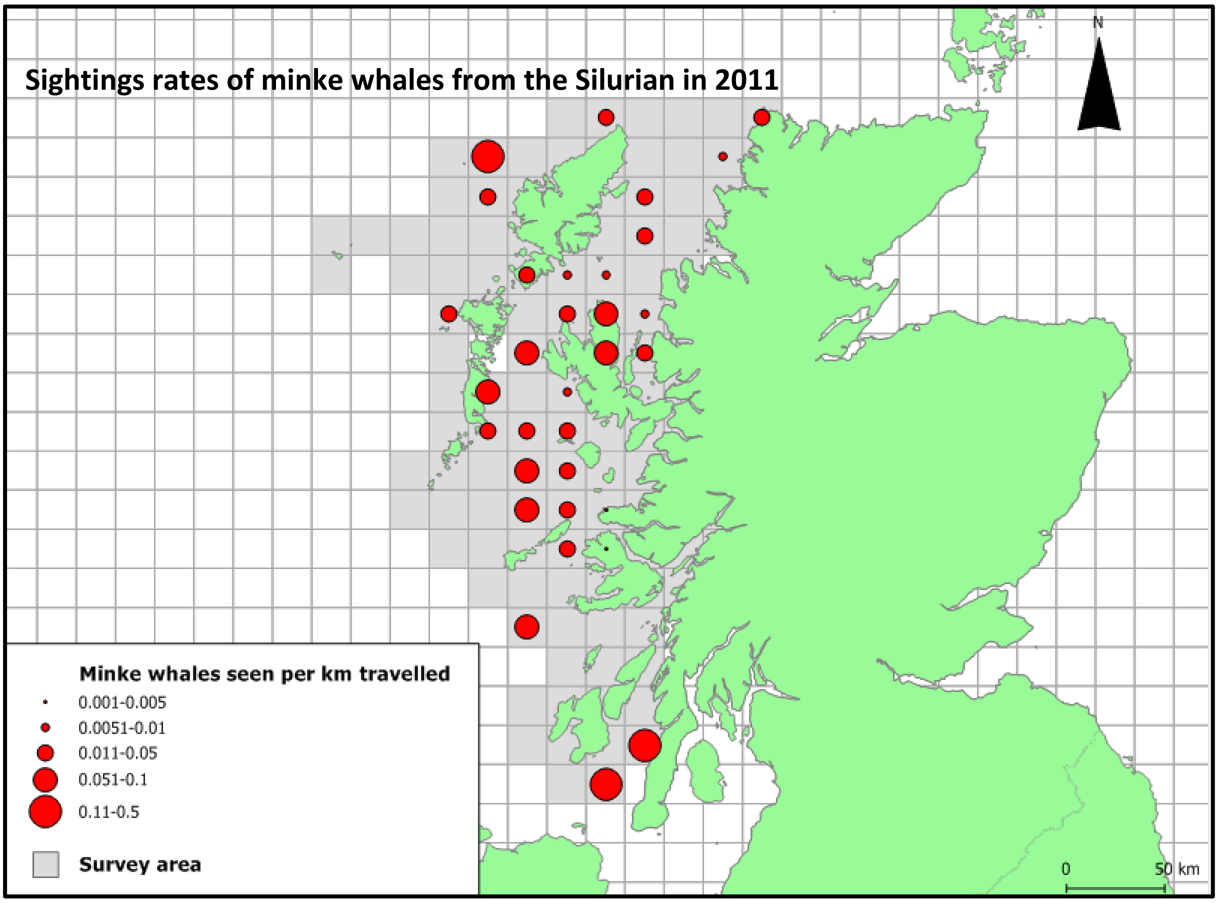
A.


Sightings rates of minke whales from the Silurian in 2009
N
Minke whales seen per km travelled
0.001-0.005
0.0051-0.01
0.011-0.05
0.051-0.1
0.11-0.5
Survey area
0
50 km

B.

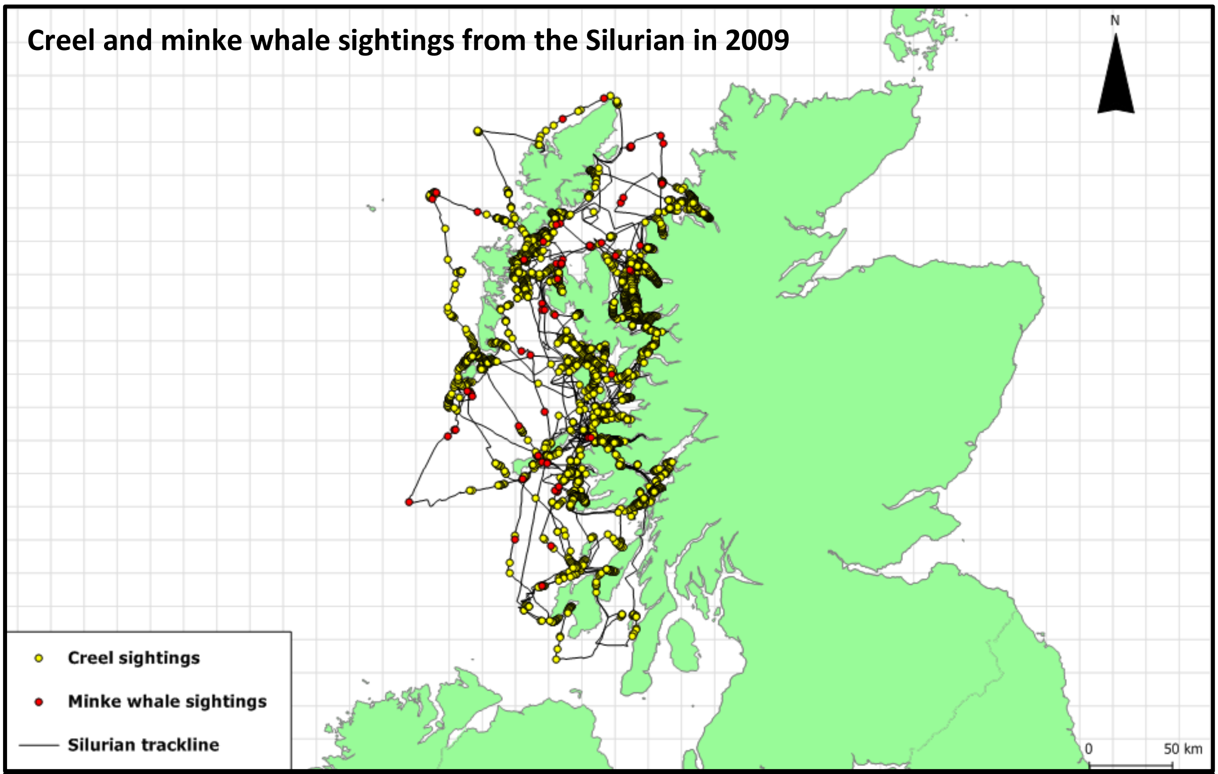

Sightings rates of minke whales from the Silurian in 2010
N
Minke whales seen per km travelled
0.001-0.005
0.0051-0.01
0.011-0.05
0.051-0.01
0.11-0.5
Survey area
0
50 km

C.

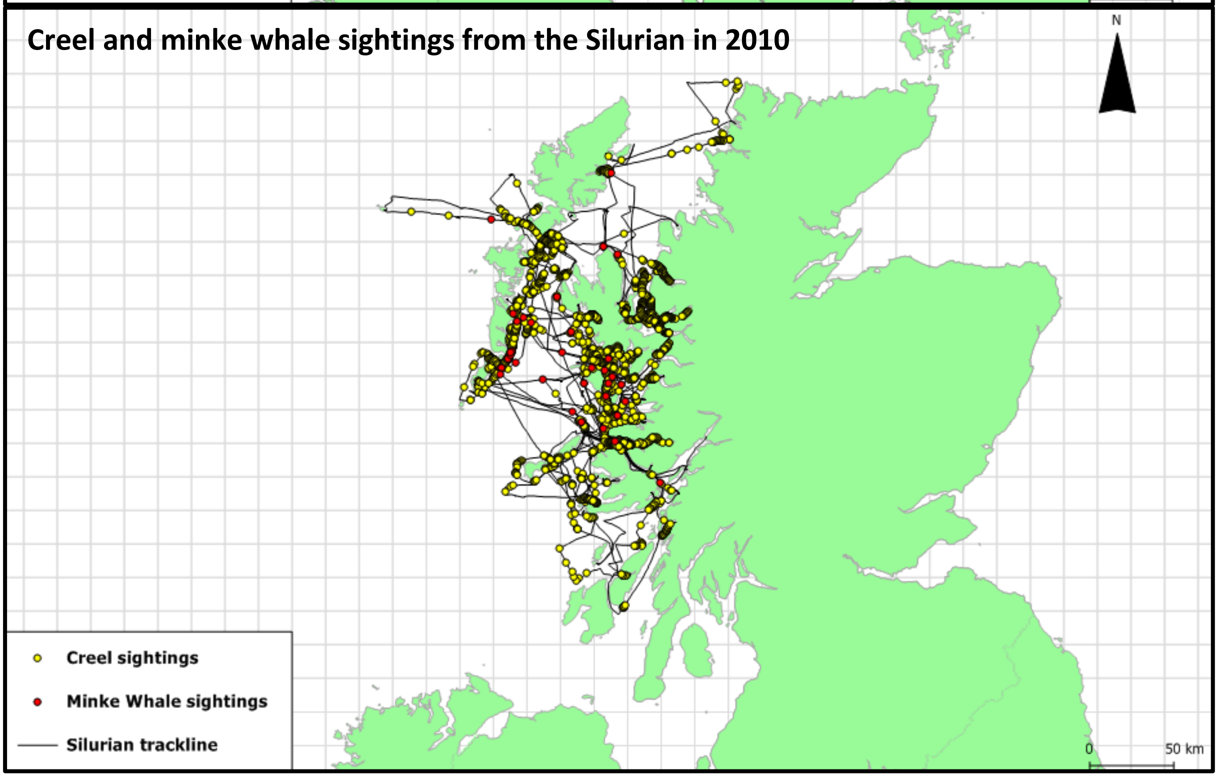


Appendix Figure 3: Maps showing sightings rates of minke whales from the Silurian for each 20km² grid cell in 2009 (A), 2010 (B) and 2011 (C). The shaded grey area shows the survey area.

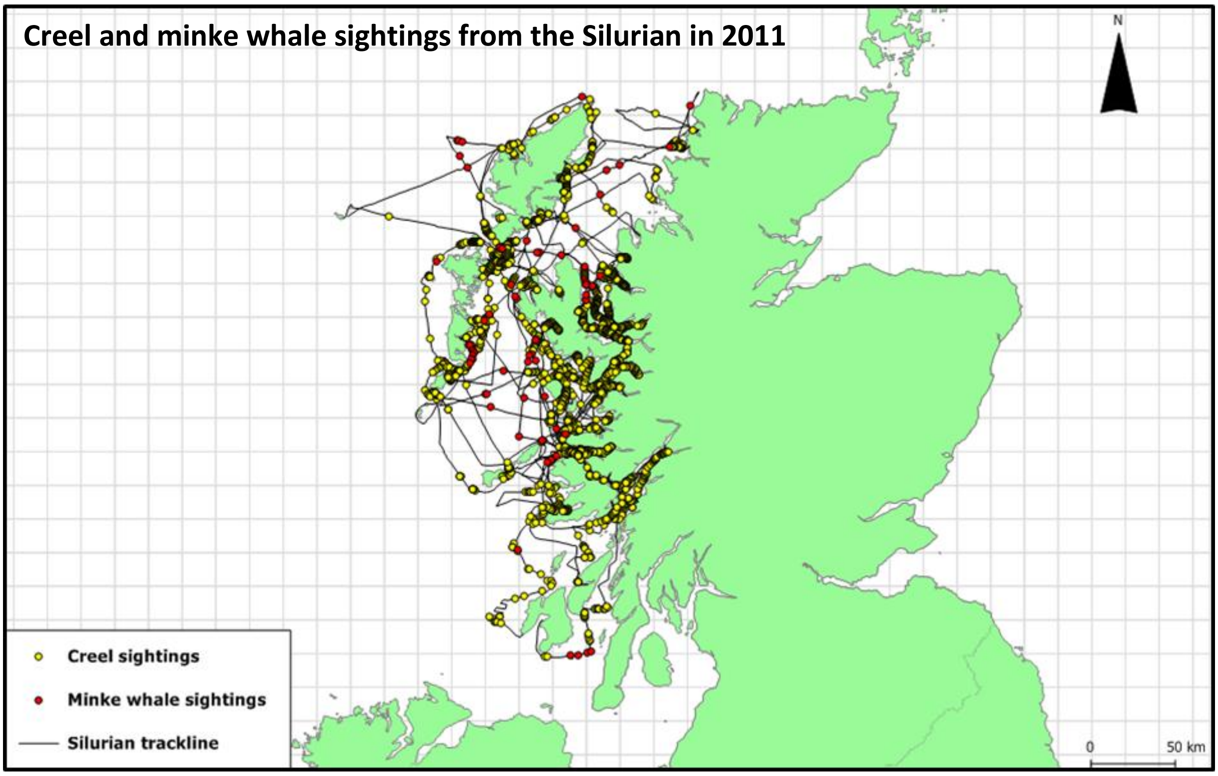
A.


Creel and minke whale sightings from the Silurian in 2009
N
Creel sightings
Minke whale sightings
Silurian trackline
0
50 km

B.


Creel and minke whale sightings from the Silurian in 2010
N
Creel sightings
Minke Whale sightings
Silurian trackline
0
50 km

C.



Appendix Figure 4: Maps showing raw creel marker buoy and minke whale sightings from the Silurian in 2009 (A), 2010 (B) and 2011 (C). The black line shows the trackline of the Silurian.

Appendix Table 4: Total amount of trackline covered by the Silurian in 2009, 2010 and 2011.

Year	Total Trackline
2009	7760324.594
2010	8531100.36
2011	6624877.106

Appendix Table 5: The percentage of time the research cruises in 2009, 2010 and 2011 spent with each sightability code. A sightability code of 1 is excellent and a code of 5 is too poor to survey.

Sightability	2009	2010	2011
0	0.02%	0.89%	0.01%
1	15.94%	18.91%	10.37%
2	43.33%	40.51%	43.54%
2.5	0.00%	0.10%	0.00%
3	31.03%	27.80%	33.96%
4	8.23%	10.47%	11.62%
5	1.45%	1.33%	0.50%

Appendix Table 6: Percentage of time observers spent conducting visual surveys, not conducting visual surveys and when ‘with whales’ for the research cruises in 2009, 2010 and 2011.

Type of Survey	2009	2010	2011
Visual Survey	77.94%	76.61%	74.34%
No visual survey	20.35%	21.20%	22.97%
With whales	1.70%	2.20%	2.65%