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# First estimates of entanglement rate of humpback whales *Megaptera novaeangliae* observed in coastal Icelandic waters

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ABSTRACT: Entanglement in fishing gear is a significant anthropogenic source of large whale injury and mortality. Although entanglements have been reported in the eastern North Atlantic, their frequency has not been previously estimated. This study used systematic scar analysis to estimate the frequency of non-lethal entanglements among individual humpback whales *Megaptera novaeangliae* off coastal Iceland, from 2005 through 2017. Images of the caudal peduncle and fluke insertions of 379 individuals were analyzed for wrapping injuries and notches known to be indicative of entanglement. The results indicated that at least 24.8% (n = 94, 95% confidence intervals [95% CI]: 20.5–29.1%) of individuals had a history of prior entanglement when first encountered. Depending on the metric used, the whales subsequently acquired new entanglement-related injuries at an average rate of 1.9% (95% CI: 0.6–3.2%) or 16.3% (95% CI: 3.0–29.3%) per year, with no statistically significant change over time. Furthermore, evidence suggests that at least some entanglements occurred locally. Observations of whales with gear still entangling the body confirmed the patterns of injury studied here. These results are lower than scar-based estimates from other parts of the world, but the cause of this difference requires further study. Scar-based methods underestimate the frequency of prior entanglement because some injuries heal beyond recognition, do not involve the caudal peduncle, and may occur on whales that die before they are studied. Long-term monitoring of humpback whale entanglement in Icelandic coastal waters is important for evaluating the local effects of fisheries, as well as the viability of the endangered Cape Verde breeding population.

KEY WORDS: Entanglement · Humpback whales · Scar analysis · Iceland · *Megaptera novaeangliae* · North Atlantic

## 1. INTRODUCTION

Entanglement in fishing gear has been identified as one of the major anthropogenic issues faced by marine mammals, with global bycatch estimated to be in the hundreds of thousands of individuals (Read et al. 2006). Most types of fishing gear (e.g. gillnets, long lines, and pot/trap lines) are known to cause entanglements (Baird et al. 2002, Johnson et al. 2005, Read et al. 2006, Song et al. 2010, Benjamins et al. 2012)

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and these can lead to serious consequences for both individuals and populations. At an individual level, entanglement can cause behavioral impairment (Kot et al. 2009), disruptions in energy budget (van der Hoop et al. 2014), an increase in stress-induced hormones, potentially causing weakening of the immune system (Hunt et al. 2006, Rolland et al. 2017), a higher chance of predatory attacks (Mazzuca et al. 1998, Moore et al. 2013), injuries and infections (Knowlton & Kraus 2001, Cassoff et al. 2011, Moore et al. 2013), and emaciation and/or drowning (Cassoff et al. 2011, Moore & van der Hoop 2012). At a population level, entanglement can increase the overall mortality (Volgenau et al. 1995, Robbins et al. 2015) and potentially decrease recruitment rates, given a higher incidence of juvenile entanglement (Lien 1994, Mazzuca et al. 1998, Robbins 2011, Knowlton et al. 2012).

Dedicated surveys, stranding records, and eyewitness reports of whales observed with attached gear have been used to assess entanglement in cetacean populations (e.g. Lien 1994, Volgenau et al. 1995, Félix et al. 2011, Benjamins et al. 2012, van der Hoop et al. 2014). Large whale entanglements present a particular challenge because the animals may carry away some or all of the gear and can either shed the gear or die before the event has been detected. Given the challenge of detecting these events in progress, injury-based studies have been used as a method of systematically assessing the frequency of entanglement interactions (i.e. used to identify whales that have had fishing gear attached to the body previously). Cetacean species in these studies include common minke whales *Balaenoptera acutorostrata* (Held-Wirz 2008), North Atlantic right whales *Eubalaena glacialis* (Kraus 1990, Knowlton et al. 2012), bowhead whales *Balaena mysticetus* (George et al. 2017), gray whales *Eschrichtius robustus* (Bradford et al. 2009), and humpback whales *Megaptera novaeangliae* (Robbins & Mattila 2001, 2004, Neilson et al. 2009, Robbins 2009, 2011). The most detailed scar-based humpback whale study has been conducted in the Gulf of Maine (GoM), where the majority of individuals have scarring indicative of at least one prior entanglement in fishing gear and the frequency of non-lethal events over time has been estimated by monitoring injury acquisition and healing (Robbins & Mattila 2004, Robbins 2009, 2011, 2012).

In Iceland, humpback whales are regularly sighted in coastal shelf waters from the spring through the autumn, and occasionally in winter months (Víkingsson et al. 2004, Magnúsdóttir et al. 2014). Photo-identification data collected in Icelandic coastal shelf waters during opportunistic boat surveys indicate that humpback whales show a certain degree of site fidelity to areas in the northeast, but also demonstrate exchange with areas to the southwest (Klotz et al. 2017, Bertulli et al. 2018). Data also suggest that humpback whales are abundant in the waters north and northwest of Iceland (D. G. Pike et al. unpubl.). Icelandic humpback whales migrate seasonally to breeding grounds in the Caribbean Sea (Martin et al. 1984, Katona & Beard 1990, Stevick et al. 2003) or off the Cape Verde Islands (Jann et al. 2003, Wenzel et al. 2009). The latter area hosts a small and distinctive breeding population (Punt et al. 2006, Ryan et al. 2014, Bettridge et al. 2015, Stevick et al. 2016), which could be negatively impacted by human activities in Icelandic waters.

Significant longline and gillnet effort occurs in both the northeast and south of Iceland (Hafrannsóknastofnun 2017), suggesting potential entanglement issues due to overlap with the areas the humpback whales are frequenting. However, limited information is available on the nature and frequency of interactions between fisheries and whales. Anthropogenic scarring and injuries related to fishing activities have been observed in Iceland in common minke whales, white-beaked dolphins *Lagenorhynchus albirostris* (Bertulli et al. 2012, 2015, 2016), and humpback whales (Basran 2014). Eyewitness reports by fishers of humpback whale entanglements in Iceland date back to 1979 (Basran 2014), and entanglement mortalities have been reported (Víkingsson & Ólafsdóttir 2003, Víkingsson et al. 2004, 2005, Víkingsson 2011).

Whale entanglement studies can provide valuable support to resource management by identifying the need for mitigation measures and evaluating effectiveness after implementation. In order to assess and manage humpback whales in Icelandic waters, it is important to obtain information on the entanglement rates and impacts. This information can then aid in assessing impacts on the breeding stocks to which these whales contribute, such as the endangered population around the Cape Verde Islands. In this study, a scar-based photograph assessment of entanglement injuries on free-ranging humpback whales was performed to provide the first estimates of non-lethal entanglement rate for the whales in Icelandic coastal waters.

## 2. MATERIALS AND METHODS

### 2.1. Study area

This study focuses on 3 main areas in the nearshore waters off Iceland: Faxaflói Bay, Skjálfandi Bay (hereafter referred to as Faxaflói and Skjálfandi), and Eyjafjörður (Fig. 1). These sites were chosen for the predictable numbers of humpback whales arriving during their feeding season, and the accessibility to data collection on-board whale-watching vessels operating tours multiple times a day in all 3 locations. Faxaflói (64° 24′ N, 23° 00′ W) is a 50 × 105 km bay (approximately 4400 km$^2$) located off the country's capital city Reykjavík on the southwest coast. Skjálfandi (66° 05′ N, 17° 33′ W) is a 10–50 × 25 km bay (approximately 1100 km$^2$) on the northeast coast harbouring the fishing and whale-watching village of Húsavík situated on its southeast shore (Stefánsson & Guðmundsson 1978, Stefánsson et al. 1987, Einarsson 2009, A. Gíslason unpubl. data). Eyjafjörður (65° 50′ N, 18° 07′ W) is a 5–15 × 60 km fjord (approximately 440 km$^2$) also located on the northeast coast of Iceland, hosting the second-largest Icelandic city, Akureyri, at the southern end and the fishing and whale-watching villages of Dalvík and Hjalteyri along the western shore (S. Jónsson unpubl. data). Skjálfandi and Eyjafjörður are ca. 80 km apart, while Faxaflói is ca. 600 km to the southwest of Skjálfandi (Fig. 1).

### 2.2. Data collection

Photographs of humpback whales were primarily collected from April to November onboard whale-watching vessels operating out of Faxaflói (FB, 2007–2017), Skjálfandi (SB, 2001–2017), and Eyjafjörður (EyF, 2015–2017). Each boat survey lasted approximately 3 h and covered morning, afternoon, and/or evening times. All photographs used in this study were taken with digital single-lense reflex cameras with zoom lenses (between 55 and 400 mm). The photographs were taken mainly by researchers and students associated with the University of Iceland (HI), though some photographs were contributed by whale-watching guides and tourists. Photo-identification images were taken of the pigmentation pattern on the ventral side of each individual humpback whale fluke (Katona & Whitehead 1981). Whenever possible, researchers photographed the caudal peduncle and insertion point of the flukes from parallel to or in front of the animal while it took a terminal dive. These features are frequently involved in entanglements and are known to be the site of injuries that can be used to determine the entanglement history of the individual (Robbins & Mattila 2001, 2004). To minimize bias, photos were taken regardless of whether the whale appeared to have any injuries or scarring.

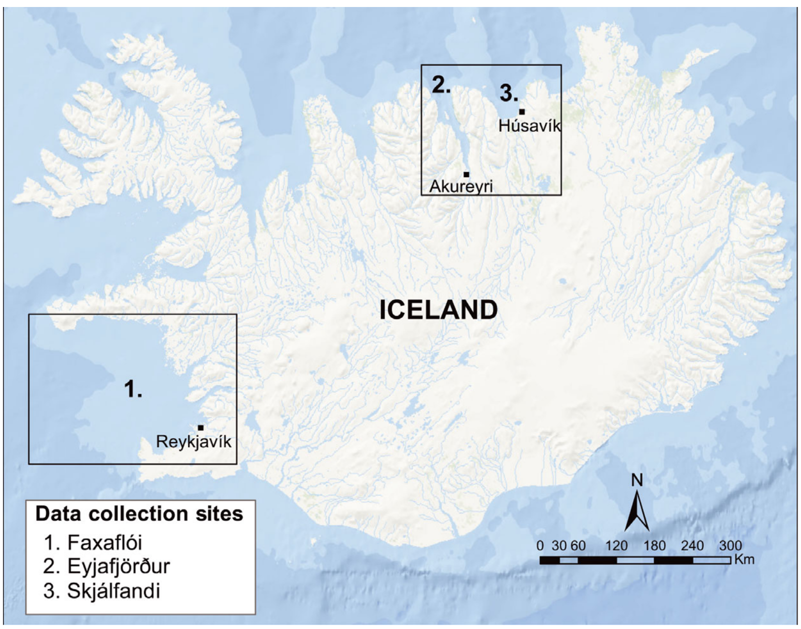


Fig. 1. Map of Iceland showing the 3 photograph data collection field sites

### 2.3. Image selection and peduncle scar analysis

The only images selected for analysis were of individuals which were photo-identifiable by the unique pigmentation pattern on the underneath side of the fluke. All images used had high enough resolution to be zoomed in without losing detail, were in good light conditions, and were taken from the correct angle (following Gowans & Whitehead 2001, Robbins & Mattila 2001). The image interpretation and coding criteria were originally defined by Robbins & Mattila (2001, 2004). Specifically, images which showed at least 2 of 6 predetermined coding areas were examined for wrapping scars and notches indicating a previous entanglement and were scored accordingly. The 6 coding areas were: (i) left flank, (ii) dorsal peduncle, (iii) ventral peduncle, (iv) left insertion point and leading edge of fluke, (v) right insertion point and leading edge of fluke, and (vi) right flank (Fig. 2). Each individual whale then received a likelihood of prior entanglement score, taking into account all usable images spanning all available coding areas. The likelihood of prior entanglement score was assigned as fol-

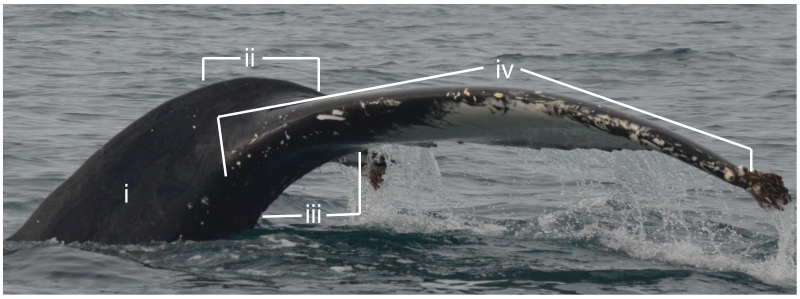


Fig. 2. Humpback whale *Megaptera novaeangliae* showing 4 of the 6 coding areas: (i) left peduncle flank, (ii) dorsal peduncle, (iii) ventral peduncle, (iv) left insertion point and leading edge of fluke. On the opposite side (not visible here): (v) right peduncle flank and (vi) right insertion point and leading edge of fluke

lows — HP: high probability of prior entanglement, if evidence was found in 2 or more coding areas; U: uncertain, if evidence was only found in one coding area; or LP: low probability of prior entanglement, if no clear evidence was found in any coding areas (Fig. 3). Image analysis was conducted by a single researcher (C.J.B.) for consistency. Whales assigned as HP then underwent expert consultation (by J.R.) to ensure accuracy. The minimum scar-based frequency of prior entanglement was calculated as HP divided by the total sample, while the maximum was calculated as HP + U divided by the total sample. Individuals were only included in this estimate once, based on the score they were assigned the first year they were recorded in the study.

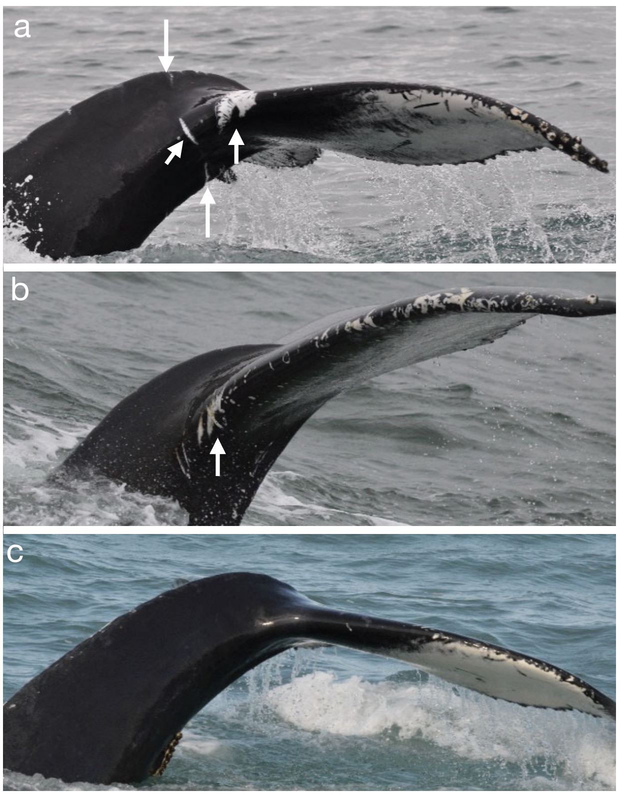


Fig. 3. Examples of prior entanglement history scoring in humpback whales *Megaptera novaeangliae*: (a) HP, high probability of previous entanglement; (b) U, uncertain; and (c) LP, low probability of previous entanglement when analyzing scarring to estimate the frequency of prior entanglement. Arrows indicate evidence of entanglement

Two metrics were used to estimate the rate at which entanglement injuries were acquired after the baseline scarring pattern was established. Firstly, individuals that had usable photographs in consecutive years, and were given an HP score in at least one year, were compared directly across the sightings to determine whether changes in entanglement-related scarring had occurred. For each year an individual was resighted, it was assigned as having increased entanglement-related scarring, equal scarring, or decreased entanglement-related scarring when compared to the previous year (Fig. 4). Images were only compared if they adequately showed the same coding areas. The inter-annual entanglement rate based on scar acquisition ($E_s$) was then calculated as the percentage of individuals resighted that were assigned increased entanglement-related scarring out of the total examined that year. Due to the sample limitations in the early part of the study, this was only calculated for each year from 2011 to 2017, and the average percentage over these years was calculated as an estimate of entanglement acquisition rate per year.

Secondly, we evaluated the yearly entanglement rate based on unhealed injuries ($E_u$) using the percentage of individuals with unhealed entanglement-related injuries in each study year (Fig. 5). These injuries were used as an indicator of a recent entanglement, likely within the past year (Robbins 2011). The percentage of individuals with unhealed injuries was calculated for each study year between 2007 and 2017 and averaged across periods of interest for comparison purposes. Due to small sample sizes in the early years of the study, entanglement acquisition rates were calculated and compared for 2 periods: 2007–2011 and 2012–2017. Statistical comparisons using Wilcoxon rank sum tests were made in JMP software (version 13.2.1, SAS Institute).

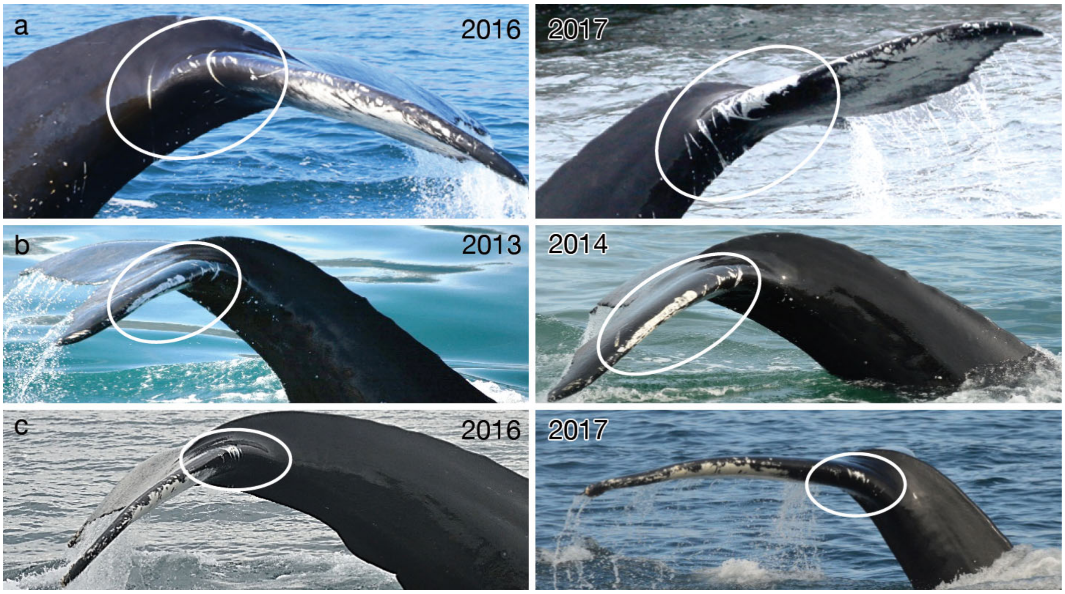


Fig. 4. Examples of changes in entanglement scar patterns in humpback whales *Megaptera novaeangliae* from one year to the next: (a) increased scarring, (b) equal scarring, and (c) decreased scarring. Ellipses indicate where comparisons in scarring can be observed. Cases such as (a) were used in the calculation of entanglement rate based on increased scarring ($E_s$)

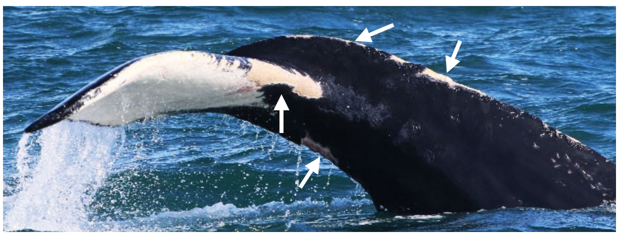

Fig. 5. Example of an individual humpback whale *Megaptera novaeangliae* with unhealed entanglement injuries (arrows) included in the calculation of the rate based on such cases ($E_u$)

When an individual was observed still entangled in fishing gear, we used these cases to evaluate the validity of our scar-based assessments and for evaluating the fraction of events that might be missed by focusing only on the caudal peduncle.

## 3. RESULTS

Overall, 379 individuals were included in the scar analysis, from 13 yr of usable photographs (2005–2017). Approximately half (n = 189) were assessed as having a low probability of prior entanglement. Of the remaining individuals, 94 were considered to have a high probability of entanglement, while the entanglement status of the remaining 96 was uncertain. Thus, at least 24.8% (n = 94, 95% confidence intervals [95% CI]: 20.5–29.1%), but potentially as much as 50.1% (n = 190, 95% CI: 45.1–55.2%), of individuals were estimated to have had a prior entanglement history (Table 1).

In total, 89 individuals were resighted (23.5%), of which 37 were scored HP in at least one year and had photos in consecutive years making them eligible to be considered for $E_s$ analysis. Of these eligible cases, 33 (8.7% of the total sample) had comparable resightings in consecutive years to be included in the analysis. However, annual resightings were primarily limited to the second half of the study. The average $E_s$ rate from 2011–2017 was 16.3% (n = 33, 95% CI: 3.3–29.3%; Table 2). Three individuals with comparable resightings (0.8%) had entanglement-related scarring that healed beyond recognition within 1 yr and 3 individuals had increased scarring that in-

Table 1. Percentage of individual humpback whales *Megaptera novaeangliae* with scar-based evidence of a likely history of prior entanglement. N: number of individuals in each estimate; %: estimated percent of the population that has been entangled at least once; 95% CI: 95% confidence intervals. Total sample size: 379 individuals

| Frequency of prior entanglement | N | % | 95% CI (%) |
|---|---|---|---|
| Minimum | 94 | 24.8 | 20.5–29.1 |
| Maximum | 190 | 50.1 | 45.1–55.1 |

Table 2. Entanglement rate estimate results based on scar acquisition ($E_s$) in humpback whales *Megaptera novaeangliae*. N with increased scarring: number of individuals with increased scarring between the years; N resights: total number of resighted individuals between each year; %: percentage of individuals with increased scarring per year; Mean: average percentage of individuals with increased entanglement scarring per year; 95% CI: 95% confidence intervals

| Year | N with increased scarring | N resights | % |
|---|---|---|---|
| 2011–2012 | 2 | 6 | 33.3 |
| 2012–2013 | 1 | 7 | 14.3 |
| 2013–2014 | 0 | 3 | 0 |
| 2014–2015 | 0 | 5 | 0 |
| 2015–2016 | 0 | 2 | 0 |
| 2016–2017 | 4 | 8 | 50.0 |
| Mean | | | 16.3% |
| 95% CI (%) | | | 3.0–29.3 |

Table 3. Entanglement rate estimate results based on unhealed injuries ($E_u$) in humpback whales *Megaptera novaeangliae*. N unhealed: number of individuals per year with unhealed injuries; N total: total number of individuals in the study each year; %: percentage of individuals with unhealed injuries each year; Mean: average percentage of individuals with unhealed injuries per year for the time period indicated; 95% CI: 95% confidence intervals

| Year | N unhealed | N total | % | Mean (95% CI) |
|---|---|---|---|---|
| 2007 | 0 | 11 | 0 | |
| 2008 | 3 | 11 | 27.2 | |
| 2009 | 1 | 16 | 6.3 | |
| 2010 | 0 | 11 | 0 | |
| 2011 | 1 | 21 | 4.8 | |
| 2007–2011 | | | | 7.7% (1.5–13.9%) |
| 2012 | 2 | 51 | 3.9 | |
| 2013 | 0 | 46 | 0 | |
| 2014 | 0 | 32 | 0 | |
| 2015 | 1 | 69 | 1.5 | |
| 2016 | 7 | 117 | 6.0 | |
| 2017 | 0 | 99 | 0 | |
| 2012–2017 | | | | 1.9% (0.3–3.2%) |

dicated they had been entangled at least twice. There were 15 individuals (4.0%) that exhibited unhealed entanglement-related injuries, 5 in the first time period and 10 in the second. The $E_u$ rate, likely representing entanglements within the prior year, averaged 1.9% (CI: 0.6–3.2%) for approximately the same time period as the $E_s$ rate (2012–2017) (Table 3). The estimates generated by these 2 metrics were not significantly different (Wilcoxon rank sum test: $p = 0.49$, $z = 0.68$), but the estimate from $E_u$ analysis was based on a larger sample size and therefore was more precise. Data on unhealed injuries were also sufficient to estimate the average annual $E_u$ rate for the earlier time period (2007–2011) at 7.7% (95% CI: 1.4–13.9%; Table 3). This was not significantly greater than the later time period (Wilcoxon rank sum test: $p = 0.39$, $z = 0.86$).

Seven individuals photographed in the study period had fishing gear still attached to the body (Fig. 6). Based on what was visible in the photographs, 2 had monofilament line (1 with hooks attached to the line),

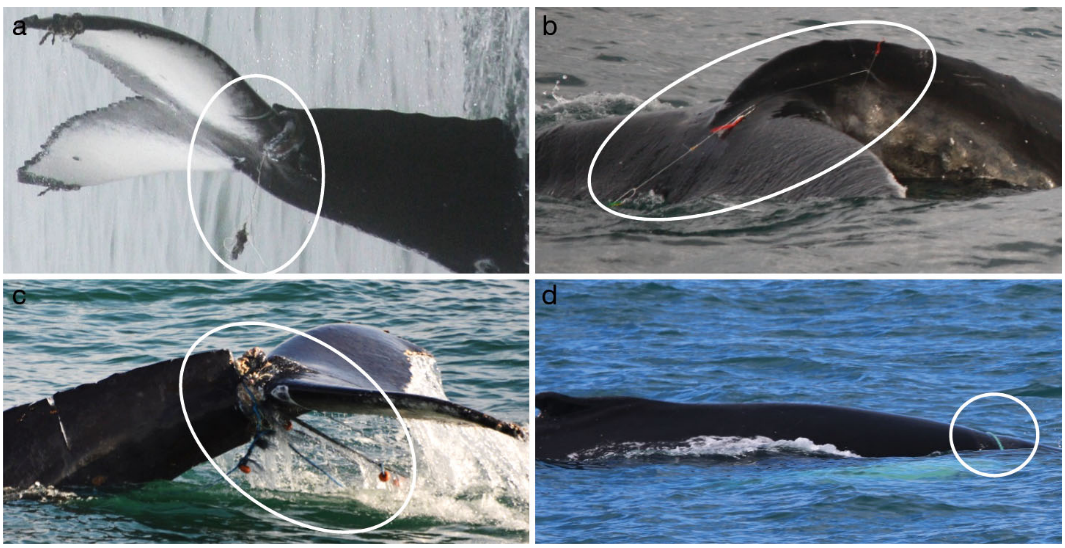


Fig. 6. Examples of individual humpback whales *Megaptera novaeangliae* with fishing gear (indicated by ellipses) still attached to the body both within and outside of the coding areas considered in this study. Visible materials included: (a) single monofilament line, (b) hooks and monofilament line, (c) rope and monofilament netting, and (d) rope

2 had rope and netting, 1 had a single rope, and 2 had just netting. The gear appeared to be attached at the coding areas in 5 individuals; however, only 3 of these had adequate photographic coverage for assessment of injuries and inclusion in scar analysis. These 3 cases confirmed the presence of diagnostic wrapping injuries. In 2 other cases, there was no documentation of the caudal peduncle or tail to determine the presence of an attachment there or the nature of the injuries. Two individuals picked up entangling gear or acquired new injuries between sightings in the same year. One was photographed gear-free 3 mo earlier in Skjálfandi, and was then resighted entangled in Eyjafjörður. Another individual was photographed in Eyjafjörðdur with new entanglement injuries that it had acquired within 9 d of first being sighted in Skjálfandi. This individual had already shed the entangling gear.

## 4. DISCUSSION

Entanglement is a known source of injury and mortality to large whales, including humpback whales. This is the first effort to quantify humpback whale entanglement rates in Icelandic waters using standard scar-based techniques for comparison to other areas. The results suggest that a minimum of 24.8% and a maximum of 50.1% of individuals in coastal Icelandic waters had a prior history of entanglement at the time they were first sighted. The annual scar-based entanglement rates averaged 1.9% ($E_u$) or 16.3% ($E_s$) of the sampled population, depending on the method used for calculation. However, none of the comparisons of entanglement rate between time periods or between the 2 methods of calculation for the same time period were statistically different. The available data therefore suggest that the non-lethal entanglement rate has remained fairly steady over the study period. Of the 2 results, we have greater confidence in the lower, more precise $E_u$ rate of 1.9% per year because it was based on larger sample sizes. Furthermore, 3 out of 33 individuals exhibited evidence of more than one past entanglement.

Although humpback whales are seasonal migrants, there is evidence that at least some of these injuries are occurring locally. Firstly, 1 individual was photographed with new entanglement injuries it had obtained within 9 d of being first photographed with no injuries. Secondly, although not based on scar analysis, another individual in this study was observed entangled 3 mo after first being seen without the entangling gear.

The specific types of entangling gear that may have caused the majority of observed injuries were generally not known. In the few cases in which fishing gear was still attached to the body, the gear type was variable, including ropes, monofilament netting, and monofilament line. This suggests that the whales are becoming entangled in several different gear types as opposed to a single type. This is consistent with what is known more generally about the gear involved in large whale entanglements (Johnson et al. 2005), and specifically with fisher reports in Iceland (Basran 2014). The greatest fishing effort in the vicinity of our data collection sites comes from longline, handline, and gillnet fisheries, which is also consistent with the types of gear observed entangling the whales (Hafrannsóknastofnun 2017).

Entanglement estimates obtained in the present study are lower than those obtained in other areas using the same assessment methods. In another area of the North Atlantic, the GoM, at least half the individuals had a prior history of entanglement when first observed (Robbins & Mattila 2004, Robbins 2009), acquisition rates were most recently estimated at 16.9% (95% CI: 10.5–23.4%, $E_s$) and 13.5% (95% CI: 9.7–17.3%, $E_u$) (Robbins 2012), and there is evidence that some humpback whales have been entangled at least 2–4 times (Robbins 2009). The minimum frequency of prior entanglement off Alaska (54%; Neilson et al. 2009) was also higher than observed here. The reason for the lower incidence of entanglement in the present study is not known, but may relate to differences in fishing gear types, potentially lower fishing effort in Iceland than in larger countries, and the extent of the spatial and temporal overlap between the whales and the fishing. Both the GoM and Alaska host pot/trap fisheries that have been directly implicated in whale entanglements (Johnson et al. 2005, Neilson et al. 2009). Iceland does not have any pot/trap fisheries, but rather only gillnet, trawl, hook-and-line, and seine fisheries (Hafrannsóknastofnun 2017). This may result in a differential risk of entanglement overall in Icelandic waters. There is, however, moderate-to-high gillnet effort in all 3 of our data collection sites, as well as moderate longline and handline effort, suggesting that the whales and the fishing in Iceland are overlapping spatially and temporally to some extent (Hafrannsóknastofnun 2017). In the GoM, juvenile whales have a higher incidence of entanglement than adults (Robbins 2011) and so demography may explain differences among areas. However, demographic research would be needed to be able to compare entanglement rates from the

Icelandic population to other humpback whale populations on the basis of age class.

The minimum frequency of prior entanglement, as calculated by scar-based techniques, is considered to be conservative. Although this is a systematic method, it does not detect entanglements that do not involve the peduncle, injuries that heal over time, and those that result in the death of the whale before it can be studied (Robbins & Mattila 2004). There were a small number of cases in this study where entanglement evidence was opportunistically photographed outside of the peduncle region, suggesting some entanglements of Icelandic whales are occurring on body parts not included in the coding areas. Furthermore, some entanglement scarring can heal beyond recognition (Robbins & Mattila 2004), suggesting that some entanglements can potentially be missed by scar-based studies. Yet, only 3 individuals in our study with comparable resightings in consecutive years exhibited entanglement scar healing beyond recognition. In addition, our study focused on free-ranging whales, and we did not necessarily encounter entangled whales carrying gear, or injured whales, before they died. There are some reports of humpback whale strandings in Iceland in which entanglement, confirmed by the presence of injuries or entangling gear still attached to the animal, was deemed the likely cause of death (Víkingsson et al. 2004, 2005, Víkingsson 2011). Our results therefore only reflect the non-lethal component of the entanglement rate. Despite this, our study provided evidence that entanglements off Iceland can be reliably detected based on scarring/injuries in the caudal peduncle areas.

The use of whale-watching boats and visiting students was essential to this study because they provided a low-cost source of data; however, it did impose some limitations on the research. The whale-watching boats were often not in the correct position for properly angled photographs for analysis, and the researchers had no control over this. In addition, though having individuals other than researchers, such as students, taking photographs greatly increased the effort in the study, it did not always result in usable, high-quality data, and likely reduced the number of individuals for which comparable coverage was available. Using whale-watching boats as a research platform was useful and mutually beneficial, although having additional dedicated surveys in order to obtain as large a sample size of usable individuals as possible and to cover larger areas would be valuable. Though the 3 data collection sites used in this study covered well-known humpback whale sighting areas, humpback whales are also seen in other areas around Iceland, and therefore our sampling may not be representative of the overall population of whales that feed off the coast of Iceland. The central North Atlantic humpback whale population around Iceland is estimated to be approximately 12 000 animals (Víkingsson et al. 2015) and some are known to make migrations to different coastal areas around the country, potentially limiting the chances of opportunistically sighting the same individuals in consecutive years when covering only limited areas. Spatial coverage and effort limitations may also explain the low resighting rates and gaps between resightings of more than 1 yr that limited the sample sizes. Though this study included usable photographs spanning 13 yr and covered field sites with predictable humpback whale sightings, usable, comparable resightings were low.

The specific effects of non-lethal entanglements on individuals and populations are not well understood. Several factors, including the severity of the entanglement and resulting injuries, and the length of time that the whale carries gear, will influence the severity of the impacts. Nevertheless, entanglement and net encirclement has been found to raise stress-induced hormones, glucocorticoids, in several cetacean species (St Aubin 2002a,b, Hunt et al. 2006, Rolland et al. 2017), and there may be other, non-lethal impacts on individuals resulting from the stress (St Aubin 2002b, van der Hoop et al. 2017). The majority of entanglement injuries in the present study were not considered to be outwardly severe; however, we do not know the long-term outcome for these individuals, particularly those with more significant injuries and those with gear that was still attached at last sighting. Further monitoring would help to better understand the long-term effects of entanglement on humpback whales off Iceland.

Some of the whales that feed off the coast of Iceland are known to belong to a small breeding stock occurring around the Cape Verde Islands. The United States recently conducted a global review of humpback whale status (Bettridge et al. 2015) and concluded that the small population of North Atlantic humpback whales that breed off the Cape Verde Islands/Northwest Africa is distinct and endangered (NOAA Department of Commerce 2016). The breeding stock around the island of Boa Vista is estimated to be 260 individuals (Ryan et al. 2014). Though this estimate is only for the main location of humpback sightings in Cape Verde and not all the islands, it lends to the hypothesis that the breeding stock is not large. These whales mix on the Icelandic feeding grounds with individuals that are part of a larger population that breeds in the West Indies. As these breeding populations cannot be differentiated on the feeding ground, negative impacts of entanglement on even a relatively small number of these humpback whales could have serious implications for the Cape Verde stock. Future long-term monitoring of humpback whale entanglement in Icelandic coastal waters is recommended to further investigate the frequency of entanglement and changes in entanglement rate over time.

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