ARCTIC
VOL. 47, NO. 3 (SEPTEMBER 1994) P. 247–255

Frequency of Killer Whale (*Orcinus orca*) Attacks and Ship Collisions Based on Scarring on Bowhead Whales (*Balaena mysticetus)* of the Bering-Chukchi-Beaufort Seas Stock

JOHN CRAIGHEAD GEORGE,[1] L. MICHAEL PHILO,[1] KATHERINE HAZARD,[2] DAVID WITHROW,[3] GEOFFRY M. CARROLL[4] AND ROBERT SUYDAM[1]

(Received 11 October 1991; accepted in revised form 27 January 1994)

ABSTRACT. Bowhead whales of the Bering-Chukchi-Beaufort Seas stock harvested by Alaskan Eskimos were examined for scars from killer whale and ship-collision injuries. We estimated that the frequency of scars from killer whale attacks ranged from 4.1% to 7.9% (depending on our confidence that the whale was properly examined) while about 1% exhibited scars from ship collisions. The frequency of killer whale scars was considerably lower than for bowhead whales of the Davis Strait stock and for other baleen whales where data are available, and was significantly lower ($P < 0.05$) for whales < 13 m. Patterns for both types of scars were quite similar to those reported for other cetacean species. Spaces between rake marks were within the range of interdental measurements from four killer whale skulls. The occurrence of attempted killer whale predation and ship strikes inferred from scars has not prevented the BCBS stock from increasing.

Key words: bowhead whale, killer whale, Alaskan Eskimos, whaling, scarring, ship/whale collision, propeller injury

RÉSUMÉ. On a examiné des baleines boréales provenant du stock des mers de Béring, des Tchouktches et de Beaufort, prises par les Esquimaux de l’Alaska afin de voir si elles portaient des cicatrices résultant de morsures d’épaulards ou de blessures provoquées par des collisions avec des navires. On a estimé la gamme de fréquence des cicatrices venant d’attaques d’épaulards comme allant de 4,1 à 7,9 p. cent (compte tenu de notre niveau de certitude quant à la qualité de l’examen de la baleine), tandis qu’environ 1 p. cent des animaux montraient des cicatrices résultant de collisions avec des navires. La fréquence des cicatrices dues aux épaulards était bien inférieure à celle observée sur les baleines provenant du stock du détroit de Davis et d’autres cétacés à fanons pour lesquels on possédait des données. Les schémas des deux types de cicatrices étaient assez semblables à ceux rapportés pour d’autres espèces de cétacés. La fréquence des cicatrices dues aux épaulards était de beaucoup inférieure ($P<0,05$) pour les baleines mesurant moins de 13 m. Les espaces entre les éraflures se situaient dans la gamme d’écartement interdentaire mesuré sur le crâne de quatre épaulards. Les tentatives de prédation par les épaulards et les coups portés par les navires—déduits des cicatrices—n’ont pas empêché le stock des mers de Béring, des Tchouktches et de Beaufort d’augmenter.

Mot clés: baleine boréale, épaulard, Esquimaux de l’Alaska, pêche à la baleine, cicatrices, collision navire/baleine, blessure infligée par une hélice

Traduit pour la revue *Arctic* par Nésida Loyer.

INTRODUCTION

Since 1978, the Alaskan Eskimo Whaling Commission has provided reliable estimates of bowhead whale hunting mortality to the International Whaling Commission (George *et al.,* 1992). Because there are no direct estimates of non-hunting mortality (hereafter, natural mortality) for bowhead whales in the Bering-Chukchi-Beaufort Seas stock (BCBS), mortality values for management decisions are largely inferred from other species of baleen whales and from population modeling (Breiwick *et al.,* 1984; Chapman, 1984; Zeh *et al.,* 1993; Givens *et al.,* 1994). Here we provide direct information on two potential sources of natural bowhead whale mortality—ship collisions and killer whale predation.

A considerable body of literature exists on killer whale attacks and predation on various cetacean species but relatively little for bowhead whales (Tomilin, 1957; Hancock, 1965; Morejohn, 1968; Scheffer, 1969; Rice and Wolman, 1971; Baldridge, 1972; Matthews, 1978; Tarpy, 1979; Katona *et al.,* 1980; Kraus *et al.,* 1986; Kraus, 1990). Mitchell and Reeves (1982) suggest that killer whale predation and ice-entrapment are significant sources of natural mortality for the Davis Strait stock of bowhead whales, and that natural mortality together with low-level subsistence hunting may be slowing the recovery of the Davis Strait stock. Finley (1990) reported that 31% of bowhead whales of the Davis Strait stock feeding in Isabella Bay, Northwest Territories showed evidence of killer whale bites. Finley also witnessed two killer whale attacks on adult

[1] North Slope Borough, Department of Wildlife Management, Barrow, Alaska 99723, U.S.A.
[2] 6818 Brookville Road, Chevy Chase, Maryland 20815, U.S.A.
[3] National Marine Mammal Laboratory, Building 4, 7600 Sandpoint Way, Seattle, Washington 98115, U.S.A.
[4] Alaska Department of Fish and Game, Barrow, Alaska 99723, U.S.A.

bowheads in the Eastern Canadian Arctic (Finley, 1990). Nerini *et al.* (1984:461) observed a bowhead whale with injuries "consistent with the dentition of killer whales."

Ship-whale collisions have been reported for other species of baleen whales (Kraus, 1990; Heyning and Dahlheim, in press). The only published report for bowheads, however, appears in Nerini *et al.*(1984), where a healed injury on a bowhead was tentatively identified as old propeller scars. Kraus (1990) gives a comprehensive summary of mortality from large ship collisions with North Atlantic right whales (*Eubalaena glacialis*). Heyning and Dahlheim (in press) provide evidence of ship collisions from injuries on dead, stranded gray whales (*Eschrichtius robustus*) and report a direct observation of a ship colliding with a healthy, migrating whale.

The skin of the bowhead whale is jet black except for healed scars and patches of white on the chin, genital groove, and peduncle. Injuries that penetrate through the epidermis apparently heal without melanocytes and become pure white (Albert *et al.,* 1980). This skin characteristic leaves a persistent record of the animal's past injuries (Rugh *et al.,* 1992). Evidence of injuries from net and line entanglement have been inferred from scarring for BCBS whales (Philo *et al.,* 1992).

In this paper we describe scar patterns on bowhead whales of the BCBS taken by coastal Alaskan Eskimos from spring 1976 to fall 1992 (Fig. 1). From these scar patterns we infer past killer whale attacks and ship collisions and draw on our own and previously published observations to estimate the frequency of these events.

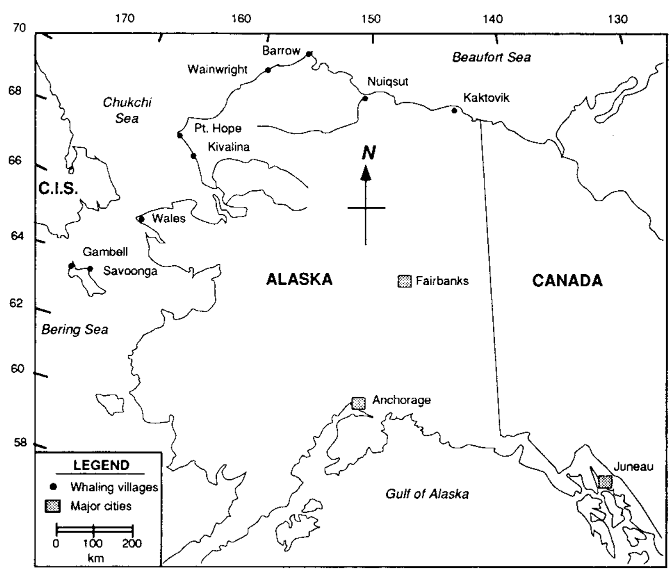


FIG. 1. Map showing the nine (as of 1992) Alaskan Eskimo whaling villages recognized by the Alaska Eskimo Whaling Commission. Biologists have examined all whales landed in Barrow since 1980 and many others in the villages of Wainwright, Kaktovik, Pt. Hope, Gambell, Savoonga and Nuiqsut.

METHODS

During routine examinations of landed bowhead whales taken by Alaskan Eskimos we investigated their scar patterns to infer the cause of these injuries. We photographed most major wounds and large or unusual scars. Unusual scars include those which intrude deeply (ca. 10 cm) into the blubber, are greater than 1 m in length, or highly structured (i.e., killer whale teeth marks). The widths, lengths and spacings of the scars reported here were estimated from photographs and/or direct measurements.

To classify the scar types, we had the photographs examined by researchers knowledgeable about scarring on North Atlantic right and humpback whales. These researchers independently identified and scored the scar types.

We analyzed only whales carefully examined or photographed between spring 1976 and fall 1992. To estimate the frequency of scar types, we sub-divided the data based on a) the period of examination, and b) our confidence that the scars were properly identified. The criteria for including whales in the sample were 1) that a biologist conducted the examination, and the examination included a fluke measurement, (indicating the flukes were available for inspection), and /or, 2) the field datasheets definitely indicated the whale was examined by either a biologist or whale hunter for conspicuous scars.

We used the data from 1980 to 1992 for demographic analysis (sex ratios, percent mature) since record keeping was better for this period. A mean length at sexual maturity of 13 m was used as a breakpoint to estimate the number of mature animals in the sample (Koski *et al.,* 1993). A Fisher's Exact Test was used to test for differences between the frequency of killer whale injuries on mature and immature whales.

We note erratic scar patterns, probably caused by sea ice, on essentially all landed bowheads. We separated these visually from the killer whale and ship collision scars by their configuration and location as described in the methods.

RESULTS

Killer Whale Attacks

Among the 355 bowhead whales landed by Alaskan Eskimos since 1976, we determined 195 whales were confidently examined for such scars. The examined whales (1976-1992) ranged from 6.1 to 17.7 m in length. Of these 195, eleven (5.6%) carried rake marks of which eight (4.1%) were definitely attributed to killer whales by us and the other examiners (Table 1; Fig. 2 a–f). Using only data from 1980 to 1992 (a period for which better records exist) these figures increase slightly to 7.9% for definite and 6.1% for possible killer whale injuries.

The average length for whales with definite rake marks was 15.4 m (SD = 2.23; N = 8), which approaches the maximum reported length for bowheads (Table 2)(Nerini *et al.,* 1984). For mature animals (>= 13 m; 1980–1992), the incidence is considerably higher as 14.9% to 19.1% carried killer whale injuries (Table 1). Scar frequencies were significantly greater (Fisher's Exact, $P = 0.008$) for mature whales (1980-1992) with definite killer whale injuries (>= 13 m, 14.9%) than on immature whales (< 13 m, 1.5%) with definite killer whale injuries.

The scar configuration was fairly consistent among the afflicted bowheads. Each rake mark consisted of several long, thin, parallel scars 2.5 to 5.1 cm apart (with the noted exception

TABLE 1. Frequency of scars on bowhead whales by size class and sample period taken by Alaskan Eskimos, attributed to killer whales and ships (Spring 1976 to Fall 1992).

Year Sample Period	No of whales landed[1]	KILLER WHALES: No. of whales confidently examined for scars	No. and % of whales with killer whale wounds: Def[2]	Pos[3]	Total	SHIP COLLISIONS: No. of landed whales examined by biologists for ship collision wounds	No. and % of whales with ship wounds: Def	Pos	Total
SPR '76-FALL '92	355	195	8 (4.1)	3 (1.5)	11 (5.6)	236	2 (0.8)	1 (0.4)	3 (1.3)
SPR '80-FALL '92	253	114	7 (6.1)	2 (1.8)	9 (7.9)	155	1 (0.6)	0 (0.0)	1 (0.6)
SPR '80-FALL '92 > = 13 m	101	47	7 (14.9)	2 (4.3)	9 (19.1)	62	1 (1.6)	0 (0.0)	1 (1.6)
SPR '80-FALL '92 < = 13 m	152	67	1 (1.5)	1 (1.5)	2 (3.0)	93	0 (0.0)	0 (0.0)	0 (0.0)

[1] Includes an additional whale found dead by Kaktovik hunters in 1991 (91FD1); whale examined by North Slope Borough biologists.
[2] Def = definite
[3] Pos = possible

of 90B5) and occurred primarily on the caudal margins of the flukes; but we also found rake marks on the flipper of one animal and near the genital groove of another (Table 3). Most whales showed multiple rake marks (Fig. 2a, c, d, f), but two showed only one rake mark (Fig. 2b, e). The individual teeth marks measured about 1 cm in width and ranged from approximately 5 to 20 cm in length. The entire assemblage of rake marks ranged from 12 to 30 cm in width (Table 3).

Whale 90B5 had killer whale-like rake marks on the caudal tip of the left flipper (Fig. 2e). Both dorsal and ventral surfaces were affected, and although the position and configuration of the scars were consistent with other killer whale injuries, the distances between individual rake marks were too great (mean = 9.6 cm) to be definitely attributed to killer whale bites. Plausible explanations for the scarring pattern include: a) the teeth marks were made by a very large killer whale, b) the marks occurred when the animal was small and the scars separated as the flippers grew, or c) an outboard motor propeller struck the whale.

The scarring on whale 78WW2 was somewhat unusual in that the scars occurred on the ventrum, appeared to curve caudally, and included two separate sets of scars (Fig. 2f). This scar pattern may have been caused by the bowhead escaping forward during the attack causing the killer whale's teeth to rake backwards. The second set of teeth marks (on the right) may have involved only the killer whale's upper jaw. Separations of the rake mark scars ranged from 2.5 to 5.1 cm. Killer whales are known to lacerate the genital region of their prey. S. Kraus (pers comm., 1992) has observed killer whale rake marks on the genital region of humpback whales. Baldridge (1972) describes his observations of a killer whale attack on a gray whale calf in which they consumed all the blubber on its ventral surface between the genital region and throat.

Ship Collisions

Of the 355 bowheads landed since 1976 we found 236 that we determined were confidently examined for scarring since 1976. Two whales from this total (0.8%) carried ship strike injuries and one other whale (76B7F) may have had a ship collision injury (Table 1, Fig. 3). Bowheads in this sample ranged from 6.1 to 17.7 m in length. For the period for which we have better records (1980–1992), we find only one ship strike event from 155 whales (0.6%). Of these, 40.3% were presumably mature (> 13 m), 55.2% were female and lengths ranged from 7.0 to 17.7 m.

TABLE 2. Basic data for bowhead whales exhibiting killer whale and ship collision scars.

Whale Number	Date of Capture	Village in Alaska	Length (m)	Sex	Scar[1] Type
76H4	5/02/76	Pt. Hope	11.2	F	S
76B6F	9/10/76	Barrow	16.0	F	K
76B7F	9/20/76	Barrow	14.3	F	S?
78WW2	5/19/78	Wainwright	15.2	M	K?
81B2	5/22/81	Barrow	8.0	F	K?
81H4	5/04/81	Barrow	10.0	M	K
82KK1	9/24/82	Kaktovik	16.0	M	K
82WW2	5/29/82	Wainwright	16.5	F	K?
83G1	4/17/83	Gambell	15.7	M	K
87B4	5/19/87	Barrow	16.8	F	K
87WW2	5/08/87	Wainwright	13.5	M	S
89B3	5/28/89	Barrow	16.9	F	K
86KK2	9/17/86	Kaktovik	17.2	F	L
90B6	5/24/90	Barrow	15.2	M	L
90B5	5/23/90	Barrow	15.9	F	K
92B2	5/28/92	Barrow	15.6	F	K
Killer whale (all)		Mean	14.8	N 11	SD 2.95
Killer whale (definite)		Mean	15.4	N 8	SD 2.23
Ship Strike (all)		Mean	13.0	N 3	SD 1.6
Ship Strike (definite)		Mean	12.4	N 2	SD 1.6

[1] K = Killer whale, S = Ship collision

The size and extent of these injuries suggest the whales were struck by the propeller of a large vessel. Bowhead whale 76H4, previously reported by Nerini *et al.,* (1984), had three distinct crescent imprints on the left lateral surface of the thorax about 1.5 m posterior to the blowhole (Fig. 3a). Each individual scar measured about 10×30 cm and the entire scar pattern was about 1.5 m in length. Whale 76B7F had a depressed injury on its dorsal surface (10×13 cm) with an hourglass-shaped scar. The examiner suggested it may have been inflicted by a harvest attempt rather than collision with a ship's propeller.

Bowhead whale 87WW2 had a large, "butterfly" shaped laceration measuring roughly 100×30 cm on the caudal edge of the left fluke (Fig. 3b). No rake (teeth) marks were associated with the injury.

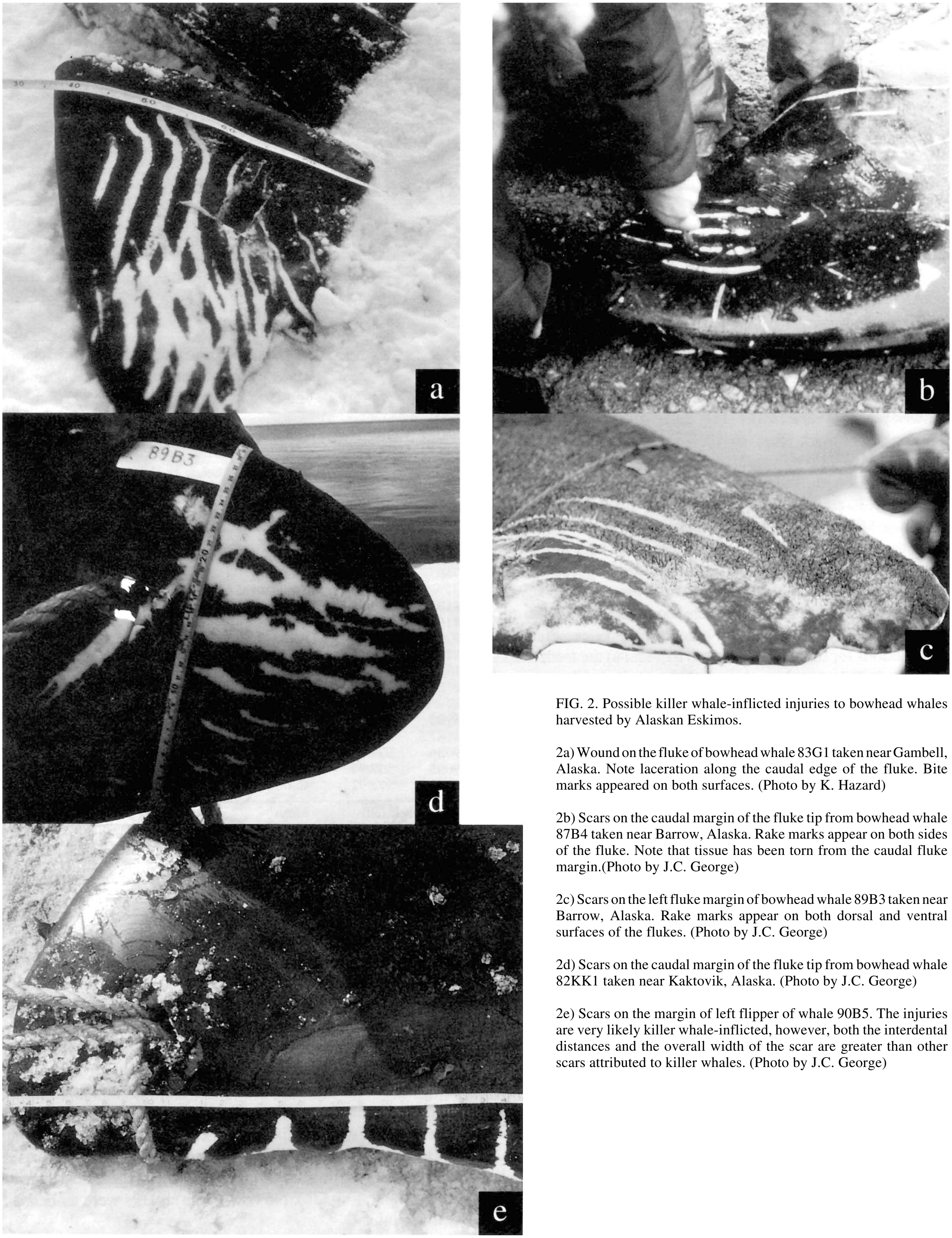


FIG. 2. Possible killer whale-inflicted injuries to bowhead whales harvested by Alaskan Eskimos.

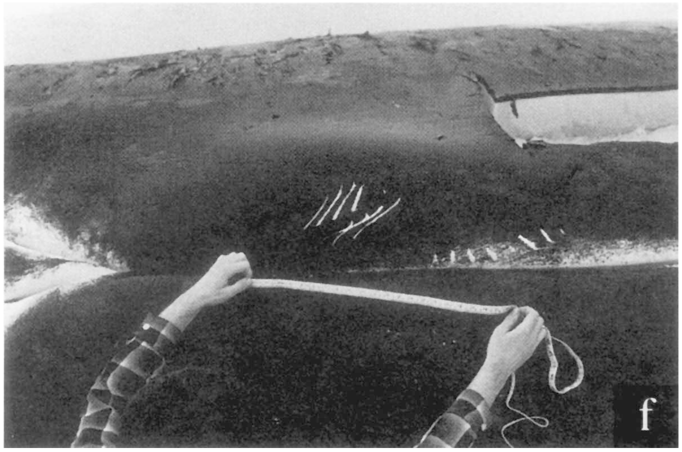
2a) Wound on the fluke of bowhead whale 83G1 taken near Gambell, Alaska. Note laceration along the caudal edge of the fluke. Bite marks appeared on both surfaces. (Photo by K. Hazard)

2b) Scars on the caudal margin of the fluke tip from bowhead whale 87B4 taken near Barrow, Alaska. Rake marks appear on both sides of the fluke. Note that tissue has been torn from the caudal fluke margin.(Photo by J.C. George)

2c) Scars on the left fluke margin of bowhead whale 89B3 taken near Barrow, Alaska. Rake marks appear on both dorsal and ventral surfaces of the flukes. (Photo by J.C. George)

2d) Scars on the caudal margin of the fluke tip from bowhead whale 82KK1 taken near Kaktovik, Alaska. (Photo by J.C. George)

2e) Scars on the margin of left flipper of whale 90B5. The injuries are very likely killer whale-inflicted, however, both the interdental distances and the overall width of the scar are greater than other scars attributed to killer whales. (Photo by J.C. George)



2f) Two separate sets of scars on the ventral surface of whale 78WW2. The injuries curve posteriorly, possibly from the bowhead escaping forward during the attack. The second set of marks (right set) may have involved only the killer whale's upper jaw. (Photo courtesy of the National Marine Mammal Laboratory, NMFS, NOAA, Seattle, WA)

DISCUSSION

One of the greatest difficulties of the analysis was to determine which whales were properly examined for scarring. In the last ten years alone, examinations have been conducted by over 50 different hunters and field biologists. Since whale hunters are required only to report the length and sex of the whale, we could not assume their whales were carefully examined for scarring, and therefore could not use them in this analysis. In past years, many examinations made by biologists (ourselves included) were also inconclusive regarding scarring and could not be used. Since 1990 we have added "check-off" boxes to the field data forms to prompt the examiners to check the whales for killer whale, ship collision and line entanglement injuries.

Killer Whale Attacks

The scars on harvested bowheads attributed to killer whales were similar to scars observed on other large mysticetes (Rice and Wolman, 1971; Tarpy, 1979; Katona *et al.,* 1980; Kraus *et al.,* 1986; Kraus, 1990) and on other killer whales (Scheffer, 1969). Spaces between rake marks (2.5 to 5.1 cm) were within the range of interdental measurements (2.3 to 5.1 cm) from four killer whale skulls (two from the National Marine Mammal Laboratory and two from the Museum of Comparative Anatomy; M. Dahlheim, pers. comm. 1989; Scott Kraus, pers. comm. 1992) (Table 3). Scheffer (1969) reported a mean tooth separation of 3.45 cm from skulls of two adult male killer whales.

The locations of rake mark injuries on the bowheads were consistent with scars attributed to killer whale attacks on other cetaceans. The rake marks on bowhead whales were primarily on the flukes, but were also found on the flipper and ventrum. Rice and Wolman (1971) reported that gray whales examined at whaling stations carried killer whale rake marks on both their flukes and their flippers. They surmised that "the predominance of scars on the flukes and flippers suggests that killer whales usually attempt to kill gray whales by seizing their flukes and flippers so as to immobilize and drown them" (Rice and Wolman, 1971:98). Hunters from St. Lawrence Island have also observed pods of killer whales waging attacks on gray whales by biting at their flukes while others flanked their sides and rammed the mouth (C. Oozeva, pers. comm. 1989). Whale 92B2 appeared to carry rake marks of varying tooth width; perhaps from more than one animal attacking it. We do occasionally see small lacerations on the distal margin of the flippers of landed whales but because rake marks are absent, we can not confidently attribute these to killer whale bites.

It may be that the scars reported here do not represent serious predation attempts. Ljungblad and Moore (1983) witnessed killer whales chase but not actually attack a gray whale. Similarly,

TABLE 3. Characteristics of selected killer whale "rake-mark" scar patterns on bowhead whales harvested by Alaskan Eskimos (Fig. 2a-f).

Whale Number	Rake Mark Width[1] (cm)	Rake Mark Length[2] (cm)	Inter-scar Distance[3] (cm)	Comments
78WW2	20–28	1.6–12	3.2 & 4.1	Two sets of rake marks near the genital slit; scars curve posteriorly (Fig. 2f).
82KK1	12	25–30	2.75	One set of rake marks on caudal margin of fluke tip; only dorsal surface examined (Fig. 2b).
83G1	20	7–20	2.8	Multiple rake marks; tissue torn from caudal edge; scars on both dorsal and ventral (d&v) surfaces (Fig. 2a).
87B4	–	10-20	3.5	Multiple rake marks; caudal edge of fluke avulsed; rake marks on both (d&v) surfaces of left fluke (Fig. 2c).
89B3	19–20	5–20	3.0 & 2.75	Two separate scars; a) series of scars on both (d&v) surfaces of left fluke tip (Fig. 2d) and b) rake marks about 1/2 way along caudal edge of fluke (no photo).
90B5	41	6.3	9.6	One set of rake marks; scars on tip of left flipper; scars appear to be killer whale marks but distances between individual scars are greater than interdental distances of killer whales (Fig. 2e).
92B2	20–30	20–30	3.6 & 4.2	Multiple rake marks; scars on both (d&v) surfaces of right and left fluke tip and caudal edge of right fluke; tissue laceration on right fluke tip; approx. five separate bites evident, one group with 3.6 cm tooth separation and another with 4.2 cm tooth separation.

[1] Width of the entire scar pattern (includes all rake marks). [2] Length range (along long axis) of individual rake marks.
[3] Mean distance between individual rake marks.

FIG. 3. Injuries attributed to ship propellers.

3a) Large laceration (30 × 100 cm) on the caudal margin of the left fluke of bowhead whale 87WW2, harvested near Wainwright, Alaska. Note the "butterfly-like" shape of the injury and the lack of rake marks associated with killer whale bites. (Photo by Charles D.N. Brower)

3b) Series of scars to the left lateral surface of bowhead whale 76H4 taken near Point Hope, Alaska. The crescent-shaped marks were attributed to a ship's propeller. (Photo courtesy of the National Marine Mammal Laboratory, NMFS, NOAA, Seattle, WA)

Whitehead and Glass (1985) reported a killer whale attack on a humpback whale (*Megaptera novaeangliae*) in which the predators apparently made no serious effort to kill the animal.

Finley (pers. comm. 1989), based on photographs and personal observations of belugas harassing a bowhead, has suggested that belugas may produce wounds similar to killer whales. Alaskan whale hunters have also made reports of bowheads being harassed by belugas. Beluga tooth spacing (ca. 1 cm) and rostrum size (ca. 10 cm) are, however, too small to produce the scarring reported here (Tomilin, 1957). Furthermore, from examinations of hunter-killed belugas, we have noted on some large animals that their teeth are worn to the gum line.

Although polar bears are known to kill adult belugas entrapped in ice (Lowry *et al.,* 1987a) they are unlikely to have caused the scarring we observed on bowheads. Marks from polar bears would likely be on the whales' backs and their claws could not affect both the dorsal and ventral surfaces of the flukes. In addition, while the claw separation on polar bears does overlap, it is generally greater than the distances between scars reported here. For example, the claw separation from the paw of a 228 cm female polar bear averaged about 4 cm but could expand to 8 cm.

Sharks were suggested as a possible source for the observed scarring. Scarring from shark bites, however, has an entirely different configuration. Shark wounds on seals, for instance, are differentiated from other injuries by the numerous penetrations in an oval configuration and by the jagged serrations caused by their sharp, knife-like teeth (Brodie and Beck, 1983; Riedman, 1990). Separations between shark bite marks were not given by these researchers.

Our present knowledge of killer whale and bowhead whale distribution in the Bering Sea indicates overlap in the ranges at least during fall. However, the exposure that bowheads have to killer whale attacks and predation is unclear because little is known about the seasonal distribution of killer whales in the Bering Sea. Bowhead whales summer in the Beaufort Sea and migrate through the northern Bering and Chukchi Seas in spring and fall (Braham, 1984; Miller *et al.,* 1986; Moore and Clarke, 1992). They inhabit the Bering Sea from approximately November through April, with considerable temporal and spatial variation in occurrence, likely dependent on pack ice cover (Brueggeman, 1982; Brueggeman *et al.,* 1987). Killer whales frequent the Bering and Southern Chukchi Seas, at least during the summer months, however, two sightings were reported from the Beaufort Sea (Leatherwood *et al.,* 1986; Lowry *et al.,* 1987b). Observations of killer whales in heavy ice cover in the Bering and Chukchi Seas indicate that they can penetrate substantial concentrations of sea ice (Leatherwood *et al.,* 1986; Lowry *et al.,* 1987b) but their propensity to do so is unknown. St. Lawrence Island hunters report that killer whales arrive in their waters in May and June and that attacks of killer whales on gray whales during the summer months are fairly common. We have never seen killer whales during 15 years of ice-based censusing at Barrow (from 15 April to 1 June, 1976–1992), but we and local hunters do see a few killer whales each year in the Point Barrow region during July and August. In addition, since 1985 Eskimo hunters have related two instances of killer whales attacking and killing gray whales in the Chukchi Sea near Barrow.

As noted earlier, Finley (1990) describes a high incidence of scarring (31%) on a subset of photographs of Davis Strait bowheads in Isabella Bay. He also describes a suite of killer whale-avoidance behaviors by bowheads that are common enough to merit a phrase (*Ardlingayuq*) by Inuit hunters. The smaller population size, as well as the greater duration of overlap in the distribution of killer whales and bowheads and differences in the vulnerability of bowheads due to environmental conditions may all contribute to the relatively greater frequency of attacks on the Davis Strait bowhead stock. By contrast, bowheads of the BCBS often have access to sea ice in the Bering and Chukchi

Seas and may escape predation by killer whales by navigating through areas of dense or complete ice cover where killer whales would be unable to follow (George *et al.,* 1989; Finley, 1990). Reeves and Mitchell (1989) propose that bowhead whales, belugas and narwhals associate with the sea ice front in part to escape and evade killer whales.

As discussed earlier, mostly very large whales (mean length = 15.4) carried definite killer whale marks. The greater frequency of killer whale marks on large whales is open to several interpretations. The absence of scarring on small whales may be attributable to: 1) inadequate examinations, 2) larger and hence older whales having had greater exposure to killer whale attack, 3) the likelihood that few small bowhead whales survive killer whale attacks, 4) killer whales selecting primarily large prey. St. Lawrence Island hunters have reported two small (< 9 m) dead-stranded bowhead whales which they were confident died from killer whale injuries (C. Oozeva, pers. comm. 1989). While it appears that killer whales are able to kill adult whales of other species, such as minke and gray whales (Baldridge, 1972; Steltner *et al.,* 1984), the literature does not assess the depredation on various size classes. It is unlikely that killer whales would select primarily large prey. The relative strength of the other three explanations cannot be fully assessed from the current data. If we assume our sample size is adequate, then some combination of explanations 2) and 3) (exposure time and small whales succumbing to attacks) seems the most plausible reason for the presence of rake marks only on large whales.

Mitchell and Reeves (1982) speculate that killer whales may be partly responsible for the failure of bowheads to recover from over-exploitation by commercial whaling in the Eastern Arctic. They and Finley (1990) propose that killer whales in the Eastern Canadian Arctic can meet their nutritional needs by exploiting other more abundant prey species, yet they still depredate bowhead whales when available. Thus, they propose that Davis Strait stock bowheads have not been spared from killer whale predation through a simple predator-prey feedback cycle (Mitchell and Reeves, 1982). With respect to BCBS bowhead whales, we question whether they migrate to the Beaufort Sea (to summer-feed and rear calves), from the rich feeding grounds of the Bering Sea, in part to avoid killer whale predation.

The relatively low frequency of bite marks on BCBS bowheads likely reflects a relatively low frequency of killer whale attacks and predation pressure (Table 1). With the exception of the two small bowheads reported by St. Lawrence Islanders, most bowheads that are attacked and successfully killed probably go unrecorded. Likewise, we may have missed some scars during the examinations which, in part, may explain why so few rake marks were reported prior to 1980 (Table 1).

Ship Collisions

Ship-whale collisions may leave severe injuries (Fig. 3a and 3b) and are frequently fatal (Kraus, 1990). The size and type of scarring on the bowhead whales reported here suggests the whales were hit by a propeller from a large vessel (over 30 m in length). Killer whales can also inflict severe lacerations (Hancock, 1965; Finley, 1990), but teeth marks are absent and the scar pattern on 87WW2 (Fig. 3a) is very similar to ship propeller injuries noted on North Atlantic right whales (Kraus, 1990). Philo *et al.*(1990) reported a harvested bowhead whale with a jaw fracture that he speculated may have been caused by a ship collision. Nerini *et al.*(1984) initially speculated that whale 76H4 carried propeller scars, which was corroborated in this analysis.

The scarcity of observations of vessel-inflicted injuries suggests that the incidence of ship collisions with bowhead whales is quite low (about 1%). This is probably largely due to the comparatively low rate of vessels passing through most of the bowhead's range but it may also be, as with right whales, that many do not survive the collision (Kraus, 1990). The most probable areas for BCBS bowheads to encounter large vessel traffic are the far eastern end of the Northern Sea Route (along the north shore of the Chukotka Peninsula) during autumn and the Eastern Canadian Beaufort Sea during August and September (Richardson *et al.*, 1987). In this portion of the Sea Route, large numbers of bowheads aggregate in the shipping lanes during October (Miller *et al.,* 1986; George, unpublished field notes).

Kraus (1990) provides evidence that ship collisions are a significant source of mortality for North Atlantic right whales. He estimated that 5 of 25 (20%) dead-stranded right whales, in which the cause of death was determined, succumbed to ship collisions. He also estimated that approximately one-fifth of ship collisions with right whales are fatal. Goodyear (1989:24) observed that right whales are oblivious to approaching ships during surface social activity and suggested that "misses by ships became merely random events." Some studies suggest that bowheads may show greater avoidance reactions to ships than the more habituated North Atlantic right whale. Richardson *et al.*(1987) report that most bowheads show avoidance reactions to approaching ships more than 1 km distant in the Eastern Canadian Beaufort, which would decrease the likelihood of a ship collision. However, these reactions were short-term and they suggest that summering bowheads could habituate to an ongoing stimulus from off-shore drilling or vessel operations. Eskimo hunters report that bowheads are less sensitive to approaching crafts when they are feeding. We noted that bowheads feeding during the spring migration near Barrow seemed almost oblivious to the presence of humans (Carroll *et al.,* 1987). Wartzok *et al.*(1989) reported that bowheads in the Eastern Canadian Beaufort Sea showed very similar behavior to right whales in the presence of ships. That is, after an initial startle response, bowheads showed little reaction (some almost oblivious) to their (32 m) vessel and over 180 whales voluntarily approached to within 15 to 500 m. Considering the above, it is not improbable for vessels to collide with feeding bowheads.

ACKNOWLEDGEMENTS

We thank the whaling captains who allowed us to examine their whales, in particular, George Adams Sr., Benny Ahmaogak Sr., Tommy Agiak, Vernon Slwooko and Joash Tukle. Funding was provided by the North Slope Borough with supplemental funding from the State of Alaska (Dept. of Community and Regional Affairs) and the

National Oceanic and Atmospheric Administration through the Alaska Eskimo Whaling Administration. Field biologists who assisted on this study include Charlie Brower, Joe Burgener, Ron Clark, Jim Cubbage, Gordon Jarrell, Carolyn Glass, Cyd Hanns, Phil Kaufman, Bill Marquette, Paul Nader, J.R. Patee, Dave Ramey, Robert Suydam, Steve Wood and Joanne Young. We thank Dr. John Hall and Dr. Lanny Cornell for providing information on killer whale dentition. We thank Robyn P. Angliss, Tina Blewett, Marilyn Dahlheim and Dave Rugh of the National Marine Mammal Laboratory, NMFS (NOAA), Seattle, WA—Robyn and Tina for their thorough search of the early harvest data, Marilyn for kindly providing her unpublished data on killer whale dentition, Dave for suggestions on the manuscript. Scott Kraus (New England Aquarium, Central Wharf, Boston, MA 02110) kindly provided additional unpublished data on killer whale dentition and advice on the analysis. Judy Allen, Steve Katona, Scott Kraus and Peter Stevick conducted an independent assessment of the photographs which greatly improved this paper. We thank Dr. Scott Newman and Dr. Raymond Tarpley for their assistance with the literature search. We thank Charlie Brower for providing the photograph of whale 87WW2. Dr. Thomas Albert and Benny Nageak provided support and useful suggestions throughout this project. We acknowledge Mary Nerini, formerly of NMML, who provided the initial impetus for this paper. We are indebted to Conrad Oozeva (Box 9, Gambell, Alaska, 99742 USA) and Kerry Finley (10232 Summerset Place, Sidney, British Columbia, Canada V8L 4X2) who shared their keen observations (personal communications) and in-depth knowledge of bowhead whales. The thorough review by Sue Moore and one anonymous reviewer greatly improved this paper.

REFERENCES

ALBERT, T., MAGAKI, G., CASEY, H.W., and PHILO, L.M. 1980. Healed penetrating injury of a bowhead whale. Marine Fisheries Review 42:92–96.

BALDRIDGE, A. 1972. Killer whales attack and eat a gray whale. Journal of Mammalogy 53(4):888–900.

BRAHAM, H.W. 1984. The bowhead whale, *Balaena mysticetus*. Marine Fisheries Review 46(4):45–53.

BREIWICK, J.M., EBERHARDT, L.L., and BRAHAM, H.W. 1984. Population dynamics of the western Arctic bowhead whales (*Balaena mysticetus*). Canadian Journal of Fisheries and Aquatic Science 41:484–496.

BRODIE, P. and BECK, P. 1983. Predation by sharks on the grey seal (*Halichoerus grypus*) in Eastern Canada. Canadian Journal of Aquatic Science 40:267–271.

BRUEGGEMAN, J.J. 1982. Early spring distribution of bowhead whales in the Bering Sea. Journal of Wildlife Management 46(4):1036–1044.

BRUEGGEMAN, J.J., WEBSTER, B., GROTEFENDT, R., and CHAPMAN, D. 1987. Monitoring of the winter presence of bowhead whales in the Navarin Basin through association with sea ice. OCS Study MMS 87–0028. Report from Envirosphere Company, Bellevue, WA, for U.S. Minerals Management Service, Anchorage, AK. NTIS PB88–101258.

CARROLL, G.M., GEORGE, J.C., LOWRY, L.F., and COYLE, K.O. 1987. Bowhead whale (*Balaena mysticetus*) feeding activities near Point Barrow, Alaska, during the 1985 spring migration. Arctic 40:105–110.

CHAPMAN, D.G. 1984. Estimates of net recruitment of Alaska bowhead whales and risk associated with various levels of kill. Report of the International Whaling Commission 35:469–471.

FINLEY, K.J. 1990. Isabella Bay, Baffin Island: an important historical and present-day concentration area for the endangered bowhead whale (*Balaena mysticetus*) of the Eastern Canadian Arctic. Arctic 43:137–152.

GEORGE, J.C. 1993. Unpub. field notes. Available at North Slope Borough, Department of Wildlife Management, Box 69, Barrow, AK 99723.

GEORGE, J.C., CLARK, C., CARROLL, G.M., and ELLISON, W.T. 1989. Observations on the ice-breaking and ice navigation behavior of migrating bowhead whales (*Balaena mysticetus*) near Point Barrow, Alaska, Spring 1985. Arctic 42:24–30.

GEORGE, J.C., PHILO, L.M., SUYDAM, R., TARPLEY, R., and ALBERT, T.F. 1992. Summary of the 1989 and 1990 subsistence harvests of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos. Report of the International Whaling Commission 42: 479–483.

GIVENS, G.H., RAFTERY, A.E., and ZEH, J.E. 1994. A reweighting approach for sensitivity analysis within a Bayesian synthesis framework for population assessment modeling. Report of the International Whaling Commission 44:377–385.

GOODYEAR, J. 1989. Feeding ecology, night behavior, and vessel collision risk of Bay of Fundy right whales. In: Abstracts of the Eighth Biennial Conference on the Biology of Marine Mammals. Lawrence, Kansas: Allen Press.

HANCOCK, D. 1965. Killer whales eat and kill a Minke Whale. Journal of Mammalogy 46:34–342.

HEYNING, J.E., and DAHLHEIM, M.E. In press. Strandings and incidental takes of gray whales. In: Braham, H.W., and Donovan, G.P., eds. The comprehensive assessment of whales: Gray whale, *Eschrichtius robustus*. International Whaling Commission (Special issue), Cambridge, England.

KATONA, S.K., HARCOURT, P., PERKINS, J.S., and KRAUS, S.D. 1980. Humpback whales of the Western North Atlantic—a catalogue of individuals identified by fluke photographs. Second edition. Bar Harbor, ME: College of the Atlantic. 169 p.

KOSKI, W.R, DAVIS, R.A., MILLER, G.W., and WITHROW, D.E. 1993. Reproduction. In: Burns, J.J., and Montague, J. eds. The Bowhead Whale. Society for Marine Mammalogy. Lawrence, Kansas: Allen Press.

KRAUS, S.D. 1990. Rates and potential causes of mortality in North Atlantic right whales (*Eubalaena glacialis*). Marine Mammal Science 6(4):278–291.

KRAUS, S.D., MOORE, K.E., PRICE, C.A., CRONE, M.J., WATKINS, W.A., WINN, H.E., and PRESCOTT, J.H. 1986. The use of photographs to identify individual North Atlantic right whales (*Eubalaena glacialis*). In: Brownell, R.L. Jr., Best, P.B., and Prescott, J.H., eds. Right whales: Past and present status. Report of the International Whaling Commission, Special Issue 10:145–151.

LEATHERWOOD, S., BOWLENS, A.E., and REEVES, R. 1986. Aerial surveys of Marine mammals in the southeastern Bering Sea. U.S. Department of Commerce, NOAA, OCSEAP Final Report 42:147–490.

LJUNGBLAD, D.K., and MOORE, S.E. 1983. Killer Whale (*Orcinus orca*) chasing gray whales (*Eschrichtius robustus*) in the Northern Bering Sea. Arctic 36:361–364.

LOWRY, L.F., BURNS, J., and NELSON, R.R. 1987a. Polar bear, (*Ursus maritimus*) predation on belugas, *Delphinapterus leucas*, in the Bering and Chukchi Seas. Canadian Field-Naturalist 101: 141–146.

LOWRY, L.F., NELSON, R.R., and FROST, K.J. 1987b. Observations of killer whales, (*Orcinus orca*), in western Alaska: Sighting, strandings and predation on other marine mammals. Canadian Field-Naturalist 101:6–12.

MATTHEWS, L.H. 1978. The natural history of the whale. New York: Columbia University Press. 219 p.

MILLER, R.V., RUGH, D.J., and JOHNSON, F.H. 1986. The distribution of bowhead whales, *Balaena mysticetus*, in the Chukchi Sea. Marine Mammal Science 2:214–222.

MITCHELL, E.D., and REEVES, R.R. 1982. Factors affecting abundance of bowhead whales, *Balaena mysticetus*, in the Eastern Arctic of North America, 1915-1980. Biological Conservation 22: 59–78.

MOORE, S.E, and CLARKE , J.T. 1992. Distribution, abundance and behavior of endangered whales in the Alaskan Chukchi and Western Beaufort Sea, 1991: with a review 1982–1991. OCS Study MMS-92-0029. Final report prepared for the U.S. Minerals Management Service, Alaska OCS Region by SAIC, Maritime Services Division. 237 p.

MOREJOHN, V. 1968. A killer whale – gray whale encounter. Journal of Mammalogy 49:327–328.

NERINI, M.K., BRAHAM, H.W., MARQUETTE, W.M., and RUGH, D.J. 1984. Life history of the bowhead whale, *Balaena mysticetus* (Mammalia: Cetacea). Journal of the London Zoology Society 204:443–468.

PHILO, L.M., HANNS, C.T. and GEORGE, J.C. 1990. Fractured mandible and associated oral lesions in a subsistence-harvested bowhead whale (*Balaena mysticetus*). Journal of Wildlife Diseases 26:125–128.

PHILO, L.M., GEORGE, J.C., and ALBERT, T.F. 1992. Rope entanglement of bowhead whales (*Balaena mysticetus*). Marine Mammal Science 8(3):306–311.

REEVES, R.R., and MITCHELL, E.D. 1989. Distribution and seasonality of killer whales in the Eastern Canadian Arctic. Rit Fiskideildar 11:136–160.

RICE, D.W., and WOLMAN, A.A. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Special Publication No. 3, The American Society of Mammalogists.

RICHARDSON, W.J., DAVIS, R.A., EVANS, C. R., LJUNGBLAD, D.K., and NORTON, P. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980–84. Arctic 40(2):93–104.

RIEDMAN, M. 1990. The pinnipeds: Seals, sea lions, and walruses. Berkeley and Los Angeles, CA: University of California Press. 439 p.

RUGH, D.J., MILLER, G.W., WITHROW, D.E., and KOSKI, W.R. 1992. Calving intervals of bowhead whales established through photographic identifications. Journal of Mammalogy 73:487–490.

SCHEFFER, V. 1969. Marks on the skin of a killer whale. Journal of Mammalogy 50:151.

STELTNER, H., STELTNER, S., and SERGEANT, D.E. 1984. Killer whales, *Orcinus orca*, prey on Narwhals, *Monodon monoceros*: an eyewitness account. Canadian Field-Naturalist 98:458–462.

TARPY, C. 1979. Killer whale attack. National Geographic Magazine 155:542–545.

TOMILIN, A.G. 1957. Mammals of the U.S.S.R. and adjacent countries. Vol. 9. Cetacea. (Translated by the Israel Program for Scientific Translations, Jerusalem, 1967). 717 p.

WARTZOK, D., WATKINS, W.A., WURSIG, B., and MALME, C.I. 1989. Movements and behaviors of bowhead whales in response to repeated exposures to noises associated with industrial activities in the Beaufort Sea. Unpub. report. Available at Amoco Production Company, 1670 Broadway, Denver, CO 80202. 228 p.

WHITEHEAD, H., and GLASS, C. 1985. Orcas (killer whales) attack humpback whales. Journal of Mammalogy 66:183-184.

ZEH, J., GEORGE, J.C., RAFTERY, A.E., and CARROLL, G.M. 1991. Rate of increase, 1978–1988, of bowhead whales, *Balaena mysticetus*, estimated from ice-based census data. Marine Mammal Science 7:105–122.