A review of the frequency and impact of entanglement on Gulf of Maine humpback whales

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ABSTRACT

Entanglement is a documented source of injury and mortality to large whales. However, the frequency of entanglement events, risk factors, and biological impacts remain poorly understood. Here we review information from the Atlantic coast of the United States where considerable data exist with which to evaluate entanglement frequency and impacts for Gulf of Maine humpback whales (*Megaptera novaeangliae*). We focus particularly on cases in which individuals were first reported alive, or survived un-witnessed events, and applications to date of those data. Since 1997, entanglement injuries have been monitored on the free-ranging population to better understand entanglement frequency, affected population segments and reporting rates. These data suggest that humpback whale entanglement rates are substantially under-reported in this region, despite a well-established reporting and response network. Both eye-witnessed and inferred events indicate that juveniles are preferentially affected. Preliminary analyses suggest that they are also involved in more severe entanglements, as judged by gear configuration and resulting injuries. Previous mark-recapture statistical studies suggest that entangled juveniles have a lower probability of survival than unexposed juveniles, although these results are currently being explored with additional data. A range of factors that potentially affect entanglement outcome (including gear severity, injury severity, animal condition and mitigation efforts) are also currently being investigated and will contribute to mark-recapture studies of entanglement survival and fecundity. Mortality rates are particularly difficult to estimate because not all carcasses are detected and cause of death is often unknown. However, scar-based studies of survivors can yield alternate estimates of entanglement mortality counts and rates, in combination with other data. An unbiased entanglement survival rate is integral to such estimates and estimates require further refinement.

KEYWORDS: INCIDENTAL CATCHES, MORTALITY RATE, SURVIVORSHIP; MARK-RECAPTURE; PHOTO-ID; NORTH ATLANTIC

INTRODUCTION

Entanglement is a documented source of injury and mortality to cetaceans. However, the frequency of entanglement events, risk factors, and biological impacts remain poorly understood. Large whale species have been known to break away from the site of the original entanglement and to carry away some or all of the entangling gear. In such cases, the likelihood of detecting an entanglement depends on factors like the visibility and persistence of the entangling gear, whale behaviour and overlap with knowledgeable observers. Eye-witnessed reports may be biased if some species or areas have better observer coverage than others. Reports and data may also be incomplete or inaccurate, further reducing the data available for understanding frequency and impacts. Finally, the biological outcome is often unknown.

Humpback whales (*Megaptera novaeangliae*) are one of several large whale species that are reported entangled off the East Coast of the United States, and a combination of data sources contribute to understanding this problem. A well-established reporting and response network exists to detect and mitigate entanglements. There has also been annually intensive photo-identification research on the free-ranging population since the 1970s. A robust commercial whale watching industry provides knowledgeable and motivated observers in some parts of the range. Finally, a well established stranding network exists to detect and evaluate stranded animals. Here, we summarize available information on the frequency and apparent impacts of entanglements on live humpback whales. However, a more detailed study of entanglement impacts on humpback whale survival and fecundity is currently in progress.

DATA SOURCES

Data from witnessed entanglement events are obtained by the Atlantic Large Whale Disentanglement Network (ALWDN) under the authority of the U.S. National Marine Fisheries Service (NMFS). Disentanglements have been performed in the coastal waters of Massachusetts since 1984, and since 1997 the ALWDN has provided formal reporting, disentanglement response and awareness training along the eastern seaboard of the United States. During responses, members of the ALWDN attempt to obtain documentation of each entanglement, which may include photo and/or video documentation, underwater observations, biopsy samples (for genetic identification and health assessment), retrieved gear and other data.

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 & Whitehead 1981). Photographs of identifying features are requested from each eye-witnessed entanglement case so that the individuals can potentially be re-

identified with or without entangling gear. Identifying shots of entangled individuals are matched to a photo-identification catalogue of Gulf of Maine humpback whales maintained by the Provincetown Center for Coastal Studies (PCCS, Provincetown, MA). Since the 1970s, annual population monitoring has produced a detailed database on individuals that is potentially useful for evaluating entanglement risk and impacts, including factors such as age and sex. In the Gulf of Maine, a skin sample of an otherwise unidentified entangled humpback whale can also be genetically matched against a large existing genetic archive of the catalogued population.

PCCS also conducts annual photo-identification surveys across the U.S. and Canadian feeding range of this population. In addition to identifying photographs, the data include high quality images of the posterior caudal peduncle at the insertion of the flukes for scar-based inference into entanglement rate (see below). Although entanglements were also detected in progress through these efforts, the primary relevance of these data is in determining the fate of entangled animals, detecting unobserved events and providing a population framework for understanding entanglement impacts.

ENTANGLEMENT FREQUENCY

Between 2003-2007, there were 75 confirmed eye-witnessed humpback whale entanglements along the U.S. East Coast (Glass et al. 2009). The vast majority of confirmed cases (95%, n=71) were live entanglement sightings; however, entanglement could neither be confirmed nor excluded for 94 observed humpback whale carcasses during the same period. Not all events are witnessed and some witnessed reports cannot be validated from the information provided. Thus, confirmed reports likely represent the minimum number of events that have occurred (Glass et al. 2009).

Entanglements produce injuries that can be detected even after gear is removed or shed. Since 1997, scar analysis has been used in the Gulf of Maine to identify humpback whale entanglements that would have otherwise been missed (Robbins 2008; Robbins 2009; Robbins 2010; Robbins & Mattila 2000; Robbins & Mattila 2001; Robbins & Mattila 2004). This approach is based on lateral, high quality images of the caudal peduncle at the insertion of the flukes (Figure 1). These images can be obtained systematically from free-ranging humpback whales at the time of the terminal dives and examined for injuries comparable to those observed in witnessed entanglements (Figure 2). In the Gulf of Maine, an entanglement rate is estimated annually based on the frequency of injuries likely acquired by individuals within the past year. Examples of such injuries are shown in Figure 3. These estimates have ranged from 6.3-25.0% per year, with a mean of 12.2% through 2008 (Robbins 2010). These results also indicate a higher frequency of entanglement among juveniles than adults (20.8% ± 9.06% versus 4.8% ± 3.47% in 2008). In 2007, scar-based inference identified 27 cases that were not reported by eyewitnesses. Applying the 2007 entanglement rate to a recent estimate of abundance (Waring et al. 2009) suggests that there may have been 79 entanglement events in the overall population in that year alone. When inferred cases have been directly compared to eye-witnessed cases based on the individual and period of acquisition, the results suggest annual detection and reporting rates of less than 12%.

Overall, scar-based studies suggest that entanglement rates that are higher than eyewitness reports would suggest. Both eye-witnessed and inferred events suggest a higher frequency of entanglement among juvenile humpback whales. Limitations to this approach include the fact that the exact timing of the event is known with less certainty. Furthermore, entanglements are still underestimated due to the fact that not all events involve the caudal peduncle and some individuals may die before their injuries can be detected (see Entanglement Mortality, below). Scar studies undertaken on humpback whales in the North Pacific suggest that entanglement is pervasive and likely as common in some areas as in the Gulf of Maine (Neilson et al. 2007; Robbins et al. 2007).

ENTANGLEMENT SEVERITY

Entanglement events are highly variable and there are several factors that may affect outcome, including gear configuration, sustained injuries, entanglement duration, the age/size and health of the individual and mitigation efforts. Unfortunately, most of these factors are difficult to determine for entangled whales at sea. The configuration of gear can shift over time and is often not visible at the water surface. Entanglement injuries are also not necessarily visible for key body parts (especially the mouth and flipper) and severity likely increases with entanglement duration. Visual health assessment techniques can provide an index of animal health, but techniques are still being developed or refined for most large whale species (Rowles et al. 2007). Most (74.4%) live humpback whales were only seen with gear on one occasion, limiting understanding of the event and trend over time. The duration of the entanglement can only be estimated if the gear is matched back to its owner (and has a known set date) or can be bracketed by the sighting history of the individual. Even mitigation efforts are not necessarily known with certainty because the whale may have been released from a portion of the gear by fishermen or other mariners. Finally, methods of ground-truthing depend upon knowing the final outcome of some events. This is generally only known for whales that survive and are re-sighted, as individuals that are not

re-sighted have not necessarily died. All of these issues introduce uncertainty into assessments of entanglement severity and outcome. A detailed comparative analysis of these factors for humpback whales and North Atlantic right whales is currently underway, with some preliminary results for humpback whales summarized here.

The most reliable insight into gear configuration often comes from the process of disentanglement. Landry and Robbins (2009) examined 37 humpback whale entanglements (1998-2007) for which entanglement configuration was known with confidence, the whale was disentangled and could be reliably re-identified by photo-identification techniques. They scored the severity of each event based on three separate criteria: a) the number of attachment sites on the body (complexity), b) the presence or absence of gear that significantly impaired movement (including surfacing) and c) the presence or absence of gear that tightly constricted the body. Whales with entanglements that substantially impaired movement were significantly less likely to be re-sighted alive after disentanglement (G=4.58, df=1, p=0.03). Otherwise, there was not a clear effect of individual categories on apparent outcome. However, entangled whales were more likely to be re-sighted when gear severity was low in at least two of the three categories (90.1% re-sightings, n=10). Entanglements judged as severe in at least two categories resulted in significantly lower re-sighting rates (46.1%, n=12, G=6.99, df=1 p=0.008). These results suggest that more severe gear configurations are more likely to produce a negative outcome, even in the event of disentanglement. Preliminary subsequent analyses also suggest that juveniles are more likely (79.1%, n=34) than adults (52.6%, n=10) to exhibit more severe entanglement configurations (G=10.55, df=1, p=0.001). However, more detailed analyses, including mark-recapture based statistical approaches that account for differing detection probabilities, are pending.

Humpback whale entanglements can be anchored a variety of body sites such as the mouth, flippers or tail, although the frequency of flipper and mouth involvement is the most difficult to assess (Johnson et al. 2005). Lambertsen *et al.* (2005) hypothesised that persistent mouth entanglements could lead to mortality in rorquals if the oral hydrostatic seal were impaired. The mouth has been involved in at least 43% of witnessed humpback whale entanglement cases (Johnson et al. 2005). Robbins et al. (2008) reported that the live individuals with the longest confirmed mouth entanglements (at least 45 days) were known to have subsequently survived. While certain mouth entanglements have the potential to be life threatening, it does not appear that the simple presence of a line in the mouth necessarily has an acute impact on survival in this species. In fact, mobile entangled humpbacks appear to exhibit fewer life threatening mouth/head entanglements than entangled North Atlantic right whales in the same region. A quantitative, comparative analysis of mouth entanglements among humpback whales and North Atlantic right whales is currently underway.

Entanglement injuries produced by eye-witnessed entanglements tend to be similar to those observed in the free-ranging population, and neither appear less severe on average than external injuries on carcasses. Nevertheless, the nature and severity of entanglement wounds are in the process of being evaluated to determine their contribution to entanglement outcome. For the purpose of comparative study, low severity injuries consist of limited skin abrasions that do not appear to extend into the blubber or cartilage. Moderate injuries include extensive areas of skin abrasion, and/or injuries that extended into blubber (but not muscle), and/or lacerations on appendages that extended beyond the skin but had a total estimated depth estimated at less than 8cm. Injuries are considered severe when extending into muscle or bone, when the individual exhibited appendage lacerations estimated to be >8cm in depth, and/or there was significant deformity. In more than half of the cases, it has not been possible to reliably determine the level of injury produced by eye-witnessed entanglements. Of the rest, at least 70% of live cases exhibited moderate or high severity injuries. Juveniles were more likely to exhibit such injuries (84.4%, n=27) than adults (52.3%, n=11). When individuals can be reliably re-identified, the probability of re-sighting appears to be inversely related to the level of injury, with 73.3% of low severity cases re-sighted, as opposed to 40.6% of moderate and 28.6% of high severity cases. As noted above, these are preliminary results and more detailed analyses of these data are pending.

A high percentage of the entangled humpback whales that can be reliably re-identified have been fully or partially disentangled, making it difficult to assess what the outcome might have been in the absence of intervention. Nevertheless, it is clear that disentanglement alone does not guarantee survival. The only entangled whale that was known to have died after a live sighting was disentangled on June 3, 2002 and found dead four days later. Unfortunately, no necropsy was done in that case, but the external injuries (Figure 4) were not qualitatively more severe than those observed on free-ranging whales (e.g., Figure 3). Furthermore, the whale was not considered to be in worse condition at the time of disentanglement than many other cases.

ENTANGLEMENT MORTALITY

The effect of entanglement on a population is difficult to assess. Of 75 recently confirmed humpback whale entanglements along the U.S. East Coast (2003-2007), four were confirmed mortalities and an additional 10 were considered likely to result in imminent death (Glass et al. 2009). This level of confirmed and expected mortalities currently exceeds what is considered sustainable for this population. However, carcasses are not

necessarily detected and, as noted previously, entanglement can neither be confirmed nor excluded as a cause of the vast majority of observed deaths. Therefore, observed cases represent an unknown fraction of the true number of entanglement mortalities that occur.

Scar-based studies on free-ranging whales study the frequency of non-lethal entanglements in a population. The results can provide insight into entanglement mortality if the entanglement survival rate can also be determined (Robbins 2009; Robbins et al. 2009). In that case, the number of entanglement mortalities (*Nm*) can be estimated Nm=((Nt*E)/S)-(Nt*E)), Where: Nt = Total population size, E = Scar-based non-lethal entanglement rate, S = Proportion of non-lethal entanglements (or entanglement survival rate). The probability of survival is the only piece of required information that cannot yet be systematically obtained. Robbins et al. (2009) used a proxy estimate of 76.6% which yielded an estimate of 29 lethal events in the target year (2003) and a 3.7% total entanglement mortality rate. By contrast, the mean annually observed number of entanglement deaths during that period was 2.8 (Glass et al. 2008). Assuming population survival estimates of approximately 96% (Barlow & Clapham 1997), this would seem to represent a high fraction of the total mortality. However, evidence suggests that entanglement acts preferentially on juveniles, animals that have lower survival rates than adults (Robbins 2007; Rosenbaum et al. 2002) and are thought to experience greater post-entanglement mortality (Robbins et al. 2008). For example, Rosenbaum et al. (2002) estimated average annual calf survival at only 70.2%. Entanglement survival rate estimates are still being refined, and higher estimates would produce lower estimated mortality counts and rates.

Mark-recapture statistical analyses usually provide the most appropriate framework for assessing apparent survival of individually identified animals. Robbins et al. (2008) undertook a mark-recapture analysis of entanglement survival and those results are in the process of being updated with larger sample sizes. However, mark-recapture techniques require that an individual be reliably recognized if it is seen again and there is not always adequate photo-ID documentation to consider a reported entangled animal "marked" for subsequent re-sighting without gear. Robbins et al. (2008) considered individual identification to be adequate in only 61% of cases, and photographs were not obtained at all in some cases. Animals with "minor" entanglements were more frequently photo-identified than animals with more serious entanglements, most probably because animals carrying more weight or in a more depressed health state present less of their body above the surface of the water. Most importantly, most eye-witnessed accounts in this region have already survived the anchoring phase of the entanglement, which may be the time of greatest risk of immediate death. Thus, even with complete knowledge of fate from the time of the first entanglement report, mark-recapture estimates likely still overestimate total entanglement survival. Alternate approaches for obtaining a less biased estimate of total entanglement survival are currently being explored. In the meantime, efforts should be made to maximize the possibility of recognizing entangled individuals without gear, whether alive or dead. In the Gulf of Maine, these approaches include the collection of skin samples for molecular genetic matching and the use of underwater video to capture identifying features below the surface.

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Figure 1: Examples of scar interpretation. Note that there are wrapping scars, notches and other injuries in at least two areas in all documented and inferred entanglement cases.

a) No scarring indicative of entanglement.

b) Healed entanglement-related injuries.

c) Unhealed injuries indicative of a recent entanglement.

d) Partially healed wounds from a documented 2007 entanglement. The injury is not completely healed.

Figure 2: Examples of unhealed caudal peduncle/fluke injuries produced by four documented entanglement events during the study period. Note the presence of wrapping injuries, notches or deformation in at least two coding areas in all cases. In the lower right image, the flukes (white material) were necrotic due to a tight entanglement at base of the caudal peduncle. Images were taken under NOAA permit 932-1489.

Figure 3: Examples of raw injuries interpreted to be entanglement related. None are known to correspond to reported entanglement events.

Figure 4: Humpback whale carcasses with entanglement evidence. Note that the injuries sustained were no more outwardly significant than observed on animals known to have survived entanglements

a) CCS-0207 (MAL02170MN), an unnamed humpback whale that stranded four days after a successful disentanglement . Photo credit Marine Animal Lifeline.

b) CCS-0235 (CCSN02-255), an unnamed humpback whale calf that stranded with entanglement evidence, including the imprint of line (right). Thought to be the same animal reported entangled (dead) one day prior.