ARCTIC
VOL. 44, NO. 1 (MARCH 1991) P. 43-46

Estimates of Bowhead Whale (*Balaena mysticetus*) Numbers in the Beaufort Sea during Late Summer

SUE E. MOORE[1] and JANET T. CLARKE[1]

(Received 23 January 1990; accepted in revised form 9 August 1990)

ABSTRACT. Broad estimates of bowhead whale numbers in Beaufort Sea outer continental shelf (OCS) waters were calculated based on raw counts of whales seen during aerial surveys conducted in late summer 1982–84, corrected by factors accounting for surface area not sampled, surfaced whales missed by observers, and whales too deep to be seen. Annual estimates ranged from roughly 700–1200 to 3000–3500 whales for the latter half of August and from 2000–2200 to 1600–2900 whales for the first half of September. Additionally, estimates of up to 3000 whales were calculated for subregions of the Beaufort Sea for two separate two-week periods, with adjacent-period estimates of only several hundred whales in the same subregions, implying that whale concentrations were highly transitory. The highest estimate (*ca.* 3500 whales) accounts for less than half of the estimated 7800 whales in the Bering Sea bowhead population. If the population estimate of 7800 whales is valid, then either a substantial number of whales summered outside Beaufort Sea OCS waters in 1982–84 or bowhead numbers are routinely underestimated by the methods used here, or some combination of both.

Key words: bowhead whale, Beaufort Sea, outer continental shelf, abundance estimates, aerial surveys

RÉSUMÉ. On a procédé à des estimations grossières du nombre de baleines franches dans les eaux au large du plateau continental de la mer de Beaufort, en s'appuyant sur des comptages bruts de baleines aperçues au cours de relevés aériens effectués à la fin de l'été de 1982 à 1984. Ces comptages ont été corrigés par des facteurs tenant compte de la superficie non échantillonnée, des baleines en surface qui n'ont pas été aperçues par les observateurs ainsi que des baleines se déplaçant dans des eaux trop profondes pour être vues. Les estimations annuelles vont d'environ 700-1 200 à 3 000-3 500 baleines pour la deuxième quinzaine d'août, et de 2 000-2 200 à 1 600-2 900 baleines pour la première quinzaine de septembre. De plus, on a estimé le nombre des baleines à jusqu'à 3 000 dans des sous-régions de la mer de Beaufort durant deux périodes de deux semaines non contigues, avec, dans les mêmes sous-régions, des estimations de seulement quelques centaines de baleines durant des périodes contigues, ce qui signifie que les concentrations de baleines sont largement transitoires. L'estimation la plus élevée (environ 3 500 baleines) représente moins de la moitié des 7 800 baleines estimées dans la population de baleines franches dans la mer de Béring. Si l'on considère comme valide l'estimation de la population de baleines à 7 800, il s'ensuit soit qu'un nombre important de baleines ont passé l'été de 1982 à 1984 hors des eaux au large du plateau continental de la mer de Beaufort, soit que le nombre de baleines franches évalué par les méthodes employées ici est régulièrement sous-estimé, soit que ces deux facteurs sont combinés.

Mots clés: baleine franche, mer de Beaufort, au large du plateau continental, évaluations de la quantité, relevés aériens

Traduit pour le journal par Nésida Loyer.

INTRODUCTION

Migratory movements of the Bering Sea bowhead whale population are well described (Braham *et al.*, 1984; Ljungblad *et al.*, 1986b). In general, whales migrate northward from wintering areas in the northern Bering Sea from March through May, pass Point Barrow, Alaska, on a northeastward course from April through June, and arrive in the Canadian Beaufort Sea from May through July. Whales usually summer in Canadian waters and then migrate westward across the Alaskan Beaufort and Chukchi seas from August through November.

Estimates of the Bering Sea bowhead population have increased from 2264 in 1979 (Braham *et al.*, 1979) to 7800 in 1989 (Zeh and Raftery, 1989), largely due to improvements in census and analysis procedures developed from counts of whales migrating past Point Barrow in spring. The use of whale calls for censusing (Clark and Ellison, 1989), the potential role of calls in bowhead ice navigation (Ellison *et al.*, 1987), and observations of whales breaking ice and feeding (George *et al.*, 1989; Carroll *et al.*, 1987) during the migration have been reported in association with the spring census. Summer and fall studies have focused on determining whale distribution and behavior in relation to oil and gas activities in Canadian and Alaskan Beaufort Sea OCS waters (e.g., Richardson *et al.*, 1987; Moore *et al.*, 1989b). These studies described bowhead feeding areas (Richardson, 1987; Ljungblad *et al.*, 1986a), migratory routes and timing (Moore *et al.*, 1988; Moore *et al.*, 1989a), and behavioral responses to offshore industrial activities, including man-made underwater noise (Richardson *et al.*, 1986; Ljungblad *et al.*, 1988; Miles *et al.*, 1987; Davis, 1987), but did not address estimates of bowhead numbers.

The number of bowhead whales that occupy the Beaufort Sea OCS in late summer is unknown. Although extensive transect aerial surveys were conducted in portions of both the Alaskan and Canadian Beaufort Sea from 1980 to 1986 (Ljungblad *et al.*, 1987; Richardson *et al.*, 1987), most of these efforts were neither fully coordinated nor specifically designed to estimate the total number of whales. However, surveys were conducted concurrently in adjacent Canadian and Alaskan OCS waters during the latter half of August and the first half of September 1982-84, and here we present a rough estimation of whale numbers based on those surveys.

METHODS

Aerial surveys were conducted in seven regions extending from shore to 72°N in the Alaskan Beaufort Sea (Fig. 1: regions 1-3) and from shore to 70°20'N to 71°30'N in the Canadian Beaufort Sea (Fig. 1: regions 4-7). Flights were conducted on north-south transect lines from fixed-wing aircraft at speeds of 200-260 km/h and at altitudes of 100-458 m during late (16-31) August and early (1-15) September in 1982-84. Objectives and results varied among surveys and are summarized for the Canadian work by Harwood and Borstad (1985) and for the Alaskan work by Ljungblad *et al.* (1987).

[1]SEACO, a Division of SAIC, 2845-D Nimitz Boulevard, San Diego, California 92106, U.S.A.

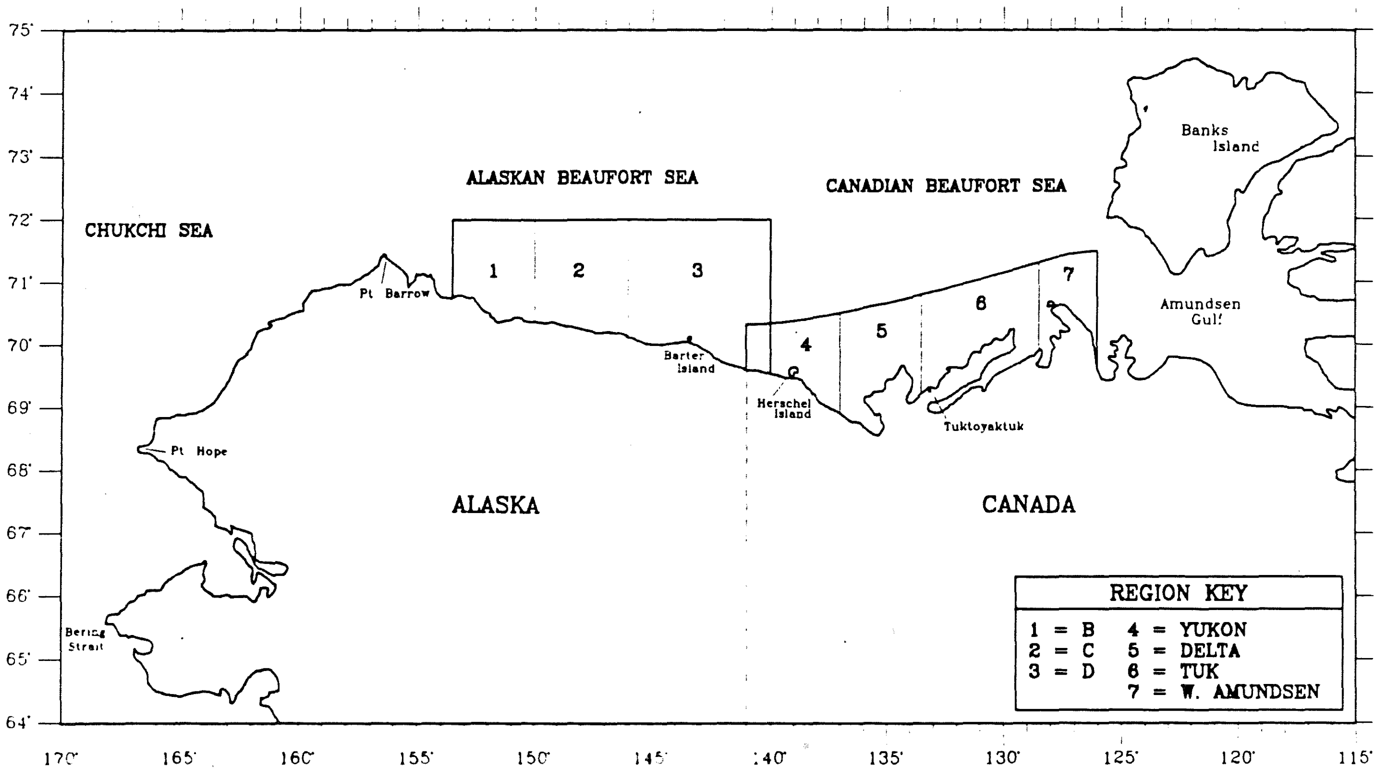

FIG. 1 Beaufort Sea OCS study area depicting boundaries for seven regions for which bowhead numbers were estimated. Region key refers to region names used in Ljungblad *et al.* (1987) and Harwood and Borstad (1985).

Estimating the total number of whales in the surveyed area from those directly observed requires correcting for a) the surface area of the region not sampled by observers, b) whales that are at the surface but missed by observers, and c) whales that are too deep to be seen when the aircraft passes them. The fraction of surface area sampled by observers was 1 km on each side of the aircraft. Raw counts were corrected for unsampled surface area by dividing the number of whales seen by the fraction of the area sampled. Whales at the surface are missed by observers 30-35% of the time (Davis *et al.*, 1982), resulting in a correction range for missed surfaced whales of 1.43-1.54. Corrections for whales deep under water were derived directly from observations of bowhead respiratory behavior. In Canadian waters, whales were at the surface 25-40% of the time (Wursig *et al.*, 1984), resulting in a correction range of 2.5-4. In Alaskan waters, whales were at the surface only 10-23% of the time (Ljungblad *et al.*, 1987), resulting in a correction range of 4.3-10. The longer surface times in Canadian waters are likely due to longer surfacings associated with feeding whales (Dorsey *et al.*, 1989) and the relatively lower incidence of feeding observed in Alaskan waters (Ljungblad *et al.*, 1986a; Richardson, 1987).

The relationship used to compute a population estimate (E) can be summarized as:

$$E = (n/f) \times (S) \times (U)$$

where E is the estimated total number of whales, n is the number of whales observed on transect, f is the fraction of the area sampled, S is the correction range for whales at the surface but missed by observers, and U is the correction range for whales deep under water. Using the aforementioned correction factors, a sample calculation for five whales seen on transect in a region where 25% of the area was sampled is: $E = (5/0.25) \times (1.43 - 1.54) \times (2.4 - 4) = 69 - 123$ for Canadian waters; and $E = (5/0.25) \times (1.43 - 1.54) \times (4.3 - 10) = 123 - 308$ for Alaskan waters. All estimates were rounded to the nearest hundred, resulting in a rough estimate of 100 whales for the Canadian example (i.e., both 69 and 123 are rounded to 100) and 100-300 whales for the Alaskan example. Estimate confidence intervals were not calculated because the variability among transects could not be ascertained for all data sources.

RESULTS

Estimates of the number of bowheads in each region varied somewhat within and among years, but total numbers for the Beaufort Sea OCS were similar (Table 1). There was greater inter-annual variation in the estimated number of whales in late August compared to early September. The highest estimate (3000-3500 whales) was calculated for late August 1982, with estimates for late August 1983 (1500-1900 whales) and 1984 (700-1200 whales) only about half to one-third as large. Early September estimates were roughly 2100-2400 whales in 1982 and 1983, with 1600-2900 whales estimated in 1984.

Estimates for region 4 in 1983 and 1984 and two relatively high single-region estimates (see *, Table 1) highlight the apparent transitory nature of bowhead distribution and relative abundance. In 1983, there were an estimated 700-1100 whales in region 4 in late August, but only 100 whales were estimated there in early September. In 1984, 1000-1600 whales were estimated in region 4 in early September, although only 100-200 whales were estimated there in late August. Similarly, the estimate of up to 3000 whales in region 3 during early August 1982 was followed by an estimate of only 200-500 whales there during late August (Table 1). Finally, an estimate

TABLE 1. Estimates of the number of bowhead whales in Beaufort Sea OCS waters by region from mid-August to mid-September 1982-84 (see Fig. 1 for region boundaries)

	1(+)	2	3(*)	4	5	6(*)	7(+)	Total
1982								
16-31 Aug	—	0	200-500	1700-1900	400	700	—	3000-3500
1-15 Sep	—	0	100-400	1600-1700	200-300	200	—	2100-2600
1983								
16-31 Aug	0	0	0	700-1100	100	700	—	1500-1900
1-15 Sep	100-200	100-200	100-200	100	600	1100	—	2000-2200
1984								
16-31 Aug	0	0	200-400	100-200	100-200	300-400	300-500	700-1200
1-15 Sep	0	300-800	100-200	1000-1600	100	100-200	300-500	1600-2900

— = no survey effort.
0 = no bowhead sightings.
(+) Regions 1 and 7 not included in totals.
(*) Single-region estimates: region 3, 1200-3000 bowheads (1-15 August 1982); region 6, 2800-3000 bowheads (16-31 August 1980).

of up to 3000 whales in region 6 for late August 1980 was preceded by an estimate of 100 whales for early August and followed by an estimate of 800–900 whales for early September 1980 (Harwood and Borstad, 1985). These serial estimates indicate that whales can become densely concentrated for relatively brief periods.

DISCUSSION

These rough estimates of bowhead whale numbers must be regarded with caution due to the nature of the correction factors applied to the raw data. The correction for surface area (n/f) assumes that whales are uniformly distributed and that the aerial sampling was representative for the entire study area. These assumptions are undoubtedly invalid because bowhead distribution appears clustered in summer and fall (Ljungblad *et al.*, 1987; Richardson *et al.*, 1987) and may be affected in part by ice conditions (Ellison *et al.*, 1987) and bathymetry (Moore *et al.*, 1988), although aerial sampling was not stratified by these features. The correction factors for whales at the surface that are missed by observers (S) are based on only one double-count field trial and do not consider the effects of whale behavior at the surface, changing survey conditions, observer fatigue, or the variation in ability of different observers that can contribute to significantly different sighting rates during aerial surveys (e.g., Pollock and Kendall, 1987; Holt and Cologne, 1987). Further, Davis *et al.* (1982) cautioned that the correction factors were specific to their surveys conducted in 1981 and were not necessarily applicable to surveys in other areas or in other years. Finally, the correction factors for whales missed because they are deep under water (U) are very broad due to the effect of behavior on whale respiration rates and therefore their time at the surface (Wursig *et al.*, 1984; Dorsey *et al.*, 1989). However, these correction factors are based on the best field measurements available and provide numbers useful for comparison and discussion.

The highest estimates of 3500 whales during late August 1982 and 2900 whales during early September 1984 represent less than half of the 7800 whales estimated for the entire Beaufort Sea bowhead population (Zeh and Raftery, 1989). Assuming the estimate of 7800 whales is valid, then either a substantial portion of the population summered outside Beaufort Sea OCS waters in 1982-84 or the methods used here consistently underestimate the number of whales, or some combination of both. In describing a similar twofold disparity in estimates of gray whale (*Eschrichtius robustus*) abundance resulting from shore-based censuses conducted during the migration and from aerial survey censuses of the winter range, Reilly (1984) concluded that whale numbers were probably underestimated by aerial surveys. The vastness of the wintering area, whale movements within and through the area during the winter season, and the problem of correcting raw counts for "missed whales," as described in this paper, were cited as reasons for the underestimation. These same factors argue against aerial surveys as a method of population estimation for bowhead whales on their summer range. However, aerial surveys remain the best method for assessing broad patterns of bowhead distribution and relative abundance required to address issues of potential impact of offshore industrial activities on the population.

Determining the distribution and abundance of bowhead whales within *and outside of* industry-related OCS study areas in summer and early fall is a prerequisite to assessing the potential impact of offshore development on the population. If a substantial portion of the population summers outside and migrates westward north of areas of offshore development, the potential impact of industrial activities on bowheads would be less than currently assumed. There is little direct evidence to support "offshore" fall distribution and movement because there has been little effort to document bowhead distribution and movements outside the boundaries of potential OCS development areas. However, recent radio-tracking studies indicate that at least some bowheads may migrate westward north of continental shelf waters (Wartzok, 1990). Conversely, if aerial survey methods consistently underestimate whale numbers, then a larger number of whales may be exposed to industrial activities than indicated by current methods. A coordinated two-week, multiple-aircraft survey covering waters from Amundsen Gulf to Point Barrow and employing double-count methods (e.g., Magnusson *et al.*, 1978) would address many of the questions remaining about bowhead distribution in late summer and the usefulness of aerial survey methods in estimating whale numbers.

ACKNOWLEDGEMENTS

Funding for the studies from which data were drawn for this paper was provided chiefly by the U.S. Minerals Management Service, the Canadian Environmental Studies Revolving Funds, Indian and Northern Affairs Canada, Dome Petroleum Ltd., and Gulf Canada Resources, Inc. We thank the many observers and pilots involved in these studies for their dedicated and professional efforts over the years. We especially thank Lois Harwood for her comprehensive technical review, Dr. Clifford Hui for his editorial comments, and four anonymous reviewers for their helpful critique of the manuscript.

REFERENCES

BRAHAM, H.W., KROGMAN, B., LEATHERWOOD, S., MARQUETTE, W., RUGH, D., TILLMAN, M., JOHNSON, J., and CARROLL, G. 1979. Preliminary report of the 1978 spring bowhead whale research program results. Report of the International Whaling Commission 29:291-306.

BRAHAM, H.W., KROGMAN, B.D., and CARROLL, G.M. 1984. Bowhead and white whale migration, distribution, and abundance in the Bering, Chukchi and Beaufort seas, 1975-78. NOAA Technical Report, NMFS SSRF-778. 39 p.

CARROLL, G.M., GEORGE, J.C., LOWRY, L.F., and COYLE, K.O. 1987. Bowhead whale (*Balaena mysticetus*) feeding near Point Barrow, Alaska, during the 1985 spring migration. Arctic 40(2):105-110.

CLARK, C.W., and ELLISON, W.T. 1989. Numbers and distributions of bowhead whales, *Balaena mysticetus*, based on the 1986 acoustic study off Pt. Barrow, Alaska. Report of the International Whaling Commission 39:297-303.

DAVIS, R.A. 1987. Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, Autumn 1986: Integration and Summary Report. Report by LGL Ltd., King City, Ontario, and Greeneridge Sciences, Santa Barbara, California, for Shell Western E&P Inc., Anchorage, Alaska. 51 p. Available at Shell Western E&P Inc., 601 West Fifth Avenue, Anchorage, Alaska 99508, U.S.A.

DAVIS, R.A., KOSKI, W.R., RICHARDSON, W.J., EVANS, C.R., and ALLISTON, W.G. 1982. Distribution, numbers and productivity of the western arctic stock of bowhead whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. International Whaling Commission document no. SC/34/PS2. Unpubl. 48 p. Available at The International Whaling Commission, The Red House, Station Road, Histon, Cambridge CB4 4NP, United Kingdom.

DORSEY, E.M., RICHARDSON, W.J., and WURSIG, B. 1989. Factors affecting surfacing, respiration and dive behavior of bowhead whales (*Balaena mysticetus*) summering in the Beaufort Sea. Canadian Journal of Zoology 67:1801-1815.

ELLISON, W.T., CLARK, C.W., and BISHOP, G.C. 1987. Potential use of surface reverberation by bowhead whales, *Balaena mysticetus*, in under-ice navigation: preliminary considerations. Report of the International Whaling Commission 37:329-332.

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(1):24-30.

HARWOOD, L.A., and BORSTAD, G.A. 1985. Bowhead whale monitoring study in the southeast Beaufort Sea, July-September 1984. Ottawa: Environmental Studies Revolving Funds Report No. 009. 99 p.

HOLT, R.S., and COLOGNE, J.C. 1987. Factors affecting line transect estimates of dolphin school density. Journal of Wildlife Management 51(4):836-843.

LJUNGBLAD, D.K., MOORE, S.E., and CLARKE, J.T. 1986a. Assessment of bowhead whale (*Balaena mysticetus*) feeding patterns in the Alaskan Beaufort and northeastern Chukchi Sea via aerial surveys, fall 1979-84. Report of the International Whaling Commission 36:265-272.

LJUNGBLAD, D.K., MOORE, S.E., and VAN SCHOIK, D.R. 1986b. Seasonal patterns of distribution, abundance, migration and behavior of the western arctic stock of bowhead whales, *Balaena mysticetus*, in Alaskan seas. Report of the International Whaling Commission, Special Issue 8:177-205.

LJUNGBLAD, D.K., MOORE, S.E., CLARKE, J.T., and BENNETT, J.C. 1987. Distribution, abundance, behavior and bioacoustics of endangered whales in the Alaskan Beaufort and eastern Chukchi seas, 1979-86. Naval Ocean Systems Center Technical Report 1177. 391 p.

LJUNGBLAD, D.K., WÜRSIG, B., SWARTZ, S.L., and KEENE, J.M. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41(3):183-194.

MAGNUSSON, W.E., CAUGHLEY, G.J., and GRIGG, G.C. 1978. A double-survey estimate of population size from incomplete counts. Journal of Wildlife Management 42:174-176.

MILES, P.R., MALME, C.I., and RICHARDSON, W.J. 1987. Prediction of drilling site-specific interaction of industrial acoustic stimuli and endangered whales in the Alaskan Beaufort Sea. Report no. 6509, BBN Lab. Inc., for the U.S. Minerals Management Service, Anchorage, Alaska. OCS Study MMS 87-0084. 341 p. Available at Minerals Management Service, Alaska OCS Region, 949 E. 36 Avenue, Room 110, Anchorage, Alaska 99508, U.S.A.

MOORE, S.E., BENNETT, J.C., and LJUNGBLAD, D.K. 1988. Comparisons of observed patterns of bowhead whale (*Balaena mysticetus*) bathymetric habitat preference to describe the fall migration route across the Alaskan Beaufort Sea, 1979-86. Abstract. Report of the International Whaling Commission 38:508.

MOORE, S.E., BENNETT, J.C., and LJUNGBLAD, D.K. 1989a. Use of passive acoustics in conjunction with aerial surveys to monitor the fall bowhead whale (*Balaena mysticetus*) migration. Report of the International Whaling Commission 39:291-295.

MOORE, S.E., CLARKE, J.T., and LJUNGBLAD, D.K. 1989b. Bowhead whale (*Balaena mysticetus*) spatial and temporal distribution in the central Beaufort Sea during late summer and early fall 1979-86. Report of the International Whaling Commission 39:283-290.

POLLOCK, K.H., and KENDALL, W.L. 1987. Visibility bias in aerial surveys: a review of estimation procedures. Journal of Wildlife Management 51(2):502-510.

REILLY, S.B. 1984. Assessing gray whale abundance: a review. In: Jones, M.L., Swartz, S.L., and Leatherwood, S., eds. The Gray Whale. Orlando, Florida: Academic Press, Inc. 203-223.

RICHARDSON, W.J., ed. 1987. Importance of the eastern Alaskan Beaufort Sea to feeding bowhead whales, 1985-86. Final report no. MMS-87-0037 for the U.S. Minerals Management Service, by LGL Ecological Research Associates. 547 p. Available at Minerals Management Service, Alaska OCS Region, 949 E. 36 Avenue, Room 110, Anchorage, Alaska 99508, U.S.A.

RICHARDSON, W.J., WÜRSIG, B., and GREENE, C.R. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 79(4):1117-1128.

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.

WARTZOK, D. 1990. Industry-sponsored bowhead whale monitoring and research in the U.S. and Canadian Beaufort Sea. Alaska OCS Region Third Information Transfer Meeting Conference Proceedings, OCS Study MMS 90-0033:39-49.

WURSIG, B., DORSEY, E.M., FRAKER, M.A., PAYNE, R.S., RICHARDSON, W.J., and WELLS, R.S. 1984. Behavior of bowhead whales, *Balaena mysticetus*, summering in the Beaufort Sea: surfacing, respiration and dive characteristics. Canadian Journal of Zoology 62:1910-1921.

ZEH, J.E., and RAFTERY, A.E. 1989. 1986 and combined bowhead population estimates: Report of the Sub-Committee on Protected Species and Aboriginal Subsistence Whaling. Report of the International Whaling Commission 39:113.