Scar-Based Inference Into Gulf of Maine Humpback Whale Entanglement: 2008

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Submitted by:

Jooke Robbins, Ph.D.
Provincetown Center for Coastal Studies
5 Holway Avenue
Provincetown, Massachusetts 02657

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. This study focused on images of the caudal peduncle and fluke insertion of 341 individual humpback whales sampled in the Gulf of Maine in 2008. Preferred photographs were obtained while parallel to the whale and slightly ahead of its flukes during the terminal dive. Suitable images were examined for evidence of wrapping scars, notches and other injuries observed in documented entanglements. Of the individuals with comparable photographic coverage in 2007 (n=120), 8.3% ± 4.95% exhibited new scarring in 2008. Using another metric, 10.3% ± 3.99% of 223 individuals with suitable coverage exhibited unhealed injuries likely obtained within the prior year. Neither approach suggested a change in entanglement rate from 2007. However, unhealed injuries provided greater insight into the higher annual frequency of entanglement among juveniles (20.8% ± 9.06%) versus adults (4.8% ± 3.47%), which may be important for tracking future changes in entanglement rate over time. Injuries documented in 2008 represented at least 23 recent events, in addition to those documented by eye-witness observers. Three events inferred from scarring were matched to entanglements reported in progress, indicating a successful entanglement reporting rate of 11.5%. Overall, scar-based inference suggested substantially more entanglement cases and associated deaths in 2008 than were actually witnessed. In the future, scar-based monitoring will provide a basis for evaluating the effect of recent coast-wide changes in fishing practices on humpback whale entanglement rates.

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 & Nichols 1982, Whitehead & Moore 1982). 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), although the latter is known to be a mixture of feeding stocks (Barco *et al.* 2002).

In the North Atlantic, humpback whales were historically subject to commercial exploitation (Mitchell & Reeves 1983, Smith & Reeves 2002) and population recovery 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 2002-2006, there were 77 confirmed entanglement events along the U.S. East Coast, of which 15 were either mortalities or considered likely to result in imminent death (Glass *et al.* 2008). 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 (Glass *et al.* 2008), and observed deaths likely underestimate total entanglement mortality.

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 & Mattila 2000, 2001, 2004, Robbins 2008, Robbins 2009). This report describes the results of sampling and scar interpretation for the 2008 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 focused 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, primarily by PCCS research vessels conducting photo-identification (photo-ID) surveys. These cruises targeted known humpback whale aggregation sites and, with the exception of the Stellwagen Bank area, sampling effort was expended roughly proportional to observed whale density. 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 & 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 & 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 & Mayo 1987, Baraff & 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 of 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 (Figure 1). High probability injuries consisted of healed scars or unhealed wounds that were consistent with wrapping around the feature (Figure 2). Healed injuries could be raised or indented and ranged from white to black in color when healed. We also made particular note of any injuries that did not appear to have healed, based on their color and texture. Unhealed injuries were gray, pink or red and had a different texture than healed injuries, with abrupt, angular edges and/or a roughened overall surface (Figures 2).

When multiple images were available from the same individual, we selected the best image per feature per day for analysis. The quality of the images was also evaluated prior to coding, taking into consideration factors such as distance to the subject, angle and focus. Images taken of the right and left sides of the animal, when available, were initially evaluated independently. Data on documented entanglements and other known sources of injury were not factored into the initial coding process.

When a new individual was added to the study, 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. However, patterns of scarring in any given image represent a composite of events over the lifetime of the whale. Some 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 focused our attention on scarring and injuries that were 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. Unhealed injuries were also flagged to better estimate the timing of injury acquisition and to identify recent events for whales without prior baseline images. New injuries were assumed not to have resulted from entanglement if they did not meet the above criteria for high probability of prior entanglement.

Entanglement frequency and impact

Two approaches were used to estimate entanglement frequency in 2008. The first was an inter-annual metric based on the frequency of new entanglement injuries among individuals with comparable photographic coverage in 2007. However, some individuals were more likely than others to be re-sighted, others were not previously available for sampling (such as calves) and photographic coverage was not always comparable when inter-annual re-sightings did occur. We therefore also calculated the frequency of unhealed entanglement injuries for all sampled individuals with high quality coverage of one or both sides. Unhealed injuries were assumed to have been acquired recently and therefore informative without a baseline sample. The results of these two approaches were later cross-referenced to produce a minimum count of entanglement events that likely occurred from one year to the next. 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 & Rohlf 1981).

We also estimated the number of entanglement mortalities (Nm) during the study period based on the following formula from Robbins (2009):

$$Nm = ((Nt * E)/S) - (Nt * E)$$

Where: *Nt* = Total population size
E = Scar-based non-lethal entanglement rate
S = Percentage of non-lethal entanglements

For the purpose of this study, *Nt* was calculated as the “minimum number alive”, or the number of unique individuals encountered in 2008, plus any individuals seen both before and after that year. As such it represents the minimum number of Gulf of Maine whales in the year in question. The non-lethal entanglement rate (*E*) was the percentage of individuals confirmed to have acquired entanglement injuries since 2007 (see above). Finally, although entanglement survival is still under investigation, a reasonable proxy value of 76.6% was used, following Robbins (2009).

Comparison to documented events

Scar-based inference was evaluated using data from documented entanglement events. We calculated the frequency with which previously entangled individuals in our sample were successfully coded as having a high probability of entanglement. We also measured the persistence of unhealed entanglement injuries from the time that the gear was successfully shed or removed by disentanglement. The latter was done to better assess the value and limitations of unhealed injuries for tracking entanglements from one year to the next. Finally, we estimated the entanglement reporting rate for the study period by cross-referencing animals exhibiting new entanglement injuries in this study with those that were reported entangled during the same period. Scar-based cases that could not be linked to a documented event based on the identity of the individual and the timing of its injuries were considered unreported events.

RESULTS

A total of 2,006 caudal peduncle images from Gulf of Maine humpback whales in 2008 were screened for potential use in this study. Images had been obtained on 91 days between March 24 and November 13, 2008, with individuals documented on an average of 1.8 days (min=1, max=7). We evaluated entanglement status based on the best daily photographic coverage from 341 individual animals. While not all images were considered to be of equal or adequate quality for determining entanglement status through blind coding techniques, most were deemed potentially valuable for monitoring the same individual over time.

Over half (65.4%, n=223) of the individuals evaluated in 2008 had prior baseline coverage, but these were predominantly adults. Most of the individuals entering the study for the first time were calves (n=42), independent juveniles (n=8) or other animals with short prior sighting histories (n=52). Only sixteen new individuals were known to be adults. Sexes have not yet been determined for many of the new individuals; however, slightly more than half of the sexed whales in the overall sample were female (56.0%, n=131). The overall demography of the sample was generally consistent with prior years. The 2008 sample also included 19 individuals that were known to have been involved in previous, reported entanglements. The vast majority (95%, n=18) still exhibited scarring clearly indicative of a previous entanglement. These prior events occurred between 1985 and 2007, although several individuals were known to have also been involved in at least one subsequent event based on scar monitoring.

Among the individuals with comparable photographic coverage in 2007 (n=120), 8.3% ± 4.95% exhibited new high probability scarring in 2008. The inter-annual scar acquisition rate across all years (1997-2008, Figure 3) averaged 12.2%, while the median over the same period was 9.4%. Using the second metric, 10.3% ± 3.99% of the individuals with suitable coverage in 2008 (n=223) exhibited unhealed injuries that were likely received within the previous year. There was no significant difference in results produced by these two metrics for the overall sample (G=0.353, df=1, p=0.552).

As in previous years, there was a higher incidence of new injuries among known and suspected juveniles as compared to adults. Inter-annual scar acquisition by juveniles (22.2% ± 19.21%, n=4) was higher than adults (5.9% ± 4.57%, n=6) in 2008, but the difference was only marginally significant (G=3.71, p=0.054, df=1). The frequency of unhealed injuries was also high for juveniles (20.8% ± 9.06%, n=16) versus adults (4.8% ± 3.47%, n=7) and the larger sample sizes for that metric yielded a strongly significant result (G=12.83, p<0.001, df=1). The higher annual frequency of entanglement among juveniles is consistent with results from previous years (Figure 4).

Scar-based inference identified 26 recent, non-lethal entanglement events in 2008. Most (76.9%, n=20) were considered likely to have been minor events based on observed tissue damage. For most of the affected individuals, this was also the first incident on record; however, two were also known to have been involved in one or more prior events. However, annual estimates of entanglement frequency, if representative, can also be extrapolated to the population level. There were at least 823 Gulf of Maine humpback whales alive in 2008, based on the number of individuals documented in that year, or seen both before and after. Given this minimum population size and 2008 inter-annual scar acquisition rate (8.3%, 95%CI: 3.4-13.3%), the number of entanglements involving Gulf of Maine humpback whales could have ranged from 28 to 109 in 2008. Furthermore, entanglement mortality (*Em*) was estimated at approximately 21 individuals in 2008, given the estimated population size, entanglement rate and assumptions regarding entanglement survival.

Only three inferred entanglement events were also witnessed in progress and reported. This represents a successful entanglement reporting rate of 11.5%. Reporting appeared more likely for cases involving greater injuries (33.3%) than those involving apparently minor injuries (5.0%), although the difference was not significant in this sample ($G=2.39$, $p=0.122$, $df=1$).

DISCUSSION

Scar based monitoring has been undertaken annually in the Gulf of Maine since 1997, as an index of entanglement rate. It provides an effort-based alternative to eyewitness entanglement reporting data, for which the amount and distribution of potential observers is rarely known. Overall, the spatial distribution and demographic composition of the sample was comparable to previous years. Two different indices generated comparable estimates of the frequency entanglements that likely occurred within the past year. These results did not suggest a change or trend in entanglement frequency over time, and most of the estimates fall within a consistent range. The estimate for 2008 overlaps the confidence interval of all prior annual estimates, except for a peak year in 2003. There has previously been no reason to expect any particular change in the entanglement rate of this species from one year to the next. However, in April 2009, NOAA mandated a coast-wide modification to fishing practices along the US East Coast that has the potential to systematically reduce the frequency of entanglement among humpback whales. The next few years of scar based monitoring will therefore attempt to specifically evaluate evidence for a reduction in entanglement rate. Although an initial evaluation is expected in our 2009 season report, it will likely take several years to confirm even a large change in entanglement rate by scar-based methods.

Results continue to indicate that juveniles may be particularly vulnerable to entanglement. Known and suspected juveniles are more frequently witnessed entangled, and scar-based monitoring confirms a higher annual frequency of entanglement versus adults. There is also evidence that juveniles may have a lower entanglement survival rate (Robbins et al. 2008), although the factors that affect entanglement survival, including age, are currently under more detailed investigation. If so, then the ability to evaluate changes in entanglement rate and impact should be improved by age class stratified estimates of annual entanglement rate.

Otherwise, changes may be obscured if there is an undetermined and potentially variable mixture of age classes within a sample. Long-term population studies of Gulf of Maine humpback whales have provided age class data for many individuals involved in both eye-witnessed entanglements and scar-based studies of entanglement. Furthermore, refinements in scar-based inference have improved our ability to monitor entanglement events among juveniles on an annual or near-annual time frame. Work to date suggests that the frequency of unhealed injuries is an appropriate alternative to inter-annual observations because it generates a comparable result but with greater precision due to the larger sample sizes. It also affords other advantages, including greater independence between annual samples. However, we will continue to evaluate and improve upon these techniques as data accumulate.

Scar based studies have previously been limited by the fact that observations are made only on live, free-ranging animals. If some individuals do not survive long enough to be sampled, then an unknown number of lethal events will be missed and the total entanglement rate will be under-estimated. However, a non-lethal entanglement rate can be used to estimate the number of lethal events, given necessary data on population size and entanglement survival rate (Robbins 2009, Robbins et al. 2009). We have applied this approach to our 2008 scar-monitoring results, with the caveat that some of the necessary information remains limited or poorly estimated. It remains unclear whether this type of estimate could be reliably calculated on an annual basis. Although entanglement rate is estimated annually, precise abundance estimates for this population are not. The “minimum number alive” value used here may substantially under-estimate true abundance, as it is not corrected for effort. More importantly, entanglement survival rate must be further evaluated in order to reliably estimate entanglement mortality in this manner. This work is currently underway and so an update should be available when 2009 results are reported.

Finally, scar-based inference continues to indicate a low (11.5%) frequency of successful entanglement reporting in the Gulf of Maine, despite a well-developed reporting and response network. Reporting success appeared to be higher for recent cases involving greater tissue damage, although it was not statistically different in this sample. Entanglement duration is one factor that can affect both the level of non-lethal injury and the probability that the entanglement is detected by observers. We will evaluate this question further in the hopes of better understanding the processes underlying eyewitness reporting.

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Figure 1: Body areas examined during this study, including the peduncle flank, the leading edges of the flukes, the dorsal and ventral peduncle. The left leading edge and left flank are not visible in this image. The image represents the preferred angle and distance for sampling.

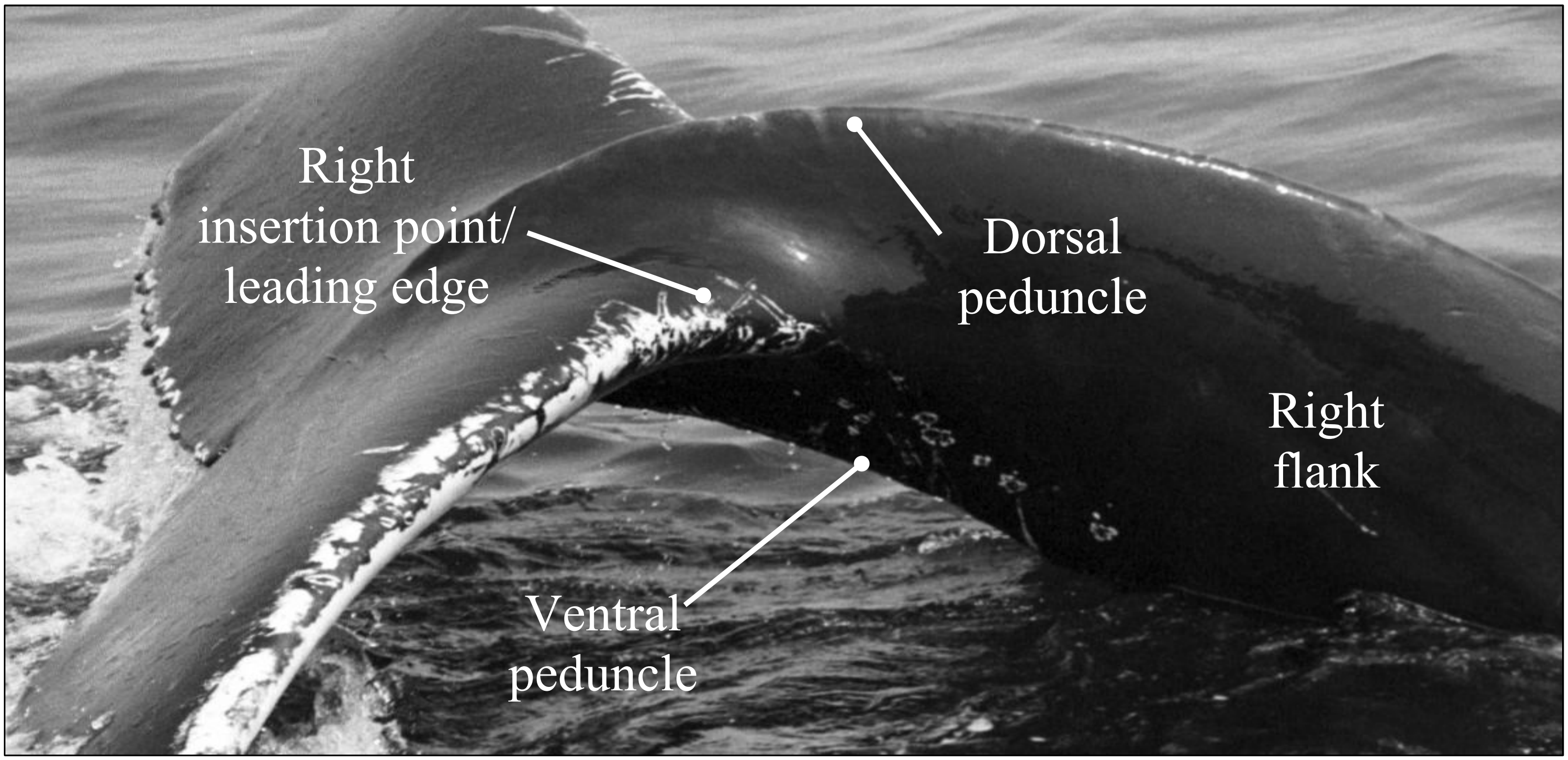
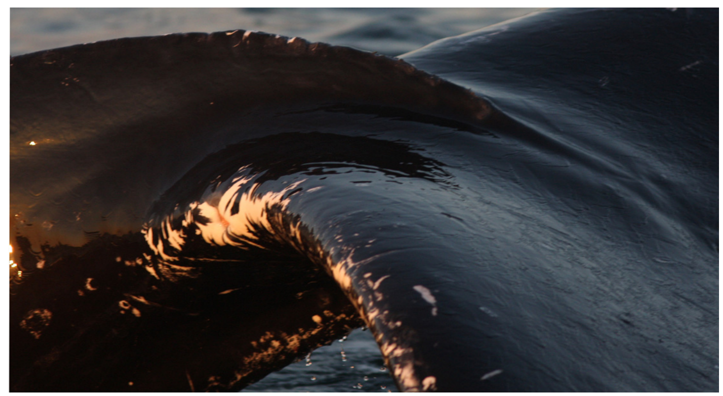


Figure 2: Examples of scar interpretation in 2008. Note that there are wrapping scars, notches and other injuries in at least two areas in all documented and inferred entanglement cases.

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 3: Inter-annual acquisition of entanglement scars, 1997-2008. These represent the percentage of individuals confirmed to have acquired new injuries between years. Error bars represent the 95% confidence interval of the percentage. Data from previous sampling periods are reproduced from previous reports (Robbins and Mattila 2004, Robbins 2008; 2009). Overall, results from 2008 are comparable to recent years.

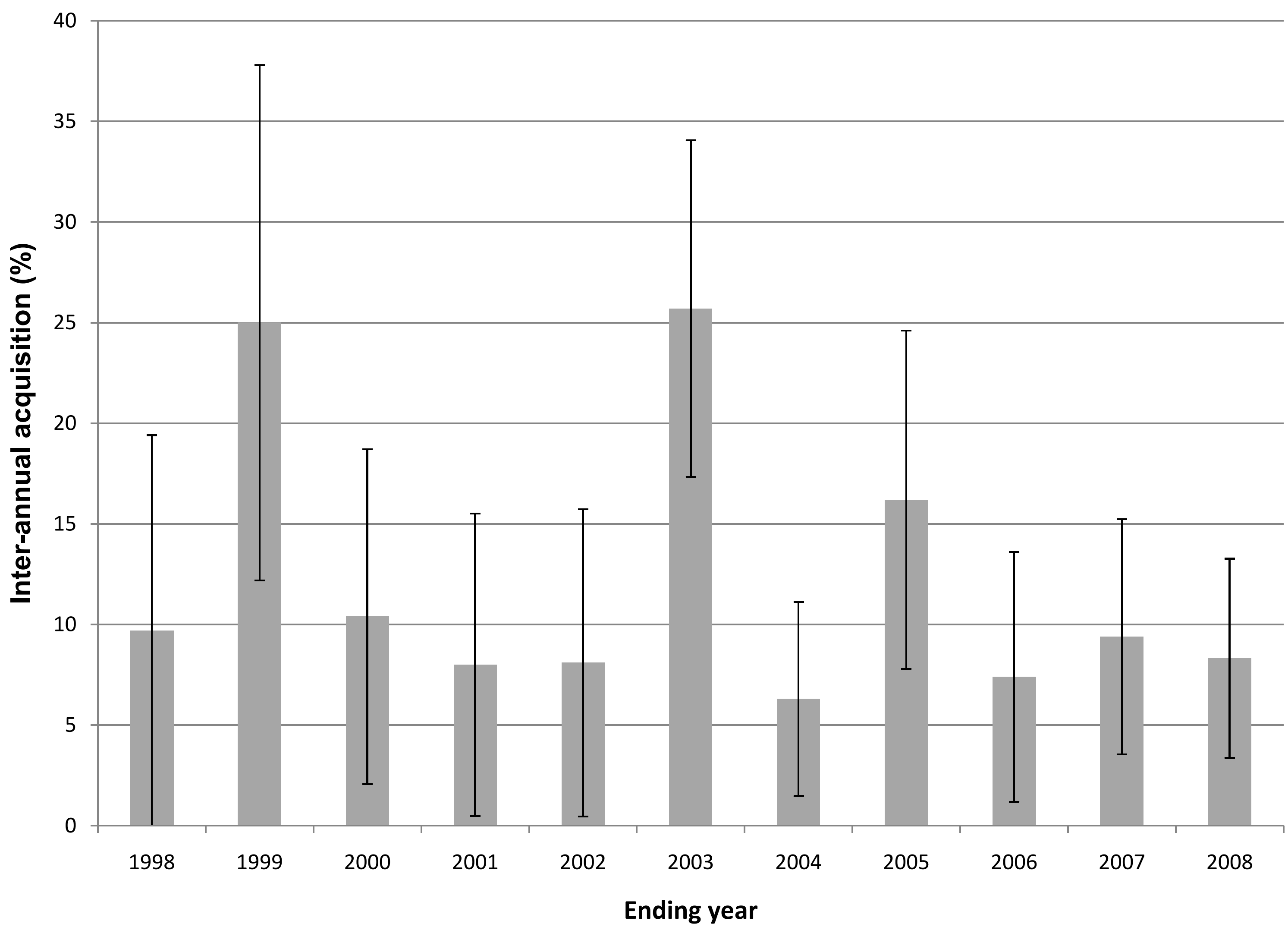


Figure 4: Frequency of unhealed injuries by year and age class, 2003-2008. Error bars represent the 95% confidence interval of the percentage. As a whole, juveniles were more frequently entangled than adults, and both classes exhibited their highest values in 2003. Results from 2008 were not significantly different from recent years.