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BOWHEAD WHALES AND ACOUSTIC SEISMIC SURVEYS IN THE BEAUFORT SEA

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ABSTRACT. Seismic survey activities in the western Beaufort Sea, involving ships and sound production, were monitored in autumn 1982 for their possible effects on migrating Bowhead whales *Balaena mysticetus*. The study, begun in 1981 by the Minerals Management Service of the US Department of the Interior, covered offshore waters between the Alaskan coast and 72°N. Distribution, behaviour and numbers of whales were recorded, and procedures were established for monitoring and controlling seismic activities in their presence.

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Introduction

The continental shelf of the western Beaufort Sea has since 1964 been an area of intensive prospecting for oil and natural gas. Most ship-borne survey work associated with prospecting is carried out during late summer and autumn, when the sea is relatively icefree, normally in August and September with occasional opportunities in late July and early October. Waters overlying the shelf are visited each year by whales, including Bowhead whales *Balaena mysticetus* of the Bering-Chukchi-Beaufort Seas or western Arctic stock, which migrate westward across the area from August onward. Bowheads are internationally regarded as endangered and subject to special protection. Concerned that the noises generated by seismic prospecting might adversely affect movements and behaviour of whales, the Minerals Management Service (MMS) of the US Department of the Interior initiated a monitoring and regulating programme in 1981 and 1982. This article describes some of the methods used and results obtained during the second seasons work.

Seismic survey and its regulation

During the period of study (28 August to 4 October 1982) five geophysical survey ships operated between Point Barrow and the Alaska-Yukon border (Figure 1). Their method was to survey predetermined transects, projecting into the water energy pulses, effectively short bursts of sound called 'shots', at intervals of 8 to 15 seconds. The pulses are of very high peak amplitude; source levels have been estimated at 248 decibels, referenced to one micropascal at one meter. Most of the energy content is in the low-frequency range of 5–500 Hz: for comparison, most documented Bowhead sounds are higher, extending from 20 to 4 000 Hz (Ljungblad and others 1982a). These seismic sounds have higher output power than any others associated with offshore oil and gas exploration or development in the Arctic. The ships trailed an array of 12 to 24 airguns 15 to 30 m astern and four to eight m below the sea surface. Sound waves generated by the guns, reflected from submarine formations, were received by hydrophones arrayed along a cable some 3 000 to 3 600 m long, also towed astern; the echoes were converted to digital signals and recorded on magnetic tape for computer processing.

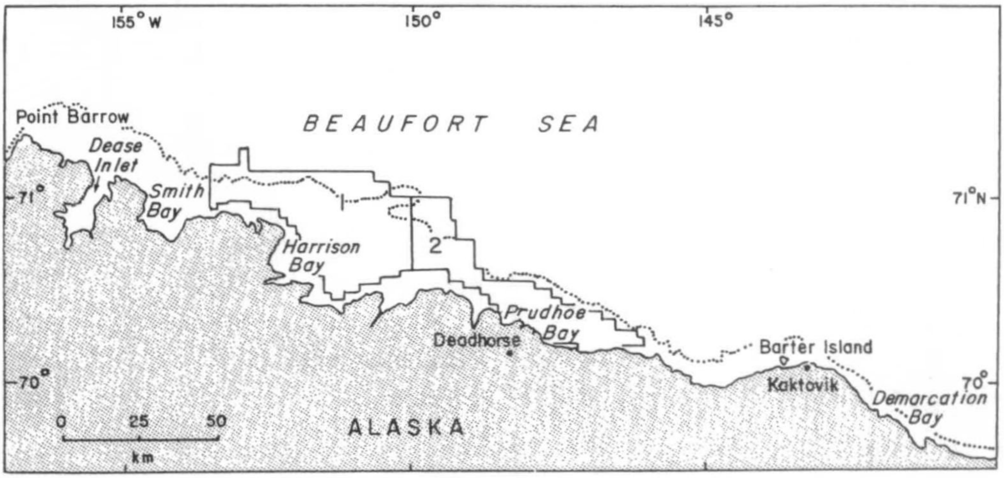

FIG. 1. Study area in the Alaskan Beaufort Sea. Blocks 1 and 2 are lease sale areas; dotted line is the 10-fathom contour.

Geophysical exploration is regulated through 'Permits and Agreements for Outer Continental Shelf Exploration for Mineral Resources', issued by the US Department of the Interior. Under Section 7 of the Endangered Species Act, any proposed action by a federal agency which may affect an endangered species requires consultation with the agency responsible for cetacean management, the National Marine Fisheries Service (NMFS), or with the US Fish and Wildlife Service; lease sales for offshore oil and gas usually involve the NMFS. Consultations by the Bureau of Land Management and US

Geological Survey (agencies that were later partially merged to form the Minerals Management Service, MMS) began formally with the NMFS over Beaufort Sea leases on 30 March 1978. In August 1978 the NMFS concluded that insufficient information was available to decide whether lease sales and resulting exploratory activity might 'jeopardize the continued existence of endangered bowhead and gray whales or result in the destruction or adverse modification of habitat that may be critical to them'.

The NMFS accordingly recommended complete closure of the Beaufort Sea joint sale area (Block 2 in Figure 1) to acoustic geophysical activities between August and October. In summer 1981 this recommendation was modified to allow restricted work to continue into the autumn. Operations were to be suspended east of Prudhoe Bay on 1 September, and west of the bay on 15 September, unless the westward-migrating Bowheads arrived earlier in either area. These dates would be extended only if aerial monitoring was available to assess whale distribution, and to evaluate any possible disruption of the normal migration caused by seismic operations. The most recent NMFS statement before the start of the 1982 season recommended aerial monitoring, and urged that seismic operations be allowed only when Bowhead whales were not likely to be close, or if close, were not being affected by operations. Operators of geophysical vessels were required to 'shut down the seismic sound source' upon being notified that whales within their zone of influence were being disturbed, and to suspend seismic operations whenever Bowheads were sighted from their vessels. Activities could resume only after the whales had left the area. If for any reason aerial observations were suspended once the autumn migration appeared imminent, the estimated speed of migration and time of last sighting would be used to establish a geographic range within which seismic survey operations would stop until flights were resumed. The MMS could also act directly to close areas to seismic survey if, after appropriate consultation, this was judged necessary under Section 7 of the Endangered Species Act.

Methods of monitoring

An amphibious high-wing, twin-turbine aircraft, specially equipped with observation bubbles on both rear doors and a sonobuoy chute, was based at Deadhorse, near Prudhoe Bay, Alaska, with a crew of five. Observation sorties were mostly flown at about 204 km per hour (110 knots), 300 m above sea level, with observers at both observation bubbles; bad weather sometimes forced us to fly lower. As safety and visibility were prime considerations, wind speed and sea state secondary, we occasionally flew when sea surface conditions were suboptimal for detecting and observing whales. Priorities were first to detect any whales that were close to active survey ships, second to observe the behaviour of whales immediately before and after seismic shooting, and third to take general note of whale numbers, movements and behaviour.

Each morning when the weather permitted, after noting the positions and operational status of the survey ships, we flew to the easternmost working ship. Working eastward in search of whales we completed a transect grid covering approximately 1 400 km^2 near the vessel (Figure 2). Continuing eastward as time permitted, we flew similar transects near other ships; working from west to east maximized our chances of intercepting westward-moving whales before they experienced noise from actively-surveying ships. Hydrophones in sonobuoys dropped from the aircraft picked up seismic shots and whale sounds, which were monitored on earphones and recorded. Size, behaviour, spacing, orientation and sounds produced by the whales were also noted on tape, using the terminology of Würsig and others (1982). From 1 August 1982 a second team, engaged

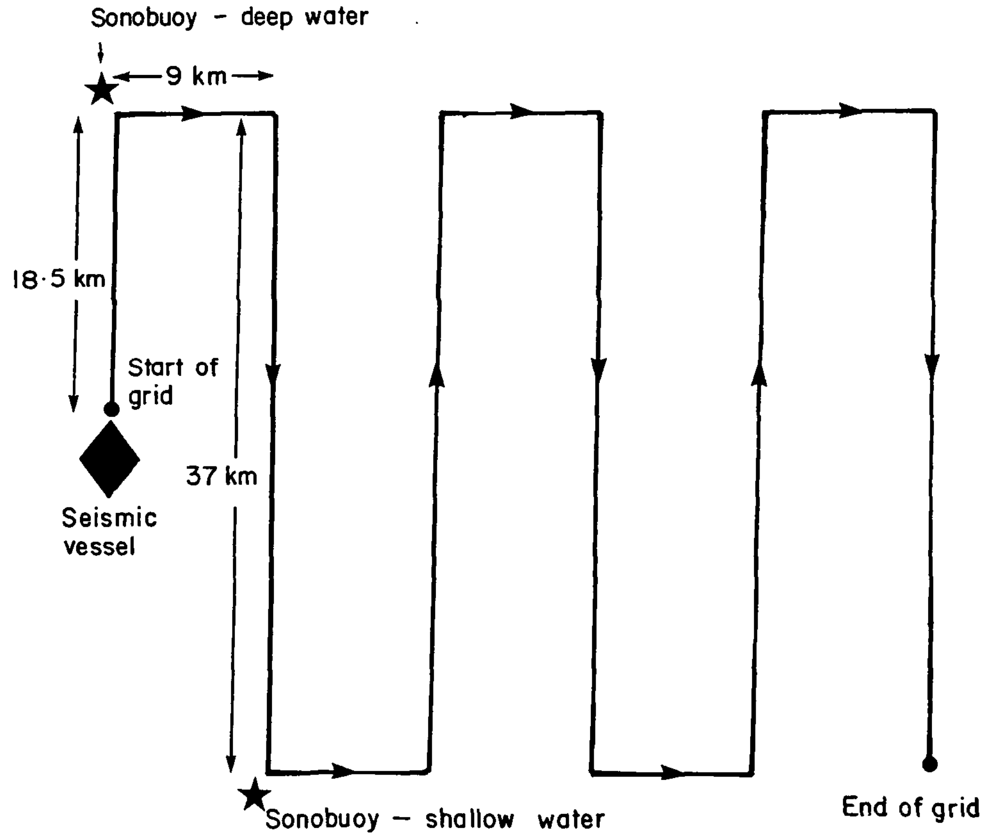

FIG. 2. Grid pattern used to survey areas near geophysical vessels.

in a long-term regional survey of whales and their distribution (Ljungblad 1981; Ljungblad and others 1980, 1982b, 1983), flew a series of broader north-south transects along the Alaskan coast from Point Barrow to the Canadian border, as far north as 72°N or the pack ice edge. From their flights we were given daily reports of Bowhead sightings, which helped us to concentrate our own monitoring efforts.

For statistical purposes three classes of whale were recognized, *calves* by their small size, *cows* by their association with a calf (one half of their own length or less) and *adults* (all other whales). We noted the time spent at the surface by individual whales, numbers and intervals of blows at each surfacing, and length of dives: these were related to distances between individuals, presence or absence of seismic sounds, depth of water and other factors. Water was classed as *deep* (over 15 fathoms, 30 m) or *shallow* (anything less). Whales were *interacting* if they swam within one whale-length (about 15 m) of each other, *non-interacting* if at a greater distance. An observation was scored as *seismic* only if repeated seismic shots were detected through a sonobuoy.

Parametric (Student's t) and nonparametric (Wilcoxon T or Mann-Whitney U) two-sample tests were used to evaluate differences in behavioural variables between dichotomous conditions (seismic vs. nonseismic, deep vs. shallow, interacting vs. noninteracting) and among classes of whales (adults, cows, calves). Sample sizes were in many comparisons too small to determine normality of distribution, so both parametric and nonparametric test results were considered; Würsig and others (1982) found dive times to be highly skewed and thus applied only nonparametric tests to their dive-time data. The principal null hypothesis was that seismic shots and related sounds made no difference to any of the four noted aspects of Bowhead behaviour. Corresponding null hypotheses were tested for other dichotomous conditions and for each class of whale. Some of the findings from these observations appear in Table 1.

Area closures

Although more ships were present in the Alaskan Beaufort Sea in 1982 than had been available to acquire data in all previous years (with the possible exception of 1981), fewer seismic data were collected. This was due partly to bad ice conditions early in the season and partly to the number of closures required by the presence of Bowhead whales late in the season. Operations were closed in all US waters east of Barter Island between 7 August and 9 September; thereafter closures were announced for different blocks on 13, 15, 17, 20 and 25 September. It had been agreed in 1981 that after 1 September, if no monitoring flights were made east of Prudhoe Bay during any 48 hour period, seismic surveys would be suspended until flying recommenced. A similar limit of 72 hours applied west of Prudhoe Bay. This suspension procedure was invoked twice during September 1981, one flight being delayed by maintenance problems and the other by weather; in both instances seismic survey began again once the flights were resumed. In 1982 the presence of a second aircraft reduced the need for such restrictions. Survey flights in 1982 included offshore areas not covered in previous years (Ljungblad and others 1983). One result was an early Bowhead sighting on 2 August, 83 km north of Barter Island. More were seen north of Demarcation Bay between 2 and 8 August, and these sightings were interpreted as an early start to migration. Alaskan waters east of Barter Island were accordingly closed to seismic operations from 7 August. East of Barter Island restrictions were lifted on 9 September, though the survey companies were told that some inshore areas remained closed after that date. The presence of whales caused further restrictions in some sectors between 13 and 25 September. Thereafter only a few transects planned for seismic testing remained uncompleted outside the closed areas; two vessels continued operations after 28 September, but ice brought work to a standstill about 2 October, four days later than in 1981.

Summary of results

Between 27 August and 3 October, we made 34 survey flights. Bowhead whales were sighted on 14 flights, and approximately 18 hr 46 min were spent in behaviour observations. Sixteen grid transects were begun near geophysical vessels and 10 completed. Nine sightings of whales were made during the grid surveys; most whales were seen as we flew to or from the ships, or in searching specific areas where experience showed Bowheads might be expected.

Throughout September the pack ice edge remained at least 150–200 km offshore. The study area was usually ice-free; an exception was fragments of grounded ice in shallows near the coast, which sometimes interfered with the survey ships but had no discernable effect on movements or behaviour of whales. The first whales seen in the area were reported from our companion aircraft on 8 September, in 71° 34′ N, 145° 37′ W. Our own first sighting was on 14 September in 70° 12′ N, 144° 37′ W, directly west of Barter

Table 1. Surfacing, respiration and diving patterns of Bowhead whales; some comparisons.

	Mean	Standard deviation	Number seen	Nonparametric z	Nonparametric p	t	Parametric df	p
Intervals between blows (seconds)								
All interacting adults	12.01	2.83	31	−2.10	< .036	2.464	112	< .02
All non-interacting adults	13.67	4.02	82					
All interacting cows with calves	15.23	6.50	15	−2.53	< .011	2.672	19	< .02
All non-interacting cows with calves	10.74	.23	5					
Number of blows per surfacing								
All adults	7.18	3.33	80	2.48	< .013	2.638	96	< .01
All cows with calves	8.41	1.18	17					
All adults: no seismic sounds	6.87	3.14	30	1.51	< .131	2.782	34	< .01
All cows with calves: no seismic sounds	8.60	.55	5					
Time spent at the surface (minutes)								
All adults: seismic sounds	1.67	.85	59	−1.51	< .131	1.988	89	< .05
All adults: no seismic sounds	1.36	.59	31					
All adults: deep water	1.77	.81	48	−2.65	< .008	2.867	89	< .01
All adults: shallow water	1.33	.67	42					
All adults	1.56	.78	90	2.14	< .032	2.077	107	< .05
All cows with calves	1.87	.51	18					
All cows with calves: no seismic sounds	1.75	.29	5	1.74	< .082	2.282	35	< .05
All adults: no seismic sounds	1.36	.59	31					
All interacting cows with calves	2.00	.50	14	−2.34	< .019	3.369	17	< .01
All non-interacting cows with calves	1.41	.22	4					
Length of dives (minutes)								
All adults	7.09	4.14	20	2.96	< .003	3.228	35	< .005
All cows with calves	12.11	4.99	16					
All adults: seismic sounds	7.57	4.55	20	2.58	< .010	2.998	22	< .01
All cows with calves: seismic sounds	13.65	4.87	16					

Island. We saw no steady, determined westerly movement until 28 September, but a general westward trend, consistent with observations from previous seasons, was noted from the second week of September onward. Our last Bowhead was seen on 2 October while we were monitoring noise made by construction work at Tern Island, in outer Prudhoe Bay; this was a solitary whale seen north of the barrier islands, swimming rapidly westward in 70° 29′ N, 147° 26′ W, and Bowhead sounds were heard several times from sonobuoys near the island. Our study ended on 4 October when all the ships had docked or left the Beaufort Sea for the winter.

Behaviour observations

We watched behaviour for long periods on six days (14, 15, 17, 23, 24, and 25 September) of good sighting conditions. Whales were concentrated in water 15 to 40 m deep; single animals and groups of two to 14 were seen, with at times 20 or more loosely aggregated within a radius of 8–10 km. Apart from associations between cows and calves, we saw no direct physical interactions which could be interpreted as boisterously social or sexual, though groups of 2–5 whales were often seen swimming together, surfacing synchronously and occasionally touching, usually snout to snout or snout to tail. Most of the whales we saw seemed to be travelling slowly, resting or feeding. As late as 28 September, when some whales were moving more rapidly westward, we saw in one group what we interpreted as feeding behaviour. Combined with evidence from stomach contents of whales killed in September and October by Kaktovik whalers (Marquette and others 1982), this suggests that Bowheads migrating through the western Beaufort Sea may be feeding and searching for food as late as the end of September and, in some years, into early October.

One possible behavioural response to seismic shooting was seen. On 14 September about 18 Bowheads were noted within a radius of 2–3 km, initially singly or in scattered groups of up to seven. Some were surfacing synchronously, others not; they did not appear to be oriented in any particular direction. A geophysical vessel about 33 km away was not shooting at that time. After half an hour seismic shooting began, continuing for more than an hour. During the shooting the whales gathered gradually into a single close concentration of 12–14 individuals (Figure 3), with four to six others within 1 km. Those in the group surfaced and dived almost synchronously, remaining submerged on average for 10–12 minutes and surfacing for 4–5 minutes; because they were so tightly bunched we had difficulty determining precise times for individuals. At the surface they huddled closely, often touching, with snouts tending to converge. They emitted sounds intermittently. Due to refuelling requirements we had to leave after 1 hr 40 min of observation. On this occasion huddling appeared as a possible response to seismic shooting, though we once saw it with fewer animals when there was no shooting.

Quantitative results

Some comparisons of behaviour patterns for which statistical testing shows significant differences between our categories of animals appears in Table 1. Providing an indication of normal behaviour in the absence of disturbance, our results suggest that cows accompanied by calves blow more frequently at surfacing, dive for longer and remain at the surface for longer than 'adults' (whales unaccompanied by calves). 'Adults' generally remain longer at the surface in deep water than in shallow, a pattern noted also by Würsig and others (1982). Relevant to our interest in the effects

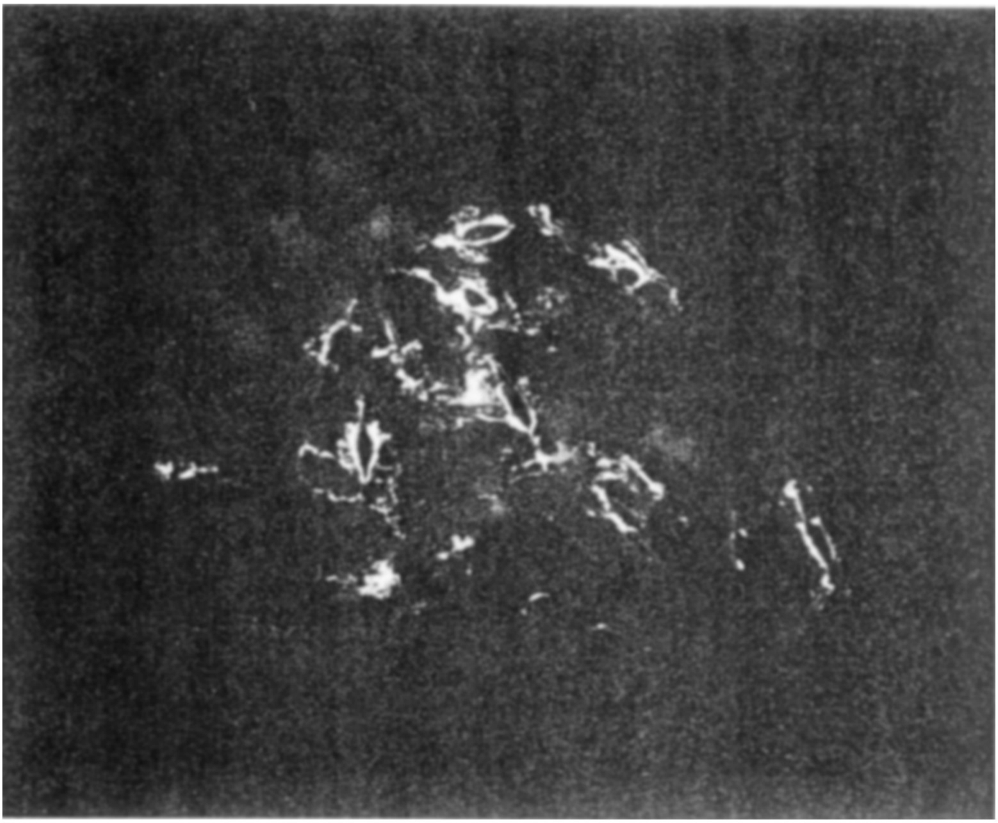

FIG. 3. A group of 12–14 Bowhead whales at 70° 11′ N, 144° 37′ W, in the Alaskan Beaufort Sea, 14 September 1982.

of seismic noise, we note that 'adults' appear to spend significantly longer at the surface when in the presence of seismic sounds. This indication, though contrary to that of Fraker and others (1982), is reinforced particularly by our observations of 24 September, when we had opportunity to watch the same group of whales before and after seismic shooting began.

Discussion and conclusions

Like that of Fraker and others (1982), this study relied on changes of behaviour and other parameters as possible indicators of disturbance. In the absence of experimental control over the sources of potential disturbance, however, we could never be completely certain that observed changes were causally related to particular stimuli; we could not, for example, ask operators to start or stop shooting in order to test whale responses. Nor could we account for the potential effects of such factors as prey distribution and density, water characteristics, and stage of migration. A further factor limiting our work was the progressive closing of areas to seismic operations as the whales moved in; monitoring and reconnaissance aspects of our mission necessarily took precedence over behavioural research. Our observations therefore need to be interpreted with caution. We interpreted huddling, for example, as a possible response to the onset of seismic noise; for other observers the disturbance caused by approaching ships has elicited the opposite reaction, an increase in inter-individual distance (Fraker and others 1982). Ljungblad and others (1983) noted that Bowheads sometimes appear to react to a low-flying aircraft by orienting head-to-head in close formation. It is still speculative to regard huddling as a specific response to acoustic stimuli, though it may serve some social purpose in the presence of an unfamiliar noise. Further studies are needed before this aspect of Bowhead behaviour can be regarded as reliably interpreted.

The question of habituation is especially important in the context of disturbance; are whales likely to become used to the presence and noises of seismic survey vessels? There is ample evidence that some wild ungulates habituate to certain kinds of disturbance, particularly repetitive and predictable ones. Fraker and others (1982) have suggested that Bowheads react to the novel stimulus provided by the start-up of seismic pulses, then habituate and resume activities. Our scheduled work did not permit us the observations that might have shed light on this question; in view, however, of the costs of suspending seismic survey operations when whales are about, this is undoubtedly a most relevant question to be addressed by future observers.

No less important is the question of whether disturbance of the kind that we and other observers have witnessed is harmful to the whales. Most studies of wild ungulates under human disturbance imply a tacit assumption that the animals' responses must necessarily prove detrimental to the stock, though they have rarely been linked to changes in reproduction, survival or any other demographic parameters (Ferguson and Keith 1982). While it may be desirable to avoid causing discomfort or annoyance to individual animals, it is important indeed to avoid interference with their numerical abundance and physical condition. Difficulties of studying free-ranging Bowhead whales make even baseline data on their demography, physiology and behaviour a challenge to collect and interpret. Physiological monitoring under controlled conditions is at present barely possible; the hearing capabilities of Bowheads have not been studied. Population parameters and factors influencing year-to-year distribution are little known, and changes favourable or adverse will be difficult to detect with any precision. If changes were suspected, it could still be impossible to identify or isolate a specific cause from the many possible candidates, which include (in addition to seismic operations) Eskimo whaling, tanker traffic, drilling noises, industrial support activities and oil spillage; all these, individually or cumulatively, may adversely affect the Bowhead population (Geraci and St. Aubin 1980; US Department of the Interior 1982). In this context our own results, suggesting some proximate changes in Bowhead behaviour relating to seismic sounds, may be considered useful as an indication of the need for further, more critical studies.

Acknowledgements

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References

FERGUSON, M. A. D. and KEITH, L. B. 1982. Influence of nordic skiing on distribution of moose and elk in Elk Island National Park, Alberta. *Canadian Field Naturalist*, 96(1): 69–78.

FRAKER, M. A., RICHARDSON, W. J., and WÜRSIG, B. 1982. Disturbance responses of bowheads. In RICHARDSON, W. J. (editor). *Behavior, disturbance responses and feeding of bowhead whales* Balaena mysticetus *in the Beaufort Sea*, 1980–81. Washington, US Bureau of Land Management: 145–248.

GERACI, J. R., and ST. AUBIN, D. J. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. *Marine Fisheries Review*, 42(11): 1–12.

LJUNGBLAD, D. K. 1981. *Aerial surveys of endangered whales in the Beaufort Sea, Chukchi Sea, and northern Bering Sea. Final Report: Fall* 1980. Prepared for US Bureau of Land Management. (Naval Ocean Systems Center Technical Document 449).

LJUNGBLAD, D. K., MOORE, S. E. and VAN SCHOIK, D. R. 1983. *Aerial surveys of endangered whales in the Beaufort, eastern Chukchi, and northern Bering seas*, 1982. Prepared for US Minerals Management Service (Naval Ocean Systems Center Technical Document 605).

LJUNGBLAD, D. K., MOORE, S. E. VAN SCHOIK, D. R. and WINCHELL, C. S. 1982b. *Aerial surveys of endangered whales in the Beaufort, Chukchi, and northern Bering seas. Final report: April-October* 1982. Prepared for US Bureau of Land Management. (Naval Ocean Systems Center Technical Document 486).

LJUNGBLAD, D. K., THOMPSON, P. O., and MOORE, S. E. 1982a. Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979. *Journal of the Acoustical Society of America*, 71(2): 477–482.

LJUNGBLAD, D. K., PLATTER-REIGER, M. F. and SHIPP, F. S., Jr. 1980. *Aerial surveys of bowhead whales, North Slope, Alaska. Final Report: Fall* 1979. Prepared for US Bureau of Land Management. (Naval Ocean Systems Center Technical Document 314).

MARQUETTE, W. M., BRAHAM, H. W., NERINI, M. K., and MILLER, R. V. 1982. Bowhead whale studies, autumn 1980–spring 1981: Harvest, biology and distribution. *International Whaling Commission Reports*, 32: 357–370.

US DEPARTMENT OF THE INTERIOR. 1982. *Final Environmental Impact Statement. May* 1982. *Proposed Outer Continental Shelf Oil and Gas Lease Sale* 71, *Diapir Field*. Anchorage, Bureau of Land Management, Alaska Outer Continental Shelf Office.

WÜRSIG, B., CLARK, C. W., DORSEY, E. M., FRAKER, M. A. and PAYNE, R. S. 1982. Normal behavior of Bowheads. In RICHARDSON, W. J. (editor). *Behavior, disturbance responses and feeding of bowhead whales* Balaena mysticetus *in the Beaufort Sea*, 1980–81. Washington, US Bureau of Land Management: 33–143.