SC/67A/HIM/04

Initial investigations of bowhead whale entanglements scar frequency and acquisition rates via aerial photography

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INTERNATIONAL WHALING COMMISSION

INITIAL INVESTIGATIONS OF BOWHEAD WHALE ENTANGLEMENT SCAR FREQUENCY AND ACQUISITION RATES VIA AERIAL PHOTOGRAPHY

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ABSTRACT

Fisheries bycatch is a leading source of mortality for whales worldwide. Entanglement scarring has been observed on Bering-Chukchi-Beaufort Sea (BCBS) bowhead whales (*Balaena mysticetus*), although historically their high-latitude distribution has been mainly north of commercial fishing operations. The black skin of the bowhead heals as a white scar, leaving a permanent record of past injury. George *et al*. (2017) estimated that ~12.2% of bowhead whales harvested by Alaska Native hunters show evidence of rope scarring, probably associated with fisheries. Similarly, our analysis of a fully independent dataset of aerial photographs (n = 693) with adequate photo quality of the caudal peduncle from the 2011 Spring Survey near Point Barrow, Alaska, suggests ~12.6% (n = 87) show evidence of entanglement scarring. An additional three whales were observed dragging gear (0.4%). Subsequently, we examined photographs of all inter-year matches (between 1985, 1986, 2003, 2004, 2005 and 2011) from a multi-year photo mark-recapture study (Givens *et al*., 2017) and identified whales that had acquired entanglement injuries during the study period, i.e., between the first photo capture and subsequent recapture. We estimated the probability of a bowhead acquiring an entanglement injury using two statistical methods: interval censored survival analysis and a simple binomial model. Both methods give similar results, suggesting about a 2.4% (1.2%, 3.6%) annual probability of acquiring a scar and about 40% after 25 years. These findings suggest that fishing gear entanglement is an increasing concern for BCBS bowheads.

KEYWORDS: bowhead whale; *Balaena mysticetus*; Arctic; Bering Sea; entanglement scarring; aerial survey; photo-identification; entanglement scarring; bycatch.

INTRODUCTION

Entanglement in commercial fishing gear is considered a leading cause of mortality for whales worldwide, creating serious conservation and humane issues. Read *et al*. (2006) estimate the annual global bycatch of cetaceans at about 308,000 whales. Fisheries bycatch is a well-documented source of mortality contributing to the extremely slow recovery of the critically endangered North Atlantic right whale (NARW) population (Knowlton *et al*., 2012; Moore, 2014). In fact, Knowlton *et al*. (2012) found that 82.9% of NARWs had been entangled at least once, and 59.0% had been entangled on more than one occasion. Bowhead whales (*Balaena mysticetus*) from the Bering-Chukchi-Beaufort Sea (BCBS) stock also bear scarring consistent with entanglement in commercial fishing gear, despite their remote distribution in northern and western Alaska (George *et al*., 1994; 2017; Reeves *et al*., 2012). George *et al*. (2017) reported 12.2% (n = 59) of bowhead whales harvested by Alaska Native hunters (n = 485) between 1990 and 2012 showed evidence of entanglement scarring.

The range of the BCBS bowhead stock includes the transboundary waters of the United States (Bering, Chukchi, and Beaufort Seas), the Russian Federation (Bering and Chukchi Seas), and Canada (Beaufort Sea). These northern waters are experiencing reductions in sea ice and an extended duration of the ice-free, open water period that are changing the Arctic ecosystem (Reeves *et al*., 2012). Potential increases in commercial fisheries, industrial ship traffic, offshore resource extraction, and tourism (Reeves *et al*., 2012) necessitate monitoring their impacts on the BCBS bowhead population.

Current evidence suggests that most BCB bowhead entanglement injuries are caused by Bering Sea crab or cod fisheries, including gear that may have been lost or abandoned. Citta *et al*. (2014) observed that bowheads wintering in the Northern Bering Sea overlap crab pot fisheries spatially but not temporally. A recent entanglement event, however, suggests possible temporal overlap with the winter crab fishery in the US Bering Sea (Sheffield *et al.*, 2015). The Alaska Bering Sea/Aleutian Island crab pot fishery is classified as a Type III Fishery, defined as “remote likelihood or no known interactions” with marine mammals. Table 1 of the NOAA 2016 List of Fisheries (LOF) includes only E. Pacific Gray whales under “Marine species and Stocks incidentally killed or injured”—with no mention of bowhead whales. It is unclear if this list refers to 2016 or all years. Regardless, several fatal and severe entanglements involving bowhead whales associated with Bering Sea crab gear have been reported (George *et al.*, 2017; Sheffield *et al*., 2015).

The utility of using aerial photographs to identify individual whales has been well documented, including estimations of abundance (Koski *et al.* 2010), survival rates (Zeh *et al*. 2002), calving intervals (Miller *et al*. 1992), and individual growth rates (Koski *et al*., 1992). Numerous studies have relied on photographs to assess entanglement scarring of marine mammals (Kraus, 1990; Robbins and Mattila, 2001; 2004; Knowlton *et al*., 2005; 2012). Wrap marks on the caudal peduncle, notches at the fluke-insertion point, scarring along the fluke leading edges, and tissue damage in the peduncle region, can be signs of rope scarring. The black skin of the bowhead whale heals with a white coloration likely leaving a permanent record of past injury. These marks are visible in aerial photos and, in the case of entanglement, can provide evidence of injuries from commercial fishing operations (Rugh *et al*., 1992; George *et al*., 1994; 2017).

While the primary objective of the 2011 Bowhead Whale Aerial Abundance Spring Survey (BAASS) was to estimate the population of the BCBS stock (Givens *et al*., 2017), additional goals included estimating other population indices, such as survival rate and anthropogenic scar types—entanglement, ship strike, gear on the whale. An initial assessment of unique whales surveyed in 2011 found 2.1% have scars consistent with rope entanglement; however, we <u>did</u> <u>not</u> account for the many images that could not be evaluated for rope scarring because of low photo quality in the region of the caudal peduncle (Vate Brattsröm *et al*., 2016). The current study updates our initial estimate of the proportion of bowhead whales observed with entanglement scarring in 2011. Additionally, we estimate entanglement scar acquisition rate using the mark-recapture data from the 2011 BAASS photo-id study.

METHODS

The study had two objectives: 1) re-evaluate the 2011 survey photos for evidence of entanglement, including a photo quality assessment to estimate the proportion of individuals with entanglement scarring, 2) examine the photo-id inter-year mark-recapture matches to estimate a scar acquisition rate for the BCBS population. To address the first goal, our dataset consisted of photos taken near Utqiaġvik (Barrow), Alaska, during the 2011 spring aerial abundance survey (19 April to 6 June in 2011). To address the second goal, we used a dataset of inter-year matched whales.

The 2011 aerial survey methodology was similar to earlier studies (Koski *et al*. 1992; Angliss *et al.* 1995). The survey was flown in an Aero Commander 690 in the region NE of Utqiaġvik, Alaska, including ~160 flight-hours over 49 days. The aircraft flew at an average air speed of ~217km/h (117kts) and altitude of 200m (656ft), and flew directly over bowhead whales during photographic passes. Photographs were taken with a handheld Canon Mark III-1DS digital camera affixed with a Zeiss 85mm fixed f/1.4 Planar T* lens pointed directly downward through the aircraft's ventral camera port that was covered with optical quality glass. Shutter speed was typically 1/2500th second or faster. Aircraft altitude was recorded every 2 seconds with a portable Garmin 76CSx GPS unit and a laser altimeter (Mocklin *et al*., 2015). Field protocols for pre-2011 data (1985, 1986, 2003, 2004, and 2005) have been documented previously (Angliss *et al.*, 1995; Koski *et al.*, 1992; 2006; 2010; Rugh *et al.*, 1992a; 1998). When available, each image was accompanied by whale lengths (m) obtained from LGL and MML as well as length grade (Koski *et al*., 2006).

A total of 4,594 aerial photos containing 6,801 bowhead whale images were collected (not accounting for re-sightings) in 2011. After within-year matching of spring and fall 2011, we totaled 2,622 images of 2,198 uniquely identified bowhead whales (including 72 calves). Standard photo-identification protocols were applied for the matching study and have been reported previously (Mocklin *et al*., 2015; Vate Brattsröm *et al*., 2016).

The dataset of matched whales was comprised of whales that were photographed in at least two different years among 1985, 1986, 2003, 2004, 2005, and 2011. There were 117 matches (some whales were matched in more than two years). Each of these matches enables us to assess whether a scar had been acquired between the time of the two sightings. Givens *et al*. (2017) describe in much more detail the photo-id capture-recapture dataset used to generate our data here.

An assessment of photo quality specifically for evaluation of entanglement scarring in the region of the caudal peduncle was integral to both objectives. Image quality was scored as either adequate for evaluation or inadequate due to low photo quality and/or obstructed view of the peduncle region. If the photo was coded as having inadequate quality, it was not examined for scarring. Similar to photo-id mark-recapture studies, judgements of photo quality are subjective and based on experience viewing aerial photographs. We focused quality assessments on the peduncle and fluke insertion point, since this region is the most likely to be entangled by gear. To be scored as adequate, the view of the peduncle could not be seriously compromised by ice, splash, fog, glare, reflections, blur, submersion, or mud on the whale. Visibility could be slightly compromised and still be considered adequate, but large, medium, and some small marks should be visible (Rugh *et al* 1992b). For each individual, all available images were viewed, including supporting and uncropped raw images, in case they provided a clear view of the peduncle.

The basic criteria for assigning entanglement scar type were the following: a) scarring patterns consistent with entanglement of the caudal peduncle, including linear and/or curvilinear scarring, b) marks, notches, and/or tissue damage at the insertion point, and c) scarring and notches on the leading edge of the flukes that appeared to be associated with entanglement scarring on the peduncle (Figure 1). Adequate photos may have some distortion and distance that can further complicate evaluation of scarring. To account for varying degrees certainty, confidence scores were recorded for whales found to have evidence of entanglement scarring. High confidence (~90 to 100%) was recorded for multiple linear and/or curvilinear marks on the peduncle and fluke insertion point, often accompanied by serious tissue damage and entanglement-related scar patterns. Probable confidence (>70% to ~90%) was scored for linear and/or curvilinear marks observed in the region of the peduncle and/or fluke insertion point, appearing to be entanglement-related scarring. Unsure confidence (~50 to 70%) was recorded for one or two linear or curvilinear marks on the peduncle and/or fluke insertion point that appeared to be entanglement-related. For consistency, one individual assessed all images, and a senior biologist reviewed all evaluations.

Proportion of Whales with Entanglement Injuries 2011

We examined both spring and fall 2011 aerial photos to estimate the proportion of whales with entanglement scars. Unlike our previous analysis, this proportion was calculated after limiting the set of whales to be only those with <u>adequate photo quality of the peduncle</u> (n=693). All available images of a whale were viewed when necessary to determine peduncle injuries, including supporting and uncropped, raw photos.

Entanglement Scar Acquisition Rate

Inter-year matches found during the mark-recapture study (Givens *et al*., 2017) were evaluated to estimate the probability of a whale acquiring an entanglement injury (Figure 2). Pre-2011 images used for the abundance study were from the BCBS bowhead photographic catalog used in previous population estimates (Rugh, 1990; da Silva *et al*., 2000; Koski *et al*., 2010). Standard photo-id protocols were applied to match the 2011 aerial photographs with all years (1985, 1986, 2003, 2004, 2005, and 2011) (Rugh, 1990; Rugh *et al*., 1992). In addition, we matched 2003, 2004, and 2005 with 1985 and 1986, thereby creating a complete set of matched photos from these six years. A total of 117 inter-year re-identifications provided an opportunity to evaluate entanglement scarring over a span of 1 to 26 years.

From this set of 117 whales, we selected all whales that were unscarred (in the peduncle region) at the first photo capture, and either unscarred or scarred in a subsequent recapture, with adequate photo quality in each (n=68). Whales that were scarred at all captures provide no information about scar acquisition. The data were aligned so that the calendar year of first photo capture was defined to be year 0. We analyzed these data in two ways.

Our first approach was maximum likelihood nonparametric interval censored survival analysis (Gentleman and Geyer, 1994; Turnbull, 1976). Survival analysis pertains to time-to-event data, and traditionally the event is death of the patient in a clinical trial. In our case, the event is scar acquisition. The concept of (right) censoring means that the event is not always observed, e.g., because the clinical trial ended before the patient died. For our bowhead data, many whales have not yet been recaptured at a time after a scar has been acquired. There is important information in such data: although we don’t know the time to acquisition, we do know that the time exceeds the observation period. The bowhead data are more complex than this—the dataset is actually interval censored. This type of censoring occurs when one only observes whether the event (scarring) has occurred yet, at a series of observation times. Interval censoring is comprised of both right censoring and left censoring, where the latter occurs because we do not know when the whales were first exposed to potential scar acquisition.

The data for interval censored survival analysis is comprised of the last time each whale was seen unscarred, and the first time when each was seen scarred. If a recaptured whale was never seen scarred, the first time of scarring is noted as censored. We use the 'interval' package in R to fit the statistical model (Fay and Shaw, 2010). Uncertainty of the fit was estimated using the bootstrap, with 1000 samples, as implemented in that package.

The second analysis was based on a binomial model. The time frame from capture to recapture constituted one trial. Unlike the survival analysis, in this case we consider all inter-capture intervals. Let y_i denote the length of the i*th* interval, in years. Let p denote the annual probability of acquiring a scar. Then, under independence assumptions, the probability of acquiring a scar after y_i years is $s_i = 1-(1-p)^{y_i}$ and the binary outcome of a trial evidencing a scar has the distribution $Bin(1,s_i)$. From this, a joint likelihood for the data can be generated, and we maximized this to estimate p. The variance of the estimated p was estimated using the Hessian in the standard manner. We comment further on this approach in the discussion.

RESULTS

Proportion of Whales with Entanglement Injuries 2011

After scoring photo quality specifically for evaluating entanglement scarring, we found 693 best images (unique individuals) in the 2011 dataset with adequate photo quality of the peduncle region. Of these, 87 whales (12.6%) were scored as having evidence of entanglement injuries (Table 1). Confidence score frequencies were as follows: 'High' (n=19); 'Probable' (n=48), and 'Unsure' (n=20); all were included in the count of 87 whales, since even the lowest confidence score still represents over 50% confidence of the scar originating from an entanglement injury.

Entanglement Scar Acquisition Rate

We examined a total of 117 whales (captures and recaptures) ranging from 1985 to 2011. After excluding low quality images and whales that were scarred in all photographed years, a total of 68 whales were available for analysis. Of these, 15 (22%) whales had acquired scars (Table 2). Injury severity varied from low, moderate, to high but is not reported in the current study. The average time elapsed for whales (n=15) that acquired entanglement scars was 17.6 years. The average length of whales[1] in the dataset when first photographed was 12.8 m (SD= 1.87m; n = 64), and 13.5 m for the last measurement without a scar ('clean length'). The average length for whales that had acquired scars was14.2 m (SD = 1.71m; n=15).

Figure 3 shows the results of the survival analysis and the binomial model for scar acquisition. The survival analysis estimate (solid black line) indicates the probability of acquiring a scar over a period of time depends on the length (i.e., elapsed years) of that period. The gray shaded boxes represent regions

[1] Only whales for which it was possible to calculate a photogrammetric length.

where no estimate is possible because there are no elapsed periods of the corresponding length. This occurs because the only observed time lapses are those between the set of years 1985, 1986, 2003, 2004, 2005 and 2011, in their various combinations. The faint gray lines show 95% confidence bands for the estimated function.

The result of the binomial model is an estimate for p, the annual probability of acquiring a scar. We estimate p=0.024, with 95% confidence interval (0.012, 0.036). Using the model described above, we can project that estimate, and its confidence bounds, forward in time. Thus the solid blue line indicates how the probability of acquiring a scar increases over time, and the blue dashed lines are the confidence bounds.

The cumulative probability of acquiring a scar is estimated to be about 20% over an elapsed time of 10 years, and about 40% over a period of 25 years. It is reassuring that both methods produce similar results.

DISCUSSION

Proportion of Whales with Entanglement Injuries 2011

The majority of entanglement scars that we observe on landed bowheads are to the peduncle. A few whales have shown entanglement scars to the mouth and pectoral fins, although scars in these regions are not part of this analysis. Scarring associated with sea ice injuries are typically found on the dorsal surface of the head, thorax and flukes and less so the peduncle. The peduncle injuries were scored as entanglement scars if they showed the typical patterns associated with such injuries noted in the Methods (Figure 1).

We found remarkable agreement (12.6%) with bowheads harvested by Alaska Native hunters (1990-2012) whereby 12.2% showed evidence of entanglement scarring (George *et al*., 2017). In addition to rope scarring, three whales were photographed carrying gear (0.4%) and seven whales were scored for ship-inflicted scarring (1%).

Entanglement Scar Acquisition Rate

The estimated annual scar acquisition rate (2.4%) may initially seem high, particularly since both analyses suggest that the probability of acquiring a scar over 25 years is around 40%. However, a simple look at the raw data confirms this finding: of the 15 recaptures, 5 whales (38.5%) when the elapsed time was at least 25 years, had acquired a scar. George *et al*. (2017) found that about 50% of large (~17 m) and presumably old, harvested whales carried entanglement scars. When we assigned ages (Wetzel *et al*., In Press) to the dataset used in George *et al*. (2017), we found that about 47% of the whales >50 years carried entanglement scars; however further analysis is underway.

For the maximum likelihood binomial approach to estimating scar acquisition rate, there were several whales that were recaptured more than once. In these cases, we considered each interval between captures to be a separate trial. Although the independence assumption may not be entirely valid in these cases, we believe that strong dependence is unlikely and the effect would be small, especially since such cases represent only a small portion of the entire dataset.

It is worthwhile to consider the relative merits of the survival and binomial approaches. Generally, we prefer the survival analysis for two reasons. First, it is nonparametric, requiring no assumed model and no particular shape of the 'survival function', i.e., the functional relationship between time of exposure and probability of scar acquisition. The survival method also doesn't require the type of independence assumption used by the binomial approach. Second, the survival analysis makes full use of the information in the data because it explicitly recognizes left and right censoring. For example, in a right censored observation, the binomial model uses the information that "the whale did not acquire a scar in the previous period", whereas the survival model uses the information that "the whale did not acquire a scar *for at least as long as* the previous period, and maybe longer".

There are several other points to note when considering these results. Our dataset is a sample of marked whales with distinctive scarring matched during the photo-id project; it is not clear if these represent a random sample of all whales. Marked/matched whales are more likely to be larger, older whales, while smaller, presumably younger, unmarked whales are less likely to be represented in this dataset. Since the sample has a bias towards older (marked) whales, entanglement cannot be easily explained as a function of age; however, length may be used as an explanatory variable, which may be a surrogate for age. Small, young whales (calves, yearlings) may be more likely to die from entanglement than adults, although estimating whale mortality from these data is not a main objective of this study. In addition, the wintering area for BCBS bowheads is not well understood. It is possible that the larger, marked whales in our sample may spend the winter in regions of higher crab pot or fishery activity. These are but two issues which would counter our assumption that whales are homogenous with respect to scar acquisition.

We recorded our degree of confidence in assigning an entanglement score to individual whales. Confidence score frequencies were as follows: 'High' (n=3); 'Probable' (n=10), and 'Unsure' (n=2); however, confidence scores were not analyzed in the entanglement acquisition rate. This raises an important issue, since 67% of recaptured whales with acquired entanglement scarring were scored as "probable". Therefore, the use of only 'probable' or better scars may introduce a positive bias in the scar rate estimate. If we use only scars scored as 'definite', the acquisition rate would be much lower. As noted earlier, however, 'probable' reflects a 70-90% confidence that the scarring on the peduncle is an entanglement injury.

Notwithstanding the considerations mentioned above, it is clear from these data that entanglement in fishing gear is a non-ignorable concern for BCBS bowheads. With warming climate and more accessible arctic waters, fishing activity is likely to increase over the bowhead habitat. With such development, an increase in entanglements is likely.

ACKNOWLEDGEMENTS

We are very thankful to the Alaska Coastal Impact Assistance Program for providing the funding for the analysis reported here. We thank the Barrow Whaling Captain's Association and the AEWC for their support and great patience with our spring 2011 survey. We thank the NSB-DWM and NOAA/NMFS for financial support of the 2011 survey. The surveys in 2011 were conducted under Scientific Research Permits 782-1719 and 14245 issued to NMML under the provisions of the US Marine Mammal Protection Act and Endangered Species Act.

Andy Harcombe of Clearwater Air, Inc., and his pilots Stan Churches and Eric Seller ably piloted the aircraft and were extremely helpful in all aspects of the survey. The staff at the NSB-DWM, including Director Taqulik Hepa, was particularly helpful and supportive of the study. We appreciate Bill Koski and Dave Rugh for providing advice and experience relative to conducting bowhead whale spring aerial abundance surveys and photo-analysis. Our survey crew consisted of Amelia Brower, Linda Vate Brattstrom, Vicki Beaver, Brenda Rone, Cynthia Christman, Becky Shea and Corey Accardo. In addition to the survey crew, Craig George, Ross Burgener, Jason Herreman, Hanson Johnson, Josh Jones, Dave Rugh, and Audrey Spach all acted as observers on one day each (except for Herreman who flew on two days).

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Table 1. Statistics on the 2011 aerial photographic survey and scar frequency.

Statistic	**(N)**
Photographic images of whales	6801
Unique whale images	2198
Marked whales for mark/recapture study	465
Number whales w/ adequate photo quality of caudal peduncle	693
Number whales with entanglement injuries	87

Table 2. Statistics for inter-year aerial photo matches used in entanglement scar acquisition rate.

Statistic	**(N)**
Total inter-year recaptures evaluated for entanglement scarring	117
Total inter-year recaptures not scarred on at least one occasion	68
Total inter-year recaptures with change in entanglement scarring*	15

*Includes only those photos with adequate photo quality for evaluating entanglement scarring.


(a)

(b)

Figure 1. Photographs of entanglement injuries to the (a) peduncle on a harvested whale (11B5) and (b) on a large adult photographed during the 2011 aerial survey (01161407.03). Note that injuries on whale 11B5 involve the leading edge of the flukes as well as the peduncle. Photo credit: (a) NSB Department of Wildlife Management, (b) NSB-MML 2011 aerial photo survey. Taken under Scientific Research Permits 782-1719 and 14245 issued to MML under the provisions of the US Marine Mammal Protection Act and Endangered Species Act.

(a) 1985 (b) 2011

Figure 2. Aerial images of an inter-year match photographed in 1985 (a) without entanglement scarring and observed in 2011 (b) with acquired entanglement injuries. Photo credit: (a) LGL Limited/MML; (b) NSB- MML 2011 aerial survey. Taken under Scientific Research Permits 782-1719 and 14245 issued to MML under the provisions of the US Marine Mammal Protection Act and Endangered Species Act.

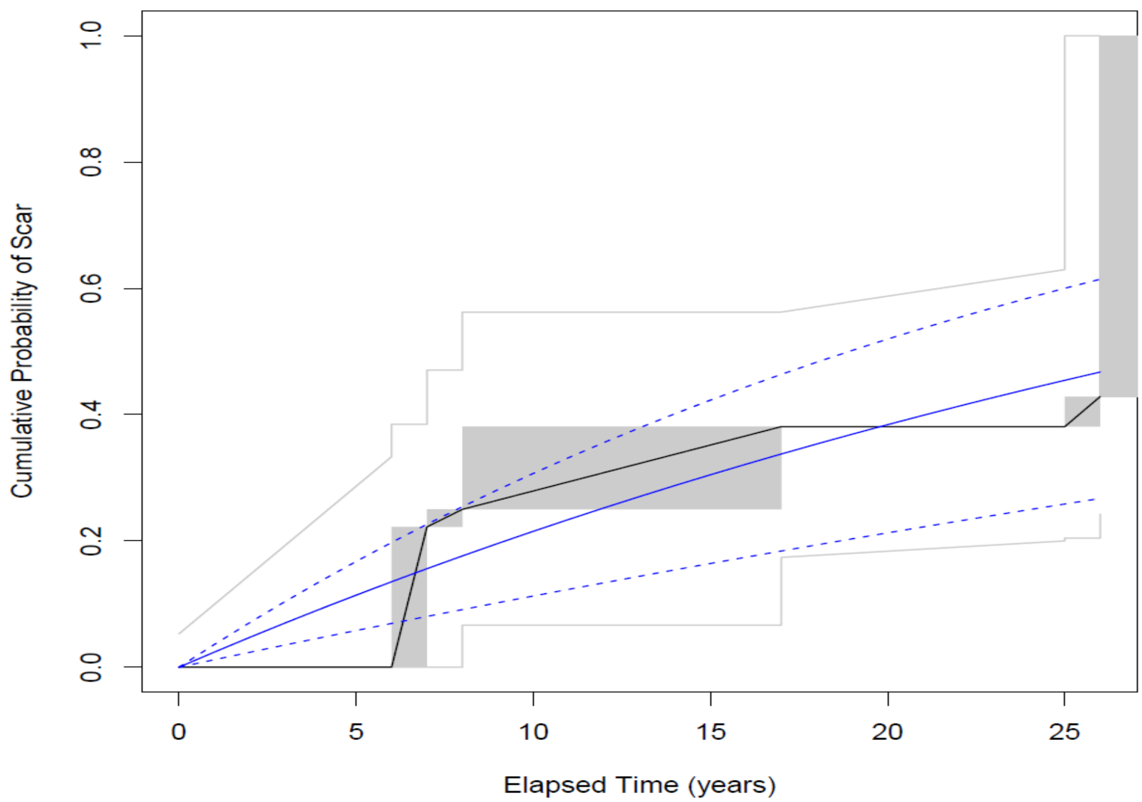

Figure 3. Estimated cumulative probability of obtaining an entanglement scar over an elapsed number of years. The black and gray lines represent the results of the interval censored survival analysis. The black line is the estimated curve, the faint gray lines are 95% confidence bands, and the gray shaded boxes are indeterminate regions due to data sampling granularity. The blue lines correspond to the estimated curve (solid) and 95% confidence limits (dotted) for the binomial analysis.