Estimating entanglement mortality from scar-based studies

ROBBINS, JOOKE[1], SCOTT LANDRY[1] AND DAVID K. MATTILA[2]

[1]*Provincetown Center for Coastal Studies, 5 Holway Avenue, Provincetown, MA 02657 USA*
[2]*Hawaiian Islands Humpback Whale National Marine Sanctuary, 726 S. Kihei Road, Kihei, HI 96753 USA*

ABSTRACT

Entanglement is one of the largest documented sources of injury and mortality for large whales, including the humpback whale (*Megaptera novaeangliae*). Impacts are typically assessed from eye-witnessed events, but these represent minimum counts of interactions and deaths. For example, despite well-established reporting and response networks in the Gulf of Maine (GOM), fewer than 10% of humpback whale entanglement events are witnessed and only a fraction of all deaths are detected. More realistic estimates of entanglement frequency and mortality are therefore necessary to accurately assess population level impacts. Since 1997, studies of caudal peduncle scarring have provided an alternate measure of entanglement frequency among GOM humpback whales. Although based on survivors, scar-based entanglement rates can potentially be used to extrapolate total entanglement mortality in combination with other data. We estimated entanglement mortality as ((Nt*E)/S)-(Nt*E), where Nt = population size, E = the non-lethal entanglement rate (from scar-based inference) and S = entanglement survival rate. The latter was the most difficult to quantify, but our best estimate with available data was 76.6%. Assuming a minimum population size of 783 GOM humpback whales in 2003 and an average annual scar-based entanglement rate of 12.1%, approximately 95 individuals survived entanglement annually. By extension, there were 124 total entanglements in this population per year, with approximately 29 likely lethal. Although these estimates were much higher than expected, a 3.7% entanglement mortality rate is not inconsistent with independent survival estimates. This is the first study to estimate unobserved entanglement deaths and an important extension of scar-based research. Estimates exceeded observed cases by an order of magnitude, suggesting that entanglement is having a much greater effect on the population than previously supposed. Under-estimates of this magnitude likely also affect humpback whales in other oceans, as well as other large whale species that interact with fixed fishing gear.

KEYWORDS: INCIDENTAL CATCHES, MORTALITY RATE

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. In the case of large whales, 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 humpback whale entanglements witnessed along the U.S. East Coast, of which 15 were either documented mortalities or considered likely to result in imminent death (Glass et al. 2008). This level of confirmed and expected mortalities currently exceeds what is considered sustainable for this population (Waring et al. 2007). Furthermore, mortality counts are based only on observed events with data that is adequate for assessment (Glass et al. 2008). Therefore, they represent an unknown fraction of the true number of mortality events that occur. 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 & Mattila 2000; Robbins & Mattila 2001; Robbins & Mattila 2004). Here we summarize a study in which scar-based inference is being used to estimate entanglement mortality in conjunction with other data (Robbins 2009).

METHODS

Sources of information

Data from witnessed entanglement events were obtained by 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 has conducted disentanglements 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. The ALWDN attempts to obtain documentation of each entanglement, including images with which to re-identify the individual with or without entangling gear.

The U.S. National Marine Fisheries Service evaluates each reported entanglement to assess possible impacts on managed stocks. As described by Glass et al. (2008), each case is evaluated to determine the reliability of the eyewitness account as well as the severity of any events that can be confirmed. Witnessed deaths were attributed to entanglement when there was evidence of constricting lines on the body as well as sub-dermal haemorrhaging (or more severe injuries). Other entanglements were considered likely to led to death when there

was a constricting line or associated tissue damage, a notable decline in health post-entanglement, evidence of ingested gear or physical anchoring (Glass et al. 2008). These counts are then used by NMFS as the mortality estimates necessary for calculations of Potential Biological Removal (Wade 1998).

Robbins (2009) used scar-based inference to estimate the annual frequency of non-lethal entanglement in the Gulf of Maine humpback whale population, 1997-2006. Annual estimates ranged from 6.3 ± 4.83% to 25.7 ± 8.36% and averaged 12.1% across the study period. Individuals with inferred entanglement injuries were demographically comparable to whales with documented entanglements during the same time period and involved significantly more juveniles than adults (G=11.27, d.f.=1, p=<0.001). Nevertheless, some individuals were entangled as adults, and as many as four times in their lifetime.

Entanglement mortality rate

Scar-based studies on free-ranging whales study the frequency of non-lethal entanglements in a population. These cases can nevertheless provide insight into entanglement mortality if the ratio of entanglement survival to mortality can also be determined. We estimated the number of entanglement mortalities (*Nm*) during the study period based on the following formula:

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

Where: *Nt* = Total population size

E = Scar-based non-lethal entanglement rate

S = Proportion of non-lethal entanglements

Entanglement mortalities (*Nm*) were estimated annually for 2003-2006, using three different estimates of total population size. The National Marine Fisheries Service (NMFS) uses a minimum population estimate of 549 Gulf of Maine humpback whales for the purpose of calculating Potential Biological Removal (PBR, Waring et al. 2007). Robbins (2009) calculated a less conservative "minimum number alive" of 783 individuals for the year 2003. This year was selected because there was particularly high photo-identification effort in that year and this produced the highest annual value for the study period. Finally, the most recent abundance estimate for this population is 847 individuals estimated from line-survey transects of the Gulf of Maine and part of the Scotian Shelf in 2006 (Waring et al. 2007). We used the point estimate of each annual scar-based non-lethal entanglement rate (*E*) as the best value for mortality estimates. However, we also calculated minimum and maximum mortality counts based on the 95% confidence limits of the entanglement rate. Information was also required on the fraction of entanglements that were non-lethal (*S*). For this, we used NMFS serious injury and mortality determinations, as those criteria are already used to determine when takes from eye-witnessed events exceed PBR (Glass *et al.* 2008). Of the confirmed entanglement cases between 2002-2006 with adequate documentation for assessment, 76.6% (n=49) were assessed as non-lethal while the remaining 23.4% (n=15) were considered serious injuries or mortalities (Glass *et al.* 2008, Tables 1 and 2). Given the sparse data available from observed events, this value was not calculated on an annual basis.

RESULTS

Mortality counts estimated from scar-based entanglement rates are shown in Table 1. Assuming a minimum population estimate of 549 whales (Waring *et al.* 2007) and a scar-based entanglement rate of 18.8%, approximately 103 Gulf of Maine humpback whales were estimated to have survived entanglement in 2003. If survivors represented 76.6% of the entanglements that occurred, then there were approximately 135 entanglements that year, of which 32 were lethal. However, photo-identification research indicates that at least 783 Gulf of Maine humpback whales were alive in 2003. Use of this minimum population size produced a higher estimate of 45 entanglement mortalities per annum. Finally, if the true population size were closer to 847 Gulf of Maine humpback whales, then 49 entanglement deaths may have occurred that year. However, 2003 exhibited the highest estimated entanglement rate and therefore the highest estimates of mortality. When calculated across the study period, mortalities averaged 18.8 to 29.3 whales per year, depending on the assumptions of population size. As shown in Table 1, these estimates exceeded eye-witnessed serious injuries and mortalities along the entire US East Coast during the same period, as well as PBR. This suggests an annual entanglement mortality rate on the order of 3%.

DISCUSSION

Scar inference provides a systematic approach for detecting entanglement events that would otherwise be missed or poorly documented by eye-witnessed observers. To date, its application has been limited to studies of entanglement survivors. However, if the frequency of non-lethal entanglement events can be estimated, then the two pieces of information can be used together for an estimate of entanglement mortality. This type of approach is intended to address the problem that fewer than 10% of Gulf of Maine humpback whale entanglements are witnessed (Robbins 2009) and the cause of most observed deaths is unknown. For example, entanglement could neither be attributed nor ruled out for 83% of humpback whale carcasses observed between 2002 and 2006 (calculated from Tables 1 and 2, Glass et al. 2008).

The biological impact of this estimate can be judged against the current PBR value used in the management of this stock. For a population size of 549 Gulf of Maine humpback whales, the annual number of human-caused mortalities should not exceed 1.1 (Waring *et al.* 2007). Our estimates of 19-29 deaths per year are nearly an order of magnitude higher and therefore may be impeding the recovery of the population. It should be noted that all other values required for the calculation of PBR are intended to produce a conservative and precautionary result. However, our results indicate a greater degree of error in eye-witnessed reports than was considered when evaluating the performance of PBR methods (Wade 1998) and so additional testing may be warranted. Given our results, it would also appear that the non-lethal entanglement rate must be less than 1% to achieve an entanglement mortality count that is equal or less to PBR.

The only previously published estimate of entanglement mortality rate for Gulf of Maine humpback whales was 0.2-0.3% for the period 1975-1990, based on a single documented entanglement death and various assumptions about the population (Volgenau *et al.* 1995). The current estimated mortality rate (3%) is quite high, but does not technically exceed the bounds of mortality inferred from independently estimated survival rates. Non-calf female survival has been estimated at 0.96 SE=0.008 for the period 1979-1991 (Barlow & Clapham 1997) and 0.950 SE=0.011 for 1992-2000 (Clapham et al. 2003). Furthermore, it is believed that entanglement is acting 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).

This is a crude, preliminary estimate of entanglement mortality, as the approach and its input values require further examination and refinement. Scar-based approaches underestimate entanglement rate and likely contribute to an over-estimate of survival because animals with entanglement injuries may still die after they are observed. The ratio of entanglement survival to mortality is a particularly vital piece of information that is presently based on relatively little data and unknown biases.

Acknowledgements

The PCCS Disentanglement Program, the Atlantic Large Whale Disentanglement Network and the National Marine Fisheries Service provided information on documented entanglement events. Joanne Jarzobski, Pauline Kamath, Amy Kennedy, Christie McMillan, PCCS naturalists and the Dolphin Fleet whalewatching company assisted with data collection or processing. When required in U.S. waters, photographic sampling was performed under NOAA ESA/MMPA permits 633-1483, 633-1778, 775-1600 or 932-1483. In Canadian waters, sampling was conducted with the authorization of the U.S. Department of State and the Department of Fisheries and Oceans, Canada. This research was supported by the U.S. National Marine Fisheries Service, the Beneficia Foundation, the Island Foundation, the National Fish and Wildlife Foundation and other donors.

REFERENCES CITED

Barlow, J. & Clapham, P. J. 1997 A new birth-interval approach to estimating demographic parameters of humpback whales. *Ecology* **78**, 535-546.

Clapham, P. J., Barlow, J., Bessinger, M., Cole, T., Mattila, D., Pace, R., Palka, D., Robbins, J. & Seton, R. 2003 Abundance and demographic parameters of humpback whales from the Gulf of Maine, and stock definition relative to the Scotian Shelf. *Journal of Cetacean Research and Management* **5**, 13-22.

Glass, A. H., Cole, T. V. N., Garron, M., Merrick, R. L. & Pace III, R. M. 2008 Mortality and serious injury determinations for baleen whale stocks along the United States Eastern Seaboard and Adjacent Canadian Maritimes, 2002-2006.

Robbins, J. 2007 Structure and dynamics of the Gulf of Maine humpback whale population. In *Biology*. St Andrews, Scotland: University of St. Andrews.

Robbins, J. 2009 Scar-based inference into Gulf of Maine humpback whale entanglement: 2003-2006, pp. 40: Report to the National Marine Fisheries Service. Order Number EA133F04SE0998.

Robbins, J., Landry, S. & Mattila, D. 2008 Entanglement impacts of Gulf of Maine humpback whales.

Robbins, J. & Mattila, D. K. 2000 Monitoring entanglement scars on the caudal peduncle of Gulf of Maine humpback whales: 1997-1999.

Robbins, J. & Mattila, D. K. 2001 Monitoring entanglements of humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine on the basis of caudal peduncle scarring.

Robbins, J. & Mattila, D. K. 2004 Estimating humpback whale (Megaptera novaeangliae) entanglement rates on the basis of scar evidence, pp. 22.

Rosenbaum, H. C., Weinrich, M. T., Stoleson, S. A., Gibbs, J. P., Baker, C. S. & DeSalle, R. 2002 The effect of differential reproductive success on population genetic structure: Correlations of life history with matrilines in humpback whales of the Gulf of Maine. *Journal of Heredity* **93**, 389-399.

Volgenau, L., Kraus, S. D. & Lien, J. 1995 The impact of entanglements on two substocks of the western North Atlantic humpback whale, *Megaptera novaeangliae*. *Canadian Journal of Zoology* **73**, 1689-1698.

Wade, P. R. 1998 Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Marine Mammal Science* **14**, 1-37.

Waring, G. T., Josephson, E., Fairfield-Walsh, C. P. & Maze-Foley, K. 2007 U.S. Atlantic and Gulf of Mexico marine mammal stock assessments - 2007, pp. 415.

Table 1: Estimated number of entanglement mortalities (N_{ME}) relative to the number of observed mortalities (N_{MO}) and Potential Biological Removal (PBR), 2003-2006. Mortalities were estimated based on annual scar-based entanglement rates, three population size (*Nt*) estimates and assuming a constant entanglement survival frequency of 76.6% (see methods for formula). Mortality estimates were higher than both eye-witnessed serious injuries/deaths and PBR during the same period.

Interval End	Scar-based Entanglement Rate (%)	N_{ME} [1] (Best [Min,Max])			N_{MO} [2]
		Nt=549	*Nt* =783	*Nt* =847	
2003	18.8 ± 4.16	32 [25,39]	45 [35,55]	49 [38,59]	5
2004	8.5 ± 3.28	14 [8,20]	20 [12,29]	22 [14,31]	2
2005	10.7 ± 4.33	18 [11,25]	26 [15,36]	28 [17,39]	0
2006	6.8 ± 3.59	11 [6,18]	16 [8,25]	18 [8,27]	4
Total		75 [50,102]	107 [70,145]	117 [77,156]	11
Average		18.8	26.8	29.3	2.8
PBR[3]		1.1	---	---	---

[1]The number of entanglement mortalities was estimated for each value of *Nt* based on the point estimate of the entanglement rate (Best) and its lower (Min) and upper (Max) confidence limits.

[2]Taken from Glass *et al.* (2008) for the entire US East Coast

[3]Potential Biological Removal (PBR) value for *Nt* =549 as reported by Waring *et al.* (2007).