Scar-Based Inference Into Gulf of Maine Humpback Whale Entanglement: 2007

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ABSTRACT

Entanglement in fishing gear is a known source of humpback whale, *Megaptera novaeangliae*, injury and mortality. However, eye-witnessed events provide limited insight into entanglement frequency, risk factors and biological impacts. The caudal peduncle is commonly implicated in humpback whale entanglements and is consistently presented during the terminal dive. Since 1997, peduncle scarring has been studied annually as a relative index of entanglement frequency. In 2007, a total of 794 images were obtained of the caudal peduncle and flukes of 289 individual humpback whales in the Gulf of Maine. Preferred photographs were obtained while parallel to the whale and slightly ahead of its flukes during the terminal dive. Suitable quality images were examined for evidence of wrapping scars, notches and other injuries that were believed to be entanglement-related. The vast majority (87.5%) of individuals involved in prior documented entanglements between 1985 and 2006 were successfully scored as having a high probability of prior entanglement. Overall, 9.4 ± 5.84% of individuals sampled in 2007 exhibited new high probability scarring relative to 2006. Similarly, 6.6 ± 2.86% (n=19) of the total 2007 sample exhibited unhealed injuries that were likely received within the past year. Neither finding was significantly different from 2006, and there were no significant differences in entanglement frequency among the Gulf of Maine areas studied in 2007. However, juveniles continue to be more likely than adults to acquire new injuries. A total of 27 acquisition events were documented in 2007, bringing the number detected by scar analysis alone to 291 events since 1997, or an average of 26.5 events per year of the study. However, none of the events inferred from 2007 scarring were reported in progress. Overall, scar-based monitoring continues to achieve large samples with which to evaluate entanglement rates on an annual basis. The use of mark-recapture statistical modeling techniques, already in progress, is expected to further enhance the inference possible from these data. This study is expected to play an important role in evaluating the effectiveness of planned coast-wide ground line modifications in 2009.

INTRODUCTION

The humpback whale (*Megaptera novaeangliae*) is a migratory large whale that feeds at mid- to high latitudes and congregates at low latitudes to mate and calve. The Gulf of Maine is the southern-most humpback whale feeding stock in the North Atlantic. This region straddles U.S. and Canadian waters and humpback whales can be found there consistently from April through December. Animals aggregate at submerged banks and ledges, although they can be found in other areas and their spatial distribution varies with prey availability (Payne *et al.* 1990; Weinrich *et al.* 1997). In winter, the majority of the population is thought to migrate to the breeding range along the Atlantic margins of the Antilles, from Cuba to northern Venezuela (Winn *et al.* 1975; Balcomb and Nichols 1982; Whitehead and Moore 1982). However, a few Gulf of Maine whales remain in coastal U.S. waters in winter, whether in the Gulf of Maine itself (Robbins 2007) or off the U.S. mid-Atlantic states (Swingle et al. 1993). Nearly half of the humpback whales sampled in the latter area were from the Gulf of Maine, although whales from other feeding stocks were also represented (Barco et al. 2002).

In the North Atlantic, humpback whales were historically subject to commercial exploitation (Mitchell and Reeves 1983; Smith and Reeves 2002) and population recovery from those activities remains uncertain (IWC 2002). In the U.S., the North Atlantic humpback whale is an endangered species that is vulnerable to human sources of injury and mortality, including fisheries by-catch (Anonymous 1991; Waring *et al.* 2007). However, the frequency of entanglement events, risk factors, and biological impacts remain poorly understood. The likelihood of witnessing an entanglement is thought to be low and variable, depending on entanglement location and overlap with knowledgeable observers. Between 2001-2005, there were 79 humpback whale entanglements witnessed along the U.S. East Coast, of which 70 were confirmed cases and 14 were either mortalities or considered likely to result in imminent death (Nelson et al. 2007). Confirmed entanglement sites of Gulf of Maine humpback whales range from Bay of Fundy, Canada to North Carolina (J.F. Kenney, pers. comm.). The number of witnessed entanglements exceeds what is considered sustainable for this population, and observed deaths likely underestimate total entanglement mortality (Nelson et al. 2007).

Entanglements produce injuries that can be detected even after gear is removed or shed. Since 1997, scar analysis has provided an additional source of information on the nature and frequency of entanglements on Gulf of Maine humpback whales (Robbins and Mattila 2000;

2001; 2004). This report describes the results of sampling and scar interpretation for the 2007 humpback whale feeding season in the Gulf of Maine.

METHODS

Witnessed entanglements

Data from documented entanglement events were obtained from the Atlantic Large Whale Disentanglement Network (ALWDN), coordinated by the Provincetown Center for Coastal Studies (PCCS, Massachusetts, USA) under the authority of the U.S. National Marine Fisheries Service (NMFS). PCCS began conducting disentanglements in the coastal waters of Massachusetts in 1984 and since 1997 the ALWDN has provided formal reporting, disentanglement response and awareness training along the eastern seaboard of the United States. The ALWDN requests documentation of each entanglement, including the configuration of gear on the animal. Identifying features of the entangled whale are also obtained whenever possible so that the individual can be re-identified with or without entangling gear. We used this documentation to identify animals with confirmed entanglements, to study the injuries produced by entanglement and as a baseline for tracking the healing process. Observed events were also used to evaluate the effectiveness of eyewitness reporting (see below).

Free-ranging animals

Entanglements may involve any body part, but are typically anchored at the mouth, flippers and/or the tail (Johnson et al. 2005). On the U.S. East Coast, the tail was an anchoring site for at least 53% witnessed entanglements (Johnson et al. 2005), and raw injuries suggested that this under-estimated tail involvement. Unlike other attachment sites, the tail can be systematically sampled when it is raised above water each time the whale takes a terminal dive. We therefore used scarring in this area as an index of the entanglement history of the individual.

This study focussed on several body areas, including the posterior caudal peduncle, the insertion point of the flukes and their leading edges. Photographs were obtained in the Gulf of Maine, aboard PCCS research vessels conducting photo-identification (photo-ID) surveys and by PCCS naturalists aboard commercial whale watching vessels. Directed surveys targeted known humpback whale aggregation sites and sampling effort was expended roughly proportional to observed whale density. In the case of commercial whale watching platforms, effort was restricted to the southwest Gulf of Maine, but humpback whales were the primary species of interest and an effort was made to photograph all animal encountered. Images were generally obtained while alongside an animal and ahead of its flukes when it began its terminal dive. Photographers were instructed to photograph this part of the body whenever it was presented, without regard for injuries or scars observed in the field. Photographs were also taken when these features were exposed during rolling or lob tailing behaviors. The latter was particularly important for calves, which are less likely than older animals to systematically raise their tails upon diving. Images were obtained using digital SLR cameras equipped with a 300-mm telephoto or a 100-300mm zoom lens and shot in 24-bit color at a minimum resolution of 2160 x 1440 pixels.

Individual humpback whales can be identified from their natural markings, especially the ventral pigmentation of the flukes and the shape and size of the dorsal fin (Katona and Whitehead 1981). Identifying shots of each individual were matched to a photo-identification catalog of Gulf of Maine humpback whales maintained by PCCS since the 1970s. Sexes of Gulf of Maine humpback whales in this catalog were determined by genetic analysis of a tissue sample (Palsbøll *et al.* 1992; Bérubé and Palsbøll 1996a; b), a photograph of the genital slit (Glockner 1983) or, in the case of females, at least one documented calf. Age was known for individuals that were dependent calves at first encounter. Calves were classified in the field based on their physical size, stereotypical behaviors and close, consistent association with a mature female. They were assumed to range from 3 to 9 months old when first observed and typically remained dependent until at least October of their first year (Clapham and Mayo 1987; Baraff and Weinrich 1993). For animals without a known year of birth, a minimum age was assigned by assuming that the whale was at least 1 year old the first year it was sighted. Female humpback whales in the Gulf of Maine have been shown capable of producing a calf as early as age five (Clapham 1992), although the average age at first reproduction was closer to nine years during the study period (Robbins 2007). Animals first cataloged as calves and less than five years old in the year that they were sampled were considered juveniles. Whales were considered adult if they were known to be at least five years old or were first sampled as an independent whale at least four years prior to being sampled. A maturational class could not be confidently assigned to whales without a known year of birth and first cataloged less than four years prior to sampling. However, these were thought to be predominantly juvenile animals (Robbins 2007),

Entanglement scar analysis

A single individual (JR) examined evidence for a previous entanglement across six body areas: the right and left posterior flank, the right and left leading edge of the flukes, the dorsal peduncle and the ventral peduncle (see Robbins and Mattila 2001; Robbins and Mattila 2004). Injuries consisted of linear marks, broad areas of scarring or more extensive tissue damage that generally appeared to have wrapped around the feature in question. They could be raised or indented and healed injuries ranged from white to black in color. Poor quality photographs (based upon distance, angle and focus) were excluded from analysis to prevent a bias toward more obvious or severe injuries.

The first time that an individual was sampled, it was assigned to an entanglement history category based on its composite scar patterns. Animals with high probability scarring in at least two body areas were assigned a ‘high’ probability of a prior entanglement. Those with no diagnostic injuries or scars were considered to have a ‘low’ probability of prior entanglement. When injuries were detected in only one body area, entanglement was neither strongly supported nor ruled out. In those cases, the whale was assigned an ‘uncertain’ probability of previous entanglement. Images taken of the right and left sides of the animal, when available, were scored independently. Data on documented entanglements were not factored into the initial coding process.

Patterns of scarring in any given image were expected to represent a composite of events over the lifetime of the whale. Some diagnostic injuries may have been acquired long ago, while others may have healed beyond recognition. Once we obtained at least one image of a feature, we focussed our attention on scarring that was not present in that baseline coverage. From one sampling period to the next, an individual’s scarring pattern could remain the same, decrease as a result of healing or increase as new events occurred. However, we also made particular note of injuries that had not healed, as determined by their color, texture and apparent severity. These allowed us to identify recent events for whales with no prior baseline images.

When reported, the 95% confidence interval (*CI*) of percentages were calculated based on the standard error, as follows:

$$CI = 1.96\sqrt{\frac{p*(100-p)}{n}}$$

Where: *p* = the percentage of interest and *n* = total number of animals examined. Categorical differences between samples were evaluated using a G-test with a William's correction (Sokal and Rohlf 1981).

RESULTS

A total of 794 caudal peduncle images were obtained in 2007 through a combination of NMFS-funded cruises (Table 1) and field efforts undertaken independently by PCCS. Of these, 435 images were selected as the best representation of 289 unique individuals for the year. While not all images were considered to be of equal quality for determining entanglement status through blind coding techniques, all were deemed potentially valuable for monitoring the same individual over time. Images were obtained between 1 April and 9 November, with 85.6% (n=680) obtained between June and September and nearly half (43.2%, n=343) in August alone. Individuals were sampled on an average of 2.1 days during the season (11 days max), with an average interval of 24.2 days between samples (188 days max). Efforts were made to sample individuals in a range of Gulf of Maine areas, but the vast majority of humpbacks were encountered in northeast and southwest portions of the region in 2007.

Over half (64.4%, n=186) of the individuals sampled in 2007 had prior baseline coverage. Most of those entering the study for the first time were calves (n=38), independent juveniles (n=4) or other animals with short prior sighting histories (n=22). New baseline coverage for adults was equally split between females (n=20) and males (n=19). However, the overall 2007 sample was slightly skewed by sex, with at least one photograph obtained from more unique females (56.5%, n=152) than males. Females were both more likely to be sampled at least twice during the season and had shorter intervals between re-sightings. This was likely due to the fact that over half of the total sample (424 images) came from commercial whale watching platforms operating in the Stellwagen Bank region where females are slightly more prevalent (Robbins 2007). However, the overall demography of the sample was generally consistent with prior years.

As in previous years, more than half of the individuals entering the study for the first time exhibited strong evidence of a prior entanglement. However, among the 96 individuals that also had photographic coverage in 2006, only 9.4 ± 5.84% exhibited new high probability scarring in 2007. Similarly, 6.6 ± 2.86% (n=19) of the total sample exhibited unhealed injuries that were likely received within the past year. Neither result was significantly different from apparent acquisition rates observed in 2006. There continues to be a higher incidence of new injuries among juveniles and other animals with short sighting histories (16.9%, n=13) than among adults (8.5%, n=18), although it was at the threshold of significance in this sample (G=3.794, df=1, p=0.05). Young males may have been at greatest risk in 2007 (33.3%, n=6), but sample sizes were too small to examine this rigorously. There were no noteworthy differences in the frequency of new injuries among adult females (7.3%, n=9) and adult males (10.1%, n=9) in 2007, with only seven adults of unknown sex.

The injuries observed in 2007 represented at least 27 events that were not documented in previous years of this study. In total, there have been 291 discrete events inferred from scarring alone since 1997, or an average of 26.5 events per year. As noted above, the most of injuries in 2007 were believed to have occurred within the prior year. The rest can be definitively placed to within six years based on prior photographic coverage. For most of the individuals affected, this was the first new injury documented since the study began in 1997. However, three individuals had acquired injuries in a prior year and one mother had been entangled on two prior occasions (see below).

None of the events inferred from scarring in 2007 were consistent with entanglements reported in 2007 or 2006. This suggests a zero reporting rate, although we know that some events were successfully reported. Missed events did not necessarily occur in poorly observed areas. One mother and her calf both acquired entanglement injuries between 10 August and 21 August, despite regular intervening sightings by whalewatching vessels in the Stellwagen Bank area. It is highly likely that the entanglement occurred in the same area, but no entanglements were reported during that period. The mother (Reflection) had previously been reported entangled in the southwest Gulf of Maine in both 2001 and 2003.

Twenty-three other individuals in the 2007 sample were known to have been involved in a prior documented entanglement, ranging in time from 1985 to 2006. Of these, 21 (87.5%) were successfully classified as having a high probability of prior entanglement based on composite scar patterns. However, as noted above, some have obtained new injuries subsequent to formally documented events.

The frequency of new injuries was compared regionally using samples obtained from Stellwagen Bank (n=156), the western side of the Great South Channel (n=71), the coast of Maine (n=12) and eastern the Bay of Fundy (n=60). New injuries were most prevalent among whales sampled off the coast of Maine (25.0%, n=3) but the sample size from that area in 2007 was too small for rigorous inter-area comparisons. Entanglement injuries appeared slightly less prevalent in the vicinity of the Stellwagen Bank National Marine Sanctuary (7.1%, n=11) relative to other US waters (12.1%, n=10), although this difference was not significant. There was also no significant difference between the frequency of entanglement-related injuries in US waters (8.4%, n=19) and the Canadian Gulf of Maine (13.3%, n=8) in 2007.

DISCUSSION

This was the eleventh season of scar-based monitoring of humpback whale entanglements in the Gulf of Maine. It was one of the most successful years of data acquisition, both in terms of the overall sample size and improved insight into the time frame of scar acquisition. As in previous years, NMFS-supported field efforts greatly enhanced available sample sizes, as well as the consistency in the spatial coverage obtained within the Gulf of Maine. Overall, the sampling spanned a similar demographic as in previous years and the incidence of new injuries was slightly higher, but not significantly different from 2006. Furthermore, two different indices of scar acquisition generated a comparable result for entanglements that likely occurred within the past year. Scar-based monitoring remains limited in that some entanglements do not involve the tail and some animals do not survive long enough to be sampled. On the former point, it is reassuring that formerly entangled whales seen in 2007 were correctly assigned a prior entanglement history 87.5% of the time.

To date, only one year has stood out as having a significantly higher entanglement rate (2003) since the study began. Even with large annual sample sizes, detecting reductions in entanglement frequency from their current levels may be an even larger challenge. Pace (2003) proposed a multi-state mark-recapture statistical approach to modeling scar acquisition, and this work is currently underway for all data obtained in this study to date. Such techniques require large sample sizes, but provide better inference when individuals are not sampled every year.

Furthermore, hypotheses regarding time variation and the influence of factors such as age, sex and spatial distribution can be evaluated more rigorously, in a single, integrated framework. The long time series that is now available (>10 years) will be particularly beneficial for modeling temporal variation to date and going forward.

This analytical improvement is also timely in light of upcoming management actions that may affect entanglement rates in the Gulf of Maine. In April 2009, the National Marine Fisheries Service will mandate coast-wide modifications to fixed fishing gear, focussing particularly on reducing the height of ground line in the water column. Ground line is one potential source of entanglement risk to humpback whales, but the magnitude of benefit has yet to be determined. This will be the first systematic change in fisheries practices since 1997 that is likely to significantly reduce entanglement rate (as opposed to entanglement severity) for humpback whales. We anticipate that the existing time series, when combined with continued monitoring, will provide the best possible insight into the success or failure of this management initiative.

Finally, the present results continue to indicate a low frequency with which entanglements in the Gulf of Maine are detected and reported in progress. Low and variable entanglement reporting rates are expected in light of the predominantly coastal distribution of potential observers, the large area in which entanglements could occur and the variable duration of entanglement events. However, the example of “Reflection” in 2007 highlights the fact that entanglements can be missed even in areas where a whale is strongly resident and observer effort is high. We therefore recommend the continued refinement and use of indirect methods of entanglement detection, even in areas with well-established reporting networks.

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Table 1: Days at sea supported by EA133F07SE2932 and resulting sample sizes for scar analysis. These are a subset of the data used in this study.			
Date	**Location**	**#Images**	**#Individuals**
07/12/07	Great South Channel	15	11
07/13/07	Stellwagen Bank	7	6
07/21/07	Jeffreys Ledge & Platts Bank	7	4
07/25/07	Great South Channel	12	8
08/10/07	Stellwagen Bank	11	8
08/12/07	Cashes Ledge, Fippinnies Ledge, Outer Fall	7	4
08/13/07	Schoodic Ridges & Manan Banks	2	2
08/14/07	Bay of Fundy	11	9
08/20/07	Bay of Fundy	17	16
08/21/07	Bay of Fundy	20	16
	Total images adequate for analysis	109	84
	Best images of the season	86	70