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INTERNATIONAL WHALING COMMISSION

EVIDENCE OF INJURIES FROM LINE ENTANGLEMENTS, KILLER WHALES, AND SHIP STRIKES ON BERING-CHUKCHI-BEAUFORT SEA BOWHEAD WHALES

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ABSTRACT

We examined scars on bowhead whales harvested by Alaska Native hunters to quantify the frequency of line entanglement, ship strike, and killer whale injuries. After data quality screening, we found records on scarring from 521 bowhead whales harvested from 1990 to 2012 from our database. Logistic regression was used to evaluate different combinations of explanatory variables (i.e., body length, year, sex) to develop a prediction model for each scar type. We also provide a list of bowhead whales entangled in commercial fishing gear that were harvested, found dead, or observed alive by hunters and during aerial surveys. Our findings suggest that about 12% of harvested bowheads show entanglement scars. The frequency of entanglement scars is highly correlated with body length—about 50% of large bowheads ($\geq$17 m) exhibit gear scars while whales $\leq$ 9 m rarely show such scars. Scars associated with ship strikes are infrequent and occur on ~2% of all harvested whales; body length was not a significant factor. Scarring from killer whale predation was evident on ~8% of landed whales. Line scars were rather frequent (~50%) on large bowheads (>16m) but less common on small whales (<10m). Killer whale scars on bowheads were also statistically more frequent in the second half of the study period (2002-2012). Our findings are consistent with a similar study conducted on Eastern Canada-West Greenland bowheads. Evaluations of scarring on landed whales are continuing and we are working with whale hunters to include examinations of landed whales in all villages.

INTRODUCTION

Reduction of arctic sea ice may lead to increased industrial vessel traffic, including but not limited to shipping, offshore resource extraction, commercial fisheries, and tourism (Reeves et al., 2012). Worldwide, the potential for anthropogenic impacts on the Bering Chukchi Beaufort seas (BCB) bowhead whale (*Balaena mysticetus*) population is a concern, particularly since the bowhead whale is essential to the nutritional, cultural, and economic health of communities from the northern Bering Sea to the eastern Alaskan Beaufort Sea. Entanglement in commercial fishing is one of the leading sources of anthropogenic mortality for whales worldwide and BCB bowheads bear both direct and indirect evidence of gear entanglement despite their remote distribution in northern and western Alaska (Moore et al., 2004; Reid et al., 2006; Reeves et al., 2012). We documented the status of scarring from three sources (i.e., maritime traffic, commercial fishing, and killer whales) on bowhead whales harvested in the subsistence hunts during 1990-2012. We also summarized opportunistic data from 1983 to 2012 of bowheads observed entangled in line or fishing gear.

Studies of diagnostic scar patterns on whales provide evidence of line entanglement, ship strikes, orca whale attacks, and other injuries. Once injured, the black epidermis [skin] of a bowhead whale heals with a pure white coloration leaving what appears to be a permanent record of past physical injury (Rugh et al., 1992; Philo et al., 1992; Reinhardt et al. 2013).

Working collaboratively with Alaska Native hunters in the Beaufort, Chukchi, and Bering seas, biologists have conducted postmortem examinations on bowhead whales harvested for subsistence since the mid 1970s for >1000 whales. For the majority of these whale examinations, biologists and hunters recorded scars and attempted to categorize scar types.

Reeves et al. (2012) reported preliminary findings from postmortem examinations of 459 BCB bowheads landed as part of the subsistence hunts at Barrow and Kaktovik, Alaska, over the period 1988 through 2007. Biologists examined about 90% of the landed whales for scarring and other biological parameters at these two villages. Preliminary analyses indicated that about 10% (41 certain, 7 possible) of the whales bore scarring consistent with line-inflicted wounds and 2–3% (9 certain, 4 possible) with ship or propeller injuries. At least two landed whales and five dead stranded whales had pot-fishing gear attached (Reeves et al. 2012).

Reeves et al. (2012) recommended that determining the origin of fishing gear found on dead whales (whether harvested for subsistence or found dead) should be a priority, along with an inventory of derelict gear found in the Arctic. They also noted overlap between bowhead whales and commercial crab gear (and potentially black cod pot gear) in the Bering Sea. Therefore, they suggested:

> A collaborative study that involves whale researchers and individuals in the crabbing/fishing industry is essential. The primary goals would be to investigate (a) the forensics of scarring and gear found or observed on bowhead whales and (b) the spatial and temporal coincidence between fishing activity and bowhead distribution. Satellite whale-tagging data, survey data, expanded harvest monitoring, and fishery records should provide relevant insights.

Citta et al. (2013) examined the question of overlap of the US crab fisheries with bowhead whales during winter. They noted no temporal but partial spatial overlap for the US blue crab fishery and concluded that lost or "ghost" gear is the most likely source of the gear that entangle bowheads.

The objectives of this paper are to:
(1) Scan our records for bowheads with injuries and/or scar patterns on landed whales consistent with line entanglements, killer whale (O*rcinus orca*) predation, and ship strikes from 1990 to 2012;
(2) Calculate baseline quantitative estimates of the likelihood of line entanglement, large vessel strike, and/or killer whale predation attempts on examined bowhead whales harvested from 1990 to 2012 as a function of body length, sex and year;
(3) Compare frequency of orca "rake mark" scarring rates between the decades of 1990 and 2000; and
(4) Provide a comprehensive list on the line and gear recovered from all bowhead whale carcasses (harvested or strandings) during 1983-2012.

METHODS

We examined records for 904 bowhead whales harvested between 1990 and 2012. Of these, 521 were examined for at least one of the three types of scars indicating injuries from line entanglement wounds, attacks by killer whales, and ship strikes (and/or propeller injuries). Characteristics of the harvested whales were included in the analysis to explain the likelihood that distinct scarring from these three different sources was observed. These characteristics, or explanatory variables, were length, sex, and year of harvest. Scars of a specific type were scored as: "yes", "no", or "possible". The scars were verified by the authors with field examination experience, familiar with injuries and scars on bowhead whales.

The basic criteria for assigning a scar type were the following:

1. Line entanglement scars are usually about 0.5 m linear or curvilinear cuts or scars into the skin around the mouth, flippers, flukes, or peduncle region (Figure 1). These injuries are consistent with the kind of damage a high-tension line would make wrapped around the whale's body (see Moore et al., 2004).

2. Killer whale wounds are typically short (~ 30 cm) linear parallel scars or "rake marks" approximately 2-4 cm apart on the posterior edge of the flukes, fluke tips, and/or flippers (Figure 2).

3. Ship Strike injuries from lacerations/incising wounds associated with contact with the spinning propeller of a boat or ship hull (Figure 3). Typically ship propeller wounds are recognized as a series of concave scars or cuts.

We decided to exclude whales with scars scored as "possible" because we could not assign a probability of these uncertain cases. Logistic regression was used to evaluate different combinations of explanatory variables to develop a prediction model for each response variable (Hosmer and Lemeshow 2000) using the "glm" function from the "stats" library in **R** (Crawley 2007; R Development Core Team 2009).

The specific forms of the logistic function can be written:

$$\pi(X) = \frac{e^{f(X)}}{1 + e^{f(X)}} \tag{1}$$

where X is a vector of explanatory variables x_i of dimension n ($X = [x_1, x_2, x_3, \ldots x_n]$) and $\pi(X)$ is the conditional expected value of our dependent variable Y given values of X. In more direct terms, $\pi(X)$ is the probability that a whale exhibited a certain type of scar, given the values of X for that whale. The logit transformation is defined in terms of $\pi(X)$ as:

$$f(X) = ln\left(\frac{\pi(X)}{1-\pi(X)}\right) = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n . \tag{2}$$

Akaike's Information Criterion (AIC) was used to rank competing models and to identify the "best" model for prediction (Burnham and Anderson 2002). Only individual and additive combinations of the three explanatory variables were considered—no second or third order combinations of explanatory variables were used. Finally, summary statistics were calculated for each scar type.

Observations about "active" line entanglements were derived from aerial photographic surveys conducted by the North Slope Borough and NOAA (see Mocklin et al., 2015) and boat-based observations from hunters.

RESULTS AND DISCUSSION

As a general note about our analyses, sample sizes varied for each scar type as not all whales could be fully examined (for all scar types). For example, if the flukes were cut off prior to the whale being hauled ashore, we could not make an assessment of killer whale injuries since they typically occur on the flukes. Similarly for line entanglement examinations, it is essential that the peduncle be available for

examination. Also, ship-strike injuries may be slightly underreported since we usually can't examine the side the animal is laying on. Model selection results are listed in Table 1.

Line Entanglement

Of 515 complete records for line entanglement, 59 of the examined whales were determined to have scar patterns consistent with line entanglement injuries (Figure 1). An additional 29 bowhead whales with "possible" entanglement scars were excluded from the analysis. The majority of the entanglement injuries occurred to the peduncle (Figure 1). Sex and body length explained most of the variation in the occurrence of line entanglement scars (Figure 4). Such scars are rare on smaller subadult and juvenile whales (<10 m).

Large mature bowhead whales had a higher frequency of entanglement scars than smaller age classes (Table 1). For instance, at ~17 m total length, about 50% of landed bowhead whales (both sexes) exhibited entanglement scars with males showing higher rates of scarring (Figure 4). While sex and age dependence is clear, for comparisons with other whale stocks, our best estimate of the occurrence of entanglement scars is ~12.1% (59/486). By contrast, Knowlton et al. (2012) estimated a much higher incidence of 82.9% for North Atlantic Right Whales photographically assessed for evidence of entanglement 'events.'

We suspect most entanglement scars are from fishing/crab gear probably from the Bering Sea (Figure 5). A common question is: *How do you know that these entanglement scars are not from harpoon lines*? We suspect these scars are mainly from fishing equipment because whales struck with a harpoon should have a penetrating injury or significant scar on the posterior portion of the back near the dorsal midline (or retain the harpoon itself). We did not notice obvious harpoon injuries on these whales with the exception of whale 92B2 that had an indent in the back with a stone harpoon end-blade lodged into it (George et al., 1992; George et al., 1999). More importantly, the line recovered from landed whales has been consistent with the typical ¾ inch (2 cm) line used by commercial fishermen while a typical harpoon line is usually ~1.2 cm thick. A portion of a crab-type pot was attached to one bowhead found dead in 2010. Also, a commercial crab pot like those used in the Bering Sea can weigh 400 kg, which would place great force on the whale and probably inflict greater trauma than a whale float.

Some whales show scarring within the fluke notch but not elsewhere - which is somewhat perplexing. An explanation was offered by two whale hunters from Saint Lawrence Island. They suggested that bowheads may use their fluke notch somewhat like a "hand in a mitten" capable of pinching a line and pulling out a harpoon (Chester Noongwook and Perry Pungowiyi, Pers. Comm.)

Male bowhead whales had significantly higher rates of line entanglement scars than females. That higher entanglement scar rate may be due to their observed greater longevity and therefore prolonged exposure to entanglement risk (George et al., 1999; Rosa et al., 2012).

Ship Strikes

Of 505 complete records for ship strikes, only 10 whales (~2% of the total sample) showed clear evidence of scarring from ship propeller injuries. Another 10 whales showed possible injuries but these were not used in this analysis. Hence, ship strike injuries appear to be uncommon on bowhead whales in Alaska (Figure 3 and 6). No significant difference in frequency of whales surviving ship propeller injuries by whale length was found.

Few whales showing scars from ship strikes may be due to: (1) relatively low levels of commercial ship traffic in the Pacific Arctic until recently, (2) these types of injuries may result in higher mortality, or (3) some other unknown factor. If commercial shipping traffic continues to increase in the Arctic, we should

expect to see an increase in scars associated with ship strikes or more carcasses with ship strike injuries beachcast across northern and western Alaska.

Killer Whales

Of 378 complete records for killer whale scars, 30 whales (7.9% of the total sample) had scarring "rake marks" consistent with orca/killer whale injuries and another 10 had possible injuries (Figures 2 and 7). Most injuries were localized to the fluke or genital groove regions although at least three had injuries to the pectoral fins. Reinhart et al. (2013) reported that 10.2% of Eastern Canada-West Greenland (ECWG) bowhead whales bore rake marks from killer whales.

Most bowheads over 17m show evidence of killer whale predation attempts, particularly in the decade since 2002. Only 1-2% of small bowheads (< 10 m) showed such injuries. Year and body length explained much of the observed variation in the occurrence of scars from killer whale predation (Figure 7).

We suspect that killer whale scars are more common on large whales simply because older whales have more exposure time to predation. Also, younger whales may more often be successfully killed in an attack. This is consistent with speculation in Reinhart et al. (2013) that younger bowheads are more likely to be killed during an attack and larger/older whales have greater exposure time to killer whales. These authors also found "a high proportion of adult females had rake marks, perhaps due to protecting their calves from killer whale predation." While we found that males had a higher proportion of rake marks, it is reasonable to assume that BCB females acquire some of their scars protecting their calves from killer whale attacks.

There was a higher probability of observing killer whale rake mark scars on bowheads during 2002-2012 than in the previous decade. This increase is also consistent with findings by Reinhart et al. (2013) indicating a dramatic increase in rake marks on ECWG bowhead from 1986 to 2012. Reasons for this increase might include: better reporting and/or sampling bias, increase in killer whale population size, an increase in occurrence of killer whales at high latitudes (Clarke et al. 2013), and a longer open water period offering more opportunities to attack bowheads.

Gear Types Recovered

Of the 14 reports of bowhead whales actively entangled with manmade line and/or commercial fishing gear attached, six were stranded dead, four were seen swimming, and three were harvested for subsistence (Table 2; Figure 8). At least three of these entanglement events were confirmed as commercial pot gear.

FUTURE WORK

Future work will concentrate on refining existing data records, statistical methodology, examining aerial photographs, continued field examinations, and data archiving. Educational materials on identifying and reporting line entanglement and injuries on bowhead whales has been distributed to whaling communities and agencies, and will continue. We anticipate working with the Bering Sea commercial fishing industry on awareness and potential solutions to the problem of gear entanglement on bowhead whales.

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Table 1. AIC values used for model selection in identifying explanatory variables for the occurrence of linewound scars, orca scars, and shipstrike scars on bowhead whales.

scar type	AIC	Explanatory variables
Line wound	297.45	length, sex
	301.75	length
	359.69	sex
	361.35	none (estimates a single overall mean)
	363.29	Yeargroup (1990-2001 vs 2002-2012)
killer whale	136.96	length, yeargroup (1990-2001 vs 2002-2012)
	139.42	length
	204.28	Yeargroup (1990-2001 vs 2002-2012)
	209.90	none (estimates a single overall mean)
	211.87	sex
Ship strike	98.87	length
	99.84	none (estimates a single overall mean)
	101.73	Yeargroup (1990-2001 vs 2002-2012)
	101.82	sex

Table 2. Opportunistic data of bowhead whales entangled in line-gear entangled with notes on gear types and other observations (1983-2012)

LOCATION	YEAR	TYPE	COMMENTS
Kaktovik	1983	Live, swimming	Whale seen swimming dragging a line (Reeves et al. 1983).
Wales	1987	Stranded - dead	Two lines attached to tail (Philo et al. 1993)
Gambell	1989	Stranded - dead	Rope wrapped around head and in mouth (Philo et al. 1992)
Barrow	1990	Harvested	Two ropes: one exiting mouth and one recovered in water (Philo et al. 1992)
Barrow	1993	Stranded - dead	Commercial pot line wrapped around flukes (NSB-DWM unpublished data)
Chukchi Sea	1994	Live, swimming	Swimming with line attached (NMML.)
Nuiqsut	1990's	Harvested	Captain Tukle's report of whale with rope in mouth, (NSB-DWM unpublished data)
Red Dog Mine	1998	Stranded - dead	Line on whale (NMFS unpublished data). Note: a second entangled bowhead reported same area and year; possibly the animal.
Barrow	1999	Harvested	Commercial pot line wrapped in mouth, flipper and tail (NSB-DWM unpublished data)
Barrow	2001	Live, swimming	Whale dragging a green line of substantial thickness (G. Brower. pers. comm., Barrow, AK)

Cinder River	2003	Stranded - dead	8 ropes (approx. ¾" diameter) of different colors attached to tail (NSB-DWM unpublished data)
Chukchi Sea	2010	Stranded - dead	Commercial pot gear recovered from mouth and tail (Sheffield 2010)
Chukchi Sea	2011	Live, swimming	Whale dragging a yellow line of substantial thickness (NSB-NOAA unpublished data) (Figure 8).

Figure 1. Typical line entanglement injury scarring on the dorsal peduncle of an adult female bowhead whale.

Figure 2. Classic killer whale injuries or “rake mark scars” on the fluke tip of whale 03B8.

Figure 3. Ship strike propeller injury scarring on the dorso lateral region of a bowhead whale harvested by Alaska Natives for subsistence purposes.

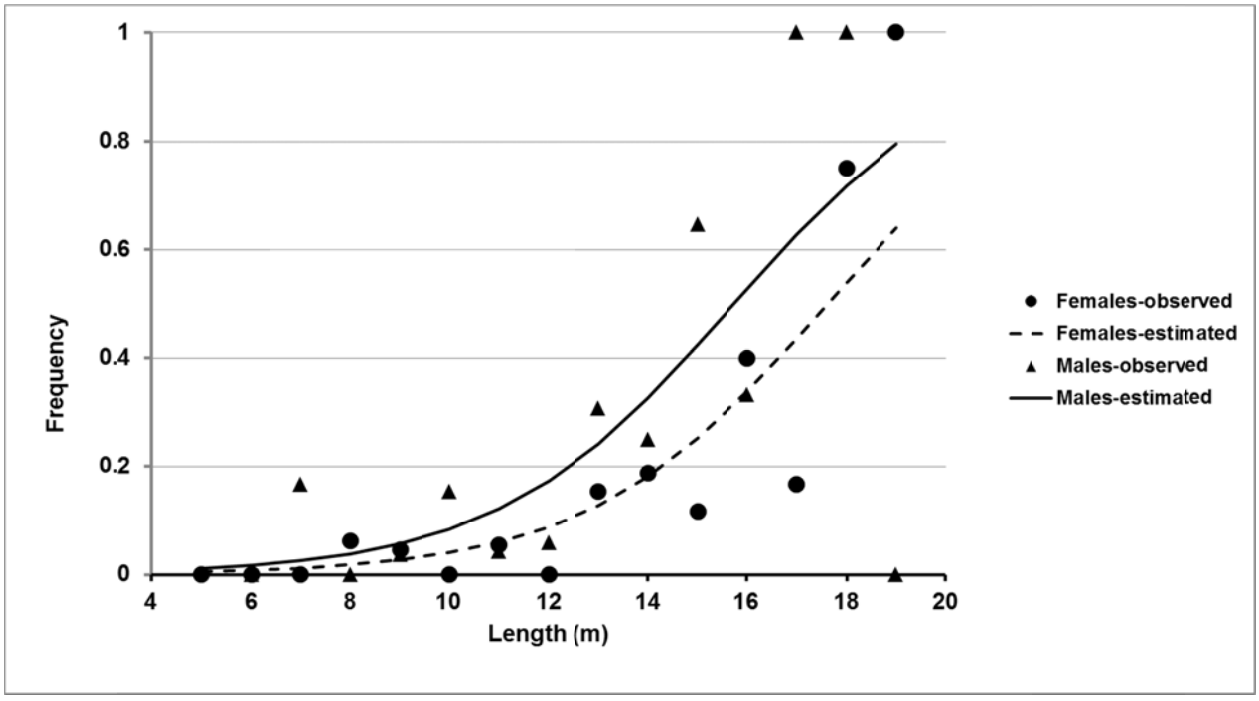

Figure 4. Estimated probabilities of bowhead whales exhibiting line entanglement scars by length and sex.

Figure 5. Commercial pot gear removed from an entangled dead adult female bowhead whale found floating in the Chukchi Sea during 2010.

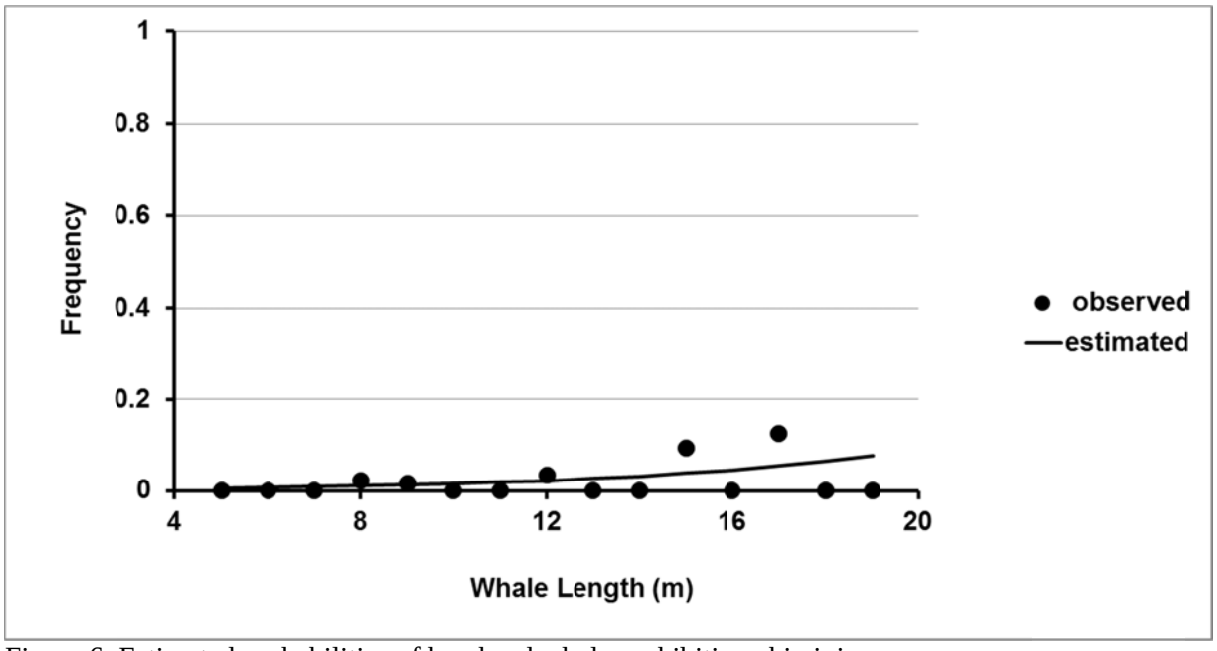

Figure 6. Estimated probabilities of bowhead whales exhibiting ship injury scars.

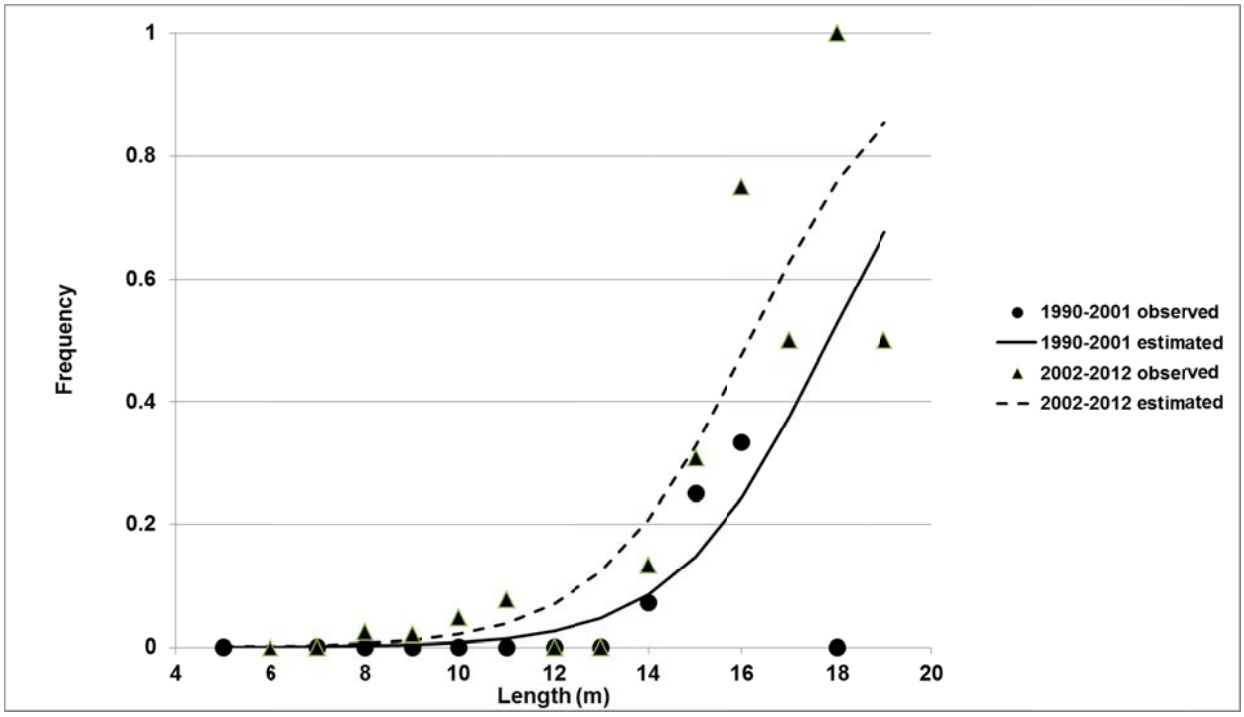

Figure 7. Estimated probabilities of bowhead whales with killer whale inflicted injuries.

Figure 8. Aerial photograph of a bowhead whale trailing a heavy line anchored through the mouth. The whale was photographed near Barrow, Alaska in 2003 during an aerial photo-ID survey.