

**BEHAVIOR, DISTURBANCE RESPONSES AND DISTRIBUTION  
OF BOWHEAD WHALES Balaena mysticetus  
IN THE EASTERN BEAUFORT SEA, 1983**

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PROJECT RATIONALE, DESIGN AND SUMMARY, 1983\*

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## INTRODUCTION

The bowhead whale, Balaena mysticetus, inhabits cold northern waters. All populations were exploited heavily by commercial whalers in the 18th or 19th centuries, and all were seriously reduced. Bowheads are considered endangered under U.S. legislation.

Bowheads of the Western Arctic population, the one group occurring in U.S. waters, winter in the Bering Sea, summer in the eastern Beaufort Sea, and migrate around western and northern Alaska in spring and autumn (Fig. 1, inset). The size of this population was much reduced by intensive commercial whaling between 1848 and 1914 (Bockstoce and Botkin 1983). The extent of the summer range was apparently also much reduced (Dahlheim et al. 1980; Fraker and Bockstoce 1980). A subsistence harvest continues annually in Alaska. The International Whaling Commission's current 'best estimate' of the stock size is 3857 individuals (I.W.C. 1983).

The spring migration of Western Arctic bowheads is close to shore in the Chukchi Sea, but well offshore in the Alaskan Beaufort Sea (Braham et al. 1980, 1984; Ljungblad et al. 1982a). Thus, the eastward spring migration through the Alaskan Beaufort Sea in April-June is well north of the area of oil exploration near the coast. However, during the westward autumn migration in August-October, many bowheads occur close to shore, within or near some offshore oil leases (Ljungblad et al. 1982a; Braham et al. 1984).

From May to early September, the great majority of the Western Arctic bowheads are in Canadian waters (Fraker 1979; Fraker and Bockstoce 1980; Davis et al. 1982). Intensive offshore oil exploration began several years earlier in the Canadian part of the Beaufort Sea than in the Alaskan portion. Offshore drilling from drillships and artificial islands has been underway in the central part of the summering area since about 1976. Seismic exploration and nearshore drilling began there earlier and still continue. The main area of offshore drilling is north of the Mackenzie Delta and the western Tuktoyaktuk Peninsula (Fig. 1). Summering bowheads are sometimes common in and around that area (Richardson et al. 1983a).

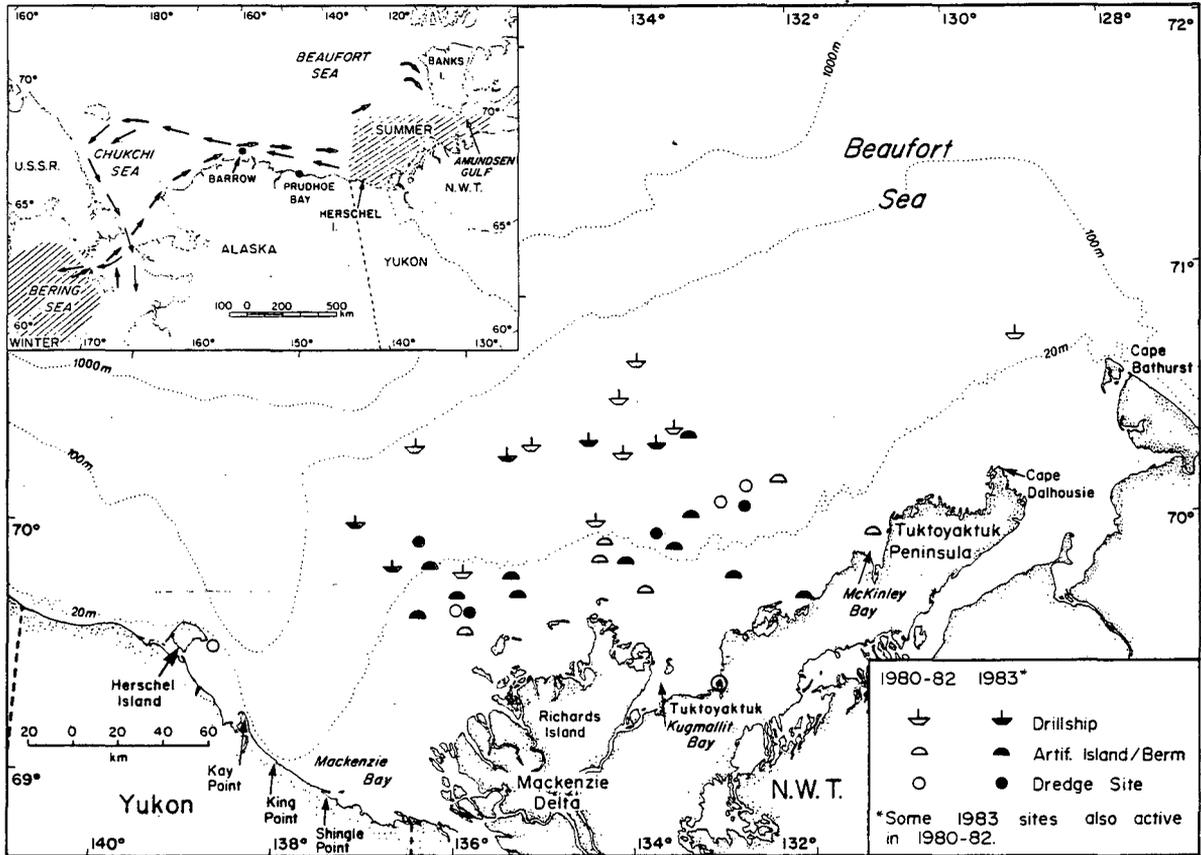


FIGURE 1. The eastern Beaufort Sea—study area for this project—showing the main sites of offshore industrial activity in August and early September 1983 (solid symbols) and 1980-82 (open symbols). Some of the 1983 sites were also active in 1980-82. **Inset:** Generalized pattern of seasonal movement of the Western Arctic population of bowhead whales.

## POTENTIAL FOR DISTURBANCE

The scientific literature contains some descriptions of the reactions of baleen whales to boats, aircraft, drillships, and other activities associated with offshore oil exploration. However, there have been few detailed or controlled studies of these reactions. Controlled studies are especially desirable because whale behavior is quite variable. In the absence of experimental control, it is difficult to determine whether a change in behavior is 'natural' or a response to some human activity. Long-term effects of offshore industrial activities on whales are even more difficult to study. The literature on these topics has been reviewed recently by Fraker and Richardson (1980), Geraci and St. Aubin (1980), Acoustical Society of America (1981), Gales (1982), Malme et al. (1983), and Richardson et al. (1983b).

Noise is one attribute of offshore oil exploration and development that may affect whales. Unlike major oil spills, noise is an ongoing component of normal offshore operations. Noise is introduced into the sea by most of the offshore activities associated with the oil industry, including boat and aircraft traffic, seismic exploration, dredging and drilling (Acoustical Society of America 1981; Greene 1982, 1983; Richardson et al. 1983b). Many of the sounds produced are at rather low frequencies (below 1000 Hz). This is the frequency range of most bowhead calls (Ljungblad et al. 1982b; Würsig et al. 1982). Hearing sensitivity of baleen whales has not been measured, but the predominance of low frequency calls (Thompson et al. 1979) plus anatomical evidence (Fleischer 1976) suggest specialization for detecting low frequencies.

Sound, unlike light, can propagate long distances through water (Payne and Webb 1971; Urlick 1975). With calm to moderate sea states, noise from boats, dredging and drilling is readily detectable by instruments, and probably by bowheads, at ranges of several kilometres or more (Greene 1982, 1983). Noise from seismic exploration in open water is much more intense, and often detectable at ranges of several tens of kilometres (Ljungblad et al. 1980, 1982a; Greene 1982, 1983; Reeves et al. 1983). It is probable, therefore, that bowheads detect noise from offshore oil exploration and other

offshore industrial operations at rather long distances--much longer than the distances to which vision or other sensory modalities could detect the industrial activity.

Within the often-large area around industrial activity where a bowhead could detect industrial noise, there is the potential for disturbance. This could take at least four interrelated forms: disruption of normal behavior, displacement (short- or long-term), physiological stress, or masking of natural sounds. The potential negative effects of these types of disturbance were discussed at length in the reviews cited above.

The importance of interference with detection of natural sounds is perhaps the least obvious of these types of potential disturbance. Increased noise levels reduce signal to noise ratios and, consequently, the range at which the sound signal becomes undetectable. Calls by baleen whales seem important for communication, sometimes over distances of kilometres (e.g. Tyack and Whitehead 1983; Watkins 1981). Increased noise levels at frequencies similar to those of the calls will reduce the distances over which the calls can be detected. Detection of other environmental sounds may also be important to bowheads. For example, noise from ice or breaking waves may be important in finding open water within areas of heavy ice. Industrial noise may reduce the range to which bowheads can detect such noises, and consequently may delay whale movements in the presence of ice, or even increase the probability of entrapment by ice.

#### **APPROACH IN THIS STUDY**

Because of the endangered status of the bowhead whale, U.S. regulatory agencies were required, before permitting offshore hydrocarbon exploration in Alaskan waters, to assess whether that exploration would harm bowheads. After consultation among the responsible agencies, it was decided that there was insufficient information to determine the degree of jeopardy. Hence, research concerning the acoustic and non-acoustic effects of offshore hydrocarbon activities on bowheads was deemed necessary.

### Objectives and Tasks

As part of its response, the U.S. Department of the Interior (USDI) awarded LGL Ecological Research Associates, Inc., a contract to investigate various aspects of potential industrial disturbance. This report includes our results from 1983, the fourth year of the study. Results from 1980-81 and from 1982 appear in Richardson (1982, 1983). The work was done for two branches of USDI -- the Bureau of Land Management in 1980-81, and the Minerals Management Service in 1982-83. Besides examining bowhead behavior in the (1) presence and (2) absence of disturbance, we have also studied (3) the characteristics of the underwater noise from offshore industrial activities, (4) the distribution of bowheads in relation to industrial activities, and (5) the zooplankton in areas where bowheads did and did not feed. All five tasks were considered important in assessing the effects of offshore hydrocarbon exploration on bowhead whales. The rationale for each task was discussed in Richardson (1982, 1983).

Fieldwork in 1983 involved continued work on all tasks except zooplankton:

1. Disturbance responses: Priority was to be placed on disturbance experiments involving noise from seismic exploration, drilling, helicopters and dredging. In practice, it was possible to conduct an airgun experiment, drillship and dredge noise playback experiments, aircraft overflights at different altitudes, and one boat disturbance trial. We were also able to observe bowhead behavior in the presence of seismic noise and near offshore industrial sites.
2. Studies of normal behavior were assigned low priority in 1983, but considerable additional information was obtained because such observations are often possible when circumstances do not permit studies of reactions to industrial operations.
3. Characteristics of the industrial noises to which bowheads were exposed in 1983 were analyzed.
4. Distribution of summering bowheads in relation to industrial activities was determined by combining our observations during this behavioral study with results from three other bowhead studies conducted in the eastern Beaufort Sea in 1983.

Limited studies of zooplankton at locations where bowheads did and did not feed were conducted as part of this project in 1980-81 (Griffiths and Buchanan 1982) but not in 1982-83.

### Study Area

The study area has been the same in each year of the study: the southeastern Beaufort Sea, including the area of offshore oil exploration and surrounding waters to the west, north and east (Fig. 1). Observation sites were between 127°W and 141°W, and from the shore to 190 km offshore. The study period each year has been from late July or early August to late August or early September. This area and season were chosen (1) to take advantage of summer weather, light and ice conditions, (2) because bowheads travel less and thus are easier to study when feeding in summer than when migrating in spring or autumn, and (3) because this is the part of the bowheads' range where offshore oil exploration is furthest advanced. The presence of extensive offshore oil exploration provided opportunities for observation that did not exist in the Alaskan Beaufort Sea.

The eastern Beaufort Sea is largely ice covered from October to June, but by July there is usually open water south and east of a line from Herschel Island northeast to Banks Island (Fig. 1). However, wind shifts can blow much ice back into this area at any time. Most of our work was on whales in open water, but some was near or in pack ice. In most parts of the study area, water depths increase very gradually out to the shelf break near the 100 m contour, and then increase more rapidly to >1000 m (Fig. 1). The 100 m contour varies from 15 to 150 km from shore.

Bowhead distribution in summer is variable within and between years. Whales occur in both open water and pack ice, both beyond the shelf break and in water as shallow as 10 m (Fraker and Bockstoce 1980; Richardson et al. 1983a). August and early September are times of peak abundance in shallow areas. Feeding, socializing and travelling are the main activities.

Offshore drilling in the eastern Beaufort Sea began in 1972, initially from artificial islands built in a few metres of water off the Mackenzie River Delta, but after 1976 in deeper water. Each summer from 1976 to 1983, three to five drillships operated inside the 100 m contour, and artificial islands and caissons for drilling were completed in waters as deep as 31 m

(Fig. 1). Dredges were widely used in constructing islands. By 1983, five drillships, six seagoing dredges, ten helicopters and many support vessels were in use offshore. Offshore seismic exploration occurs in the study area each summer. At most times in recent open water seasons, two or three seismic boats using airgun arrays or other high-energy noise sources have operated in the eastern Beaufort Sea. Each seismic boat produces an intense noise pulse every 6-15 s.

### Approach and Logistics

The general approach in 1983 was similar to that in 1980-82. Whenever possible, we conducted experimental tests of reactions of bowheads to industrial activities. In these tests, we compared behavior of a specific group of bowheads before, during and after exposure. This method is more sensitive than uncontrolled observations of some whales in the presence of the industrial activity and others in its absence. Many factors aside from industrial activity may differ between groups of whales observed at different places and times. However, the uncontrolled observations were also of interest. For example, they showed that some bowheads approached full-scale industrial sites that could not be simulated adequately during experiments. Behavior of undisturbed bowheads was studied before and after disturbance experiments, and on other occasions when experiments were not possible.

Logistic support in 1983 consisted of observation aircraft and the same 12.5-m boat (MV 'Sequel') used in 1981-82. Two aircraft were used: a Twin Otter on 1-12 August and an Islander on 14 August-1 September. Most behavioral observations were from the aircraft. The aircraft crew also dropped sonobuoys to record underwater sounds from industrial sources and bowheads. The main functions of the boat were to conduct disturbance experiments and to record underwater sounds. Both the boat and the aircraft crew were based at Tuktoyaktuk, N.W.T., as in past years.

Shore-based observations were attempted at Herschel Island and King Point (Fig. 1) in 1980-81 but not in 1982 or 1983. Many whales had been seen near King Point in 1976 (W.R. Koski in Fraker and Bockstoce 1980), but virtually none were there in 1980-82. As events developed, 1983 proved to be the one year when shore-based observers could have collected valuable data on

disturbance responses of bowheads. Bowheads occurred at King Point in mid and late August 1983, and much of our aircraft- and boat-based work was in this area.

In last year's report, we analyzed the distribution of summering bowheads during 1980-82 relative to industrial activities in those years (Richardson et al. 1983a). (Systematic information about bowhead distribution in the eastern Beaufort Sea was not obtained before 1980.) The objective of the analysis was to assess whether there was any evidence of long-term displacement of bowheads from the area of oil exploration. It was recognized that a 3-yr series of data beginning after offshore oil exploration began would probably be inconclusive, and this was in fact the case. Whales became progressively less common in the main industrial area from 1980-82, but this could have been attributable either to disturbance or to natural variation.

In 1983, this study plus three other investigations (McLaren and Davis 1984; Cabbage et al. 1984; D.K. Ljungblad pers. comm.) provided data on the distribution of bowheads summering in the eastern Beaufort Sea. One objective of this study was to draw together the distributional information arising from all four studies. The combined evidence about bowhead distribution was compared with the distribution of industrial activities in 1983, and with the 1980-82 results.

#### **SUMMARY OF RESULTS**

This section consists of slightly amended versions of the Abstracts from the following four self-contained sections of this volume. Readers planning to read the Abstracts later in the volume may wish to skip this section.

##### **Normal Behavior of Bowheads, 1983**

The report with the above title (Würsig, Dorsey, Richardson, Clark, Payne and Wells 1984) describes the 'undisturbed' behavior of bowhead whales summering in the southeastern Beaufort Sea. The emphasis is on the 1983 results, but the report contains considerable integration of results from 1980-83. Detailed accounts of results from 1980-81 and 1982 appear in Würsig et al. (1982, 1983).

Behavior of bowhead whales was observed from an aircraft during 15 of 28 flights in the period 1 August to 1 September 1983, mainly near shore in the Beaufort Sea between Herschel Island (Yukon Terr.) and Richards Island (Northwest Terr.), Canada. Detailed behavioral observations were made while we circled over whales for 38.4 h. Bowheads were 'presumably undisturbed' during 37.0% of the observation time (14.2 h), and these observations of 'normal behavior' are described in the present report. This represents the fourth consecutive year of detailed behavioral observations of bowhead whales in the eastern Beaufort Sea in summer. Methods were similar during all four years.

During most flights in 1983, bowheads were observed near shore in water 5-35 m deep. Whales dove for brief periods, socialized often, and--at least after mid August--spent time skim-feeding at the surface or apparently feeding near the bottom. These behaviors were somewhat similar to behaviors seen in shallow water in 1980 and 1981. Behavior in 1983 differed from that in 1982, when whales spent most time apparently feeding in the water column in water >100 m deep.

Social interactions--nudges, pushes, chases, and close proximity--were observed at a rate similar to that in 1981, less than that in 1980, and greater than that in 1982. The rate of social activity in 1983 up to and including 18 August was higher than after this date. This decrease in late August was consistent with data from 1980 and 1981 (with too little information on socializing in 1982 for analysis). There was no consistent relationship between rate of socializing and depth of water. As in previous years, socializing whales tended to turn while at the surface more frequently than did non-socializing whales. We observed no apparent mating in 1983. However, during one flight groups of whales interacted with each other by rolling and nudging in a fashion similar to that seen in mating groups of bowhead whales in spring and right whales in winter. On 31 August, two whales repeatedly slapped each other with their pectoral flippers and flukes, and this observation represented the most obviously aggressive interaction we have noted in four seasons.

We saw 347 underwater blows in 1983, including both 'presumably undisturbed' and 'potentially disturbed' whales. The rate of underwater blowing was positively correlated with the rate of socializing. This suggests that underwater blows are in some manner linked to social behavior. However, we do not know whether underwater blows represent aggression, as believed in southern right whales, or whether they have some other function.

Aerial activity occurred sporadically, and included brief bouts of tailslaps, flipper slaps, and/or breaches. However, on 22 August, we observed two longer bouts lasting about 12 min and 75 min. The latter was the longest uninterrupted bout of aerial activity seen in four years of observations.

As in earlier years, some whales were recognizable by distinctive features such as unusual white pigmentation, or scars and marks on the back. This allowed us to identify individuals for up to several hours. We obtained no known resightings on different days. In 1983, few whales near shore had distinctive white chin patches or patches of white on the tail or tail stock, and a sample of about 20 of these whales that we measured via photogrammetry

were only 7-12 m long. Thus, most whales near shore were yearlings and older subadults.

The mean blow interval for presumably undisturbed non-calves in 1983 was  $17.0 \pm \text{s.d. } 13.49$  s,  $n = 866$ , which was significantly higher than combined data for 1980-1982. Number of blows per surfacing and duration of surfacings were significantly correlated, as in previous years. Mean number of blows per surfacing for non-calves was  $3.2 \pm \text{s.d. } 2.37$  blows,  $n = 229$ ; and mean surface time for non-calves was  $1.05 \pm 1.484$  min,  $n = 248$ . These values were much lower than those for 1982, but not significantly lower than those for 1980 and 1981. The mean dive time for non-calves was  $1.88 \pm 2.357$  min,  $n = 140$ , shorter than in any of the three previous years.

Several factors were related to surfacing-respiration-dive characteristics. Durations of surfacings and number of blows per surfacing were longer for socializing whales than for non-socializing whales. Blow intervals of skim-feeding whales averaged more than twice as long as for non-feeding whales. Mean duration of surfacing, number of blows per surfacing, and proportion of time at the surface were higher in skim-feeders than in others, while mean duration of dives was slightly lower for skim-feeders than for others. Blow rates, however, were approximately equal for skim-feeders and other whales.

Only 4 or 5 calves were seen in 1983, all in water  $>1000$  m deep on 7 August. Two calves interacted at the surface for at least 5 min. This represents our only observation in four years of apparent play between calves. One apparent subadult associated with a mother-calf pair for at least 40 min. Because we sighted calves only in deep water far north of Herschel Island and not with the many small whales close to shore in 1983, we surmise that the population was at least partially segregated into (1) mature animals, including females and calves, far offshore and perhaps in other areas not searched by us, and (2) subadult whales near the Yukon shore.

Sounds of bowheads were analyzed from 33.7 h of sonobuoy recordings (11.0 h from presumably undisturbed whales). The types of sounds recorded were no different from previous years, and, as in previous years, the majority of sounds (85%) were tonal, frequency modulated calls lasting 1-2 s. Most loud pulsive calls were heard during socializing, consistent with results from 1980-1982. Blow sounds were associated with periods of much underwater blowing, and slap sounds occurred during periods with aerial behavior, especially on 22 August.

We have observed considerable year-to-year variation in the distribution and behavior of bowhead whales from 1980 to 1983. Aside from the aforementioned relationship between activities and water depth, no consistently repeating pattern is discernible. A consideration of year-to-year variations in the distribution and behavior of other cetaceans demonstrates that variations in distribution and abundance of prey species may often be responsible.

Disturbance Responses of Bowheads, 1983

The report with the above title (Richardson, Wells and Würsig 1984b) describes the behavior of bowhead whales in the presence of actual or simulated industrial activities. The report presents the 1983 data in detail, with some integration of results from 1980-83. The 1980-82 results were given in detail by Fraker et al. (1982) and Richardson et al. (1983c).

Studies of the behavioral responses of bowhead whales to offshore oil and gas exploration were conducted in the Canadian Beaufort Sea from 1 August to 1 September 1983. This study, on behalf of the U.S. Minerals Management Service, was a continuation of similar studies in the same area in late summer during 1980-82. The general objective was to assess short-term behavioral responses of bowheads to noise and other stimuli associated with boat and aircraft traffic, seismic exploration, dredging and drilling. In 1983, we emphasized reactions to aircraft, seismic exploration and drilling, but also collected data on reactions to boats and dredging.

Methods in 1983 were very similar to those in previous years. Both experimental and opportunistic methods were used. During experiments, we tried to observe whales before, during and after simulated industrial activity. In 1983, we conducted the following disturbance experiments: 3 aircraft, 1 boat, 1 airgun, 3 drilling noise playbacks, and 1 dredge noise playback. We also observed whales opportunistically in the presence of aircraft at low altitudes, seismic exploration, a drillship, and a dredge; we compared behavior in these circumstances with behavior in the absence of potential sources of disturbance. Most observations were from an Islander or a Twin Otter aircraft circling at altitudes of 457 or 610 m (1500 or 2000 ft). Underwater sounds from whales and industrial sources were recorded via sonobuoys dropped from the aircraft and via hydrophones deployed from a boat. The boat was also used to conduct the boat, airgun and playback experiments.

Reactions to aircraft were evaluated mainly by assessing responses to the Islander observation aircraft. New information in 1983 included (1) three experiments in which we circled above the same group of whales at two different altitudes, and (2) subjective interpretation of apparent reactions to the aircraft. Although no controlled experiments with helicopters were possible, we twice observed bowheads while a helicopter flew at low altitude over the whales.

As in 1980-82, reactions to the observation aircraft were conspicuous when it was below 457 m above sea level, occasional at 457 m, and undetectable at 610 m. However, the responses of some whales to the aircraft circling at 457 m seemed more marked in 1983 than in earlier years, possibly because of lower ambient noise levels and/or greater lateral propagation of aircraft noise in the shallow water where most 1983 observations were obtained. During 1 or 2 of 3 experiments when the aircraft circled at two altitudes, mean blow interval was shorter, mean number of blows per surfacing lower, and mean duration of surfacings shorter when the aircraft was at 305 m than when it was at 457 or 610 m. Considering all 7 such experiments in 1981-83, only mean blow interval has been significantly different depending on aircraft altitude (lower mean at lower altitude,  $p < 0.001$ ). During experiments in 1983, the frequency of pre-dive flexes was also reduced when

the aircraft was at 305 m. No reactions to the two helicopter overflights were detected, but conditions were not favorable for detailed behavioral observations.

In general, sensitivity of bowheads to aircraft seems to vary with season, whale activity, and perhaps water depth. Bowheads seem more sensitive to aircraft than are other species of whales.

The one boat disturbance experiment in 1983 employed 'Sequel', the same 12.5-m boat used in 1981 and 1982. Results were similar to those from previous boat disturbance trials. Bowheads began to orient away when the boat was within 4 km. They swam rapidly away from the track of the oncoming boat as it came closer. Both blow intervals and durations of surfacing were reduced ( $p < 0.05$ ) when the boat was within 4 km. As in 1980-82, reactions to the boat were stronger than to any other type of disturbance tested.

We observed bowheads in the presence of noise from seismic vessels on four days in 1983. One controlled test of reactions to a single 40 in<sup>3</sup> airgun was done in 1983, replicating two similar tests in 1981. In 1983, bowheads 26-99 km from full-scale seismic vessels or 3-4 km from the single airgun exhibited normal activities. There was no evidence that they moved away from the noise sources. Received levels of seismic or airgun noise were, at 18 m depth, ~107 to at least 138 dB//1  $\mu$ Pa in 1983. Levels received by whales at the surface would have been a few dB lower. Spectral and temporal characteristics of noise received from the one airgun were similar to those from more distant seismic ships.

The 1980-82 results suggested that seismic noise may have subtle effects on surfacing and respiration behavior of bowheads. However, the 1983 results did not confirm that any behavioral variable is affected consistently by seismic or airgun noise. When all opportunistic and experimental data from 1980-83 were pooled, surface and dive times, number of blows per surfacing, and blow intervals did not differ significantly in the presence and absence of seismic or airgun noise. Considering only the three airgun tests, mean blow interval was longer with airgun noise ( $p < 0.01$ ). Mean surface time and mean number of blows per surfacing were slightly lower in the presence of airgun noise during each airgun experiment, but the overall trends were not statistically significant. We conclude that noise from distant seismic ships (> 6 km away, received level <160 dB) has no pronounced effect on overt behavior of bowheads despite the high levels of seismic noise occurring to ranges far beyond 6 km. Experiments are needed to determine if subtle effects occur at ranges >6 km, or if pronounced reactions occur when seismic vessels are <6 km away.

There was no drilling from artificial islands in the Canadian Beaufort Sea during our 1983 field season, but 4-5 drillships were working. There were very few bowheads in the main industrial area in August 1983. We saw no bowheads closer than 12 km from a drillship in 1983, but industry personnel reported one bowhead ~3.7 km from a drillship. Bowheads have been seen closer to drillships in previous years.

Two drillship noise playback experiments were completed successfully in 1983, replicating two similar tests in 1982. Drillship noise levels received by the whales during the 1983 tests were 112 dB//1  $\mu$ Pa in the 10-1000 Hz

band; such levels occur ~5 km from the actual drillship. As in 1982, calling rate decreased and bowheads tended to orient away from the playback site during playbacks. However, some whales did not orient away, and the dispersal was not nearly as rapid or consistent as occurs when a boat approaches. Aside from calls and orientation, other behaviors did not change in any consistent manner during drillship playbacks.

In 1980, bowheads frequently were seen <5 km from a dredging operation. In 1983, 1-2 bowheads were seen within a few kilometres of the same suction dredge for >2 days. We also conducted one playback experiment using noise from that dredge. No noticeable change in general activities occurred during the playback. Bowheads were slightly more likely to orient away from the playback site during the playback than during control periods. This trend was consistent with results from drilling noise playbacks, but was of marginal statistical significance. No other behavioral variables differed significantly during playback and control periods.

Overall, the behavior of bowheads can be affected markedly (but temporarily) by the close approach of ships or aircraft. Reactions to industrial activities that continue for hours or days, such as seismic exploration, drilling and suction dredging, are less obvious. Bowheads sometimes occur close enough to drillships, dredges and especially seismic boats to be exposed to considerable industrial noise. When seen near these ongoing operations, bowheads are not swimming consistently away. However, playback experiments showed a weak tendency for bowheads to orient away from sources of drillship or dredge noise when this noise first became evident. Whether whales that remain near industrial operations are subject to stress or other negative effects cannot be determined from short-term behavioral observations. The possibility of long-term displacement is examined in a different section of this report.

#### Characteristics of Waterborne Industrial Noise, 1983

The report with the above title (Greene 1984) documents the underwater sounds to which bowhead whales were exposed during the experiments and observations summarized above. Corresponding results from 1980-81 and from 1982 were reported by Greene (1982, 1983). The report also includes analyses of noise from various industrial sources recorded when no bowheads were nearby. A new feature of the 1983 results was simultaneous recordings of noise at two or more depths in the water column.

Underwater industrial noises in the Canadian Beaufort Sea were recorded in August 1983 in support of a study of the behavior of bowhead whales near actual and simulated oil industry activities. Bowheads are believed to be more likely to react to underwater sounds than to other stimuli associated with industrial activities. 1983 was the fourth year of research, which has always been in August. Sounds were again recorded via two systems: (1) sonobuoys dropped and monitored from the aircraft used for behavioral observations, and (2) hydrophones suspended beneath a sparbuoy drifting near a boat. In 1983, the boat system included hydrophones deployed at depths of 3, 9 and 18 m. This permitted us to compare ambient noise, noise from aircraft, and noise from in-water sources as received simultaneously at three depths. Unless otherwise noted, levels quoted below were at 9 or 18 m depth.

The ambient noise data revealed that very low levels of background noise sometimes occur in the Beaufort Sea. The lowest levels observed in 1983, about 0-10 dB below the 'Knudsen sea state zero' curve, were recorded in water 12 m deep with the hydrophone on the bottom. At frequencies below about 20 Hz, noise levels were greater at depth 3 m than at 9 or 18 m. The greater levels at 3 m probably represented hydrostatic pressure variations due to surface waves. At higher frequencies there was no apparent distinction in levels at the three depths.

Measurements of aircraft noise in 1983 included a Sikorsky 61 helicopter and the Twin Otter and Islander fixed-wing aircraft used for behavioral observations. For a large helicopter, the Sikorsky 61 appeared relatively quiet, although it did not pass directly over our hydrophones. Its strongest tone, at 102 Hz, was 95 dB//1  $\mu$ Pa during a pass at altitude 152 m. The strongest tone from a Bell 212 helicopter at that altitude in 1981 was 109 dB at 20 Hz. A Twin Otter at altitude 457 m, circling at reduced power, produced an 82 Hz tone of level 100 dB. All of these values are averages over 4 s.

The Islander flew over the hydrophones at several altitudes and two power settings. Received noise levels were less with circling than with cruise power, less at high than at low altitudes, and less at 9 or 18 m depth than at 3 m depth. Differences were a few dB in each case. Also, in shallow water (15 m) the Islander sometimes could be heard continuously as it made a circle of radius about 2 km. In deeper water, aircraft noise is detectable in the water for only a brief period when the aircraft is almost directly overhead.

Boat noise recorded in 1983 included the survey boat 'Arctic Sounder' (anchored; generators only), the crewboat 'Imperial Sarpik' underway at high speed, and the project's chartered boat 'Sequel'. As expected, 'Arctic Sounder' was relatively quiet, with tones from the generators dominating its sound spectrum. 'Imperial Sarpik' was noisy, with a dominant tone at 195 Hz (100 dB level at range 2.8 km). 'Sequel' showed a strong family of tones, evidently originating from its shaft rotation rate and possibly caused by a damaged propeller blade; we did not observe these tones in 1981 or 1982.

The geophysical survey ship 'Canmar Teal', recorded while underway at range 4.6 km, showed strong tones at 52, 291 and 301 Hz. The received level of the 52 Hz tone was 85, 96 and 99 dB at hydrophone depths 3, 9 and 18 m, respectively, making 'Teal' potentially as noisy as 'Sarpik'. These noises were from the ship itself, not the seismic gear. The hopper dredge 'Cornelius Zanen' underway at ranges from 2.4 to 7 km provided noise levels from 127 to 100 dB in the 20-500 Hz band. This large vessel produced noise levels comparable to those of other large vessels we have studied.

Most seismic survey signals analyzed in 1983 were recorded via sonobuoys, which can overload and distort with pressure levels as low as 124 dB, depending on frequency and type of sonobuoy. However, received signal levels from sources 26-80 km away varied without strong dependence on range, indicating that other factors (e.g. water depth, properties of the ocean bottom) strongly affect signal strength at these distances.

Seismic signals from 'Canmar Teal' at ranges 3 to 10.4 km were received via hydrophones at depths 3, 9 and 18 m. 'Teal' was using a small array of three airguns of total volume 5.2 L (320 in<sup>3</sup>). The signal at 3 m was generally 4 to 10 dB less than that at 9 m. Levels at 9 and 18 m were not consistently different. This depth effect was consistent with that for boat noise; the shallow hydrophone received lower sound levels. In contrast, the shallow hydrophone received the highest level of aircraft noise.

Noise from three dredges was recorded while they were dredging in 1983. The noise from 'Beaver Mackenzie' was different than it had been during measurements in 1980 and 1981; the signals were weaker and the characteristic tones were missing. This dredge has evidently been modified to some extent since 1981. Hopper dredge 'Cornelius Zanen' picking up a load at Ukalerk radiated noise at levels comparable to those from a similar dredge, 'Geopotes X', measured in 1982. The 10-500 Hz band levels usually were between 140 and 145 dB/1  $\mu$ Pa for ranges from 0.63 to 1.19 km. The suction hopper dredge 'Aquarius', moored in place at Nerlerk and transferring sand from the bottom to construct a berm, did not radiate as much noise, but neither was it underway. At range 0.2 km, its level in the 20-500 Hz band was 139 dB/1 $\mu$ Pa at depth 3 m, 143 dB at depth 9 m and 140 dB at depth 18 m. For ranges from 0.20 to 14.8 km, the relationship between received levels and range followed cylindrical spreading at all three hydrophone depths, with additional linear losses of 0.82 dB/km for depth 3 m, 0.43 dB/km for depth 9 m and 0.27 dB/km for depth 18 m.

The noise levels from the Kadluk construction site were about the same when recorded at ranges 0.93, 1.8, and 3.8 km. At depth 3 m the levels were close to 114 dB and at 9 m the levels were close to 117 dB in the 40-1000 Hz band. About 9 h passed between the times of recording at the 3.8 and 1.8 ranges, and no doubt the activities changed. At the 0.93 km range the noise levels varied considerably. To avoid noise from a work boat nearby, we chose a quiet time to analyze.

#### Distribution of Bowheads and Industrial Activity, 1983

The report with this title (Richardson, Norton and Evans 1984a) summarizes the distribution of bowheads summering in the eastern Beaufort Sea in 1983 relative to the distribution of industrial activities. Results are compared with a corresponding analysis of data from 1980-82 (Richardson et al. 1983a).

Methods. -- Sightings of bowheads during this and other studies conducted in the Canadian Beaufort Sea from 1 August to 10 September 1983 are compiled here onto a series of maps by 10-d periods. Survey routes are also shown on these maps. For each 10-d period, we include a map showing the sites of offshore drilling, dredging, etc., along with the approximate number of boat trips along each route. Additional maps show locations of seismic lines and low-energy sounding, helicopter traffic, and ice conditions.

We use the phrase 'main industrial area' to refer to the region off the Mackenzie Delta where there is island construction, drilling, dredging, and intensive boat and helicopter traffic. Seismic exploration occurs over a wider area, and noise from distant seismic exploration is detectable over a still wider area.

Results in 1983. -- In 1983, as in 1982, most bowheads remained outside the main industrial area. In early August, bowheads were found far offshore just east of the Alaska-Yukon border and far north of Herschel Island. These whales were far outside the main industrial area, but were exposed to noise from distant seismic exploration. There were only a few sightings in more easterly parts of the Beaufort Sea.

In mid and late August, there was a dense concentration of several hundred bowheads, most if not all subadults, in shallow water along the Yukon coast southeast of Herschel Island. These whales were not exposed to much industrial activity. In mid and late August there were also some bowheads in shallow water in the main industrial area, plus a few far offshore near the Alaska-Yukon border. In addition, during late August bowheads were widely dispersed off Cape Bathurst and the Tuktoyaktuk Peninsula, mainly outside the industrial area.

In early September, there were many widely dispersed whales off the Tuktoyaktuk Peninsula, outside the main industrial area but probably exposed to distant seismic noise. Whales had left the Yukon coast by 6 September, and few were present in the main industrial area.

Discussion. -- Qualitatively, bowhead numbers in the main industrial area in 1980-83 were 'many, some, very few and few', respectively. We consider the difference between 1982 (very few) and 1983 (few) to be insignificant. Thus, the trend for reduced utilization of the main industrial area identified from the 1980-82 data continued in 1983.

Intense offshore industrial activity began in the central part of the main industrial area in 1976. In that area, limited data on bowheads were obtained in 1976-79. Bowheads were numerous there in the summers of 1976 and 1977, not numerous in 1978 or 1979, very numerous in 1980, less so in 1981, and not numerous in 1982 or 1983. The reappearance of many whales in 1980, after being scarce for two years, makes it questionable whether the trend toward reduced utilization of the main industrial area was attributable to industrial activity. However, the intensity of offshore industrial activities has increased gradually since 1976, and industry may have begun to affect bowhead distribution since 1980.

In 1980-83, seismic exploration occurred over much of the Canadian Beaufort Sea -- both within and beyond the main industrial area. Numerous bowheads were in areas with seismic exploration in 1980-82. Fewer bowheads were in such areas in 1983, but many whales were apparently exposed to noise from distant seismic vessels. There was a possible trend for reduced numbers of bowheads in areas where they were exposed to intense seismic noise in previous years, but there were important exceptions to this trend.

Bowhead distribution in summer may or may not be influenced by industrial activities, but some whales still do enter the main industrial area and other areas with seismic exploration. Aside from possible industrial effects, bowhead movements probably depend strongly on the distribution and abundance of zooplankton. Until zooplankton dynamics and resultant effects on bowheads are better understood, it will be difficult to assess whether changes in bowhead distribution are partly in response to industrial activities.

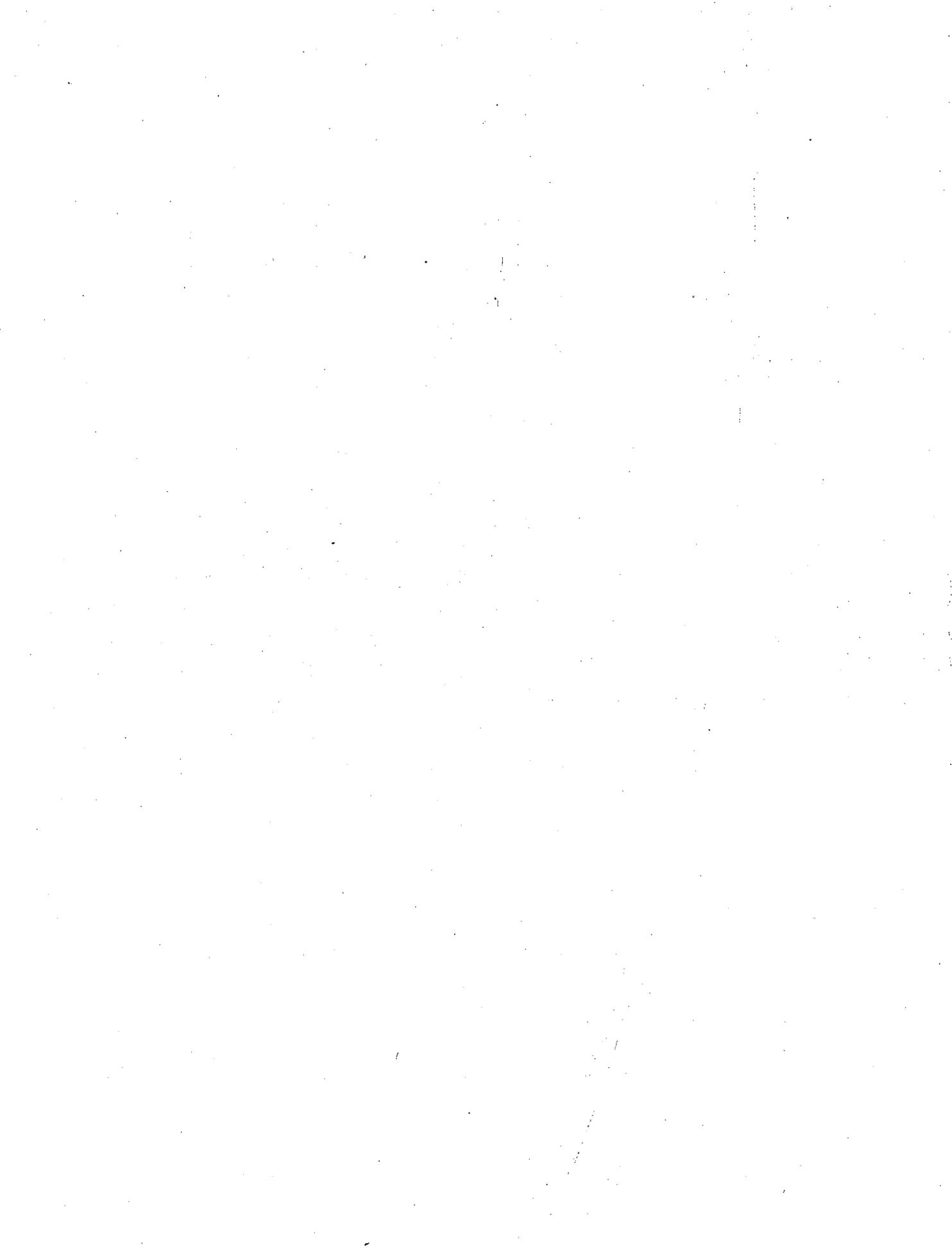
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**NORMAL BEHAVIOR OF BOWHEADS, 1983\***

By

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## ABSTRACT

Behavior of bowhead whales was observed from an aircraft during 15 of 28 flights in the period 1 August to 1 September 1983, mainly near shore in the Beaufort Sea between Herschel Island (Yukon Terr.) and Richards Island (Northwest Terr.), Canada. Detailed behavioral observations were made while we circled over whales for 38.4 h. Bowheads were 'presumably undisturbed' during 37.0% of the observation time (14.2 h), and these observations of 'normal behavior' are described in the present report. This represents the fourth consecutive year of detailed behavioral observations of bowhead whales in the eastern Beaufort Sea in summer. Methods were similar during all four years.

During most flights in 1983, bowheads were observed near shore in water 5-35 m deep. Whales dove for brief periods, socialized often, and--at least after mid August--spent time skim-feeding at the surface or apparently feeding near the bottom. These behaviors were somewhat similar to behaviors seen in shallow water in 1980 and 1981. Behavior in 1983 differed from that in 1982, when whales spent most time apparently feeding in the water column in water >100 m deep.

Social interactions--nudges, pushes, chases, and close proximity--were observed at a rate similar to that in 1981, less than that in 1980, and greater than that in 1982. The rate of social activity in 1983 up to and including 18 August was higher than after this date. This decrease in late August was consistent with data from 1980 and 1981 (with too little information on socializing in 1982 for analysis). There was no consistent relationship between rate of socializing and depth of water. As in previous years, socializing whales tended to turn while at the surface more frequently than did non-socializing whales. We observed no apparent mating in 1983. However, during one flight groups of whales interacted with each other by rolling and nudging in a fashion similar to that seen in mating groups of bowhead whales in spring and southern right whales in winter. On 31 August, two whales repeatedly slapped each other with their pectoral flippers and flukes, and this observation represented the most obviously aggressive interaction we have noted in four seasons.

We saw 347 underwater blows in 1983, including both 'presumably undisturbed' and 'potentially disturbed' whales. The rate of underwater blowing was positively correlated with the rate of socializing. This suggests that underwater blows are in some manner linked to social behavior. However, we do not know whether underwater blows represent aggression, as believed in southern right whales, or whether they have some other function.

Aerial activity occurred sporadically, and included brief bouts of tailslaps, flipper slaps, and/or breaches. However, on 22 August, we observed two longer bouts lasting about 12 min and 75 min. The latter was the longest uninterrupted bout of aerial activity seen in four years of observations.

As in earlier years, some whales were recognizable by distinctive features such as unusual white pigmentation, or scars and marks on the back. This allowed us to identify individuals for up to several hours. We obtained no known resightings on different days. In 1983, few whales near shore had distinctive white chin patches or patches of white on the tail or tail stock, and a sample of about 20 of these whales that we measured via photogrammetry were only 7-12 m long. Thus, most whales near shore were yearlings and older subadults.

The mean blow interval for presumably undisturbed non-calves in 1983 was  $17.0 \pm$  s.d. 13.49 s,  $n = 866$ , which was significantly higher than combined data for 1980-1982. Number of blows per surfacing and duration of surfacing were significantly correlated, as in previous years. Mean number of blows per surfacing for non-calves was  $3.2 \pm$  s.d. 2.37 blows,  $n = 229$ ; and mean surface time for non-calves was  $1.05 \pm$  1.484 min,  $n = 248$ . These values were much lower than those for 1982, but not significantly lower than those for 1980 and 1981. The mean dive time for non-calves was  $1.88 \pm$  2.357 min,  $n = 140$ , shorter than in any of the three previous years.

Several factors were related to surfacing-respiration-dive characteristics. Durations of surfacings and number of blows per surfacing were longer for socializing whales than for non-socializing whales. Blow intervals of skim-feeding whales averaged more than twice as long as for

non-feeding whales. Mean duration of surfacing, number of blows per surfacing, and proportion of time at the surface were higher in skim-feeders than in others, while mean duration of dives was slightly lower for skim-feeders than for others. Blow rates, however, were approximately equal for skim-feeders and other whales.

Only 4 or 5 calves were seen in 1983, all in water >1000 m deep on 7 August. Two calves interacted at the surface for at least 5 min. This represents our only observation in four years of apparent play between calves. One apparent subadult associated with a mother-calf pair for at least 40 min. Because we sighted calves only in deep water far north of Herschel Island and not with the many small whales close to shore in 1983, we surmise that the population was at least partially segregated into (1) mature animals, including females and calves, far offshore and perhaps in other areas not searched by us, and (2) subadult whales near the Yukon shore.

Sounds of bowheads were analyzed from 33.7 h of sonobuoy recordings (11.0 h from presumably undisturbed whales). The types of sounds recorded were no different from previous years, and, as in previous years, the majority of sounds (85%) were tonal, frequency modulated calls lasting 1-2 s. Most loud pulsive calls were heard during socializing, consistent with results from 1980-1982. Blow sounds were associated with periods of much underwater blowing, and slap sounds occurred during periods with aerial behavior, especially on 22 August.

We have observed considerable year-to-year variation in the distribution and behavior of bowhead whales from 1980 to 1983. Aside from the aforementioned relationship between activities and water depth, no consistently repeating pattern is discernible. A consideration of year-to-year variations in the distribution and behavior of other cetaceans demonstrates that variations in distribution and abundance of prey species may often be responsible.

## INTRODUCTION

This study was a continuation of research on normal, undisturbed behavior of the bowhead whale, Balaena mysticetus, summering in the eastern Beaufort Sea. Results from the summers of 1980, 1981 and 1982 were described by Würsig et al. (1982, 1983). As in 1980-82, the observations of bowhead behavior in the summer of 1983 were part of a broader analysis of the potential effects on these whales of offshore oil and gas exploration and development in the Beaufort Sea. Results from previous summers showed that bowhead behavior differs among years. Thus, to interpret the 1983 studies of the possible effects of industrial activities on behavior, it was necessary to examine normal behavior during the same season. The other tasks in 1983 were studies of the responses of bowheads to various offshore industrial activities (Richardson et al. 1984b), studies of the characteristics of waterborne industrial noise (Greene 1984), and an analysis of the distribution of summering bowheads in relation to industrial activity (Richardson et al. 1984a). For reviews of previously existing knowledge of the behavior of bowhead whales, see Fraker and Richardson (1980) and Würsig et al. (1982, 1983).

### Objectives

The two main objectives of the 'Normal Behavior' task for 1983 were (1) to provide a description of presumably undisturbed behavior immediately prior to experimental disturbance trials, against which the results of these trials could be compared, and (2) to provide additional information about normal behavior, with emphasis on aspects not studied in detail in 1980-82.

Additional pre-disturbance 'control' information was considered essential because the 1980-82 studies showed that bowhead behavior is quite variable. To recognize and evaluate disturbed behavior, it is desirable to obtain observations of 'presumably undisturbed' behavior from the same individual whales immediately before and after the period of potential disturbance.

The second main objective of the normal behavior study in 1983 was, in periods when studies of disturbance effects were not possible, to observe aspects of 'presumably undisturbed' behavior that had not been studied in sufficient detail in previous years, or that showed significant variation from year to year. Because of the variability in behavior among years, it is instructive to assess behavior of presumably undisturbed whales during several years. An understanding of year to year variability is important in assessing whether whales might be more susceptible to disturbance in some situations or years than others.

### Approach

The general approach in 1983 was very similar to that in 1980-82. Background information concerning the rationale and design of the study, and the choice of the eastern Beaufort Sea as the study area, is given in the previous section 'Project Rationale, Design and Summary, 1983' (Richardson and Würsig 1984). As in 1982, no shore-based observations were collected in 1983.

Field work extended from 1 August to 1 September 1983 and, as in previous years, was based at Tuktoyaktuk, Northwest Territories (Fig. 1), a coastal settlement with facilities for personnel, aircraft and boats. Observations of behavior were conducted from the air and from a boat. Aircraft-based observers had the advantage of high mobility and a good vantage point and consequently collected most of the behavioral data. Sonobuoys were dropped from the aircraft to allow us to hear and record bowhead sounds; boat-based observers had hydrophones for this purpose. Sonobuoys also allowed us to determine when industrial noises were present in the water. Observations of bowheads in the presence of industrial noise may not represent undisturbed behavior and have been excluded from this 'Normal Behavior' section.

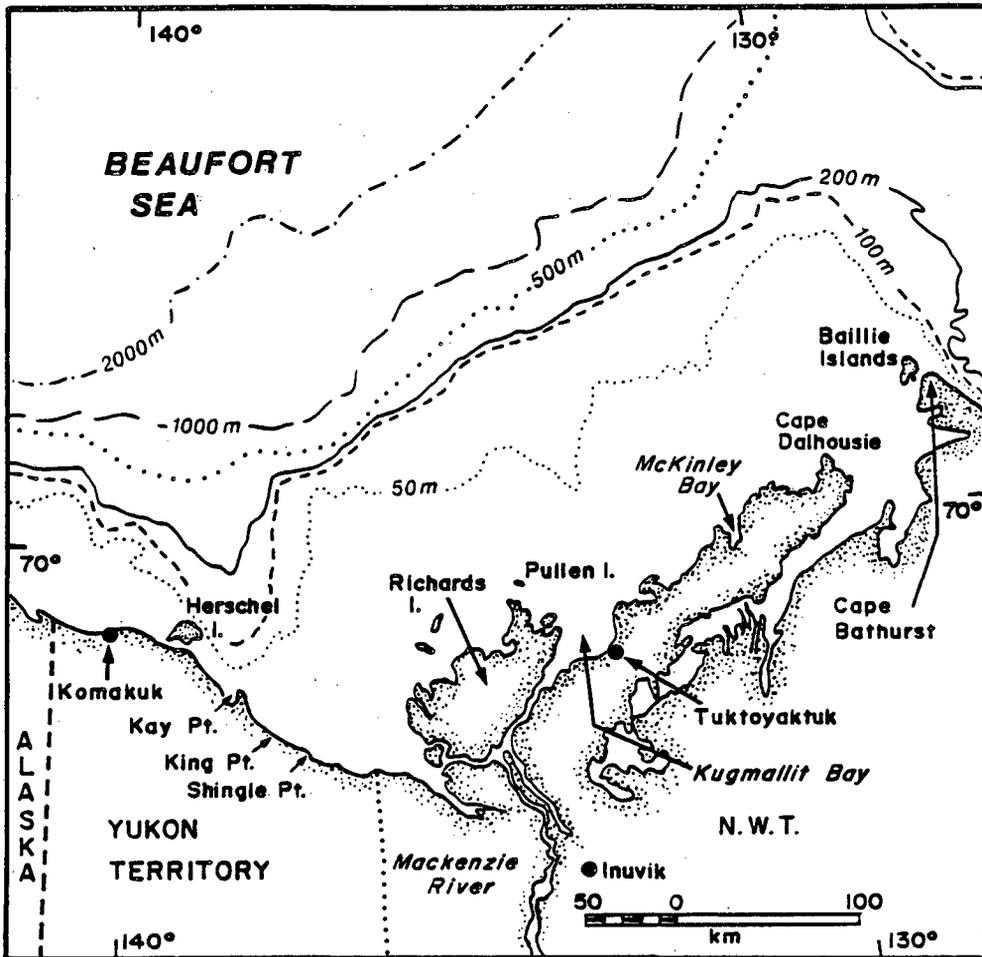


FIGURE 1. The eastern Beaufort Sea region, showing bathymetry and locations mentioned in the text.

## METHODS AND DATA BASE

### Aerial Observations

As in the previous two years, most of the behavioral observations were made from the air. From 1-12 August, when the aircraft that we normally use was unavailable, we used a de Havilland Series 300 Twin Otter aircraft. The Twin Otter has two turboprop engines, high wing configuration, low stall speed, and bubble windows. After 12 August, when most of the 1983 observations were made, we used the same Britten-Norman Islander aircraft that was used for behavioral observations in 1980-1982. The Islander has two piston engines, high wing configuration, and low stall speed. Both aircraft were equipped with radar altimeters and Very Low Frequency (VLF) navigation systems, which continuously computed position, usually within 1.8 km of the real position. Positions and flight tracks were recorded manually from the VLF systems. Both aircraft had an endurance of about 5.5-6.0 h plus reserves. The Islander had a forward-looking radar useful for determining distances to industrial sites, shore, etc. Sonobuoys (AN/SSQ-57A or AN/SSQ-41B) were deployed and monitored from both aircraft in order to record waterborne sounds from bowheads and industrial sources (details in Greene 1984). A hand-held color video camera (Sony HVC-2000) connected to a portable videocassette recorder (Sony SL-2000) was used through the side windows to record oblique views of bowheads.

Our usual strategy was to search until we encountered bowheads and then circle over them as long as possible while making observations. Once contact was lost, we searched for another group. We created a fixed reference point about which to circle when bowheads were below the surface by deploying a dye marker (1-2 teaspoons of fluorescein dye in about 1 litre of water in a plastic 'freezer' bag which burst on impact with the water). Near the start of most periods of circling above whales, a sonobuoy was deployed to record waterborne sounds.

In 1983 we made 28 flights between 1 August and 1 September, and we made behavioral observations of bowheads during 15 of the flights. Except when the aircraft required maintenance, we flew twice per day whenever weather

conditions permitted. However, as in previous years, inclement weather precluded useful observations on about half of the days. Each flight typically lasted 4 to 5.5 hours. Total flight duration in 1983 was 113.6 hours, and we observed bowhead whales for 38.4 hours.

We usually did not fly when wind speed exceeded 25 km/h; whales are difficult to detect and behavior is not reliably observable in more severe conditions. While searching for whales, we usually flew at 457 or 610 m (1500 or 2000 ft) above sea level (a.s.l.), and at 185 km/h. In previous years, bowheads rarely appeared to be disturbed by the aircraft when it remained at or above 457 m (see Richardson et al. 1983b). However, whales observed on 17 August 1983 appeared to be disturbed by the aircraft circling at 457 m, so subsequent observations were from 610 m whenever conditions allowed (Richardson et al. 1984b). The greater sensitivity to aircraft in 1983 may have been partly attributable to the shallow water at most observation locations; lateral underwater propagation of aircraft noise is greater in shallow than in deep water (Greene 1984).

The aircraft crew consisted of four biologists and the pilot. In the Islander, from which most behavioral observations were obtained, three biologists were seated on the right side of the aircraft, which circled to the right when we were obtaining behavioral observations. As in earlier years, biologists seated in the right front (co-pilot's) seat and in the seat directly behind it were responsible for describing whale behavior. This information was recorded onto audiotape and also, on most occasions, recorded onto the audio channel of the videotape recorder. A third biologist, in the right rear seat, operated the video camera during most periods while we circled above whales visible at the surface. That individual was also responsible for some record keeping, radar measurement of distances to industrial activities, and overall direction of the work. A fourth biologist, in the left rear seat, searched for bowheads outside of the circle on the left side of the aircraft, launched sonobuoys and dye markers, and operated sound recording equipment. The biologists and pilot were in constant communication via intercom. The Twin Otter circled to the left during behavioral observations; three biologists were seated on the left side behind the pilot and one in the right front (co-pilot's) seat.

We obtained consistent data of 13 types:

1. Location of sighting (and therefore water depth);
2. Time of day;
3. Number of individuals visible in area; number of calves;
4. Individually distinguishing features (if any) on whales;
5. Heading in degrees true, turns, and swimming speed of each whale;
6. Distances between individuals (estimated in adult whale lengths);
7. Duration of time at surface and sometimes duration of dive;
8. Timing and number of respirations, or blows;
9. Indications of feeding: e.g., open mouth, defecation, mud streaming from mouth;
10. Socializing;
11. Underwater blow (releasing a large burst of bubbles underwater);
12. Aerial activity: breaches, tailslaps, flipper slaps, lunges, rolls;
13. Type of dive: fluke out, peduncle arch, pre-dive flex.

Water depths were determined by consulting Canadian Hydrographic Service chart #7650 (1980 printing) and Dome Petroleum Ltd. chart E-BFT-100-03. Descriptions of the behaviors mentioned above appear later in this report. In 1983, we looked for but did not see several other types of behavior recorded in earlier years: play with surface debris or logs, probable mating, and probable nursing.

The 15 flights during which we made behavioral observations in 1983 are summarized in Table 1. The distributions of behavioral observations by flight, hour of day, and water depth are presented in Figures 2, 3 and 4. Most observations in 1983 were in shallow water, comparable to water depths where bowheads were observed in 1980 and very different from depths where whales were seen in 1982.

The observation times in Figures 2, 3 and 4 are divided into periods with and without known sources of potential man-made disturbance in the observation areas. In this section of the report, with rare exceptions that are specifically indicated, we describe only the behavior observed with no known potential disturbances. Data collected during the periods of potential disturbance are described separately in the 'Disturbance' section (Richardson et al. 1984b). Whales were classified as 'presumably undisturbed' only if the observation aircraft was at an altitude of at least 457 m (1500 ft) a.s.l. and if no vessels or other industrial activities were close enough to create detectable waterborne sound. Some observations were collected when

Table 1. A summary of aerial observations of bowhead behavior, 1983.

Date	Time Observing Bowheads			Distance From Shore & Location	Depth of Water (m)	Est. Number of Whales		Est. Area Under Obs. (km <sup>2</sup> )	Potential Disturbance (and distance from it)	General Behavior
	Start MDT	Stop MDT	Total hours			Adults	Calves			
7 Aug Flt #1	16:52	17:33	0.7	109 km NNE of Herschel I.	950	2	0	20	Seismic (79 km)	Unknown
	17:40	18:59	1.3	128 km NNE of Herschel I.	1370	6	4	20	Seismic, which stopped at 18:50 (95-99 km)	Two calves interacting actively; trio of mother, calf, and subadult traveling rapidly
7 Aug Flt #2	21:44	22:13	0.5	217 km N of Herschel I.	1670	1	1	1	None	Slow travel by lone mother-calf pair, in small ice-free area
9 Aug	13:34	17:03	3.5	41 km N of Herschel I.	190	12	0	10	Seismic started at 13:47 (57 km)	Much socializing
15 Aug	10:31	11:32	1.0	28 km NE of King Point	12	6	0	10	None	Lone whales moving medium speed
	12:04	13:21	1.3	43 km NE of King Point	7	6	0	10	None	Some socializing
	13:46	14:28	0.7	13 km N of King Point	30	14	0	10	None	Some socializing, but most whales >5 whale lengths apart
17 Aug Flt #1	09:53	10:09	0.3	61 km NE of King Point	11	2	0	10	Aircraft <457 m overhead	Unknown
	11:35	13:12	1.6	7 km E of Kay Point	30	15	0	10	Aircraft <457 m for first hour	Much socializing
17 Aug Flt #2	18:59	22:01	3.0	2-5 km E and NE of Kay Pt.	16-25	7-10	0	30	Drillship playback experiment (0.7-3 km)	Mostly lone whales with unknown behavior
18 Aug Flt #1	11:27	12:36	1.2	16 km NNW of Kay Point	20	9	0	30	None	Very little socializing
	12:36	14:38	2.0	17 km NNW of Kay Point	12	13	0	30	Drillship playback experiment (0.4-1.7 km)	Some socializing, some lone whales
18 Aug Flt #2	19:55	21:41	1.8	6 km NNW of Kay Point	10	7-20	0	25	Boat experiment (9 to <1 km)	Socializing, repeated tail slaps by one whale

Continued...

Table 1. Concluded.

Date	Time Observing Bowheads			Distance From Shore & Location	Depth of Water (m)	Est. Number of Whales		Est. Area Under Obg. (km <sup>2</sup> )	Potential Disturbance (and distance from it)	General Behavior
	Start MDT	Stop MDT	Total hours			Adults	Calves			
22 Aug Flt #1	10:04	11:34	1.5	13 km ENE of King Point	18	3-6	0	40	Aircraft experiment	Aerial activity, possible bottom feeding, otherwise unknown
22 Aug Flt #2	13:46	18:03	4.3	19 km N of King Point	32	9-11	0	15	Drillship playback (0.8-1.8 km) and aircraft experiments	Mostly lone whales with little or no forward movement, but some brief socializing
26 Aug Flt #1	16:15	18:45	2.5	1-2 km off King Point	8	5-8	0	10	Boat approaching (6 to 1.5 km)	Skim-feeding
26 Aug Flt #2	20:58	23:24	2.4	2-3 km N of King Point	18	8	0	10	Dredge playback experiment (0.5-2.0 km)	Lone whales hanging at surface between long dives; occasional socializing
28 Aug	09:38	10:02	0.4	26 km ENE of King Point	5	4	0	10	None	Travelling medium speed
	10:04	13:40	3.6	17 km E and ENE of King Point	11-12	6	0	25	Airgun expt. (3-4 km)	Some bottom feeding; lone whales moving medium speed
31 Aug	14:19	17:15	2.9	82 km WNW of Pullen I.	19	6	0	10	Seismic (52 km)	Bottom feeding and some socializing
1 Sept	15:26	15:29	0.1	82 km WNW of Pullen I.	19	4	0	20	Seismic (31 km) and aircraft	Unknown
	16:28	18:17	1.8	82 km WNW of Pullen I.	19	5	0	20	Seismic (26-30 km) and aircraft	Some bottom feeding, some socializing, long dives

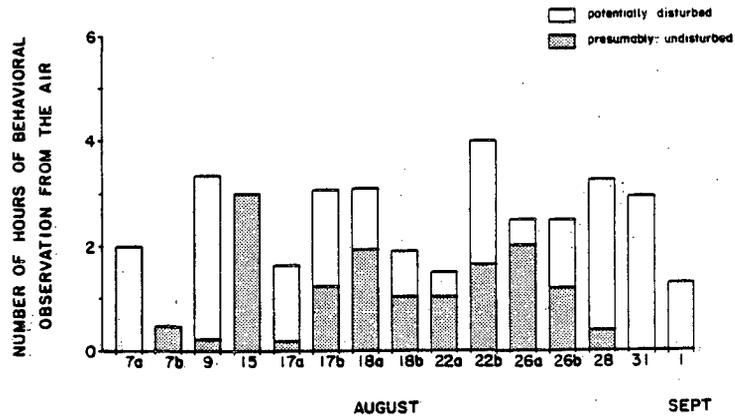


FIGURE 2. Distribution of behavioral observation time from the air by flight in 1983. Time spent over presumably undisturbed whales is distinguished from time spent over potentially disturbed whales.

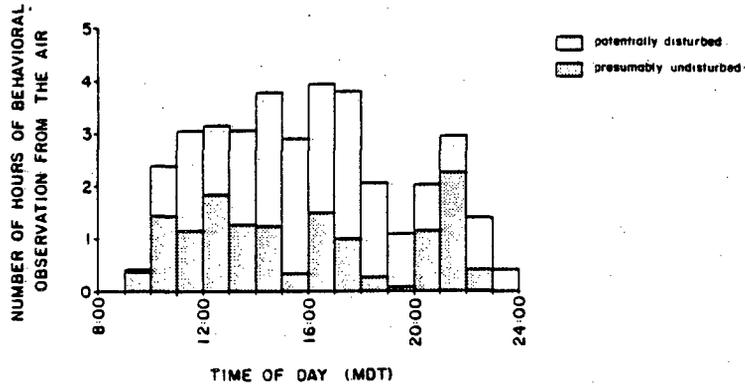


FIGURE 3. Hourly distribution of behavioral observation time from the air, 7 August - 1 September 1983. Time spent over presumably undisturbed whales is distinguished from time spent over potentially disturbed whales.

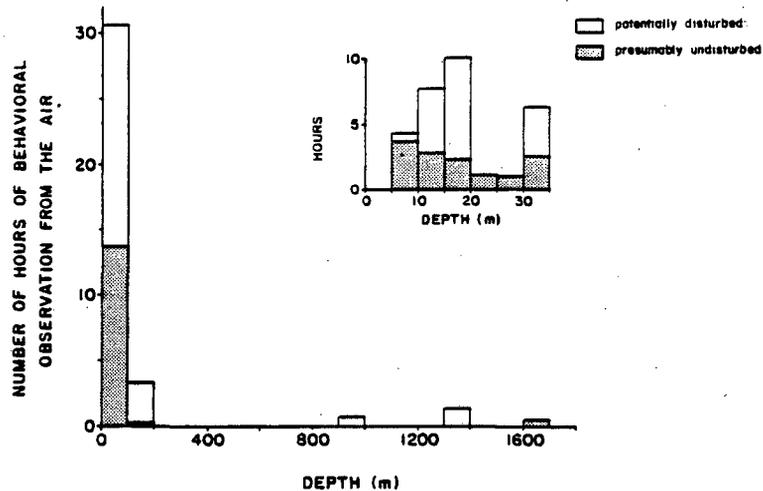


FIGURE 4. Distribution of behavioral observation time from the air by depth of water in 1983. Time spent over presumably undisturbed whales is distinguished from time spent over potentially disturbed whales. All behavioral observations at depths <100 m were actually at depths <35 m.

our 12.5 m boat was nearby; the whales were considered to be presumably undisturbed if the boat had been anchored or drifting quietly with engines off for at least 30 min. In 1983, of 38.4 h spent observing bowheads, 14.2 h (37.0%) were 'presumably undisturbed'.

The behavioral observations were transcribed from audiotape onto data sheets during periods of poor weather between observation flights. The videotape was also examined at this time to provide additional details not noted in real time. After the field season, these transcribed observations were checked again with the audiotape and converted into a standardized numerical format with one record per surfacing or dive of each whale that was under detailed observation. These records were hand-checked by a different individual and entered into a microcomputer for subsequent computer validation, tabulation, and statistical analysis. The standardized data files now contain the following:

<u>Year</u>	<u>Surfacing Records</u>	<u>Dive Records</u>	<u>Total Records</u>
1980	562	223	785
1981	778	223	1001
1982	312	141	453
1983	1401	242	1643

These counts include both presumably undisturbed and potentially disturbed whales. In 1983, there were 545 surfacing and 154 dive records from presumably undisturbed periods.

Methods of analysis of bowhead sounds recorded via sonobuoys are described in the 'Bowhead Sounds' section of the results, below.

#### Boat-Based Observations

Behavioral observations were again made from the 12.5 m diesel vessel 'Sequel' based at Tuktoyaktuk. The 'Sequel' cruised at about 13-15 km/h and required about 24 h to travel from Tuktoyaktuk to the usual locations of bowheads in 1983. The boat crew consisted of two biologists making behavioral observations, one acoustician to obtain underwater recordings and to play back industrial noise, and the captain.

## RESULTS AND DISCUSSION

### Descriptions of Behaviors

Descriptions of behaviors have been given in detail in earlier reports (Würsig et al. 1982, 1983), and we here summarize only those descriptions necessary for an understanding of our analyses of the 1983 results. Unless otherwise noted, the descriptions apply specifically to undisturbed bowheads exclusive of calves.

#### Surface-Dive Sequence

The respirations of bowhead whales are usually not spaced at even intervals but are clustered together in groups. The groups of breaths are separated by longer periods without breathing ('apneas'). Behavior at the surface during these breath groups depends upon overall activity. When 'making a passage', i.e. migrating or otherwise travelling for relatively long distances, the breaths in breath groups are separated by short dives. These short dives have been called series dives (Rugh and Cabbage 1980) to distinguish them from the long dives between breath groups, called sounding dives. When bowheads are not travelling, but are engaged in other behavior like feeding or socializing, they usually remain at the surface between breaths in a breath group, and dive for varying lengths of time between these surfacings. Most of the bowheads we observed in this study behaved in the latter manner. As a result, we discuss only one type of dive, the sounding dive.

On occasions when a whale made short dives between respirations, we did not consider its surfacing to be interrupted if it remained visible from the air. Observers working from low vantage points on ice, shore or a boat, however, would treat such an occasion differently, because the whale would usually be out of their sight as soon as it went below the surface. Thus the definition of a surfacing and a dive used in this study is in part a function of our aerial vantage point. We consider a shallow and brief submergence during which the whale is in sight from the air as part of a surfacing. This is necessary because our aerial vantage point does not always allow us to

determine whether a whale is at the surface or slightly below it. One must use caution when comparing data collected from different vantage points.

### Blow

A blow is an exhalation of air by a whale. It can occur either above or below the surface. Most surface blows were probably immediately followed by an inhalation. Underwater blows occurred with high frequency in 1983, and are discussed later.

### Pre-dive Flex

The pre-dive flex is a distinctive concave bending of the back, with the back about 0.5 to 1 m below the level of the rostrum tip and the tail. Rostrum and tail usually lift slightly out of water during the flex, and considerable whitewater may be created at these two points. The whale then straightens its back and lies momentarily still before arching the back convexly as it begins to pitch forward and down. During 25 timed observations in 1983, pre-dive flexes occurred a mean of  $15.4 \pm$  s.d.  $12.00$  s before the dive. (All  $\pm$  figures quoted in the text are  $\pm$  1 standard deviation.)

During 1983, pre-dive flexes occurred in presumably undisturbed non-calves before 43 of 277 dives (15.5%), and there did not appear to be a change in the frequency of pre-dive flexes over the study period. Furthermore, there was no significant difference between the durations of dives that were and were not preceded by pre-dive flexes. This situation was different from that of 1982, when pre-dive flexes occurred more often later in the month of August than earlier, and when dives following pre-dive flexes were about twice as long as those without pre-dive flexes (Würsig et al. 1983). The differences may be related to the lower incidence of pre-dive flexes in 1983, the very shallow water, and the generally short dives.

There was no significant difference in the durations of surfacings with and without pre-dive flexes in 1983, but there were significantly more blows during surfacings with pre-dive flexes (surfacings with flex: mean =  $5.1 \pm$

s.d. 2.77 blows,  $n = 32$ ; surfacings without flex: mean =  $2.9 \pm 2.19$  blows,  $n = 177$ ;  $t = 4.89$ ,  $df = 207$ ,  $p < 0.001$ ).

### Dive

During the dive, the whale arches (makes its body convex) and pitches forward and down. During 51 timed arches in 1983, the arch began a mean of  $5.1 \pm$  s.d. 8.36 s before the final disappearance of the whale's body. If the angle of dive is steep, the tail is usually raised above the surface; if not, the tail may remain below or just touch the surface. Seventy-six of 390 dives (19.5%) of presumably undisturbed non-calves were preceded by raised flukes. Of the 43 dives preceded by a flex and the 76 dives preceded by raised flukes, 18 were preceded by both actions. These two pre-dive behaviors occurred together more frequently than would be expected by chance ( $\chi^2 = 9.51$ ,  $p < 0.005$ ,  $df = 1$ ), just as they did in 1982.

There was no difference in the duration of dives depending on whether or not flukes were raised preceding the dive. However, the mean duration of surfacings was shorter when ended by raised flukes (mean =  $0.80 \pm$  s.d. 0.492 min,  $n = 40$ ) than when flukes were not raised (mean =  $1.11 \pm 1.614$  min,  $n = 204$ ;  $t' = 2.27$ ,  $p < 0.05$ ). [In this report,  $t'$  represents the Student's  $t$  statistic calculated assuming unequal population variances.] Surfacing preceding raised flukes also showed shorter blow intervals (mean =  $13.97 \pm 8.434$  s,  $n = 144$ ) than surfacings not ending in raised flukes (mean =  $17.97 \pm 14.796$  s,  $n = 614$ ;  $t = 3.13$ ,  $df = 756$ ,  $p < 0.002$ ). There was no significant difference in number of blows during surfacings with and without raised flukes.

### Social Interactions

Behavior was termed social when whales (1) appeared to be pushing, nudging, chasing each other, or otherwise interacting, or (2) were within one-half body length of one another but not obviously interacting. In the 1983 analysis, we coded and analyzed these two situations separately, with the realization that animals merely in close proximity may not be socializing to the same degree as those that are physically interacting. We also

recognize that whales far apart could have been interacting by sound, but we have no way of evaluating such communication at present, and therefore do not include it as socializing here. Details of socializing are given in a later section.

### Recognition of Individuals

Except in their first few months of life, bowhead whales are usually black or dark gray with white chin patches. Many individuals also have smaller white dots or lines (some of these presumably are scars) on their backs, and a variable amount of light skin on the tail peduncle and on the tail itself. Davis et al. (1982, 1983) showed that clear photographs allow for identification of many individuals.

In 1983, as in past years, we were at times able to identify whales by sight, within an observation flight, from distinctive chin patch shapes or white marks on the back or tail, and we were then able to determine dive durations for these individuals. However, few of the whales encountered close to shore in 1983 had extensive patches of white pigmentation on the chin or at the fluke/caudal region. Davis et al. (1983) showed that small juvenile whales tend to have fewer such white marks than do large adult whales. We saw few white marks and almost no calves amongst the whales close to shore and had the general impression that most of those whales were smaller than adults previously seen. Hence, we believe that these whales were mostly subadults. This impression was confirmed in a small sample of whales that we measured by the vertical photography method of Davis et al. (1983). The segregation by age is discussed below in the section on mothers and calves.

### Respiration and Surfacing Characteristics

Four characteristics of a surfacing lend themselves to repeated quantitative sampling: the interval between blows in a surfacing (blow interval), the number of blows per surfacing, the duration of surfacing (surface time) and the duration of dive between surfacings (dive time). Because these variables are comparatively easy to assess quantitatively, they

are suitable for use in analysis of responses to disturbances. A detailed understanding of respiration and surfacing behavior under undisturbed conditions is a prerequisite for interpretation of disturbance responses.

The measurement of each of these four quantities depends upon how a surfacing and a dive are defined. In all four years of this study, a surfacing was defined as the period of time when a whale was at the surface or visible just below the surface. Thus, the shallow 'dives' that often occurred for a few seconds between blows were not counted as dives or as interruptions of a surfacing or of a blow interval. On rare occasions a whale remained visible just under the surface of the water for periods of up to several minutes; these were considered dives if they exceeded an arbitrary minimum of 60 s. We used an additional convention in 1983 because the water was usually more turbid than in previous years, which meant that whales were less easily visible while underwater. Periods of submergence lasting less than 15 s were not counted as dives unless before submerging the whale lifted its flukes out of the water, arched strongly or performed a pre-dive flex. The ability to see a whale just under the surface of the water depends not only on the clarity of water, but also on the vantage point from which the observations are made; thus, some of our definitions would not be appropriate for observations from shore, ice, or a boat.

Calves, because of their small size, are much more difficult to observe than are adults when just under the surface of the water. We have analysed the few observations of calves in 1983 separately and will present that analysis after consideration of the non-calf observations. The remainder of this section considers undisturbed whales excluding calves, i.e. all adults and subadults that we observed.

In 1983, we measured the blow interval, number of blows per surfacing, surface time, and dive time for undisturbed non-calves 866, 229, 248, and 140 times, respectively. Figures 5 through 8 present the frequency distributions of these observations. Figures 9 to 12 present the mean value for each of these four variables during each of our observation flights. Table 2 summarizes each of these variables for 1983.

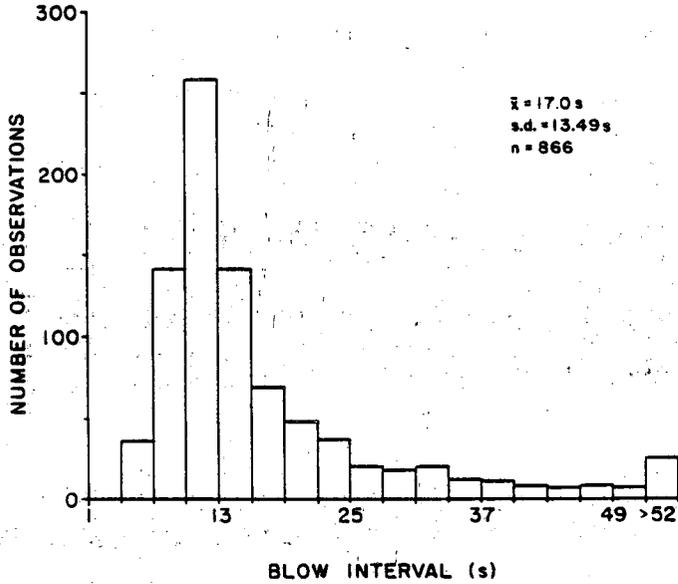


FIGURE 5. Frequency distribution of blow intervals for presumably undisturbed non-calves in 1983.

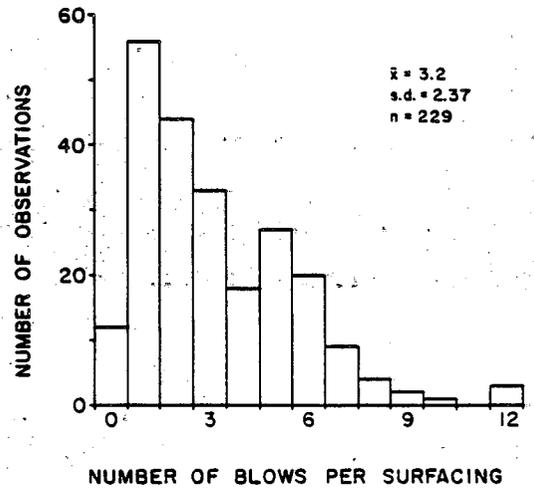


FIGURE 6. Frequency distribution of number of blows per surfacing for presumably undisturbed non-calves in 1983.

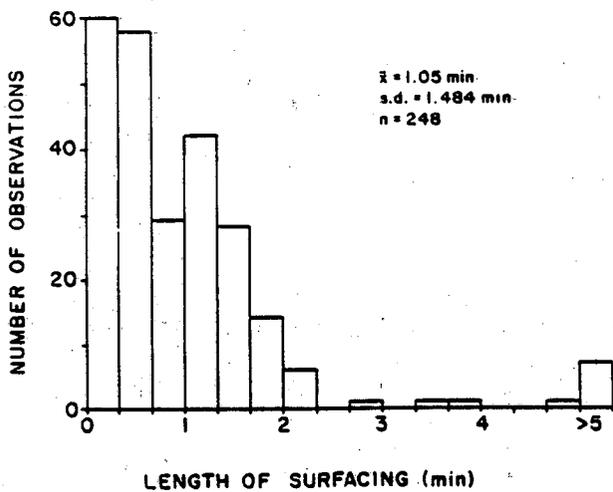


FIGURE 7. Frequency distribution of length of surfacing for presumably undisturbed non-calves in 1983.

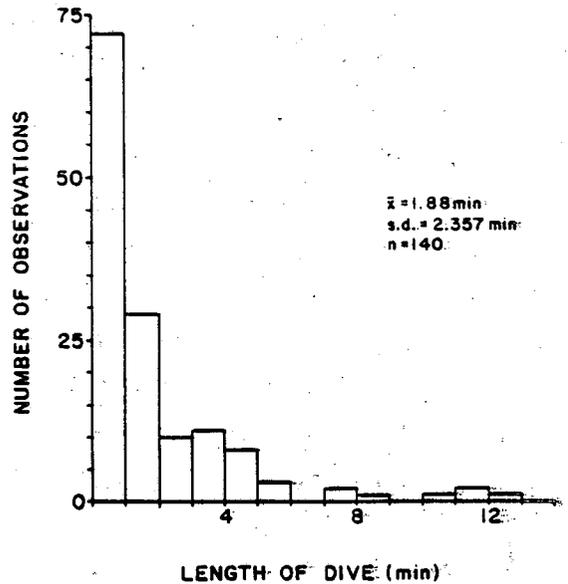


FIGURE 8. Frequency distribution of length of dive for presumably undisturbed non-calves in 1983.

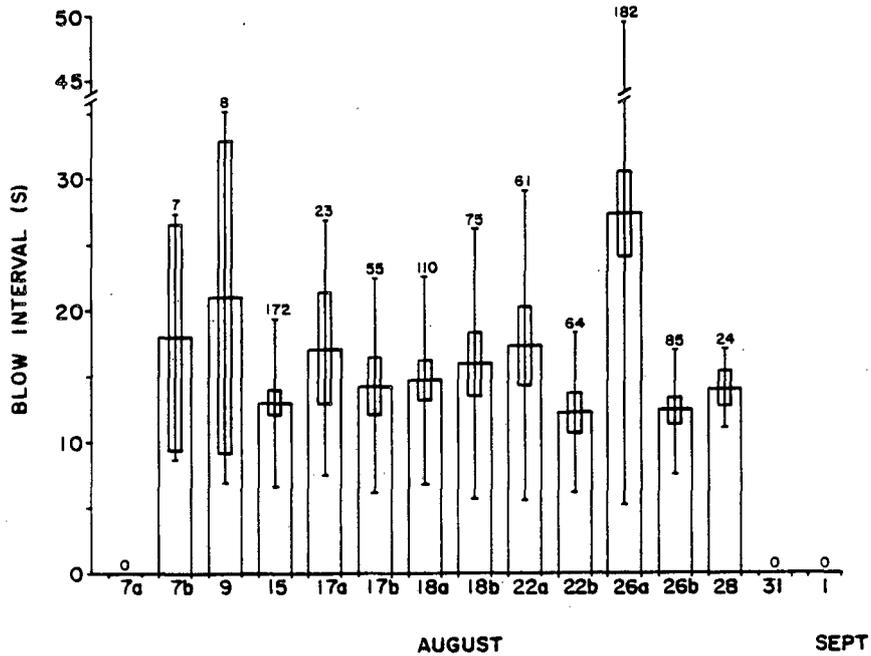


FIGURE 9. Mean interval between blows for presumably undisturbed non-calves during each observation flight in 1983. The vertical line in each column represents one standard deviation on either side of the mean, the box represents the 95% confidence interval for the mean, and the number at the top is the sample size.

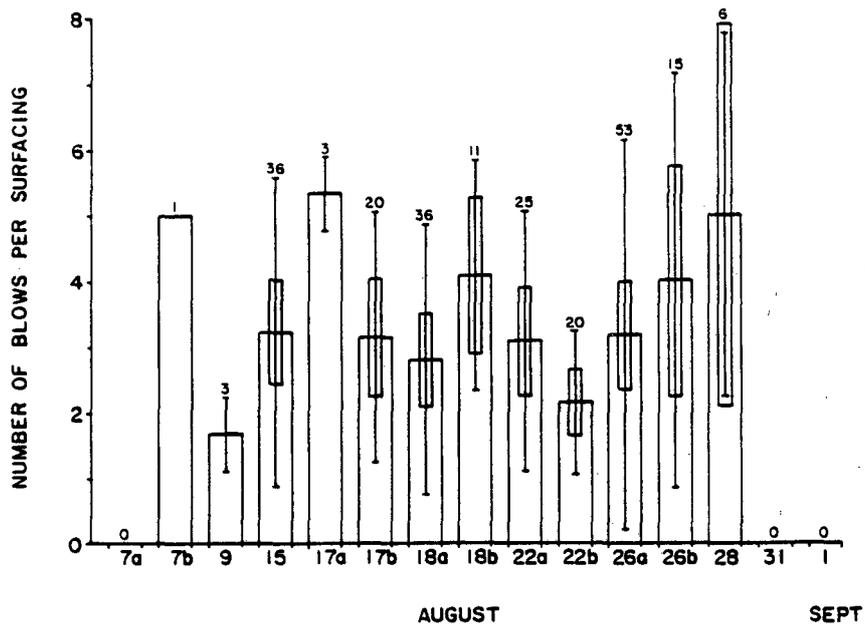


FIGURE 10. Mean number of blows per surfacing for presumably undisturbed non-calves during each observation flight in 1983. Presentation as in Fig. 9.

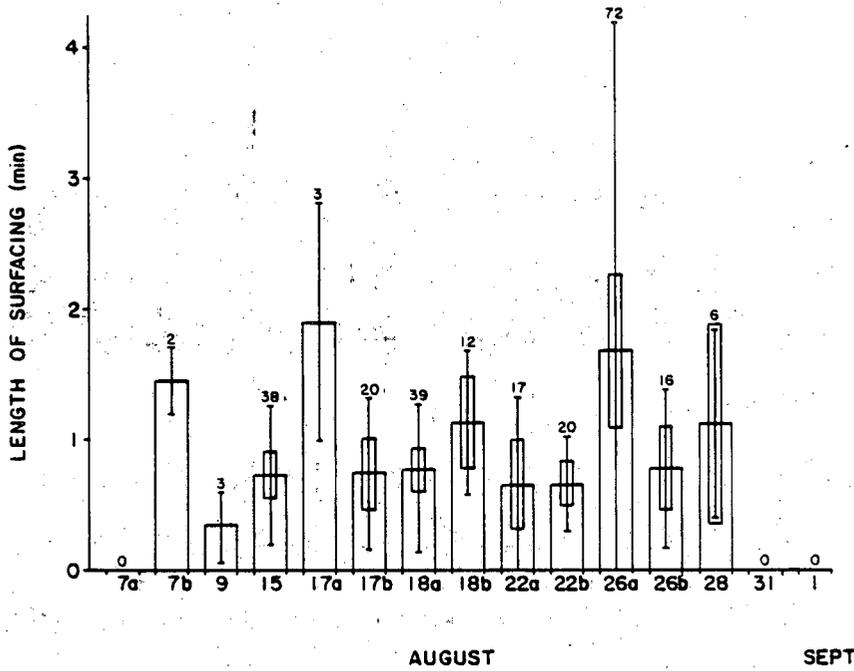


FIGURE 11. Mean length of surfacing for presumably undisturbed non-calves during each observation flight in 1983. Presentation as in Fig. 9.

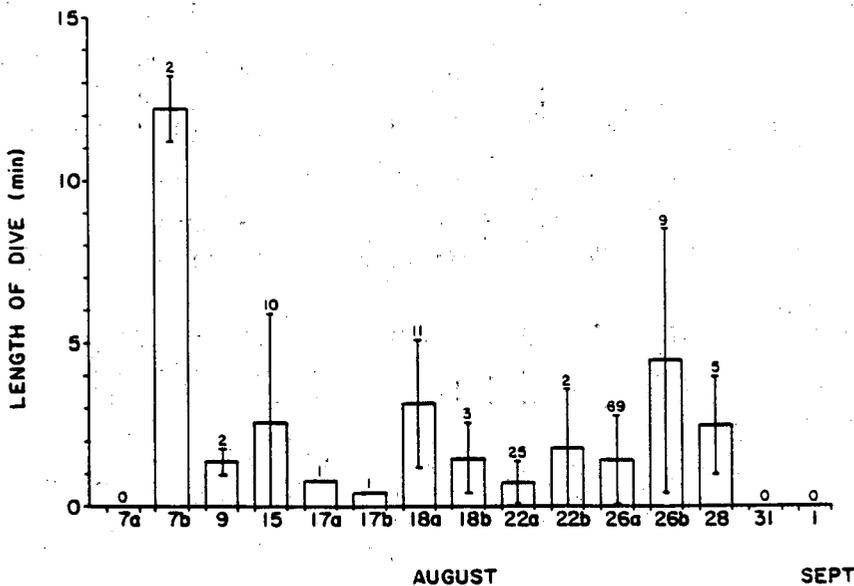


FIGURE 12. Mean length of dive for presumably undisturbed non-calves during each observation flight in 1983. The vertical line in each column represents one standard deviation on either side of the mean, and the number at the top is the sample size.

Table 2. Summary statistics for the principal surfacing, respiration and dive variables in presumably undisturbed bowheads in 1983. Calves are excluded from every line except that labelled 'calves'.

	Blow Interval (s)			Number of Blows per Surfacing			Length of Surfacing (min)			Length of Dive (min)		
	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n	mean	s.d.	n
All non-calves	17.0	13.49	866	3.2	2.37	229	1.05	1.484	248	1.88	2.357	140
Calves	11.5	5.07	4	1.1	0.90	7	0.36	0.478	8	1.98	2.720	7
Adults with calf	18.0	9.29	7	5.0	-	1	1.45	0.259	2	12.18	1.002	2
All others	17.0	13.52	859	3.2	2.37	228	1.05	1.489	246	1.73	2.015	138
Skim-feeding whales	31.7	23.79	120	6.9	3.99	10	5.20	3.636	15	0.93	1.001	16
Bottom-feeding whales	11.6	6.02	5	6.0	-	1	-	-	0	0.40	-	1
Non-feeding whales	14.5	8.95	651	2.9	2.17	199	0.76	0.586	212	2.03	2.510	115
Socializing whales, type #1 <sup>a</sup>	15.6	9.70	85	4.3	2.46	13	1.22	0.711	14	0.62	0.235	3
Socializing whales, type #2 <sup>b</sup>	10.7	5.02	15	3.0	-	1	1.11	0.474	3	2.34	2.722	2
Non-socializing whales	17.3	13.92	766	3.1	2.36	215	1.04	1.527	231	1.90	2.381	135
Non-socializing whales, excluding skim-feeders	14.6	8.90	646	2.9	2.10	205	0.75	0.584	216	2.03	2.482	119
Single whales excluding skim-feeders	14.0	7.89	521	3.0	2.15	151	0.71	0.540	151	2.12	2.466	74
Whales in groups excluding skim-feeders	15.9	10.93	225	3.0	2.12	68	0.91	0.683	82	1.83	2.451	50
Depth (m)												
<16	19.4	16.58	459	3.4	2.66	111	1.32	1.934	131	1.69	1.757	87
16-50	14.0	7.71	392	3.0	2.07	114	0.75	0.568	112	1.83	2.456	49
101-250	21.0	14.13	8	1.7	0.58	3	0.34	0.275	3	1.36	0.389	2
>250	18.0	9.29	7	5.0	-	1	1.45	0.259	2	12.18	1.002	2

<sup>a</sup> Socializing by activity: touching, chasing, otherwise interacting.

<sup>b</sup> Socializing by proximity only: within 1/2 body length.

Blow Interval

The frequency distribution for blow intervals in 1983 (Fig. 5) was very similar to that obtained in all three previous years. However, in 1983 there was more variability between observation flights (Fig. 9) than in the previous years, when blow intervals were quite consistent from flight to flight. The overall mean blow interval for all undisturbed non-calves was significantly longer in 1983 (mean =  $17.0 \pm$  s.d.  $13.49$  s,  $n = 866$ , range 4-173 s) than in 1980, 1981, and 1982 combined (mean =  $13.5 \pm 8.46$  s,  $n = 2822$ ) ( $t' = 7.21$ ,  $p < 0.001$ ). As will be explained below, much of the variability in blow intervals within 1983 and much of the increase in mean blow interval over previous years can be attributed to a single flight, the first flight on 26 August (Fig. 9), when most of the whales were skim-feeding.

Blows per Surfacing and Duration of Surfacing

In spite of the increased variability in blow intervals in 1983 compared to previous years, the number of blows per surfacing and the duration of surfacing were again very highly correlated (Fig. 13), as they had been in each of the three previous years. Both of these variables were significantly lower in 1983 than in 1980-82 combined. The mean surface time for non-calves in 1980-82 was  $1.3 \pm$  s.d.  $0.960$  min ( $n = 368$ ), whereas in 1983 it was  $1.05 \pm 1.484$  min ( $n = 248$ , range = 0.03-13.17 min) ( $t' = 2.34$ ,  $0.01 < p < 0.02$ ). The mean number of blows per surfacing for non-calves in 1980-82 combined was  $4.9 \pm 3.61$  blows ( $n = 322$ ), whereas in 1983 it was  $3.2 \pm 2.37$  blows ( $n = 229$ , range = 0-12 blows) ( $t' = 6.67$ ,  $p < 0.001$ ). This latter difference is attributable mostly to the high value for number of blows per surfacing in 1982. The mean number of blows per surfacing in 1981 was almost identical to that in 1983, and there was no significant difference between the 1983 mean and the 1980-81 combined mean.

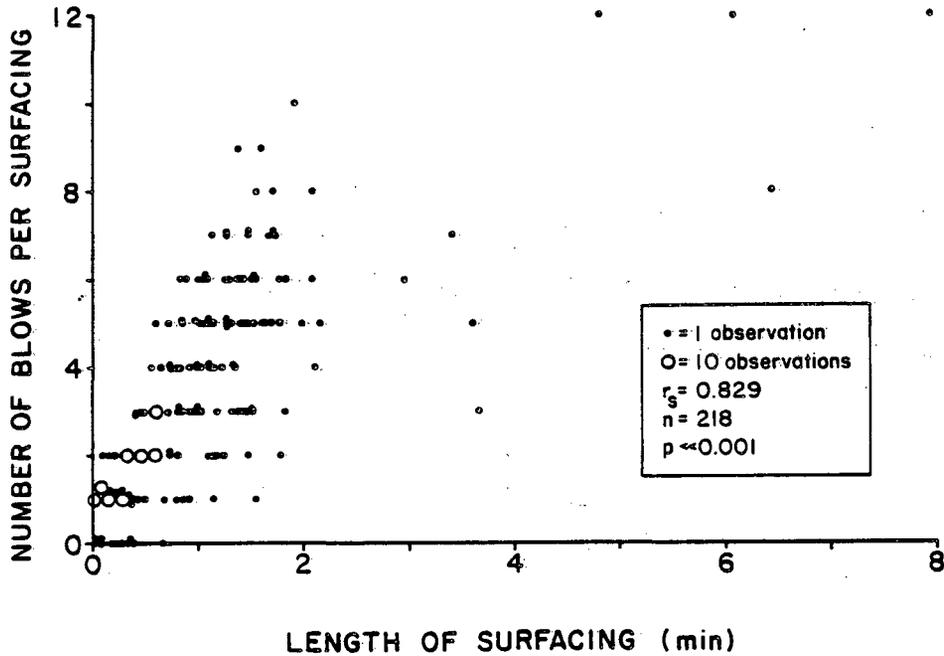


FIGURE 13. Correlation of number of blows per surfacing with length of that surfacing for presumably undisturbed non-calves in 1983.  $r_s$  is the Spearman rank correlation coefficient.

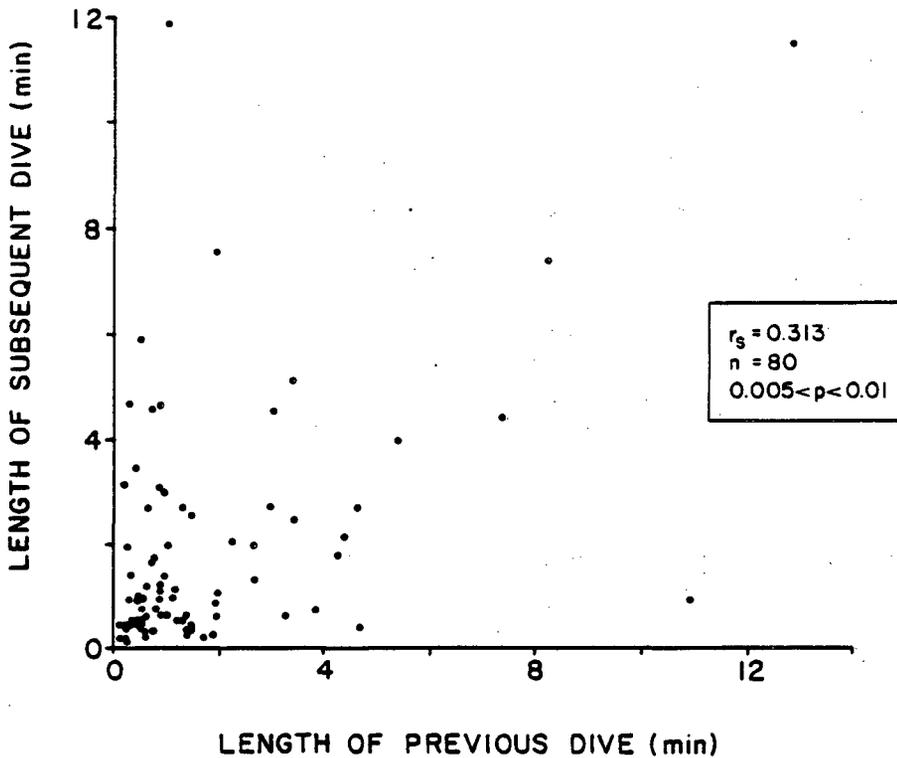


FIGURE 14. Correlation of length of dive subsequent to surfacing with length of dive previous to that surfacing for presumably undisturbed non-calves in 1983.  $r_s$  is the Spearman rank correlation coefficient.

### Duration of Dives

Our estimates of mean dive duration are biased downward to a degree that has varied somewhat from year to year (Würsig et al. 1983). The reason for this bias is that it is more difficult to find and recognize a whale when it re-surfaces after a long dive than after a short dive. In 1982, the conditions for measuring durations of long dives were better than in previous years because many of the whales were recognizable and we often circled over only one or two whales and could be certain that we had not missed any surfacings. Thus the mean dive duration in that year was probably less of an underestimate of the real mean duration than in 1980 and 1981. In 1983, there was again an especially strong sampling bias against long dives. We usually encountered whales in larger groups than in 1982, and most whales we circled in 1983 had few or no distinguishing marks.

The frequency distribution of dive times recorded in 1983 (Fig. 8) was strongly skewed toward short dives; 51% of those recorded were <1 min in duration. In this respect the frequency distribution for 1983 was much more similar to that for 1980 and 1981 (Würsig et al. 1982, Fig. 11) than to that for 1982 (Würsig et al. 1983, Fig. 7). The stronger sampling bias in 1980-81 and 1983 than in 1982 was partly responsible. However, we believe that the relative increase in short dives observed in 1983 as compared to 1982 was due also to an increase in the number of short dives made by the whales. As in past years, all statistical comparisons of dive times in 1983 were done non-parametrically.

The overall mean dive time for non-calves in 1983 was  $1.88 \pm \text{s.d. } 2.357$  min ( $n = 140$ , range = 0.13-12.88 min). This was shorter than the mean dive time observed in any of the three previous years. In addition to a real increase in short dives and a strong sampling bias in favor of short dives in 1983, a third factor may have contributed to this low value: an increase in water turbidity compared to previous years. Most 1983 observations were of whales in shallow turbid water close to shore. This probably resulted in whales disappearing from sight while 1-2 m closer to the surface than in previous years. Some shallow submergences that would not have been considered dives in clearer water in earlier years might have been counted as dives in 1983.

As in previous years, the length of the dive before a surfacing was significantly correlated with the length of the dive after that surfacing (Fig. 14). This indicates that a whale tends to make a series of dives of similar length rather than alternating short and long dives. However, the correlation in 1983 was not as close as that in 1982 (Spearman rank correlation coefficient  $r_s = 0.313$  vs.  $0.695$ ) perhaps partly because of the narrow range of dive times in 1983. The number of blows per surfacing in 1983 was significantly correlated with the length of the previous dive ( $r_s = 0.225$ ,  $df = 96$ ,  $0.02 < p < 0.05$ ) but not with the length of the subsequent dive ( $r_s = 0.114$ ,  $df = 98$ ,  $p > 0.2$ ). The length of surfacing was not significantly correlated with the length of either the previous dive ( $r_s = 0.033$ ,  $df = 114$ ,  $p > 0.50$ ) or the subsequent dive ( $r_s = 0.101$ ,  $df = 108$ ,  $p > 0.20$ ).

#### Blow Rate

The blow rate was calculated by dividing the number of blows during a complete surfacing by the sum of the durations of that surfacing and the subsequent dive (surface-dive cycles in which the dive was  $< 30$  s long were excluded from this analysis). The resulting number of blows per minute is a function of the surface time, dive time, and number of blows per surfacing, and provides a variable that describes the respiratory activity of a whale during a longer period of time than any of the constituent variables considered separately. The mean blow rate for undisturbed non-calves in 1983 was  $1.12 \pm$  s.d.  $0.709$  blows/min ( $n = 70$  blow rates by 32 whales, range =  $0-2.82$  blows/min). The 1983 value falls between the mean blow rates for 1982 ( $0.70 \pm 0.470$  blows/min,  $n = 25$ ) and for 1980-81 ( $1.28 \pm 1.140$  blows/min,  $n = 43$ ). Figure 15 presents the frequency distribution for blow rates in 1983.

#### Proportion of Time Visible from the Air

The proportion of time that a whale was visible from the air was calculated from all surfacings of known length in 1983 that were followed by dives of known length. As in 1982, we did not consider shallow submergences between blows to be dives. Figure 16 presents the frequency distribution of time visible from the air for presumably undisturbed non-calves in 1983. The mean proportion of time visible in 1983 was  $0.41 \pm$  s.d.  $0.279$  ( $n = 110$

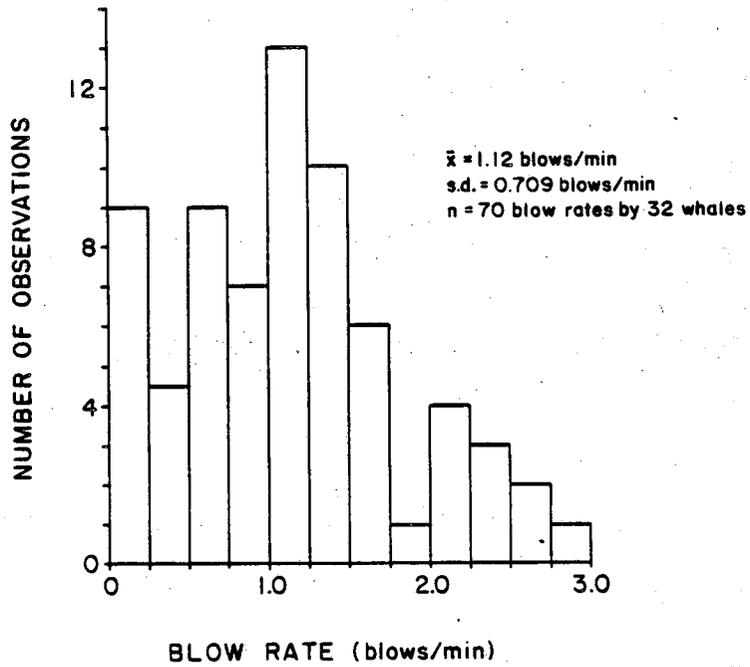


FIGURE 15. Frequency distribution of blow rates of presumably undisturbed non-calves in 1983.

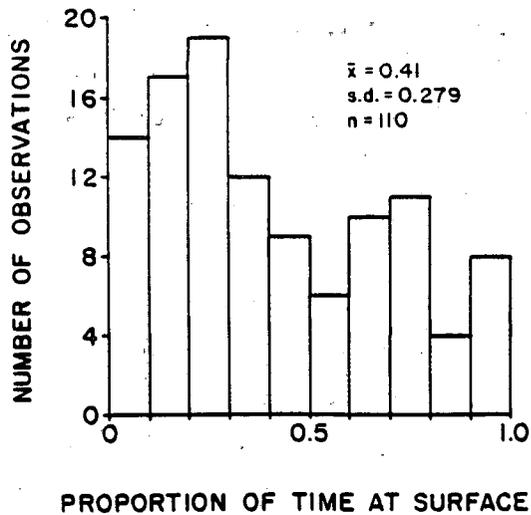


FIGURE 16. Frequency distribution of proportion of time visible from the air for presumably undisturbed non-calves in 1983.

surface-dive cycles, range = 0.007 - 0.969). This is significantly higher than the mean value obtained in 1982 (mean =  $0.24 \pm 0.170$ ,  $n = 31$ ) ( $t' = 4.20$ ,  $p < 0.001$ ). As presented below, skim-feeding whales in 1983 had considerably higher values for proportion of time visible than other whales. Even if the skim-feeding whales are excluded, however, the 1983 mean proportion of time visible is still significantly higher than the 1982 value (1983 mean excluding skim-feeders =  $0.35 \pm 0.234$ ,  $n = 95$ ;  $t = 2.42$ ,  $0.01 < p < 0.02$ ).

#### Depth of Water

From 1980 through 1982 there was a progressive increase in the average distance from shore and the average depth of water at the locations where we observed bowheads. Most of the 1982 observations were in markedly deeper water than during 1980 or 1981. In 1982, mean values of the four primary surfacing, respiration and dive variables were higher than in 1980-81. Analyses of the data did not support the hypothesis that there was, within any one year, a positive correlation between depth of water and any of the four variables (Würsig et al. 1983). However, in no one year were whales observed regularly over a wide enough range of depths to allow a good test of the hypothesis that behavioral variables are related to water depth.

In 1983, most of the whales observed were very close to shore and were in water as shallow as in 1980, with just a few observations in water deeper than 35 m (Fig. 4). If depth has a major influence on the surfacing, respiration, and dive patterns of these whales, then we would expect the values for these variables in 1983 to have been lower than in 1982 and comparable to what we saw in 1980 and 1981. As explained above, this was true only for the length of surfacing. Blow intervals were considerably longer in 1983 than in any previous year or, if skim-feeding whales are excluded, were approximately equal to the 1982 mean for blow intervals. Number of blows per surfacing and dive time were both lower than in any previous year. This suggests again that factors other than depth of water determine how these whales dive, surface, and respire.

An analysis of the effect of depth of water within 1983 is not meaningful because of the highly skewed distribution of observation time with depth (Fig. 4). Sample sizes for the surfacing, respiration, and dive variables in water deeper than 50 m are extremely small; only two depth categories, <16 m and 16-50 m, have enough observations for statistical treatment (Table 2). Although both blow intervals and surface times were significantly longer in water <16 m than in water 16-50 m deep ( $t' = 6.23$ ,  $p < 0.001$ , and  $t' = 3.22$ ,  $0.001 < p < 0.01$ , respectively), these differences are not evident if skim-feeding whales are excluded from analysis.

### Time of Day

Figures 17 through 20 present the mean values for each of the four main respiration, surfacing, and dive variables in relation to time of day. Both blow intervals (Fig. 17) and surface times (Fig. 19) show an apparent peak at 16:00-19:00 Mountain Daylight Time (MDT). Of the 2.8 hours of observation within that time of day, however, over 70% were from the first flight of 26 August, when many whales were skim-feeding and when most of the skim-feeding observations in 1983 occurred. As discussed below, skim-feeding whales had considerably higher values for blow intervals and for surface times. The peaks in Figures 17 and 19 at 16:00-19:00 MDT were apparently not related to time of day, but rather to skim-feeding, our observations of which happened to be concentrated during that time of day.

Aside from those apparently spurious relationships, there were no clear relationships between any of the four variables and time of day. This result is consistent with our findings in 1980-1982 (Würsig et al. 1982, 1983).

### Calves and Mothers

In 1983, we saw calves less frequently than in any of the three previous years, considering both presumably undisturbed and potentially disturbed periods (Table 3). There were just over one-third as many calf sightings in 1983 as in any preceding year, based on both the number of observation flights and the number of hours of observation time. The proportion of all

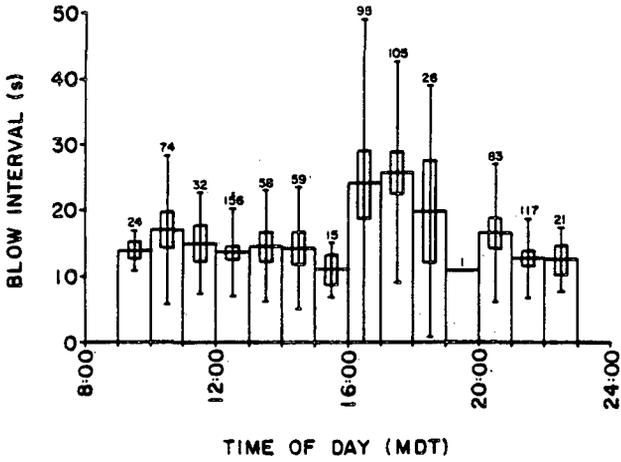


FIGURE 17. Mean interval between blows in relation to time of day for presumably undisturbed non-calves in 1983. Presentation as in Fig. 9.

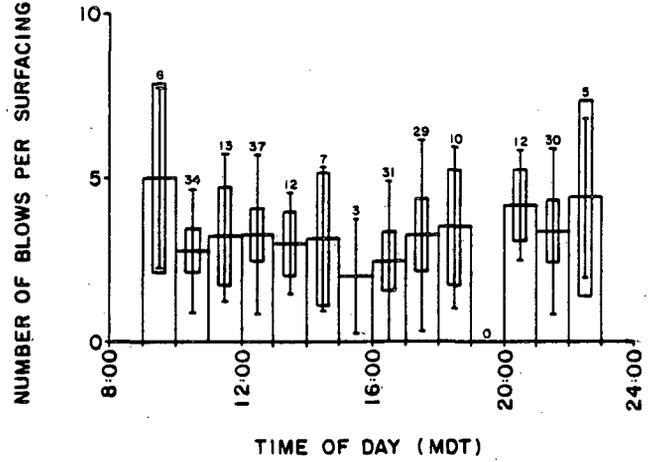


FIGURE 18. Mean number of blows per surfacing in relation to time of day for presumably undisturbed non-calves in 1983. Presentation as in Fig. 9.

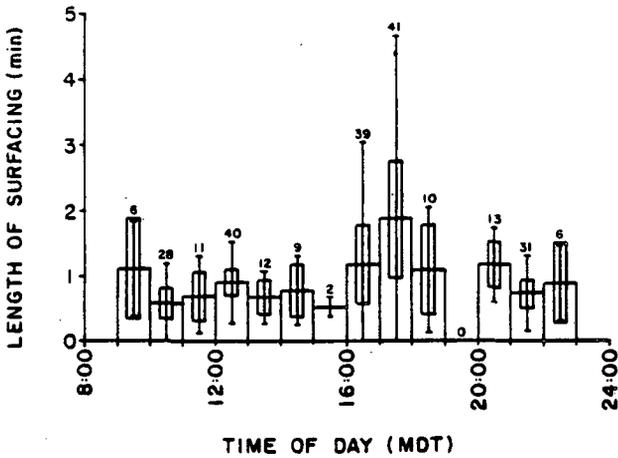


FIGURE 19. Mean length of surfacing in relation to time of day for presumably undisturbed non-calves in 1983. Presentation as in Fig. 9.

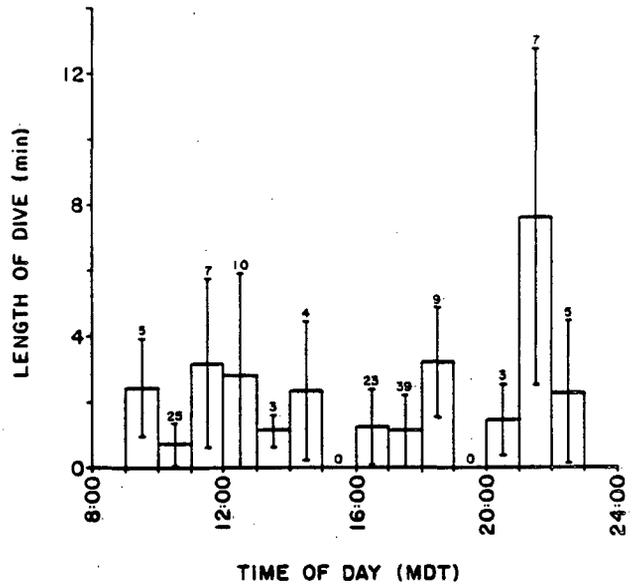


FIGURE 20. Mean length of dive in relation to time of day for presumably undisturbed non-calves in 1983. Presentation as in Fig. 12.

Table 3. Calf sightings and observation time in 1980-83. Both presumably undisturbed and potentially disturbed periods are included. The number of sightings of calves is an approximate count because multiple counts of the same calf were possible where the calf and its mother were not recognizable.

	1980	1981	1982	1983
Number of calf sightings	12	16	16	5
Number of flights*	14	18	14	15
Calf sightings per flight	0.86	0.89	1.14	0.33
Hours in plane over whales	30.4	30.8	36.5	38.4
Calf sightings per hour	0.39	0.52	0.44	0.13
Calf time at surface with mother (min)	20.4	17.5	63.1	8.6
Calf time at surface unaccompanied by mother (min)	1.6	12.7	38.2	11.5
Total calf time at surface (min)	22.0	30.2	101.3	20.1
% of calf surface time unaccompanied by mother	7.3%	42.1%	37.7%	57.2%
Whale-hours of observation at surface	10.03	14.98	10.95	17.91
Calf-hours of observation per whale-hour of observation	0.037	0.034	0.154	0.019
Calf time at surface per sighting (min)	1.57	1.89	6.33	4.02

\* Only flights with behavioral observations considered.

whale-hours of observation at the surface that were of calves was lower in 1983 than in any previous year. The total length of time that calves were in sight at the surface in 1983 was slightly lower than the lowest previous value, in 1980, and calves were seen without an adult for a higher percent of the time than in any previous year. The length of time that calves were seen at the surface per sighting in 1983 was considerably higher than in 1980 or 1981, but not as high as in 1982.

#### Segregation of Bowheads by Age Class

The few calves seen during behavioral observations in 1983 were all sighted during the first two observation flights, both on August 7. These were the only two flights in 1983 that were far from shore and over very deep water; the calves were seen over depths of about 1370 m and 1670 m in areas with much ice. No other behavioral observations were made in water deeper than 190 m, and most of the other observations were of bowheads in water less than 30 m deep, very close to shore (Table 1). The bowheads observed near shore in 1983 appeared to be lacking not only calves but also whales with large white chin patches and white pigmentation on the tailstock and flukes. Davis et al. (1983) have shown that both types of white pigmentation occur more frequently on larger whales, suggesting that the white patches develop with age. Our impression in 1983 was that we were seeing mostly whales that were not fully grown, except during the two 7 August flights over deep water.

In 1983, we measured a limited number of whales using the photogrammetric technique developed by Davis et al. Sixteen whales photographed close to the Yukon coast near King Point on 26-27 August were 8-12 m long, and four or five whales WNW of Pullen Island on 1 September were 7-12 m long (W.R. Koski, LGL Ltd., unpubl. data). These lengths are typical of yearlings and other subadult whales; adults with calves are 13 m or more in length (Davis et al. 1983).

This suggests that the bowheads in the study area in 1983 were at least partially segregated by age into two groups — (1) fully mature animals including females with calves in deep water offshore, and perhaps also in other areas that we did not search, and (2) immature animals, probably of a

variety of ages, but not including young of the year, in shallow water near the Yukon shore. Most of our observations were of the nearshore group because they were closer to our base at Tuktoyaktuk and provided dense concentrations of whales for observation and experiments (Richardson et al. 1983b).

Simultaneous with our study, Cubbage et al. (1984) measured a larger sample of whales over a wider area, although they obtained few measurements on the major concentration along the Yukon coast. Cubbage et al. also found that bowheads west of Tuktoyaktuk tended to be small (mostly <13 m). A higher proportion of those off the Tuktoyaktuk Peninsula were >13 m long, and almost all of those farther east in Franklin Bay and Amundsen Gulf were >13 m. In summary, we found that bowheads close to the Yukon coast were small, and Cubbage et al. (1984) found that there was a general trend for increasing size from west to east across the summer range.

In past years we have not had the impression that the bowheads we encountered were segregated by age to the same extent as in 1983. However, we have at times noted clumping of mother-calf sightings and of 'nondescript whale' sightings. Our ability to detect such segregation is weak, however, because we usually do not have length measurements for whales we observe. Davis et al. (1982, 1983) measured bowhead whales photogrammetrically in the eastern Beaufort Sea in the summers of 1981 and 1982. In both years they found geographic variation in the distribution of length classes over several hundred kilometres. In 1982 they also had evidence of temporal variation, on a scale of days or weeks, in the distribution of length classes within a single area.

#### Behavior of Mothers and Calves in 1983

In 1983, for the first time in this study, we observed interactions between two calves. More than half of the 'calf time at the surface unaccompanied by mother' (Table 3) consisted of a single 5-min observation of two calves interacting quite boisterously. This occurred in the presence of seismic noise during the first flight on 7 August. The two calves were about the same length, but one was distinctly darker than the other. While

remaining within about a calf's length of each other, they rolled onto their sides or back, circled tightly as if chasing each other's tails, made slicing movements with their tails, and--while just under the surface--performed other boisterous movements that produced white water. During this 5-min period, an adult moved toward the calves from 12-15 adult lengths away. However, we did not see it join the calves. Toward the end of the period, when the first adult was still in sight, a second adult surfaced for 43 s within a half body length of the two calves. The calves continued interacting boisterously when the second adult appeared, but when the adult dove again, one of the calves dove 17 s later and did not reappear. The remaining calf apparently then stayed by itself for at least 13 min, tail slapping and rolling at the surface for part of that time. We did not observe this calf joining an adult.

Another behavior pattern that we saw for the first time in 1983 was the persistent association of a subadult with a mother-calf pair. During the first flight on 7 August, also in the presence of seismic noise, we encountered a recognizable trio consisting of a large whale with very large white chin patches, a light calf, and a darker whale of intermediate size. They maintained their positions relative to one another over several surfacings. In at least 5 of 6 surfacings observed in about 40 minutes, the subadult swam behind the adult, usually by about 1/2 body length, while the calf swam on the left side of the adult, either touching or within 1/2 body length.

All other sightings of calves in 1983 were of lone calves or adult-calf pairs, except for one group of a calf and two adults. We saw only one potential nursing dive in 1983, when a calf briefly submerged at its mother's side; the mother reacted by turning its body in such a way as to move its belly away from the calf. This may have been an attempt on the mother's part to forestall nursing.

#### Mothers and Calves Compared to Other Bowheads

Of the two flights when we encountered mothers and calves in 1983, only one (the second flight on 7 August) was during presumably undisturbed

conditions. Our only observations during that flight were of a single mother-calf pair amongst ice pans, and we were able to obtain very few data (Table 2). Because of the small sample sizes, we will not discuss these data in detail. The two measured dives by undisturbed mothers were noticeably longer than for any other category of undisturbed bowhead in 1983, but they were in very deep water, about 1670 m. All other timed dives by undisturbed non-calves in 1983 were in water less than 35 m deep. We do not have enough data for mothers in 1983 in order to consider whether long dives occurred because they were mothers or because they were in deeper water, or for some other reason.

### Feeding Behavior

During the four years of this study we have observed several types of feeding behavior. We have seen bowheads skim-feeding with open mouths at or just below the surface, sometimes in echelon formation. Feeding at or near the bottom has been indicated by whales surfacing with muddy water emanating from their mouths. And we have hypothesized feeding in the water column when whales made long dives interrupted by short surfacings with little forward motion and occasional defecation. Würsig et al. (1982) provide detailed descriptions of these behaviors.

During 1983, we saw no indications of feeding (except for 6 defecations on 15 and 17 August) until 22 August, when a whale that was aerially active for 75 min (see below) surfaced twice with mud pouring from its mouth. We observed much skim-feeding on 26 August, and more apparent bottom feeding on 28 and 31 August and 1 September. Skim-feeding occurred in 8 m depth, only several hundred metres from shore at King Point, Yukon. Apparent bottom feeding, on the other hand, occurred in water from 11 to 19 m deep, and from 11 km from shore (off King Point on 28 August) to about 82 km WNW of Pullen Island (on 31 August and 1 September). No skim-feeding whales seen in 1983 were in echelon formation. In 1983, dives were generally short, and we obtained no direct evidence that feeding in the water column took place.

Figure 21 and Table 2 present the surfacing, respiration and dive characteristics of **skim-feeding** and 'non-feeding' bowheads during presumably

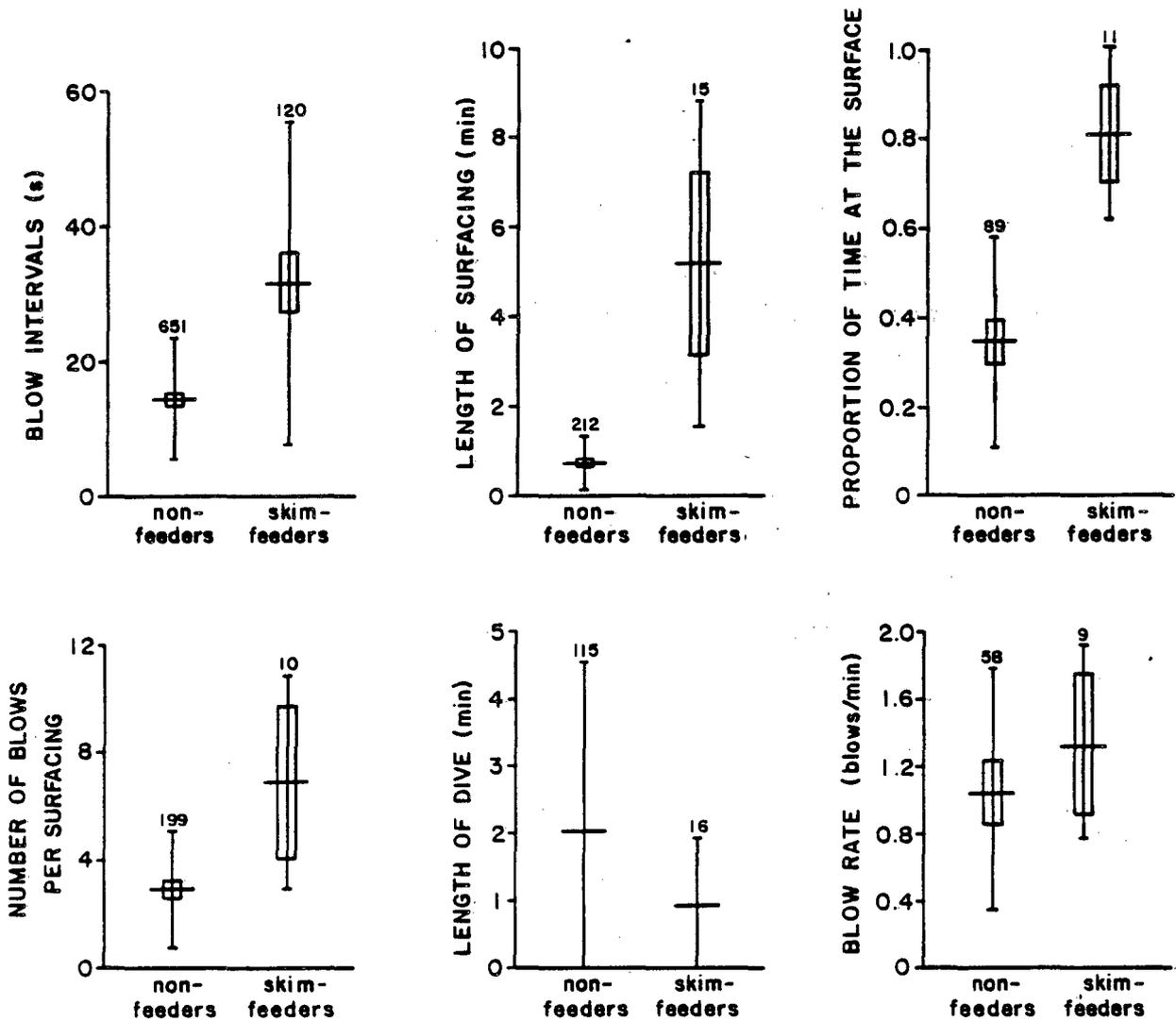


FIGURE 21. Comparison of respiration, surfacing and dive characteristics of skim feeding whales and non-feeding whales in 1983. Only presumably undisturbed non-calves are included.

undisturbed periods in 1983. The mean blow interval of skim-feeding whales was more than twice that of non-feeding whales ( $t' = 7.82$ ,  $p < 0.001$ ). Skim-feeding whales in 1983 had the longest mean blow interval yet observed for any category of whales during this study. In 1980-81, the mean blow interval for skim-feeding whales was also longer than that for 'non-feeders', but the difference was not statistically significant. In 1983, both the mean surface time and the mean number of blows per surfacing were significantly higher for skim-feeding whales ( $t' = 4.72$ ,  $p < 0.001$ , and  $t' = 3.12$ ,  $p < 0.02$ , respectively). Neither of these trends was evident in the quantitative data collected in previous years. (However, our previous data on skim-feeding whales were biased toward short surfacings. In 1981, we were unable to include several whales that skim-fed for several minutes, so long that we missed the beginning or the end of the surfacing. Thus the data collected in 1981 on surface times and number of blows per surfacing for skim-feeders were unrepresentatively low.) The mean dive time of skim-feeding whales in 1983 was lower than in non-feeding whales, but the difference was not statistically significant; a similar trend was evident in 1980-81.

In 1983, skim-feeding whales spent a significantly higher proportion of time at the surface than did whales that were not feeding (skim-feeding mean =  $0.81 \pm$  s.d.  $0.195$ ,  $n = 15$ ; non-feeding mean =  $0.35 \pm 0.234$ ,  $n = 89$ ;  $t = 7.26$ ,  $p < 0.001$ ). The mean value for skim-feeders may be biased upwards since we may have recognized skim-feeding more easily when animals stayed at the surface for long periods, but we do not feel that this bias was very strong. The blow rate was only slightly higher in skim-feeding whales (mean =  $1.34 \pm 0.557$  blows/min,  $n = 9$ ) than in non-feeding whales (mean =  $1.06 \pm 0.706$  blows/min,  $n = 58$ ), and the difference was not significant.

On 28 August 1983, while the bowheads under observation were potentially disturbed by a nearby boat, we observed a whale swimming along a windrow of debris. The whale surfaced with mud near its head, as if it had been bottom feeding like other whales that day. It then swam at medium speed in the drift line for all 35 s of its surfacing. During three subsequent surfacings the whale was progressively farther from the windrow. There was no indication that the whale's mouth was open or that it was feeding in the windrow, but we mention the incident because it was the first observation of

such behavior in an adult whale. In 1982, we saw a calf play in a windrow of debris for over 12 min, and in that case, also, there was no indication of feeding.

The indications of **bottom feeding** in 1983 were the first we had observed since 1980. Mud was definitely seen to come directly from the mouths of bowheads during 19 surfacings in 1983, at times in considerable quantities. The only baleen whale known to feed on organisms that burrow into bottom sediment is the gray whale (Eschrichtius robustus), and it has been suggested that the relatively short, coarsely fringed baleen of that species is particularly adapted to such feeding. Bowhead whales, in contrast, have very long, very finely fringed baleen that would not suggest similar feeding strategies to those of gray whales. Nevertheless, the amount of mud that we have seen pouring from the mouths of bowhead whales, both in 1980 and in 1983, appeared to be too great to have been picked up incidentally while feeding on water column organisms near the bottom. We are forced to conclude that at times bowhead whales must plow up the bottom considerably while collecting epibenthic prey or perhaps while taking inbenthic prey, as gray whales do. We have suggested this earlier (Würsig et al. 1982), but we wish to emphasize this unexpected conclusion. By all indications, bowhead whales feed in this manner only rarely.

Although apparent bottom feeding occurred in 1983 on 28 and 31 August and on 1 September, underwater industrial sounds were detectable near the whales most of the time. As a result, the samples of surfacing, respiration and dive data for undisturbed bottom feeding whales were too small for meaningful analysis (Table 2).

### Social Behavior

Behavior was termed social when whales (1) appeared to be pushing, nudging, chasing each other, or otherwise interacting, or (2) were within one-half body length of one another but not noticeably interacting. The first category is definitely social behavior, while the second category is less clearly so, since those whales may simply be in close proximity without interacting. We found that blow intervals were significantly longer for type

#1 than for type #2 socializing whales in 1983 ( $t' = 2.93$ ,  $p < 0.01$ ) (see Table 2); for other variables, sample sizes from #2 socializing were too small to allow comparisons. Because #1 socializing represents more active socializing, and because there is some evidence that surfacing-dive-respiration characteristics may not be similar for the two categories, we separated the two socializing categories in most tabulations of 1983 data, and we considered only #1 socializing in the statistical analyses. Our analysis of socializing in 1983 is, therefore, slightly different from the analyses of 1980-82 data, when the two socializing categories were not separated. When we compared 1983 results with those from 1980-82, however, we included both types of socializing in order for the data to be comparable.

As in past years, interactions between mothers and calves and between whales skim-feeding in close proximity were not included in the analysis of social interactions. Whales may, of course, communicate by sound and thus may interact over far greater distances than those described here. Since we cannot verify whether acoustic communication is occurring between any particular whales, we restrict our definition of socializing to visible behavior. Because groups of whales usually could not be reidentified positively from one dive to the next, we treated observations of social behavior at intervals of  $>5$  min as independent for the purpose of counting number of interactions. Conversely, we did not score social behavior in the same area more than once in 5 min unless we could distinguish groups.

#### Frequency of Socializing

We calculated rates of socializing by dividing the number of instances of socializing by the number of whale-hours at the surface (the sum of the durations of all observed surfacings). The overall socializing rate for presumably undisturbed whales was much higher in 1983 than in 1982, and was comparable to that in 1981 (Table 4). In 1983, when both undisturbed and potentially disturbed whales are considered, at least some social activity was observed on every day with behavioral observations. More instances of #1 socializing occurred up to and including 18 August than after that date (Fig. 22). The rate of #1 socializing up to and including 18 August was 4.13

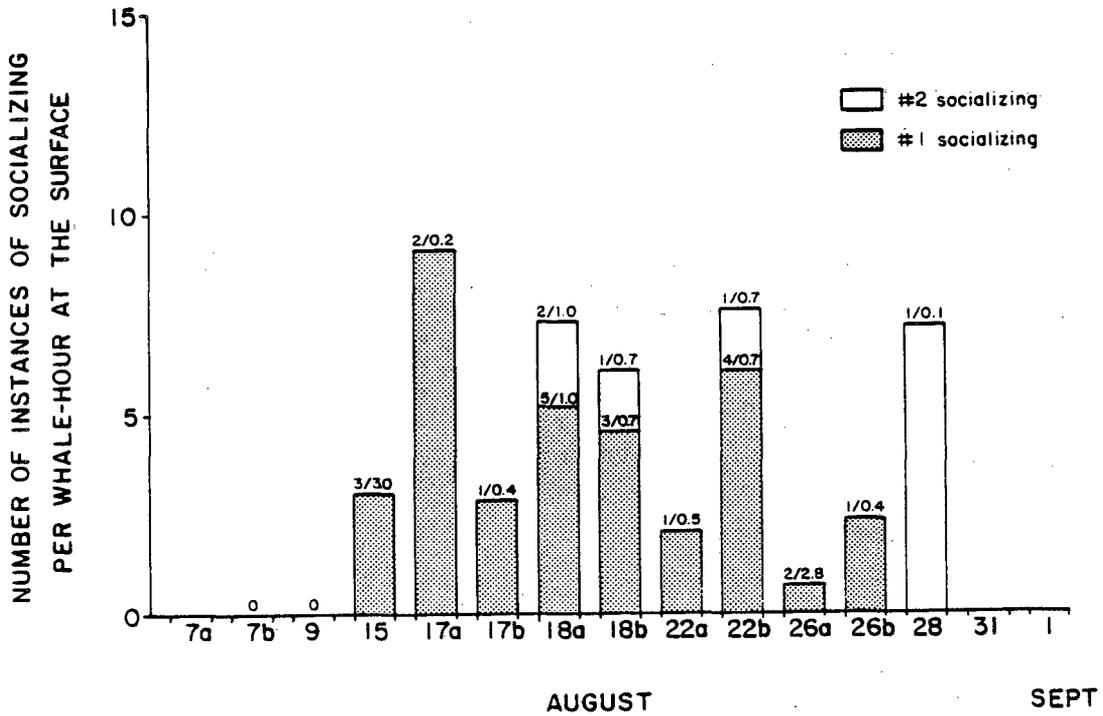


FIGURE 22. Rate of socializing during each flight in 1983. #1 socializing is distinguished from #2 socializing (see text for definitions). Only presumably undisturbed periods are included. The numbers at the top of each column are number of social interactions/number of observation hours.

social interactions per whale-hour at the surface, while the rate later in the study period was only 1.77 interactions per whale-hour (chi-square = 3.87, df = 1,  $p < 0.05$ ). The decrease in rate of social activity during late August in 1983 was consistent with a similar trend in 1980 and 1981 (considering both types of socializing).

Table 4. Rate of socializing among presumably undisturbed bowhead whales, 1980-83, calculated according to number of whale-hours of observation at the surface. Both type #1 and type #2 socializing incidents (see text) are included.

	1980	1981	1982	1983
A. Number of instances of socializing	42	39	7	27
B. Whale-hours at the surface	5.9	10.1	6.3	7.9
C. Socializing rate (A/B)	7.1	3.9	1.1	3.4

Figures 23 and 24 show rate of socializing vs. depth of water and time of day for presumably undisturbed bowheads in 1983. There was no discernible relationship between amount of socializing and depth of water (Fig. 23). It appears that #1 socializing occurred more frequently around 12:00 - 15:00 MDT and during evening than during late afternoon (Fig. 24). Sidereal noon occurs at approximately 15:00 MDT in the study area, and the rate of socializing was low from 15:00 to 20:00 MDT. The high rates of #2 socializing from 09:00-10:00 MDT and from 19:00-20:00 MDT are both based on very short observation periods, and may not be representative. Our 1983 results on diurnality of socializing are interesting, because we had evidence from previous years that there was a peak of social activity at or just after sidereal noon (Würsig et al. 1983), and this was not the case in 1983. However, for the 1980-81 data, the rate of socializing by hour of day was calculated based on time spent circling over whales and not on whale-hours at the surface, as in 1983, so comparisons between years may not be valid here.

#### Types of Social Behavior Observed

Most incidents of socializing in 1983 consisted of brief interactions between two whales, with one nudging the other or orienting towards the other

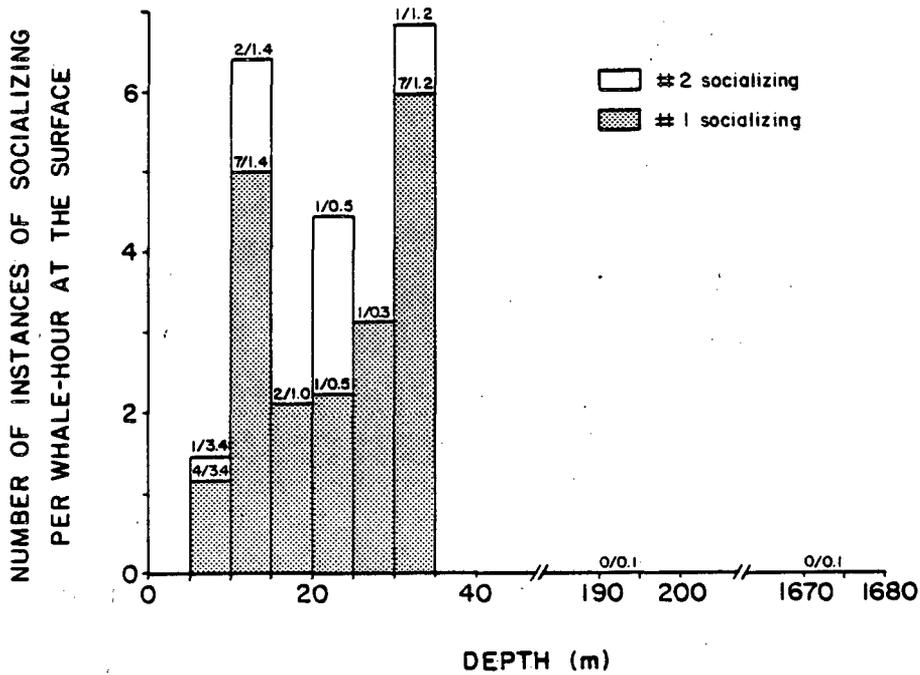


FIGURE 23. Rate of socializing in relation to depth of water in 1983. #1 socializing is distinguished from #2 socializing. Only presumably undisturbed periods are included. Presentation as in Fig. 22.

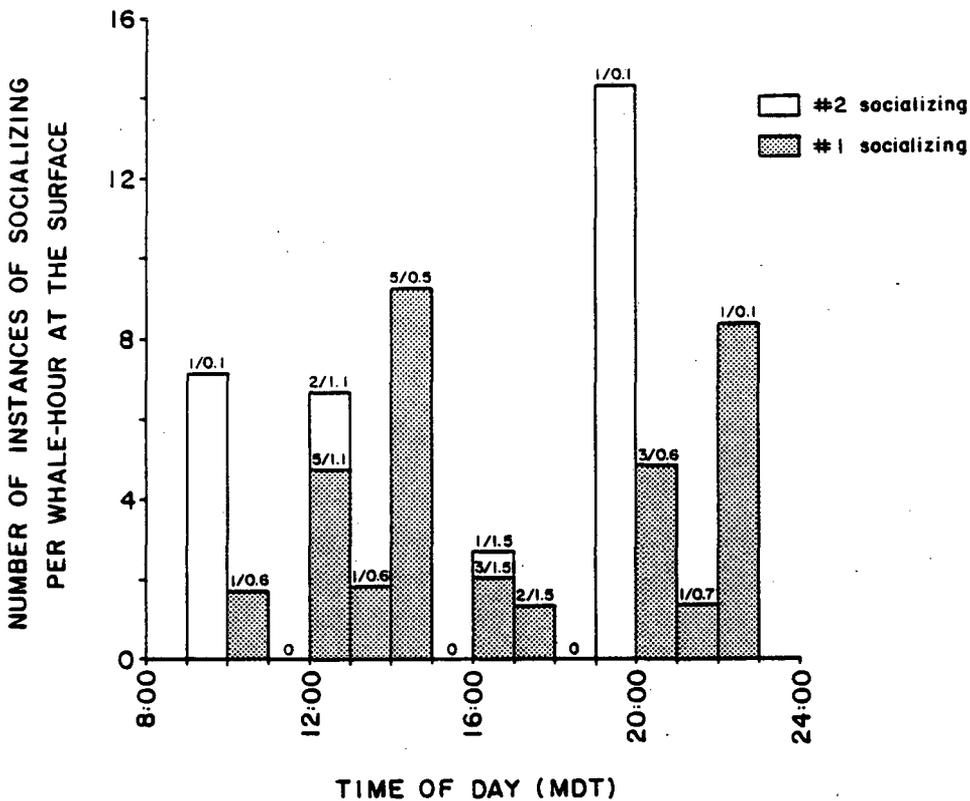


FIGURE 24. Rate of socializing in relation to time of day in 1983. #1 socializing is distinguished from #2 socializing. Only presumably undisturbed periods are included. Presentation as in Fig. 22.

at close distance. However, we also saw six apparent chase sequences, when one whale swam rapidly behind a second whale along the same route. None of these chases lasted longer than 10 s, and only one occurred under presumably undisturbed conditions in 1983.

On 9 August 1983, we observed several groups of interacting whales in water 190 m deep, 41 km north of Herschel Island. Seismic noise was present most of the time (Richardson et al. 1983b). We identified few whales by natural marks and therefore obtained few dive times and no precise count of the number of socializing groups. However, there were about 12 whales in three to four groups within our approximately 10 km<sup>2</sup> circle of observation. Although the instances of socializing at the surface generally lasted for only about 1 min, whales surfaced and dove while interacting, and we suspect that socializing continued underwater. A further impression was that there was usually one whale toward which the two or three other whales oriented, and these whales nudged or pushed the focal whale. The activity in these groups was never as boisterous as in the mating groups of bowheads observed during spring migration (Everitt and Krogman 1979) or southern right whales (Eubalaena australis) observed during winter (Payne and Dorsey 1983; Payne in prep.). In the latter case, the focal animal of such groups is usually a female and the other animals are males attempting to mate with her. We saw no evidence for copulation in the socializing bowheads that we observed in the summer of 1983 (although we observed apparent mating activity in 1981). We also saw no signs of whales attempting to avoid copulation, for example by rolling belly up in an active group. Therefore we do not know whether the socializing that we observed in 1983 was of a sexual nature.

On 31 August 1983, we witnessed a particularly violent interaction between two whales that had apparently been bottom feeding. At least four other whales were bottom feeding in the area, which was about 82 km WNW of Pullen Island, in 19 m depth. All whales observed that day were exposed to seismic blasts. One whale surfaced beside a second whale and began slapping one of its pectoral flippers onto the mid-body of the second whale. There were three such slaps, after which the second whale rolled on its axis and then slapped its flukes onto the mid-body of the first whale six times in 1.33 min. The last two fluke slaps were particularly high and forceful, and

hit the first whale squarely on the back. We could not see what immediate reaction the first whale had, if any, because we lost sight of the action for 12 s after the last slap. When we resighted the whales, they lay side by side and then slowly sank below the surface together. We do not know how to interpret this apparent aggression between the two whales; we have not seen such behavior in other cases when whales were exposed to seismic noise.

While interacting with nearby whales, socializing whales often turn while at the surface. In contrast, non-socializing whales often come to the surface and dive again without changing direction. The data from 1980-82 showed significantly more turns for socializing whales than for non-socializing whales. In 1983, during presumably undisturbed periods, socializing whales also made turns during a higher proportion of surfacings than did non-socializing whales. However, the difference was not statistically significant in 1983 (chi-square = 2.49, df = 1,  $0.10 < p < 0.25$ ).

	<u>#1 socializing whales</u>	<u>non-socializing whales</u>
surfacing with turns	7	60
surfacing without turns	6	147
	<hr/>	<hr/>
total surfacings	13	207
% surfacings with turns	54%	29%

#### Socializing Whales Compared to Non-socializing Whales

The surfacing, respiration, and dive characteristics for socializing and non-socializing whales, considering only presumably undisturbed non-calves, are presented in Table 2 and Figure 25. As explained above, the socializing whales are divided into two categories, #1 and #2 socializing. The non-socializing whales are also presented in two ways, both with and without the inclusion of skim-feeding whales. In past years, we have compared socializing whales to all non-socializing whales without regard to feeding behavior. However, in 1983, the behavior of skim-feeding whales differed dramatically from that of non-feeding whales, especially in the mean interval between blows. The following statistical analyses therefore compare only #1 socializing whales with non-socializing whales that were not skim-feeding.

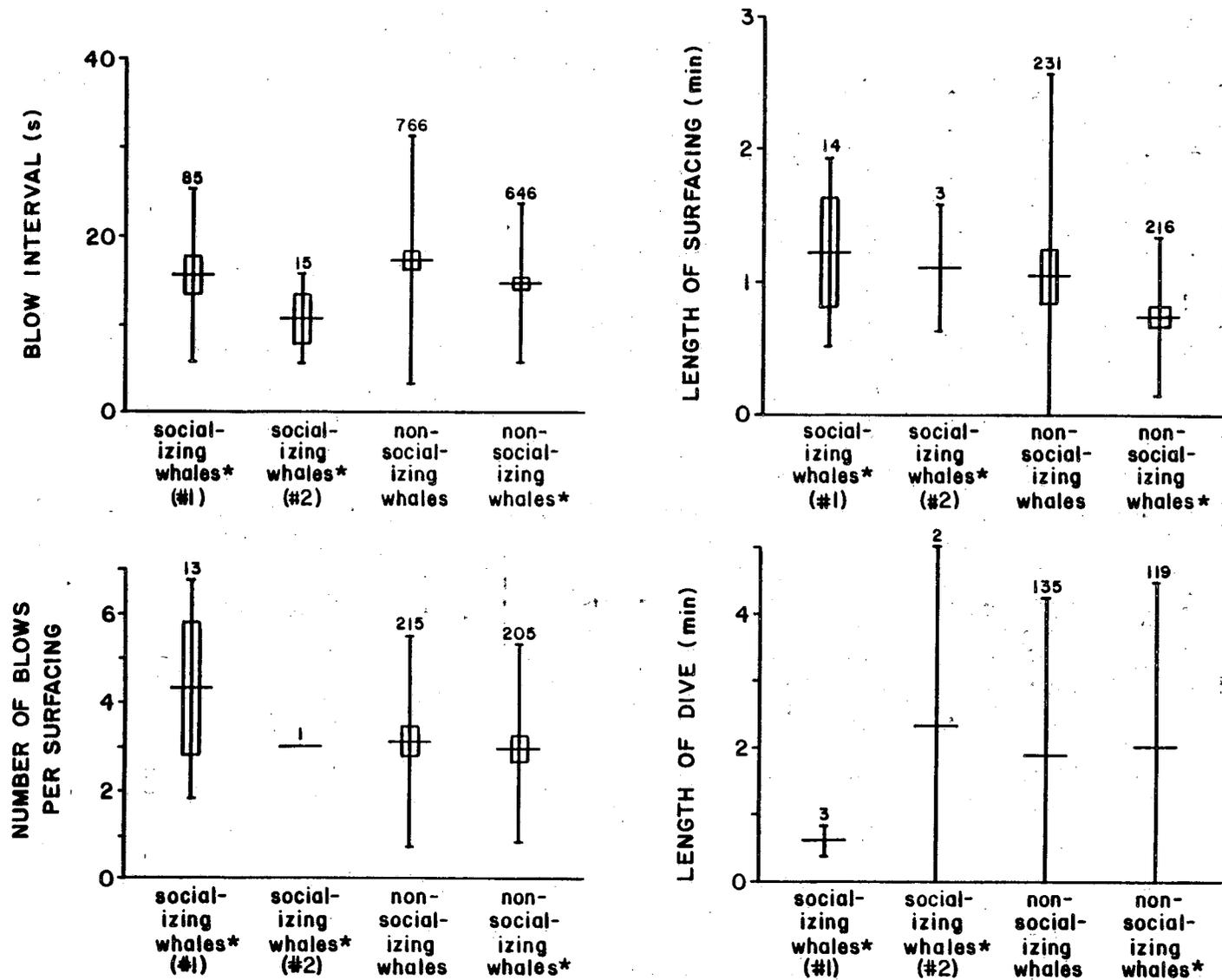


FIGURE 25. Comparison of respiration, surfacing and dive characteristics of socializing whales in two categories (#1 and #2 socializing) and non-socializing whales in 1983. \* = skim-feeding whales excluded. Only presumably undisturbed non-calves are included.

Blow intervals were not significantly different for #1 socializing whales and non-socializing whales (skim-feeding whales were excluded from both categories). Mean duration of surfacing, however, was significantly longer for #1 socializers than for non-socializers ( $t = 2.88$ ,  $df = 228$ ,  $p < 0.005$ ), and the mean number of blows per surfacing was also significantly greater for #1 socializers than for non-socializers ( $t = 2.31$ ,  $df = 216$ ,  $p < 0.05$ ). Although #1 socializing whales had a shorter mean dive time than non-socializers, the sample size for the former group was very low, and the difference was not statistically significant. The sample sizes for proportion of time at the surface and for blow rates in socializing whales were too small for meaningful comparison with non-socializing whales.

#### Lone Whales vs. Whales in Groups

We also analyzed the effect of group size on the main surfacing, respiration, and dive variables by comparing lone whales to whales in groups of two or more. A group was defined as all whales within five body lengths of each other. Whales in a group are not necessarily interacting socially in the way that we have defined for socializing above. However, the proximity required for whales to be classified as being in a group of two or more normally must represent at least a minimum level of social interaction. For this analysis of lone whales vs. whales in groups, we excluded skim-feeding whales from both categories in order not to confuse the effect of skim-feeding with any effect of group size.

The mean blow interval was significantly longer for whales in groups than for single whales ( $t' = 2.36$ ,  $0.01 < p < 0.02$ ), and the mean surface time was also longer in groups of whales ( $t = 2.40$ ,  $0.01 < p < 0.02$ ) (see Table 2). Because longer blow intervals tended to accompany the longer surface times for whales in groups, there was no difference in number of blows per surfacing between whales in groups and single whales. Lengths of dives by whales in groups appeared slightly shorter than those by single whales, but the difference was not statistically significant.

Correlation of Socializing with Underwater Blows

We observed 347 underwater blows during 1983; 216 of these occurred during potentially disturbed times and 131 during presumably undisturbed times. We often noted underwater blows within or near socializing groups of whales in 1983, so we looked for a correlation between the two behaviors. We felt it necessary to use a new basis for the calculation of underwater blow rates. Because one might expect the rate of underwater blows to vary directly with the number of whales in an area, and because underwater blows --by definition--can occur only when a whale is underwater, we standardized using 'number of whale-hours underwater'. This quantity is intended to be the sum of durations of all dives by whales being circled by the aircraft during a behavioral observation session. Since we were never able to measure all dives of the whales under observation, we estimated the number of whale-hours underwater in the following way. The number of hours of behavioral observations from the aircraft was multiplied by the estimated number of whales in the circle of observation to get the total number of whale-hours of observation, both at and below the surface. From this figure we subtracted the number of whale-hours at the surface (determined by summing the durations of all observed surfacings) to obtain the number of whale-hours underwater. The number of underwater blows observed was then divided by this value to obtain the underwater blow rate.

Figure 26 presents the underwater blow rate for presumably undisturbed whales during each observation flight in 1983. During the first flight on 17 August, the rate of underwater blows was very high (Fig. 26). The highest observed rate of socializing occurred during that same flight (Fig. 22). Over all observation flights, the correlation between the rate of underwater blows and the rate of #1 socializing was indeed positive and highly significant (Fig. 27).

We have been uncertain how to interpret underwater blows ever since we first observed them in 1980. We tentatively classified them as a potential type of feeding behavior in that first year, because of their similarity to some bursts of bubbles associated with feeding in humpback whales (Megaptera novaeangliae) (Hain et al. 1982). We did not see any direct evidence of

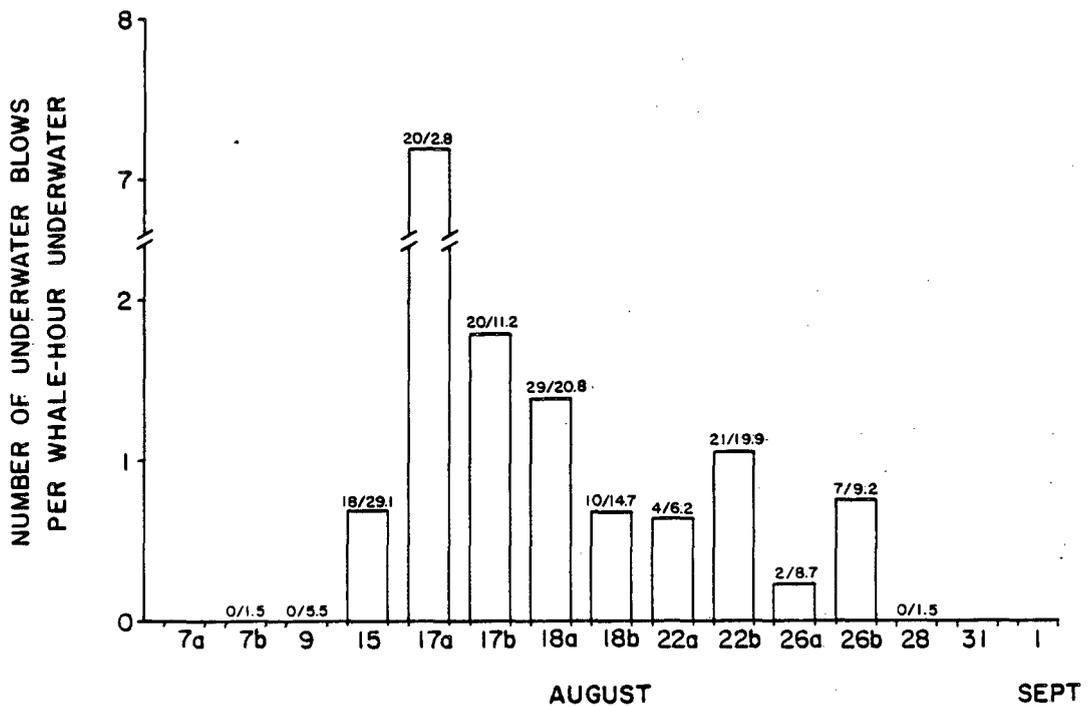


FIGURE 26. Rate of underwater blows during each flight in 1983. Only presumably undisturbed periods are included. The numbers at the top of each column are number of underwater blows/number of whale-hours underwater.

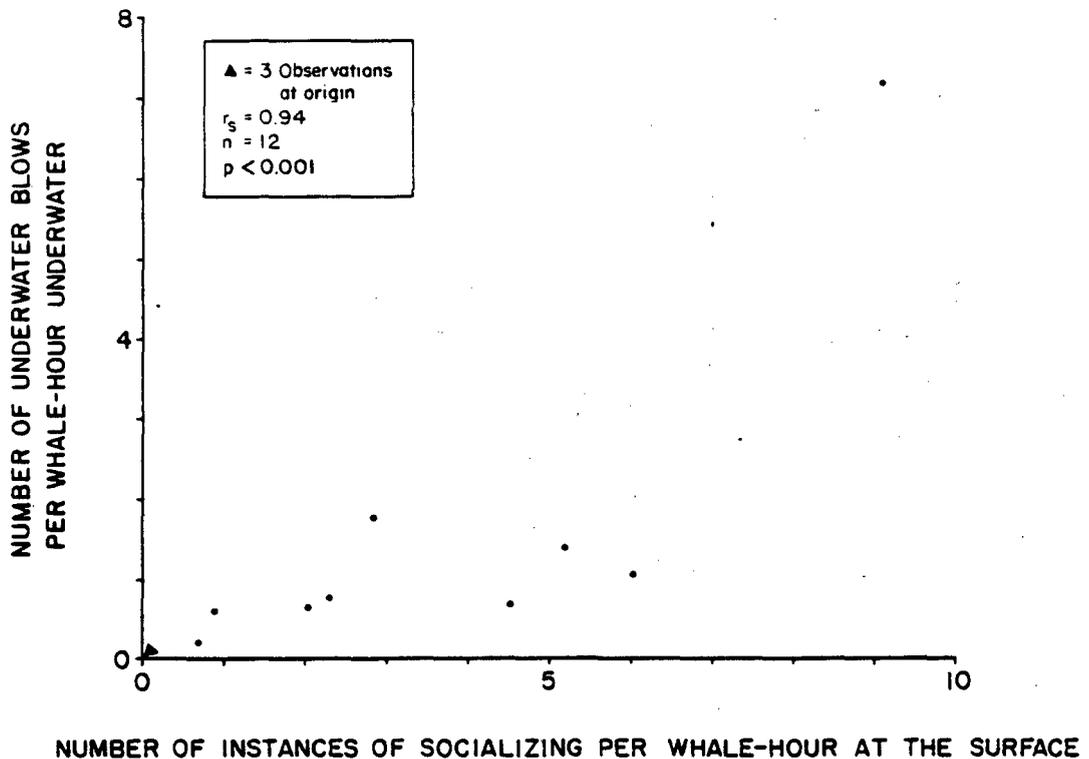


FIGURE 27. Correlation between the rate of #1 socializing and the rate of underwater blows during each observation flight in 1983. Only presumably undisturbed periods are included.

feeding in connection with underwater blowing that year, but the incidence of underwater blows seemed correlated with the incidence of various feeding behaviors. In 1981, there were again some indications that high numbers of underwater blows occurred on occasions with much feeding behavior. In both 1980 and 1981, the rate of underwater blows, when calculated by hour of day, appeared to be lowest when the rate of socializing was the highest, around sidereal noon (Würsig et al. 1982). Thus the incidence of underwater blows appeared to be negatively correlated with socializing in 1980 and 1981. The calculation of underwater blow rates in those two years, however, was based only on number of observation hours and did not consider the number of whales in the area. In 1982, underwater blows were seen too rarely for analysis (Würsig et al. 1983). We thus do not feel that we have properly analyzed the relationship between underwater blows and socializing except in the present analysis of data from 1983.

We have not had time to re-analyze the data on underwater blows from past years to see if the correlation with socializing existed then as well. The total numbers of underwater blows observed in the four years, considering both disturbed and undisturbed periods, and without determining the rates based on whale-hours underwater, were as follows:

<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>
158	66	6	347

The fact that socializing rates showed a similar pattern -- a progressive decline from 1980 to 1982 followed by an increase in 1983 (Table 4) -- suggests, on a crude level, that the 1983 relationship between underwater blows and socializing may hold for past years as well.

We observed the whales that made (or probably made) 43 of the 131 underwater blows seen during presumably undisturbed periods in 1983. Those 43 underwater blows were produced as or just after the whale dove out of sight. Of those 43, more than half (23) were produced by whales that were within five body lengths of one or more other whales, and 14 of those were produced by whales that were actively socializing just before the underwater blow. In at least one case it appeared that the interacting continued underwater after the whales dove. Of the 88 underwater blows where we did

not observe the whale that produced it, 23 appeared within five body lengths of one or more whales at the surface. The remaining 65 underwater blows appeared at the surface with no whales visible nearby. We suspect that at least some of those blows marked the locations of groups of whales socializing underwater and out of sight.

The strength of the correlation between rates of underwater blows and of socializing in 1983, coupled with the observation of underwater blows within actively socializing groups of whales, strongly suggests that underwater blows were a form of social interaction, at least for much of the time in 1983. Clark (1983) reported frequent underwater blow sounds in interacting groups of southern right whales. One of us (RP) has noted that forceful underwater blows in these right whales often occur during aggressive social interactions. For humpback whales, Darling et al. (1983) have reported both forceful underwater blows and curtains of bubbles produced by exhaling underwater while moving forward, in apparently aggressive social contexts. We do not know whether the underwater blows we observed in bowhead whales were also of an aggressive nature.

#### Aerial Activity

Aerial activity, consisting mainly of breaching, tailslapping and pectoral flipper slapping, occurred sporadically throughout our 1983 observations. General descriptions of these aerial activities are given by Würsig et al. (1982). Aerial behavior presents certain difficulties for the definition of surfacings and dives. We excluded breaches from our surfacing analysis because we considered a breach to be an abnormal surfacing of uncertain duration. We also could not be certain whether or not a blow accompanied a breach, so we measured blow intervals only for blows between breaches. (One of us [RP] has noted from films of breaching southern right whales that a blow accompanied every breach that was examined in slow motion. Our aerial vantage point in this study, however, made detection of blows in breaching bowheads impossible.) A breach was considered to represent the end of a preceding dive, but the dive following a breach was not coded for analysis. Tailslaps, flipper slaps and rolls were not considered to be interruptions of a surfacing if the whale remained in sight.

In 1983, we observed 19 bouts of aerial activity, ranging from single events to the long series of activities on 22 August, described below. Aerial activity bouts consisted of eight single tailslaps, six single breaches, one bout with two and one with three breaches, one bout with three pectoral flipper slaps, and two long bouts on 22 August. The incidence of aerial activity in 1983 was slightly higher than that of previous years (Table 5). Aerial activity occurred too infrequently to allow many comparisons of presumably undisturbed and potentially disturbed situations, so all sightings are included in Table 5. However, the longest bout of aerial activity by a whale on 22 August began during presumably undisturbed conditions and continued during potentially disturbed conditions (aircraft at 305 m a.s.l.). Possible differences in aerial activities due to the aircraft are discussed by Richardson et al. (1984b).

Table 5. Frequency of aerial activity, 1980-83, based on whale-hours of observation at the surface. Both presumably undisturbed and potentially disturbed periods are included.

	1980	1981	1982	1983
Bouts of aerial activity	6	14	9	19
Whale-hours at the surface	10.03	14.98	10.95	17.91
Bouts/whale-hour	0.60	0.93	0.82	1.06

On 22 August 1983, we encountered an aerially active whale in water approximately 18 m deep about 13 km ENE of King Point, Yukon. We observed the whale for 11.8 min, during which it tailslapped 49 times and breached 6 times. The whale was tailslapping when we first arrived overhead at 610 m a.s.l., and breaches occurred during the latter part of our observations. Although there may have been many aerial activities by the whale before we arrived, the sequence we observed consisted of 38 tailslaps, 1 breach, 7 tailslaps, 2 breaches, 4 tailslaps, 3 breaches. As the whale surfaced after the last breach sequence, a second whale began breaching 300 m distant. The first whale moved away from the second one at medium speed, and we lost it after a dive and another surfacing during which it moved at medium speed. It was not aerially active during the last two surfacings, and it may have

stopped its aerial activity and moved away due to the onset of aerial activity by the second whale.

The first group of tailslaps by the first whale occurred during a 3.5 min period which was interrupted by only 8 brief surfacings of the head in order to breathe; the mean interval between tailslaps was  $5.6 \pm \text{s.d. } 2.56 \text{ s}$  ( $n = 37$ ). The six breaches by this whale occurred during a 4.5 min period, and the interval between breaches was  $0.89 \pm 0.584 \text{ min}$ . Nineteen blows were observed within 11.8 min of observation, for a blow rate of 1.61 blows/min. However, if respirations occurred during each of the breaches as well, the blow rate would be 2.12 blows/min. The mean blow interval for blows occurring between breaches was  $19.60 \pm 9.125 \text{ s}$  ( $n = 15$ ).

The second whale was aerially active during the entire 75 min that we observed it. It breached 64 times, tailslapped 36 times, and pectoral flipper slapped 48 times. While breaches and tailslaps predominated at the beginning, pectoral flipper slaps--produced as the whale rolled on its longitudinal axis at the surface--occurred more often towards the end of observations. The breaches were distinctly clumped into short series with the pauses between breach series lasting over 1 min and the intervals between breaches within a series lasting only about 0.5 min. There were 15 breach series, with  $3.1 \pm \text{s.d. } 1.41 \text{ breaches/series}$ . Fourteen longer intervals separated these series of breaches; they ranged from 1.2 to 3.9 min in length, with the exception of one 16.25 minute interval (mean =  $2.72 \pm 0.903 \text{ min}$ ). The mean interval between breaches within a series was  $0.48 \pm 0.095 \text{ min}$  ( $n = 47$ ).

Tailslaps occurred sporadically throughout observations of this second whale. While 10 tailslaps occurred singly, there were 8 series of two or more tailslaps uninterrupted by a blow. The average number of tailslaps in a series was  $3.25 \pm \text{s.d. } 0.707 \text{ s}$  and the interval between tailslaps within a series was  $4.8 \pm 2.46 \text{ s}$  ( $n = 18$ ). Pectoral flipper slaps, associated with the whale rolling at the surface, occurred only towards the end of observations. There were three occasions with a single flipper slap during a surfacing, 6 series of two or more slaps uninterrupted by blows, and 12 occasions when 2 flipper slaps were separated by a blow. The average number

of flipper slaps in a series was  $4.5 \pm 2.35$  ( $n = 6$ ), and the interval between slaps within a series was  $3.6 \pm 3.12$  s ( $n = 27$ ). Double flipper slaps separated by a blow occurred at a mean interval of  $22.1 \pm 9.97$  s ( $n = 12$ ).

The second whale that was aerially active blew at least 89 times within the 75.0 min of observation, and possibly as many as 153 times if it blew during all breaches. The blow rate was thus between 1.19 and 2.04 blows/min. The mean blow interval for blows between breaches was  $19.50 - \text{s.d. } 14.399$  s ( $n = 60$ ). This whale apparently also fed at the bottom; mud emanated from its mouth during at least two surfacings, and mud was visible near the whale during three other surfacings.

Although this whale was alone during most of the observed sequence, it was joined by another whale about 10 min before the end of observations, and it continued aerial activity while the other whale was near by. We detail the actions of the two whales in case they might provide insight into the function of aerial activity. The newcomer swam at the surface toward the breacher during a breach series and made a dive in the direction of the breacher while only 4 body lengths away. After the breach series ended, the newcomer made three short surfacings within 1 body length of the breacher, which was hanging at the surface. The breacher made a single flipper slap during one of the newcomer's surfacings close by. The two dove while converging head to head, and one of the two surfaced briefly just afterwards. While the newcomer was out of sight underwater, the breacher then made another series of breaches, followed by several tail slaps and flipper slaps while hanging at the surface for over two min. Toward the end of that time, the newcomer surfaced behind the breacher and swam to within  $1/4$  body length beside the breacher, which again flipper slapped once. The two whales then dove simultaneously side by side with flukes raised, but the newcomer surfaced again briefly 4 s later. After that, one of the two whales surfaced briefly and submerged again, and the breacher next surfaced with mud near its chin and then made two more breaches, followed by a spyhop, a tailslap, and then a flipper slap. After the breacher dove again, we saw an underwater blow near where it went down. We saw only two more short surfacings by a whale that may have been the newcomer before we had to leave the area to refuel.

Overall, the blow intervals of whales engaged in all types of aerial activity were significantly longer than those of whales not aerially active ( $23.3 \pm$  s.d.  $22.89$  s,  $n = 84$  vs.  $16.3 \pm 11.88$  s,  $n = 782$ ;  $t' = -2.75$ ,  $p < 0.01$ ). However, this apparent difference may be an artefact if an undetected respiration occurred during some or all breaches. Number of blows per surfacing and length of surfacing did not differ significantly on occasions with and without aerial activity. However, the mean duration of dive during aerial activity was briefer than that during non-aerial behavior ( $0.52 \pm 0.293$  min,  $n = 20$  vs.  $2.01 \pm 2.283$  min,  $n = 116$ ; Mann-Whitney test,  $z = 4.02$ ,  $p < 0.001$ ).

Many of the breaches and tailslaps by the second aerially active whale on 22 August were detected by a sonobuoy located about 300-600 m from the whale. A lower proportion of the pectoral flipper slaps were detectable by the sonobuoy (see following section).

#### Bowhead Sounds

In recent years the acoustic behavior of the bowhead whale has been studied during spring and fall migration (Ljungblad et al. 1980, 1982, 1983; Clark and Johnson in press) and during summer (Würsig et al. 1982, 1983). It appears that the full range of call types produced by these animals during spring, summer and autumn has been documented, although winter studies and a detailed quantitative analysis of their sound repertoire are still needed. Because of the difficult field conditions during most acoustic observations, our limited understanding of the biological significance of the various sound types is based upon their association with a general social context rather than a specific context. For example, both Würsig et al. (1982) and Ljungblad et al. (1983) present data associating (1) swimming or migrating whales with low (<250 Hz), frequency modulated (FM) upsweeps, and (2) socially active whales with either complex-pulsive calls or high (>400 Hz) FM calls. Both of these general contexts, swimming and socializing, include a range of behaviors that are probably not mutually exclusive. Nonetheless, these are important results, and they are in general agreement with the notion that low FM sounds function for long range communication in baleen whales, while higher frequency, broadband and pulsive sounds are used in

social activities when whales are in close proximity to one another (Payne and Webb 1971; Clark 1982, 1983).

In August and September 1983, sonobuoys were deployed in the eastern Beaufort Sea on most occasions when bowhead whales were under observation, and tape recordings were made throughout most observation periods. The sonobuoy hydrophone was always set to deploy to 18 m below the surface. Water depths where sonobuoys were dropped ranged from about 12 m to 950 m, so on some occasions the hydrophone dragged on the bottom. During the first two days of recording, 7 and 9 August, water depths were 950 m and 210 m, respectively. Water depth at the sonobuoy during subsequent recording sessions was 12-35 m, including periods of potential disturbance.

All recordings were analyzed according to the methods used in previous years (see Würsig et al. 1982, 1983). Each tape was played back at normal speed while one of us (CWC) listened to the direct acoustic output from the tape and observed its continuous spectrographic representation on a memory oscilloscope. Spectrographic output was obtained by playing the taped analog signal into a Spectral Dynamics SD301C realtime analyzer which was coupled to a Tektronix 5111 memory oscilloscope. By this procedure the observer could simultaneously hear the sounds and see their spectrographic images. Such a method greatly facilitated both the detection of faint signals as well as the categorization of the sounds.

Using both the visual pattern of the spectrographic display and an aural judgment, each sound was categorized (by CWC) as one of the seven previously identified sound types (see Fig. 28 on page 117 of Würsig et al. 1982). The number of sounds of each type was tabulated for each minute of sound recording. In addition, a subjective decision was made as to whether the sound was loud or faint. This acoustic analysis was performed on all 33.7 h of tape recordings without knowledge of the experimental conditions or behavioral observations during the period of recording. (However, much information about potential disturbance was unavoidably available to CWC, since industrial sounds were often detected by the sonobuoys.) Later, all recording periods were divided into subsets according to experimental condition.

Table 6 presents the sound recording data for 1983 during periods when there were no known potential disturbances. Next to each date is a listing of the number of whales within an approximate 2 km radius of the sonobuoy, the general behavior of the animals, the calculated rate of calling expressed as total loud calls per whale-hour, and a tabulation of the number of loud and total sounds of each type. Call rate was computed by dividing the total number of loud calls by the duration of the observation period and by the number of whales seen within about a 2 km radius of the sonobuoy. Bowhead calls during potentially disturbed conditions are summarized in Richardson et al. (1984b).

#### Blow and Slap Sounds

The following discussion of blow and slap sounds includes both presumably undisturbed and potentially disturbed periods. A total of 484 blow sounds and 39 slap sounds were recorded in 1983 (213 blow sounds and 23 slap sounds during presumably undisturbed periods; Table 6).

During both flights on 17 August 1983, some of the blow sounds recorded by sonobuoy coincided with visual observations of underwater blows near the sonobuoy. The blow sound was almost always heard on the recording several seconds before it was announced by the observers in the observation aircraft. The delay could be due, in part, to the time it took the exhalation to reach the surface. Underwater blows from socializing whales were especially frequent on 17 August (Figs. 22, 26). During the first flight on 17 August, 66 of the 118 recorded blow sounds were coincident with visually confirmed underwater blows. The whales being observed were very close to the sonobuoy on this occasion.

The underwater blow sounds were acoustically distinct from the typical blow sounds made by a whale exhaling and then inhaling with its nostrils above the surface of the water. The typical blow sounds are noisy with unstructured broadband energy at 300-800 Hz and durations of about 1 s. On the recordings of 17 August, two types of underwater blow sounds were heard. The first and most common type sounded similar to the noise made by the exhalation from a scuba respirator, that is, a sustained 1-2 s high

Table 6. Daily summary of bowhead sounds recorded during presumably undisturbed periods in 1983. For each period, the upper row of values represents loud sounds and the lower row represents all sounds. Call rate was computed on the basis of the number of loud calls and the number of whales within about 2 km of the sonobuoy. A question mark after number of whales and behavior signals a recording session that extended after the aircraft crew ended behavioral observations and left the area of the sonobuoy.

Date	Recording Time (MDT)	Depth (m)	# of Whales	Behavior	Call Rate (calls/whale-h)	Whale-h of Recording	Total Calls (loud & all)	# Sounds of Each Type									
								Calls								Other	
								Up	Down	Con-stant	Double or Inflected	High	Har-monic	Pul-sive	Blow	Slap	
9 Aug 1983	13:37-13:48	210	12	socializing	0.0	2.2	0	0	0	0	0	0	0	0	0	0	
							0	0	0	0	0	0	0	0	0	0	
15 Aug 1983	11:01-11:51	15	6	lone whales moving medium speed	0.2	5.0	1	1	0	0	0	0	0	0	0	0	
	11:51-14:56	15	6?	lone whales moving medium speed?	1.7	18.5	31	4	3	3	8	0	13	0	6	0	
17 Aug 1983	13:00-13:19	30	15	socializing	2.3	4.8	11	4	2	2	1	1	1	0	45	0	
	20:49-21:32	30	15?	unknown behavior	0.3	10.8	3	1	0	0	0	0	0	2	28	2	
	21:06-22:36	25	10	mostly lone whales, unknown behavior	0.5	15.0	7	3	1	0	0	0	3	0	40	0	
18 Aug 1983	14:14-14:39	12	13	some socializing some lone whales	0.4	5.4	2	0	0	0	0	0	2	0	8	0	
	14:39-15:08	12	13?	some socializing some lone whales?	0.5	6.3	3	2	0	0	1	0	0	0	5	0	
	20:24-20:57	12	?	no data	-	-	0	0	0	0	0	0	0	0	0	0	
22 Aug 1983	10:23-11:05	20	6	some aerial activity, possible bottom feeding, otherwise unknown	2.6	4.2	11	3	3	0	2	1	2	0	35	21	
	14:07-14:21	35	9-11	mostly lone whales; little or no forward movement	0.9	2.3	2	2	0	0	0	0	0	0	6	0	
	15:31-16:45	35	9-11	mostly lone whales; little or no forward movement	1.0	12.3	12	10	0	0	0	0	1	1	40	0	
26 Aug 1983	17:04-17:49	17	5-8	skim-feeding	0.0	4.9	0	0	0	0	0	0	0	0	0	0	
TOTAL							91.6	83	30	9	5	12	2	22	3	213	23
								253	103	34	17	31	16	43	9		

frequency, broadband noise mixed with a chorus of lower frequency, short duration broadband gurgles. The longer durations of these hissy, gurgly underwater blows were presumably attributable to the time it took the bubbles from each exhalation to reach the surface. The second type of underwater blow sound was heard only during the first flight on 17 August. It was more structured than the hissy, gurgly blow sound and consisted of a series of broadband pulses repeated 10-20 times a second. These pulsatile blow sounds would have been categorized as harmonic or pulsive calls had there not been visual observations of underwater blows several seconds after many of these sounds were heard. These observations are similar to those of Clark (1983) for southern right whales; in large groups with social and sexual activity, right whales often exhaled underwater and thereby produced pulsive sounds.

Thirty-seven of the 39 slap sounds (including both presumably undisturbed and potentially disturbed periods) were recorded during the morning flight of 22 August 1983, when the second of two whales was engaged in a prolonged bout of breaching, tailslapping and pectoral flipper slapping (see Aerial Activity section, above). During the 75 min of recording, 40 breaches, 29 tailslaps and 40 pectoral flipper slaps were seen. Of these, 15 breaches, 13 tailslaps and 9 pectoral flipper slaps were distinctly audible on the recordings. Within most bouts of aerial activity, some breaches or slaps were audible, but others were not. For example, between 10:52:13 and 10:54:35, there was a series of six breaches by one whale. Of the six, only the first three in the series were clearly audible. Similar results were found for both tailslaps and pectoral flipper slaps. Apparently, there was considerable variability in the acoustic level of different breaches, tailslaps and flipper slaps within a single series. Greene (1984, this volume) documents the spectral and temporal characteristics of sounds from a breach and tailslap recorded on 22 August. The predominant frequencies were lower for the breach.

### Call Types

Excluding blow and slap sounds, the majority (85%) of sounds recorded in 1983 were tonal, frequency-modulated calls lasting 1-2 s. All the types of

sounds previously reported and illustrated by Würsig et al. (1982, p. 117) were also recorded in 1983. We did not hear any of the 'twittering' sounds reported by Würsig et al. (1983, p. 86). However, in 1983 we did very little recording near calves, the context in which the 'twittering' sounds were heard in 1982.

### Context of Call Types

The behaviors and contexts observed in 1983 were quite variable. They included lone whales with little to no forward movement, swimming, skim-feeding, bottom feeding and socializing. Because of the variation in contexts and the low sample sizes, it is difficult to reach any firm conclusions associating context and call types (see Table 6). However, we observed socializing during 22 of the 27 cases when we recorded loud pulsive calls in 1983, considering both presumably undisturbed and potentially disturbed periods. Nine pulsive calls, both loud (3) and faint (6), were recorded under undisturbed conditions and none of these was known to be associated with socializing. However, of the 5 loud pulsive calls recorded during all periods when whales were not socializing, 1 was heard during a period of aerial activity just after two whales were seen head to head, two were heard during a period of unknown behavior, and only 2 were heard when there were lone whales in the area. Thus pulsive calls again tended to be associated with socializing animals in 1983, as reported earlier by Würsig et al. (1982) and Ljungblad et al. (1983). For all other call types, there were no distinguishable associations with any particular behavior.

### Interspecific Interactions

White whales (Delphinapterus leucas) were seen near bowhead whales on 17, 22 and 26 August. The closest approach occurred on 17 August when two white whales were approximately 45 m from a bowhead whale and oriented toward it. However, we did not see any interaction by the two species. This was the closest that we have observed members of the two species in all four years of this study. The sounds made by white whales underwater are at higher frequencies than most bowhead sounds, but are often intense (e.g.,

Ford 1977; Wood and Evans 1980). It is likely, therefore, that bowhead whales and white whales knew of each other's presence on several occasions, but we do not know what effects their sounds may have had on each other. Ringed seals (Phoca hispida) and gray whales, which were seen near bowhead whales in previous years, were not seen near them in 1983.

Birds were seen near bowheads on ten separate occasions in 1983. They may have been attracted to areas of whale activity in search of food, but we had no direct evidence of interaction between bowheads and birds in 1983. Gulls (probably glaucous gulls, Larus hyperboreus) were seen to pass over skim-feeding whales three times on 26 August. Flocks of phalaropes (probably red-necked (= northern) phalaropes, Phalaropus lobatus) were seen sitting on the water near whales on 17 and 18 August. On 17 August, there were two occasions when phalaropes landed in the location where a whale had been only seconds before. We do not know whether these whales were feeding in the water column, but defecation by one of these whales near where phalaropes landed indicates that feeding had taken place sometime previously. Gulls and small birds, probably phalaropes, each flew over a whale not known to be feeding on 18 August, and later that day about 60 phalaropes were seen in an area with about 30 bowheads.

#### Comparisons with Bowheads During 1983 Migration

Würsig et al. (1983) reviewed the information on behavior of migrating bowheads and demonstrated that, during the spring and fall migrations into and out of the Beaufort Sea, bowheads probably engage in the same types of behaviors observed on their summering grounds (feeding, socializing, travelling, and aerial behavior), but with different relative frequencies. We discuss here the little additional information about bowheads during migration that is available at this time.

Durations of dives by bowheads migrating in the spring of 1983 were measured by observers stationed on the ice at Point Barrow, Alaska. The mean dive time obtained was  $18.01 \pm \text{s.d. } 13.986 \text{ min}$  ( $n = 98$ , range = 1.77 - 76.00 min) (Krogman et al. 1983). This was very much longer than the mean dive time that we observed in presumably undisturbed bowheads summering in 1983

( $1.88 \pm 2.357$  min,  $n = 140$ ). It was also longer than the mean dive time that we observed in 1982 ( $12.08 \pm 9.153$  min,  $n = 51$ ), when we saw the longest dives in any year of this study. These figures may exaggerate the real difference between the mean dive times for migrating and non-migrating bowheads, because of the bias in our data toward short dives, explained above. However, we believe that the direction of the difference is correct and that migrating bowheads that are actively travelling do indeed make longer dives on average than do summering bowheads.

Reports on behavior of bowheads during fall migration have been limited. One of us (BW) was involved in a study of bowhead whales in the Alaskan Beaufort Sea during the fall migration of 1983. Quantitative data from that study are not yet available, but some behavioral observations are of interest. The ice closed in near shore relatively early, in late August and early September, and most of the whales observed in September were moving rapidly. Very little feeding behavior was observed in areas where feeding occurred in previous years during fall migration (D. Ljungblad, pers. comm.). Socializing was observed only occasionally, consisting of nudges and low-intensity chases. No apparent mating and no groups actively milling at the surface were seen. However, observers working farther from shore at the same time noted some instances of quite boisterous socializing (G. Silber, pers. comm.).

#### 1983 Compared to Previous Years

Striking variations in behavior from year to year have been one of the major generalizations derived from this study to date. In preceding sections of this report, comparisons between 1983 and previous years have been mentioned for many behaviors. Here we review those comparisons to summarize the ways in which 1983 was different from and similar to 1980, 1981, and 1982.

Year-to-year differences in locations where we encountered bowhead whales were one of the more dramatic annual variations observed. Richardson et al. (1983a, 1984a) review the results of systematic and opportunistic surveys of bowhead distribution in the study area. In 1980, many bowheads

came close to shore off the Mackenzie Delta and Tuktoyaktuk Peninsula. From 1980 to 1982 there was a progressive increase in the depth of water where bowheads were observed in August and early September. In 1983 we again found bowheads in very shallow water close to shore, but in a different part of the study area. In 1983, the nearshore whales were along the Yukon coast, west of the area where they were so common in 1980.

Another difference between 1983 and 1980 was the age composition of the nearshore whales. In 1980 these whales included calves and mothers and other presumably mature whales (as indicated by large white chin patches and white areas on the tailstock and flukes), but in 1983 we did not see such whales in the nearshore group. In 1983, mothers and calves were encountered only in very deep water over 100 km north of the immature group (this study) and in offshore areas much farther east (McLaren and Davis 1984; J. Cabbage pers. comm.). As indicated earlier, there appeared to be stronger segregation of bowheads by age class than in the three previous years. Probably because of that segregation and because we rarely flew far offshore in 1983, our calf sighting rate was lower in 1983 than in any of the previous years of study (Table 3).

Feeding is presumed to be the predominant activity of bowheads summering in the Beaufort Sea. The frequencies of various types of feeding have varied from year to year; in 1980 we saw indications of bottom feeding, skim-feeding, and water-column feeding; in 1981 we saw skim-feeding and water-column feeding; and in 1982 we presumed that most whales were water-column feeding but had little direct evidence for this aside from observations of long dives. 1983 was probably most like 1980, as the feeding behavior observed near shore was bottom feeding and skim-feeding. Contrary to 1980 and 1981, none of the skim-feeding observed in 1983 was by whales in echelon formation. Water-column feeding was not detected in 1983, but may have occurred. There was a progressive decrease in the observed rate of defecation from 1980 to 1982. The 1983 value was similar to that in 1981 and therefore intermediate between 1980 and 1982.

We have seen some social behavior every year, with a progressive decrease in the rate of socializing from 1980 through 1982. The rate of

socializing in 1983 was back up to the approximate level in 1981, and was thus intermediate between the levels in 1980 and 1982 (Table 4). In 1983, as in 1980 and 1981, the rate of socializing was lower in the second half of August than in the first half. (In 1982, the rate was too low to analyze in relation to date.) We presume that this seasonal decrease is part of a longer term seasonal decline in frequency of socializing from spring migration, when mating and boisterous interacting appears to occur, to fall migration, when there is little social behavior.

There has been considerable variation in the number of underwater blows seen each year, with by far the highest number in 1983. At least in 1983, there was a strong correlation between rates of underwater blowing and of socializing.

The rate of aerial activity in terms of 'bouts per whale-hour at the surface' has not varied very much from year to year. The 1983 value was slightly higher than that for the highest previous year, 1981. It is interesting that the rate of aerial activity should have been so stable over four years when so many other activities have varied to a much greater extent.

Over the four years of this study, several distinct types of behavior have been seen at such low frequencies that it is not meaningful to compute yearly rates. Considering social behavior, we have observed only two instances of probable mating activity, both in 1981; one instance of aggressive tail lashing by a mother with a calf toward two other adults, also in 1981; and a single incident, in 1983, of apparently aggressive physical contact (one whale striking another forcefully with its pectoral flipper, and the second whale then striking the first with its tail flukes). Considering behavior of calves, we have seen interaction between two calves only once, in 1983; and play by a calf with a substance in the water twice (with fluorescein dye in one case and with a windrow of debris in the other), both cases occurring in 1982. We have observed log play by non-calves three times, twice in 1981 and once in 1982. 1983 did not appear to have either a lower or a higher incidence of rare behaviors.

The types of sounds recorded underwater in the presence of bowheads have been almost the same in all four years of this study. Call rates, however, varied considerably between years. There were indications that changes in depth of water and social context were related to the variations in call rates. For example, in 1982, when there was a six-fold increase in average water depth during recording sessions compared to 1980-81, there was a dramatic increase in the total number of calls recorded. Calls from whales far away are more likely to be detected in deep than in shallow water. In 1982, the majority of the calls were low, frequency-modulated calls and the rate of socializing decreased as compared to 1980-81. Associated with this drop in socializing was a decrease in the proportion of complex harmonic or pulsive sounds from 56% in 1980-81 to 10% in 1982. In 1983, this value increased to 15%, concurrent with an increase in socializing. Complex pulsive sounds are believed to be associated with socializing in southern right whales as well as bowheads.

We have wondered whether there might be some cyclicity to the changes that we have observed from year to year in the behavior of bowhead whales. Their close relatives, southern right whales, show a cycle in the constituency of the mature females present on calving grounds in the winter (Payne in prep.). This occurs because most females bear calves only once every three years and are absent from the calving grounds in Argentina during the two years in between calves (except for a brief stay early in the winter by some females the year after giving birth to a calf). There is, therefore, a different population of mature females on the calving grounds each year for three years, after which the pattern is repeated.

In 1980-82, a number of the year-to-year changes in the behavior of bowhead whales appeared to be progressive, as detailed above. Depth of water frequented, rate of socializing, number of underwater blows, and rate of defecation all changed progressively from 1980 to 1982, and feeding behavior changed considerably from year to year, though not with any consistent trend. In some respects, the bowheads in 1983 behaved like those in 1980. Many whales were in very shallow depths as in 1980, feeding behavior was most similar to that in 1980, and the number of underwater blows was again very high, even higher than in 1980. In other aspects of behavior,

however, 1983 did not appear to be a repeat of 1980. A different shallow water area was occupied than in 1980. The rates of socializing and of defecation in 1983 were both much closer to 1981 rates than to 1980 rates. The calves seen far offshore were not observed exclusively next to their mothers as was true of calves in nearshore waters in 1980, but spent time away from their mothers as in 1981 and 1982. The nearshore whales in 1983 appeared not to include calves, mothers and other full grown whales, contrary to the situation in 1980. In summary, after four years of study, there is no consistent evidence that the considerable year-to-year variation in behavior of bowheads forms a repeating pattern.

#### Annual Variations in Behavior of Other Cetaceans

Not all whales show as much year-to-year variability in behavior and distribution as we have seen in bowhead whales over the four years of this study. Dorsey (1983; Dorsey et al. 1983) studied the behavior of individually recognized minke whales (Balaenoptera acutorostrata) on summer feeding grounds in Washington state for four consecutive years. The uniformity in distribution and behavior of this species from year to year provides a striking contrast to the variability we have observed in summering bowhead whales. The minke whales were studied in an area of only about 600 km<sup>2</sup>, two orders of magnitude smaller than the area covered in this study of bowheads, but within that area, minke whales were found every year, consistently, at about the same time. There are three smaller regions within that area where minke whales tend to concentrate. Some of the recognized individuals were seen in the study area for all four years, and most of those were sighted in only one sub-region each year and in the same sub-region every year. Two main types of feeding behavior were observed, with no major change in the frequency of the two types from year to year. The minke whales were observed feeding on small schooling fish, like Pacific herring (Clupea harengus). Unfortunately, there is no information about variability in supply and distribution of the fish over the years of this study.

Bowhead distribution within the eastern Beaufort Sea and the frequency and type of feeding were two of the main attributes that varied from year to year. Both might reflect changes in prey distribution, abundance, or species

composition. We do not have sufficient data on the prey of these bowheads to test such a relationship. Stomach contents of bowheads from the eastern (i.e. Canadian) Beaufort Sea have not been examined, and factors affecting zooplankton dynamics in that area have not been studied in any detail. Studies on other baleen whales, however, provide quite direct evidence for changes in whale distribution in response to changes in their prey. Humpback whales are a good example of this because they feed on different kinds of prey in different areas and they have been studied intensively in recent years.

An example of humpback whales returning to the same area in consecutive years to feed on stable prey comes from research by Mayo (1982, 1983). He worked on Stellwagen Bank, a small shoal located near the tip of Cape Cod in the Gulf of Maine. He studied the summer movements of humpbacks within and between years as they fed on sand lance (Ammodytes americanus), a small schooling fish present on Stellwagen Bank in large concentrations during Mayo's study. Mayo recognized virtually all of the individual whales that fed on Stellwagen Bank and observed almost every day of the feeding season. Many individuals returned in consecutive years and their movements within each summer were quite predictable even to the extent of which points on the bank (separated by only 25 km) they occupied early and late in the season.

In contrast to this finding is work by Whitehead (1982) who made detailed studies of the distribution of humpback whales on their feeding grounds near Newfoundland, farther north in the western North Atlantic than Mayo's study. Capelin (Mallotus villosus) is the principal prey here. Sighting rates for humpbacks in one small nearshore area roughly quadrupled over three years. This increase was much too rapid to have been caused by population growth; even assuming maximum possible recruitment and zero mortality, the humpback population could grow by only 15% per year. There was a second area farther offshore from Whitehead's study area where humpbacks had been plentiful, but from which they disappeared over the same three years. Capelin stocks offshore from Whitehead's study area collapsed at the same time that spawning schools of capelin and humpbacks became so plentiful inshore. Whitehead concluded that the pronounced change in summer distribution of humpback whales in that region was in direct response to the failure of the offshore capelin stocks.

A similar study by Bryant et al. (1981) showed that the most probable explanation for the disappearance of humpback whales from Glacier Bay, Alaska, in 1980 was the fact that Glacier Bay had a low krill population in that year.

Thus, in a situation where the prey species remained in the same place in high abundance, humpback whales returned each year to the same area. Where the prey of the humpbacks moved dramatically, the whales also moved. These examples are all from whales that summer and feed near shore, but the same kinds of conclusions have been drawn from studies of whales feeding farther from shore, in open ocean areas in the Antarctic and in the North Pacific.

In the early days of research on mysticetes, data obtained from the 'Discovery' expeditions showed that the changing distributions of the rorquals then being caught in the Antarctic Ocean were related to the variable distributions of their principal prey, the krill Euphausia superba (Mackintosh 1965). Mauchline and Fisher (1969) demonstrated that major concentrations of krill in the Antarctic may occur in different places in different years, appearing unpredictably in any given year at new locations often hundreds of kilometres away from the concentration centers of a previous year. This unpredictability may well confer a selective advantage on the krill by making it difficult for local krill-dependent predator populations to build up.

Beklemishev (1960) correlated the distribution of Antarctic blue whales (Balaenoptera musculus), fin whales (B. physalus), and humpback whales with overall krill distribution and then pointed out that the krill distribution is affected by atmospheric cyclones in the following way. Water rises 'very intensively' in the centers of cyclones because of the low atmospheric pressure and sinks along their peripheries. The longer a cyclone stays in a given place, the more intensive is the upwelling it induces near its center. Thus 'the krill is more abundant, and there are more blue and humpback whales in regions where the cyclones are more frequent and stay longer... The position of individual regions rich in krill and whales is largely determined not only by the local Antarctic conditions but also by the tracks of the ...

cyclones as well.' This presumably means that the annual differences in krill distribution are affected by annual differences in the tracks taken by major storms. According to Beklemishev, fin whales are less closely restricted to the areas of upwelling than are blue and humpback whales.

Nemoto (1959) analyzed stomach contents of rorquals caught by Japanese whalers in the North Pacific over a six year period. His results clearly show that in rorquals feeding in the open ocean, it is common to see great year-to-year variability in diet, geographic distribution, and time of arrival at and departure from the feeding grounds. To take these in order: Nemoto showed that the principal prey of fin whales in the eastern Aleutian Islands alternated each year between two types. In one year the great majority of food in fin whale stomachs was euphausiids. In the following year, the principal food in fin whales from the same area was Calanus copepods. From an analysis of plankton tows, he demonstrated that this alternation of 'Calanus years' and 'Euphausiid years' was a reflection of alternating abundance of these prey items in the area (Nemoto 1957) and was not just due to choice by the whales.

The geographic distribution of the blue whales varied greatly from year to year in the area that Nemoto studied. He noted, for example, that 'blue whales never migrate to the grounds [whaling ground A, an area southeast of the Kamchatka Peninsula] if euphausiids are not abundant. When euphausiids are abundant [as in] 1954, blue whales arrive at the whaling ground A already in June' (Nemoto 1957, p. 77) i.e., earlier than in other years. He further noted that the entire migration route of blue whales in the North Pacific may be determined by annual fluctuations in the distribution of the main centers of euphausiid concentration.

It is not surprising to find that annual changes in the distribution of a whale's prey can cause changes in the distribution of the whale. Whales apparently cannot obtain enough food by feeding in areas of average prey abundance; they must feed selectively in areas of concentrated prey (Nemoto 1970; Brodie et al. 1978; Brodie 1981; Griffiths and Buchanan 1982). However, it is less immediately apparent whether changes in the availability of prey could affect other aspects of behavior, such as social behavior or

aerial behavior. Two well-documented studies of odontocetes show that the occurrence of socializing may depend on when and where feeding has occurred.

Würsig and Würsig (1980) studied the dusky dolphin (Lagenorhynchus obscurus) in Argentine waters and found that when the dolphins are apparently searching for food, they are spread out and there is very little social interaction. Once schools of anchovies (Engraulis anchoita) are located, the dolphins rapidly congregate to feed. Following feeding bouts, the dolphins produce many social displays including aerial acrobatics not often seen under different conditions. In studies of Hawaiian spinner dolphins (Stenella longirostris), Norris and Dohl (1980) found periods of intense social behavior to be clearly distinct from periods of feeding. If patterns of feeding behavior changed from year to year--say, in response to a change in prey distribution--then patterns of socializing presumably would also change.

Based on the above considerations, we suspect that the observed annual variation in bowhead behavior is principally a reflection of the varying distribution of their prey. If we wish to understand and perhaps predict for any given year where bowheads are likely to concentrate and how they are likely to feed, it will be necessary to develop an understanding of factors affecting the distribution of their principal prey. It is not known to what extent the distribution of the prey of bowheads in the eastern Beaufort Sea is affected by factors like (1) timing and extent of spring runoff from the Mackenzie River, (2) distribution of ice during spring and summer, (3) paths of major storms, and (4) the variable distribution of the plume of turbid brackish water from the Mackenzie River. Any or all of these could affect prey distribution and therefore bowheads (Richardson et al. 1983a).

A further uncertainty is the degree to which the present Western Arctic bowhead stock is food-limited. The total size of this stock is clearly lower than it was before commercial exploitation, so one could argue that the present stock is probably not food-limited. If so, then details of the summer distribution of bowheads might not be predictable even with a detailed understanding of the variability in prey distribution. However, the number of bowheads now summering in the eastern Beaufort Sea may be a high proportion of the number that summered there before commercial exploitation

(Fraker 1983). Also, it is not known whether the populations of potential food competitors (e.g., arctic cod, Boreogadus saida; Lowry and Frost 1981) have increased since the beginning of commercial whaling. Thus, it is possible that bowheads summering in the eastern Beaufort Sea are food-limited at the present time. In any case, the important limitation for bowheads is probably not the total amount of food available relative to the total requirements of the bowhead population. Bowheads apparently must concentrate their feeding in areas with dense patches of zooplankton (Brodie 1981; Griffiths and Buchanan 1982). If the locations of these patches vary within and between years, as is likely, then the distribution of bowheads is also likely to vary. Thus, an understanding of prey variability would be especially important in understanding the variable activities and distribution of bowheads.

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